Reading Machines for the Blind
A Study of Federally Supported Technology Development and Innovation

by

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(ABSTRACT)

In 1943, Vannevar Bush established a federal government program within the wartime Office of Scientific Research and Development to develop sensory aids for the blind. From the first, the program was intended to benefit not only veterans but all blind Americans. Over the next forty years, six firms worked to develop reading machines for the blind, with various kinds of federal government support. This dissertation reconstructs the history of that development and innovation effort in order to provide a basis for a broader consideration of technology and social change for persons with disabilities, and to provide recommendations for federal policy in the field of assistive technologies, based on that history, as informed by innovation theory.

Between 1943 and 1947, RCA worked under OSRD auspices to develop working prototypes of the A-2 Reader and a unique letter-recognition device. At the same time, Haskins Labs initiated research into the information content of articulated speech which later provided a basis for computer-driven speech synthesizers. This first federal program was terminated at the end of the war, but in 1957, Eugene Murphy of the Veterans Administration revived the program as Congress expanded the scope for federal research. Haskins, Battelle, and Mauch Laboratories worked with the VA in a three-pronged program, but ultimately failed at reading machine innovation. Jim Bliss and John Linvill of Stanford sought but failed to receive VA support. Working with blind students, they ultimately secured funds in 1968, from the newly-established Bureau of Education for the Handicapped. In 1971, they established a firm to produce the Optacon, a reading machine which converts print into a Times Square sign-type tactile output. Over 12,000 Optacons were sold by 1990.

In 1975, Raymond Kurzweil sought help from the National Federation of the Blind to develop a synthetic speech reading machine. Kurzweil drew on the knowledge of blind readers, his own expertise at pattern recognition, and a speech synthesizer operating on

principles established at Haskins Labs to develop a software-centered reading machine that has sold over 4,000 units.

The successful innovators sought knowledge from blind readers early on. They systematically pursued innovation. They stabilized a design through reiterative development drawing on social as well as scientific and engineering knowledge. They understood their practice of technology development in a different way from the linear model implicit in the practices of those developers who failed.

The historical cases provide a basis for informing federal innovation policy when considered in the light of emerging innovation theory. Technology developers should seek to incorporate social knowledge in their development practices prior to innovation and the establishment of a market.

Table of Contents

List of Figures

List of Acronyms

A-2	Model number of RCA's direct translation reading machine
AAWB	American Association of Workers for the Blind
ACB	American Council of the Blind. Est. 1961 as breakaway group from NFB.
ADA	Americans with Disabilities Act of 1990
AFB	American Foundation for the Blind
APH	American Printing House for the Blind
AT&T	American Telephone and Telegraph Company. Parent of Bell Telephone Laboratories.
BEH	Bureau of Education for the Handicapped (Agency in DHEW)
C-1	Model number of production model of FM-slit device
CCD	charge coupled device. An electronic photosensor employed in the first KRM prototype.
CMR	Committee on Medical Research (of OSRD)
CSD	Committee on Sensory Devices (of OSRD)
DHEW	Department of Health, Education and Welfare (U.S. cabinet dept.)
FM-slit	Frequency modulated prototype reading machine. Haskins Lab.
IWRM	Interim Word Reading Machine (Haskins Labs compiled-speech reading machine)
KRM	Kurzweil Reading Machine
MIT	Massachusetts Institute of Technology
NAC	National Accreditation Council for Agencies Serving the Blind and Visually Handicapped (est. 1967)
NAS	National Academy of Sciences
NFB	National Federation of the Blind (Advocacy group est. 1940)
NIDRR	National Institute on Disability and Rehabilitation Research (Formerly NIHR).
NIHR	National Institute for Handicapped Research in DHEW
OCR	optical character recognition
OSRD	Office of Scientific Research and Development
PSAS	Prosthetics and Sensory Aid Service (of the Veterans Administration)
RCA	Radio Corporation of America
REC	Rehabilitation Engineering Center. Initially established by RSA, later part of NIHR
RESNA	Rehabilitation Engineering Society of North America
RSA	Rehabilitation Services Administration (Agency in DHEW)
SRI	Stanford Research Institute, later Stanford Research International
STS	Science, Technology and Society or Science and Technology Studies. Used interchangeably here.
TSI	Telesensory Systems, Inc., Manufacturer of the Optacon.
VA	Veterans Administration
WWII	The Second World War

Chapter 1. Introduction

This work represents the intersection of two different kinds of interest in the field of science and technology in society (STS). The first is the application of new technologies to assist people with disabilities. The other is the practice of new technology development. The meeting ground between these interests is the innovation of assistive technologies, that is to say the process of bringing a new tool into existence and common use to meet the needs of some particular group of people with disabilities.

Assistive technologies and the decision to conduct historical case studies of the development of reading machines for the blind

The use of tools to compensate for a physical disability is an inescapably social process. The principal function of an assistive device is to enable or facilitate the participation of a person with a disability in some social activity. This includes individual activities which take place within a built environment designed to meet the needs of persons without disabilities. Examples of assistive technologies, also called adaptive technologies, include telecommunications devices for the deaf (TDDs) which allow people with speech or hearing impairments to communicate via the common telephone system, environmental control units which allow people in wheelchairs to operate controls in their homes or work place that are out of reach, and reading machines which give blind readers access to printed documents. Not all assistive technologies are "high tech." The term also embraces such non-electronic devices as canes, optical aids and grip enhancers.

The term "assistive technologies" is a recent one, coming into general use in the 1980s. Its adoption recognized several technology trends as well as the fact that for the first time people with disabilities were able to acquire commercial products designed to "assist" them to overcome the limitations caused by a disability.[1] One trend was the application of new electronic technologies, especially microprocessor-based products, to create innovative tools to assist persons with disabilities. To a large extent, this industry emerged among young scientists and engineers outside of the established field of rehabilitation engineering. The case of Raymond Kurzweil and the Kurzweil reader, discussed in Chapter 10, provides an early example of this trend. The field of assistive technologies thus represents the common ground shared by rehabilitation engineers and the developers of electronic assistive devices. It also includes a wealth of innovative technologies initially created by disabled persons to meet their personal needs or by rehabilitation professionals, such as occupational therapists, to meet the needs of their clients.

Adoption of the term assistive technologies also reflects a second trend: an expansion, over the years, of rehabilitation engineering practices to serve a broader clientele seeking access, not just to employment, but to all areas of society. The profession of rehabilitation engineering emerged in the United States during and after World War II. At first, the profession was largely concerned with medically prescribed devices, such as prosthetics and orthotics, and with tools intended to help injured soldiers and workers to return to work. Over time, the field expanded to include a wider range of tools serving new groups of people in all areas of daily life. One factor behind the expansion was social: federal and state governments, from the time of the New Deal, incrementally extended medical and social services to a broader and broader population, to include not only veterans and injured workers, but also children with disabilities, mothers, and elders disabled by the diseases or frailties of old age. The needs of these people, as indeed those of young workers, extended beyond the work place to include home, school, and other social environments.[2] A second factor was the ability of medicine to save the lives of persons with more severe disabilities, including certain congenital defects, brain trauma, and upper spinal cord injuries. Increasingly, rehabilitation professionals applied their knowledge and skills to design tools to serve persons with more severe disabilities in social environments outside the work place.

The growth of the field of assistive technologies has been contemporary with trends in the fields of architecture and environmental design which seek to provide a more accessible built environment. Both of these fields are in turn related to a post-war political movement for civil rights among people with disabilities. A major achievement of this movement was the passage, in 1990, of the Americans with Disabilities Act (ADA). ADA articulated a new national ethos and social policy in the form of legislation guaranteeing access to employment, state and local government services, commerce, transportation, and telecommunications to persons with disabilities, as a matter of civil right. ADA mandates not only the accessibility of facilities and sites where public events, activities, and commerce take place. It also requires the provision of assistive technologies by employers and those providing public services or accommodations, in order to ensure, insofar as practical, the unsegregated participation in society of persons with disabilities.

It is a long-term project, of which this research is a first step, to understand the historical relationship among the evolution of these two disciplines of design and the institution of accessibility as a civil right. This work, however, has a narrower focus. When I first considered this research, I found that there were few, if any, historical studies of assistive technology development. Insofar as I could determine, the only scholarly account of innovation in the field was Sandra J. Tanenbaum's 1986, history of the development and dissemination of a prosthetic device known as the Boston elbow.[3] As I began to assemble documents relating to the development of assistive devices for persons with mobility, vision, and hearing impairments, I found that in every case it was necessary to go to primary documents – research reports, prototype evaluations, and contemporary accounts in the popular press – in order to sort out the history of development and innovation for a particular technology. The history of social and political movements of persons with disabilities is much better documented,[4] but in order to write about the relationship of technological and social change in the area of disability and assistive technologies, it was first necessary to conduct basic historical research into the course of development and innovation for specific assistive devices.

I selected reading machines for the blind for this study for several reasons. I had briefly explored the topic before, so I knew there were interesting problems to be solved and historical documents available to address them.[5] I was intrigued by finding that reading machine research started as early as World War II, and I was eager to examine the archival records of that research, as I had been unable to do in my preliminary work. It was a field where there had been both successes and failures, providing a potential to compare and contrast technologies which achieved innovation with those which did not.

Reading machines were meant to serve an identifiable and historically important group of people with disabilities, namely blind persons, more specifically those unable to read using magnification devices. This is a community with strong institutions and a documented social history which could support this work, thus allowing this research to focus on the relatively unexplored area of technology development, with an ability to draw upon or refer to the existing social history.[6] Moreover, that social history had not overlooked technology issues. In particular, Frances A. Koestler's classic study, *The Unseen Minority: A Social History of Blindness in America,* provides a solid consideration of such issues, drawing upon the resources and perspectives of the American Foundation for the Blind (AFB). Other major, published resources include a variety of contemporary conference proceedings or special reports devoted to technology issues which provide a snapshot of participants' perspectives on technology and social change at the time they were published.[7]

The decision to research the development of reading machines for the blind implied a case study methodology. Technology development occurs within specific laboratories and institutions over a particular period of time. The following eight chapters address seven different institutions which sponsored or performed research and development toward a reading machine for the blind. One firm, Haskins Laboratories, is considered in two chapters, because they first conducted reading machine research between 1943 and 1947, under the sponsorship of the wartime Office of Scientific Research and Development (OSRD), and then returned to the field from 1957 through 1978, with support from the Veterans Administration (VA).

For the convenience of the reader, the case studies are considered in three sections. Section I deals with the OSRD period. It comprises three chapters. Chapter 2 considers the establishment of a federal research program to develop a reading machine for the blind by OSRD. The following two chapters consider the OSRD-sponsored programs at Haskins Laboratories (Chapter 3) and RCA Corporation (Chapter 4). Section II concerns reading machine development efforts conducted under the sponsorship of the VA. Chapter 5 considers the postwar revival of reading machine research under auspices of the VA's Prosthetic and Sensory Aids Service (PSAS). This is followed by case studies of development at the three PSAS contractors, Battelle Memorial Institute (Chapter 6), Mauch Laboratories (Chapter 7), and Haskins Laboratories (Chapter 8). Section III presents the final case studies which consider work that took place at Stanford University, Stanford Research Institute and Telesensory Systems, Inc., leading to the innovation of the Optacon in the 1970s (Chapter 9), and the development efforts at Kurzweil Computer Products, which resulted in the innovation of the Kurzweil Reading Machine in the 1980s (Chapter 10). These case studies cover all of the major reading machine development efforts which occurred in the United States in the postwar period.

Technology development case studies and the problem of innovation

A concentration on the practices of technology developers required a shift in focus on issues as well. There is no practical way to link technology development in a single sector, such as reading machines for the blind, with the overall course of social change for people with disabilities. Even if the postwar social and political movements were exclusively or primarily a phenomenon of blind persons – which they were not – it would be impossible to isolate the impact of a single technology, such as reading machines, given the importance of other technologies such as the long cane, recorded books, radio services, refreshable braille computer displays, and public transportation, among others. The original purpose in approaching this study must be relegated to the background for the time being, pending not only the completion of this study of reading machines, but also additional studies of the development and innovation of other assistive devices such as the powered wheelchair, and TDDs or others among the many assistive technologies which have been adopted by people with disabilities in growing numbers in recent decades.

I approached the case histories with the idea that they would provide a resource for a future study of the relationship between technological change and social change among people with disabilities in the United States. I had an informed desire, therefore, to include in the case studies whatever information was available on developers' interactions with blind persons, organizations serving the blind, and other social institutions including their federal government research sponsors. I also wanted each case study to be comprehensive and autonomous, so they would be useful to other researchers with other perspectives, and, hopefully, to engineers and managers of assistive device development projects.

This last criterion reflects the second interest underlying this project: A concern with the practice of new technology development. The concern is professional -- I spent fifteen years in systems development, integration, and assessment of emerging technologies, before turning to STS with the hope that studying practices of technology development could provide knowledge that would help to improve those practices. The decision to study eight different, but related cases of technology development practice provided an opportunity to look for lessons which might inform technology developers.

The most interesting common issue to the history of reading machine development seemed to me to be that of innovation. Some firms succeeded at developing a reading machine which was adopted and used by some blind people. Others failed. Given the axiom that no person, institution or society undertakes a development effort with the intention of failing at innovation, uncovering and explaining patterns of success and failure is an important task for STS research. At any rate, if there are actions or approaches which technology developers can take to reduce the risk of innovation and improve their rate of success, then most would presumably like to know them.

The problem of innovation is one which has been most broadly studied by the field of innovation economics. Their research has been largely, but not exclusively, concerned with industrial innovation within the firm, most recently within the context of international economic competition.[8] A growing, interdisciplinary interest in the problem of innovation within the field of STS is summarized in Robert McGinn's 1991 text, *Science,* *Technology, and Society.* As presented by McGinn, much of the interest in innovation outside of the discipline of economics has been in developing theoretical understandings of the relationships between technological and social change on the broad scale. He describes the work of Jacques Ellul and Langdon Winner which is concerned with the global impacts on society of institutionalized technological change, and that of Nathan Rosenberg which seeks to explain how Western societies have, over time, come to institutionalize an innovation system.[9] Jon Elster's 1983 study, *Explaining Technical Change,* presents an earlier critique of economic and social science macrotheories of innovation.[10]

This study's concern with the problem of innovation has more in common with the perspective of innovation economists than the social macrotheorists. Several STS researchers have been concerned with social aspects of innovation at this level, notably Wiebe Bijker and Trevor Pinch, John Law and Michael Callon,[11] among others. Their work, like that of some historians of technology, as described by John Staudenmaier,[12] has often been concerned with activities and social relations between individuals at the level of the user and the firm. Recently, Thomas Misa edited a volume of *Science, Technology and Human Values* devoted to issues of technological change, suggesting that a general theory of innovation can emerge only from the synthesis of such empirical accounts by historians, sociologists, and economists.[13]

It is the modest goal of this study to contribute to such a synthesis by providing some related accounts of innovation in the field of assistive technologies. The cases studied here have several features which should be of value and interest to a synthesis concerned with innovation at the level of the firm. Taken together, they comprise seven cases of development within six different firms, all concerned with the innovation of reading machines for the blind (Haskins Labs, RCA, Mauch Labs, Battelle, Stanford/TSI and Kurzweil). This is important, not only because of the relatively large number of cases for comparison, but also because the interactions of the firms with each other, and with individuals and institutions external to the firm, help us discover some of the characteristics of innovation as a social process.

In a recent article, Sørensen and Levold discussed the importance of "meso-level" institutions to the innovation process, that is to say organized groups of people which are larger in scope than the firm and the individual or corporate innovator but smaller than the state or global social units which comprise the domain of macrotheories of innovation.[14] The history of the innovation of reading machines for the blind is one where such meso-level institutions played important roles. They included an identifiable community of researchers, organizations and communities of organizations providing services to the blind, organized groups of blind consumers, philanthropic foundations, and federal government agencies, all of which played important roles in the development and innovation of reading machines for the blind.

The intimate involvement of federal government agencies as sponsors of technology development lends another dimension of interest to this study. Increasingly, since the Second World War, federal government agencies have sought to sponsor research to the benefit of the general welfare, or to the benefit of some target group within the general population. Examples include not only programs in the field of technology and disability, but in an immense variety of other areas including alternative energy systems, computer assisted manufacturing, fire suppression devices, police equipment, medical techniques and drugs, agricultural tools and methods, educational technologies – the list is endless.

Within the framework and rhetoric of "technology transfer" and, more recently, "defense conversion" and "dual use technologies," there has emerged a great debate over the value of federal investment in technology development based upon a perception that, in the past, large investments have not reliably, or even regularly, resulted in innovation to the benefit of the citizenry. The concern is universal within the federal government's science and technology community. NASA, for example, has established a large technology transfer effort which attempts on the one hand to export NASA-developed technologies, and on the other to justify space exploration based on the byproduct technological benefits. But problems of innovation are not exclusive to inter-sector applications. In my own experience, federal agencies as diverse as the Veterans Administration, the Department of Energy, and the Army Research Laboratory are concerned that their sponsored projects often pass through the development process without achieving innovation by a group of interested users.

Many case studies of innovation have been concerned with industrial innovation within a firm, where user and developer inhabit a common organization. Some have considered the innovation of consumer products by commercial firms, where sales departments provide a channel for communication between developer and user. Others have addressed the development of research instruments by communities of scientists, weapons systems within the Department of Defense, and new aircraft within the aerospace industry – all cases where institutions have evolved for communicating technical and social knowledge between developers and the intended users of an innovative technology. When government implements a policy of sponsoring technology development in order to benefit all or some group of its citizens, those institutions may not exist. In the case of reading machines for the blind, as we shall find, they did not exist. It is an inherent feature of government sponsorship of third-party research that at least three distinct interested parties are involved – the government sponsor, the intended beneficiary, and the firm conducting the research. This pattern is the norm for U.S. government sponsorship of technology development. It is a pattern of relationships which is more complicated than the cases of industrial or consumer innovation.

Part of the story of the development and innovation of reading machines for the blind is the discovery that certain developers did not understand the relationships between development and innovation. These developers were not particularly aware that something was missing in their concept of technology development and thus in their development practices – an ignorance which could have a deleterious effect.

Writing in 1985, Stephen J. Kline, a professor of mechanical engineering and of values, technology, science and society, at Stanford University, noted a lack of clarity regarding innovation, which he attributed to "the implicit use of an inappropriate model of industrial innovation processes." Specifically,

> The linear model views innovation as 'an orderly process, starting with the discovery of new knowledge, moving through various stages of development, and eventually emerging in a final, viable form.' This model has not been made explicit as a diagrammatic model in any publication this writer has been able to find. Indeed many scholars... are quite clear that they see the linear model as far too simple to be adequate. However, the linear model continues to underlie the thinking in many current speeches and much writing.... The common current name for innovation processes – R&D – also implies the linear model: the phrase itself suggests a direct and unique path from research to development and product. This continued use of the linear model very probably results from the fact that no other model has been available – discussions cannot proceed without talking about something.[15]

If an implicit linear model has characterized industrial approaches to innovation, it has also characterized R&D programs sponsored by federal government agencies.

One social consequence of a developer's ignorance of the innovation process can be a failure at innovation. The result can be the loss of invested time and money. This straightforward consequence was experienced by several of the developers of reading machines for the blind. A more problematic outcome can be the experience of unanticipated, negative social consequences of a technology subsequent to innovation. Often, this takes the form of benefits to one group in society at the expense of another, without the intent of the developers. A technology may even create new social groups based upon its differential effects. An example might be the distinction between blind people who can read braille and those who cannot. The limits of foresight constrain the extent to which developers can take such factors into account, but those constraints are not universal. It is a matter of common experience that developers do make design choices which influence the boundaries of the community of potential users. They also make design choices which seek to control the impacts of a technology on its physical or social environment. Even in the absence of perfect foresight, democratic governments which sponsor technology development have a responsibility to consider both the taxpayers' investment and the consequences of innovation to all sectors of society.

In recent years, government sponsorship of technology development has come under fire from both the left and the right. Liberal critics have been concerned with the differential impacts of technology on disadvantaged groups and the use of technologies to the short-term benefit of the few at the long-term expense of the many. Conservative critics have questioned the ability of government-sponsored research to benefit society on other grounds, claiming that only the private sector can bring new technologies efficiently to market and that only the economic marketplace should arbitrate technological innovation.

Both these perspectives seem to presume that technology developers cannot improve their practices in ways which enhance the likelihood and efficiency of desirable innovation. They incorporate a type of technological determinism which allows for political intervention at the national level to control or regulate the practice of technology development, but they neglect or overlook the potential for reform at the level of the firm and the individual federal sponsor of research. In short, they overlook the possibility suggested by Kline that some of the negative outcomes of technology development programs are the result of sponsors and developers' employment of a faulty understanding of the innovation process. If the innovation process often seems to be technology-driven, it may be partly due to the fact that developers act as if it is. If, on the other hand, the practice of technology development, properly understood, includes an element of social arbitration which is essential to innovation, then the democratic control of innovation may be more readily and thoroughly accomplished through reform of the technology development process rather than through political control at national-level institutions. Chapter 11, Practices of Technology Development and Innovation, addresses some of these issues based upon the limited, but productive example of federally-sponsored programs to develop reading machines for the blind.

As a final introductory word on innovation, it is important to note how the terms "development" and "innovation" are used here. Development is the less problematic term. By development I mean the systematic, reiterative and goal directed process of designing a tool for manufacture and eventual use by some group or category of persons. Development may be practiced by different people in different ways in different social contexts. The development practices considered here were conducted primarily by small teams of engineers and scientists working in industrial, commercial or university laboratories, although they also included testing and design recommendations by blind readers in schools, rehabilitation centers, and in the work place.

The term *innovation* has been used in different ways by different writers. Edward Roberts, for example, uses the equation, "Innovation = Invention + Exploitation."[16] Willem Dijkhuis, in contrast, suggests "Innovation is invention's child – if it is born," and "Innovation is the essential embrace of the results of science and technology."[17] Robert McGinn notes that *innovation* is commonly used in two different senses. On the one hand, borrowing from Everett Rogers, he notes that innovation may refer to "'an idea, practice, or object that is perceived as new by an individual or other unit of adoption,' such as a group or a whole society." At other times, innovation refers to a process, "namely that by which an innovation (in the first sense) comes into being and is distributed in a social system."[18]

John Staudenmaier tells us that historians of technology have come to understand the process of technological change as comprising three dimensions: invention, development, and innovation. The term, *innovation,* originated in a tradition of economic analysis and focuses attention on the entry of new technology into the marketplace.[19] I use the term *innovation* more in the sense of Dijkhuis and Staudenmaier, to mean the initial embrace of a product of the development process by some group of society. Innovation is the adoption by some group or category of individuals of a new tool and therefore it is the adoption of a new way of life.

A capsule history of reading machine development and innovation

It may be useful to readers to have an outline of the events considered in the following chapters in order to place each chapter in context. The following is a capsule history of the development and innovation of reading machines:

The idea of a reading machine for the blind was first described by Fournier d'Albe in 1913. His idea was that photosensitive materials, such as selenium, could be used to detect black print and convert it into an audible output which could be interpreted by a blind person. D'Albe built several models of his Reading Optophone which converted print into a six-tone scale. A small number of optophones were manufactured and sold in the U.K. by the Scottish engineering firm of Barr and Stroud. The device was known in the U.S. but not widely, nor was it commercially available here.

In 1943, Vannevar Bush and Caryl Haskins of the wartime Office of Scientific Research and Development (OSRD) decided to direct the resources of that office to the development of technologies to assist wounded veterans. They established a Committee on Sensory Devices (CSD), under the chairmanship of George Corner, a colleague of Bush at the Carnegie Institution. The program was managed by Haskins Laboratories. In addition to its management role, Haskins conducted research toward development of a reading machine, at one time seeking to develop an optophone-like, "FM-slit device" which embodied their initial research findings that a simple code carried as much information to a listener as a more complex one. At the same time, RCA worked to develop an improved optophone, designated the A-2 Reader. Haskins Laboratories turned sour on such "direct translation" devices, dropping development of the FM-slit device and discouraging innovation of the A-2 Reader. At the end of the war, RCA was working on a prototype machine which could "recognize" letters and spell out words. Only a single prototype was built. With the demobilization of OSRD, these early research programs came to a halt, although Haskins Laboratories continued its research into speech recognition and the generation of synthetic speech, under the sponsorship of the Carnegie Corporation and the Department of Defense.

In 1948, a Ph.D. engineer named Eugene Murphy joined the Veterans Administration as the first Assistant Director of Research of the new Prosthetic and Sensory Aids Service (PSAS). Murphy thought reading machine development should be continued. He also thought it was premature to abandon the A-2 Reader. It was 1957 before he could secure VA funding, but the program founded by Murphy worked continuously for twenty-one years toward the development of reading machines for the blind. It was initially a three-pronged approach. Battelle Memorial Institute was funded to develop an improved optophone. Haskins Laboratories was to conduct research toward eventual innovation of a synthetic speech reading machine. Mauch Laboratories was to work on an intermediate device to produce speech-like sounds, either an artificial language or spelled-speech. Murphy reached out to the service community serving blind people, in ways which the wartime OSRD did not. He also established a reading machine research community which provided a forum for developers and a common meeting place with the service community. In spite of his efforts, the PSAS program ultimately failed at the innovation of a reading machine for the blind, in spite of the fact that it developed several working prototypes.

Working closely with the reading machine research community, James Bliss and John Linvill conducted basic research in the field of tactile perception and circuit design for the control of tactile stimulators. They then developed the Optacon, a reading machine which converted print into a tactile signal, moving across an array of raised pins, like letters moving across the Times Square Sign. Failing to secure financial support from PSAS, this Stanford University team first took advantage of defense contracts before securing funds in 1967, from the new federal Bureau of Education for the Handicapped (BEH) in the Department of Health, Education and Welfare. They worked closely with a small group of blind readers to develop a manufacturing prototype, and then established a manufacturing firm, Telesensory Systems, Inc., (TSI) to bring the Optacon to market in 1971. Initial innovation depended heavily on purchases subsidized by BEH for schools serving blind students. By 1990, 12,000 Optacons had been sold at prices of about $3,000 each.

Raymond Kurzweil decided to develop a reading machine in 1973, to apply his interests and talents in computer programming and pattern recognition. Lacking any academic connection or prior contact with the reading machine research community, he raised venture capital from friends, relatives, and a corporate sponsor to build a prototype device. When the sponsor withdrew support, Kurzweil focused his efforts on a machine for the blind, and sought the participation of the National Federation of the Blind (NFB) in his development effort. Within four years, Kurzweil brought a synthetic speech reading machine to market. This was done without the advantage of a federal research grant, but not without federal support. Kurzweil Computer Products, with the help of NFB and the Blinded Veterans of America (BVA) persuaded BEH, the VA, and the Rehabilitation Services Administration (RSA) to purchase fourteen prototype machines for evaluation. NFB had secured donations from philanthropic foundations to buy the first five machines, a total of nineteen prototypes, which generated about $1 million in capital. In 1978, Kurzweil brought the Kurzweil Reading Machine to market. By 1990, 4,000 machines had been sold at prices from $12,000 to $30,000.

TSI and Kurzweil remained alone in the reading machine industry until the late 1980s, when the advance of microcomputer technologies brought new competitors into the field. The PSAS reading machine research program was abandoned in 1978, in the face of TSI and Kurzweil's success.

The following nine chapters seek to explain how these programs came about and how they were conducted, and with what results. Chapter 11 examines the case histories in order to seek conclusions about the relationships between the historical events of technology development and innovation of reading machines for the blind.

Section I. The Office of Scientific Research and Development (OSRD): Mobilizing Science and Engineering to Aid the Blind (1943 - 1954)

In 1944, the United States government undertook the development of reading machines for the blind, under the auspices of the Office of Scientific Research and Development (OSRD). OSRD was a wartime agency, directed by Vannevar Bush, which mobilized the efforts of civilian scientists and engineers, and applied them to the development of new technologies for fighting and supporting a global war. OSRD's agency for the reading machine effort was its Committee on Sensory Devices (CSD). CSD also conducted a program to develop travel aids for the blind, based on the reflection of light or sound from obstacles in the environment. This study will follow the development of reading machines alone. Their development and innovation proceeded in parallel with work on guidance devices. It was generally conducted by different research groups in separate laboratories and firms, without co-development or major interchange of problem-solving approaches.[1]

This section will consider the establishment of CSD and the committee's efforts to develop reading machines from January 1944 through June 1954, although CSD was largely reduced to an information clearinghouse after October 1947, when its major funding as a wartime agency was cut off. Two major groups of scientists and engineers were responsible for CSD's technology development efforts: Haskins Laboratories in New York City, and RCA Laboratories in Princeton, New Jersey. Between 1944 and 1945, their efforts centered on the development of direct translation devices, which convert a printed letter to an audible or tactile signal, based on the shape of the letter. The signal must be interpreted by the reader, and recognized as a representation of written English. Between 1946 and 1947, the focus of research and development shifted to recognition devices – machines which recognize print as a particular letter, and produce an output which is similar to speech.

There was no significant group of scientists or engineers actively pursuing the development of reading machines in the United States when CSD initiated its program in 1944. This meant that the CSD program created a research community. Such beginnings are important because they establish boundaries, conventions, and directions for the community. Chapter 2 describes the establishment of CSD as a new research community, and considers its relationships with other communities with interests in technology for the blind.

Within the new research community were administrators, advisers, evaluators and researchers. The major research on reading machines in the CSD period was performed by two firms, Haskins Laboratories and RCA Laboratories. Haskins Labs also served CSD as a program manager for both the reading machine and guidance device development programs.

The two laboratories brought rather different perspectives to the technology development problem. The principal staff at Haskins Labs were biophysicists and psychologists with a special interest in the psychology of auditory perception. They approached technology development as the application of scientific knowledge to a given problem, namely, how to provide an efficient reading device for people who cannot use their eyes for perception. Efficiency was, by and large, taken to be represented by the speed which a reader could achieve using the device. Chapter 3 first considers Haskins Labs' efforts to develop a direct translation reading machine – a technology which they abandoned in 1945. It seeks to understand why Haskins Labs rejected direct translation as a viable technology and turned its attention to the development of more complex recognition machines.

RCA, in contrast, approached technology development as an engineering design problem. Given a design concept, the problem became to select or create the right components to best embody that concept. Chapter 4 first provides an account of RCA's development of the A-2 Reader, a prototype direct translation reading machine. It then considers RCA's efforts to demonstrate the concept of a letter recognition machine, as proposed by Haskins Labs, by designing and fabricating a prototype device for the translation of text into spelled speech.

CSD operated from January 1944 through October 1945, as a committee of the Office of Scientific Research and Development. During demobilization the committee and its operations were transferred from OSRD to the National Research Council (NRC) of the National Academy of Sciences (NAS), with sufficient funds to continue its program through mid-1946.[2] OSRD's director, Vannevar Bush lobbied with Secretary of War Henry Stimson,[3] and with General Omar Bradley,[4] the postwar chief of the Veterans Administration, to continue funding the CSD research program, and funds were provided by the Army and the VA through fiscal 1947, when their direct support of CSD ended. According to A. A. Bombe, CSD's Technical Aide, the withdrawal of VA support for CSD Research was the consequence of a drastic reduction in Congressional appropriations for 1948.[5]

From 1948 through 1954, the committee survived on a small grant from the Kellogg Foundation. Between 1947 and 1957, former CSD contractors, including Haskins Laboratories, found research support from a variety of sponsors. The U.S. Army Signal Corps provided funds for the development of guidance devices. The Department of Defense and the Carnegie Corporation of New York funded Haskins Laboratories' research in areas related to synthetic speech and voice communications.[6] Efforts to develop reading machines for the blind, however, were largely dormant until revived by the Veterans Administration in 1957. These developments are the subject of Section II, below.

Chapter 2. The Committee on Sensory Devices (CSD): Creating a Research and Development Community

Prologue

In 1913, Edmund Fournier d'Albe, a British physicist, outlined his idea for a "reading optophone" in the journal *The Electrician.*[7] By 1917, he had built a prototype device which was demonstrated in the inventor's laboratory by eighteen-year-old Mary Jameson. Though blind from birth, she was able to use the device to read printed text at a rate of about one word per minute.[8] Active in the promotion of reading machines throughout her long life, by 1923, Ms. Jameson had achieved reading speeds of up to sixty words per minute, using an improved optophone.[9]

By rotating a disk with five sets of holes at different circumferential distances, the optophone separated light from an incandescent lamp into five vertically aligned beams. The light was pulsed through the holes at rates from 383 Hz at the bottom to 767 Hz at the top. The beams were reflected from a page of print, and focused on a selenium bridge. Selenium undergoes a change in conductivity as a result of the incident light – an inherent property of the material, first noted in 1873 by Willoughby Smith. The selenium bridge was connected in series with a battery and a telephone receiver, so that five tones were generated in the earphone (G, C^1, D^1, E^1, and G^1, or so, do, re, mi, so), based upon the frequency of the five pulses carried to the selenium by the five rays of reflected light. The focus of the light could be adjusted to span the vertical height of a line of print. Then, as the five vertical beams were moved horizontally along a line of print, the black portion of the letters would absorb one or more of the beams of light, and one or more of the corresponding tones would be interrupted. The letter, "I" for example, would first interrupt the highest and lowest tones, then briefly interrupt all five tones at once, as the stem of the letter passed under the beams, Then, once again the three middle tones would sound as the right side if the capital and pedestal passed under the probe. The letter "V" in contrast would make an arpeggio of silence, first descending then rising as the light probe traced out the letter.[10]

As a result of Mary Jameson's demonstrations, a Glasgow firm, Barr and Stroud, Ltd., undertook the production of a small number of optophones (see Figure 1).[11]

THE OPTOPHONE

OSRD - LIAISON OFFICE
REFERENCE NO.
..WA-1492...8B

1456

BARR AND STROUD, LTD., GLASGOW, SCOTLAND
LONDON OFFICE: 15 VICTORIA STREET, WESTMINSTER, S.W.1

Figure 1. The Barr and Stroud Optophone

The production model used six beams (adding F^1, or fa, to the octave). It also employed a second selenium cell, called a balancer, in opposition to the primary bridge. In this way, reflections from the white paper canceled the output of the balancer bridge, and the black portion of the letter generated the tones. Thus, the letter "I" would rise out of silence as low and high G, followed by a six-tone dissonant chord, and resolving again to high and low G. The letter "V" would be an arpeggio of sound descending from high to low G and back again.

Mary Jameson's eventual fluency with the optophone was remarkable. The reader was cumbersome to use and difficult to learn, and few people could achieve her skill. The device, never well-known, was not a commercial success in Britain, and was virtually unknown in the United States. In response to an inquiry in 1943, Barr and Stroud replied, "We discontinued making it several years ago and it is unlikely we shall resume manufacture of it. The optophone was used successfully by several blind people but it was difficult to get it introduced on account of the popularity of the braille system which was used in most institutions."[12]

At some time during the early development of the optophone, Fournier d'Albe was visited in London by a young Russian graduate of the St. Petersburg Institute of Technology, V. K. Zworykin – probably in 1913, while Zworykin was a postgraduate student in the College de France. The following year, with the beginning of the First World War, Zworykin returned to Russia to serve as an officer in the signal corps.[13] Thirty years later, in the second great war, now 54 years old and an accomplished, American research scientist, Zworykin remembered meeting Fournier d'Albe and he remembered the design of the optophone.[14]

Wartime Meetings

On Sunday, November 7, 1943, Vannevar Bush and Caryl P. Haskins met to discuss the possibility of launching a new research program to develop aids for the blind.[15] Bush, 53, had left his post as Dean of Engineering and Vice President of the Massachusetts Institute of Technology (MIT), four years before, to assume the presidency of the Carnegie Institution of Washington, D.C. In June 1940, as the European continent was falling to the German blitzkrieg, Franklin Roosevelt asked Bush to chair the National Defense Research Committee (NDRC) which, in June 1941, was merged into OSRD as its basic research arm. The NDRC chair was then assumed by James B. Conant, a former chemist and President of Harvard University.

Haskins, 35, was a biologist, whose doctorate was from Harvard. Upon graduation in 1935, he had founded Haskins Laboratories, a multidisciplinary research and development firm seeking to combine research in the physical and biological sciences, and also psychology. Haskins had joined the war effort as an NDRC Assistant Liaison Officer in 1940. He became head of the Liaison Office in 1942, responsible for information exchange with scientists in the allied nations. In September 1943, Haskins assumed the position of executive assistant to Conant. In March 1944, he would be named Deputy Executive Officer of NDRC.[16]

The Sunday meeting was to prepare for a discussion between Haskins and Zworykin, Associate Research Director of RCA Laboratories, in Princeton, New Jersey. Between 1927 and 1942, Zworykin's research group had been responsible for many of the patents underlying American television technology. Zworykin was a member of three NDRC subcommittees, through which his work was being applied to new uses including sniper scopes, reconnaissance systems, aircraft fire control, and improved radar.[17] According to Bush's memorandum of November 8, he and Haskins had previously discussed the subject of aids to the blind in some depth. Bush had also discussed the topic with Zworykin, who must have told Bush, as he later told Bush's staff, of his meeting with Fournier d'Albe, and of his inspection of the optophone in London, "many years before." Zworykin thought this early device was capable of great improvement.[18] Bush felt that Zworykin might lead such a project , and he asked Haskins to meet with him to explore the possibilities

Bush's memorandum appears skillfully crafted to serve three purposes. It established a justification for the expenditure of government funds for technology development, by claiming it to be war-related. The memorandum somewhat ingenuously justified its agenda as "...attempts to restore incapacitated individuals to the point where they can again aid in the war effort, which certainly puts the work in the scope of OSRD efforts." More realistically, it cited the possibility of post-war aid to blinded veterans. The memorandum outlined a strategy for the proposed effort: OSRD would pursue a simple, short-range objective, to be determined, whose success could lead to a postwar effort which might be funded by "some of the large foundations." Finally, the memorandum documented a priority claim to the technological ideas which Bush and Haskins had crafted prior to the meeting with Zworykin. As Bush put it, "While we will undoubtedly wish to follow Zworykin's own ideas, we have developed together a number of suggestions in our discussions which may well appeal to him, or suggest other approaches."[19]

Bush's idea was to use a beam of light, interrupted by a variable shutter, then reflected from an object to a collimated photocell, to provide information about the distance to the object. The reflected light striking the photocell could be converted to an alternating current, and amplified using small vacuum tubes. The current would then be converted into mechanical vibration, whose frequency would correspond to the distance of the object reflecting the beam of light. In the longer term, Bush thought, this concept could be combined with a scanner to provide a two dimensional tactile array, delivered to the chest or forehead of a blind user. Frequency response could be converted to amplitude by appropriate circuitry to improve intelligibility of the signal. Haskins elaborated this idea with the observation that a very small scanning device with finer optics could provide for close vision, and a very fine scanner, or light pencil, could be designed to read ordinary print. Since print could be kept at a constant distance, "the light pencil can be simply a fine conical beam with a single frequency of interruption, and the electric circuits correspondingly simple. It would be exceedingly interesting," Bush wrote, "to find out whether, if one used such a device to scan along some rather large type, the impression of sensation on one's chest or forehead could be made to substitute for the usual impression in looking at type of that sort to give any substantial fraction of the same mental response. If it could, then the possibilities are very farreaching indeed."[20] Although OSRD would not pursue this particular reading machine concept, Bush's idea would be independently stated and developed in the 1960s, by James C. Bliss (See Chapter 9).

There is no record that the planned meeting between Haskins and Zworykin actually took place. If it did, Zworykin declined the opportunity to lead an OSRD research program. We know from later discussions in April 1944, that Zworykin did have reservations about pursuing aids for the blind through OSRD – reservations concerning the conservation of patent rights, which would accrue to the government under a standard OSRD contract.[21] It seems more likely that Bush and Haskins had further thoughts about the best way to approach the development program, and cancelled the planned meeting. In any event, by December, 1943, they had agreed that the effort should be led, not by RCA, but by Haskins Laboratories.

The Committee on Sensory Devices

Haskins and Bush proceeded, according to standard OSRD procedures, by establishing a Committee for Sensory Devices (CSD), to initiate, direct, and evaluate research projects in the area of "rehabilitation of the blind and deaf, [with the understanding that] it might later go beyond this."[22] Bush appointed as chair of the committee, George W. Corner, M.D., 54, his subordinate at the Carnegie Institution, where Corner had been Director of the Department of Embryology since leaving the Professional School of Medicine and Dentistry at Rochester in 1940. In his instructions to Corner, Bush articulated an approach to research that explains his preference for Haskins Labs:

> Now a word as to the general philosophy of the approach to research in this area, as I see it. As you will notice from the general summary of literature in the field of mechanical aids to vision which Mrs. Auchincloss has prepared, a fair amount of work has already been done. Most of this, however, is relatively primitive in character, and has fallen far short of its goal. I believe that one cause of this may have lain in the approach which was made. The great majority of workers have approached their problem from the instrument side first, and have only secondarily considered the physiological and psychological requirements which condition and limit perception and interpretation. This seems to me dead wrong. Modern instrumentation is in such shape today that it can be counted on to produce an instrument to satisfy almost any reasonable set of conditions. This can be taken for granted. It follows, then, that setting the conditions that the instrument must satisfy, and setting them accurately, is the real core of the problem. That is a job for the physiologists and psychologists to tackle....

To avoid any doubt, Bush suggested to his subordinate that operational responsibility for CSD's research projects,

> ...might well rest with a Central Laboratory of the Committee, which should by preference be a rather small, compact, working group, operated on a non-profit and non-commercial basis. As I have already indicated to you, I feel that the Haskins Laboratories in New York City might be particularly suitable in this connection.[23]

In a departure from standard OSRD procedures, Bush continued, "For several reasons, I think it would be desirable for the contract with this central laboratory to be made directly with O.S.R.D," thus bypassing the National Defense Research Council and the Committee on Medical Research (CMR), through which contracts were normally administered. We are left to speculate about Bush's reasons. Perhaps one reason was to minimize awareness that CSD was engaged in research that did not directly benefit the active duty military. As Irvin Stewart, OSRD's Deputy Director said of CSD in 1948, "The problem of the rehabilitation of wounded soldiers was on the threshold of OSRD jurisdiction." OSRD also implemented a program to improve artificial limbs, but this work was performed indirectly, through a committee of the National Academy of Sciences

(NAS), by way of a contract administered by CMR.[24] Vannevar Bush's personal interest in electronic aids for the blind probably led him to seek a closer relationship than this. By having CSD report directly to him, Bush could indulge his interest while avoiding an intermediate level of review. He could also act directly, as he did, to steer the work to Haskins Laboratories.

Clearly Corner had some concerns about his instructions. Addressing Bush on December 29, 1943, he said, "I would appreciate a word from you regarding the relation of Dr. Haskins to the committee. His help will be needed, but if his laboratory is likely to receive contracts, I suppose he should not be a member. Should he receive any special designation to make his advice available from time to time?"[25] Bush replied tersely, "The relation of Dr. Haskins to the Committee is this. Dr. Haskins is the Executive Assistant to the Chairman of NDRC, in which his function is to advise and assist Dr. Conant and myself on various matters. I have asked him to take the initiative for all of us in the setting up of this program, and his advice therefore is and will be continually available whenever needed."[26] Corner did not raise the issue again, and an initial contract was executed between OSRD and Haskins Laboratories at an annual rate of $70,000.[27] Oddly, Conant's detailed memoirs, published in 1970, do not mention Haskins or his services. On the other hand, Conant credited Bush with a "revolutionary scheme" for transforming the relationship of university to government:

> Scientists were to be mobilized for the defense effort in their own laboratories. A man who we of the committee thought could do a job was going to be asked to be the chief investigator; he would assemble a staff in his own laboratory if possible; he would make progress reports to our committee through a small organization of part-time advisers and full-time staff.[28]

Assignment of the CSD contract to Haskins Laboratories may have represented an extreme version of this scheme, but not a departure from it.

There is no doubt that the Haskins organization benefited from its OSRD contract. During its first 20-month period, the Haskins Laboratory staff expanded from six people to twenty-six, and facilities were similarly expanded to include the third and fourth floors of its Manhattan building.[29] On the other hand, in June 1947, the firm had to reduce its staff from twenty-one to five with three part-time employees.[30] Although Haskins Laboratory benefited from overhead funds, the use of capital equipment, and knowledge resources generated by its contract, it did not take a profit for the work, and assigned all patents to the government. Thus, the decision to make Haskins Laboratories CSD's central laboratory might equally be understood as opportunism or service, in the context of OSRD's wartime mission. The scientific community was too small to segregate researchers from administrators, and most if not all of OSRD's staff and committee members were employed by the same academic and industrial research organizations which received OSRD contracts for research. What was unusual here was the fact that the resources, methods and means of a wartime agency were being applied toward social objectives that were military only by derivation. There is no evidence that Haskins or Bush had any desire for personal benefit from the project

Bush and Corner together recruited the other members of the Committee on Sensory Devices who were likewise drawn from the distinguished ranks of academic scientists. They were: Henry A. Barton, 45, a Ph.D. in physics from Princeton, who had worked at AT&T and Cornell University. In 1944, he was Director of the American Institute of Physics and Vice Chairman of the Division of Physical Sciences of the National Research Council; Anton J. Carlson, 68, Ph.D. in physiology from Stanford. Thirty-nine years as professor and professor emeritus in physiology at the University of Chicago, he was also a member of the National Research Council; Wallace O. Fenn, 50, Ph.D. in physiology from Harvard. For eighteen years a professor at the Professional School of Medicine and Dentistry at Rochester, he was a former member of the National Research Council; Stacy R. Guild, 53, Ph.D. in anatomy from the University of Michigan. He had directed the Johns Hopkins Otological Research Laboratory since 1927; and K. S. Lashley, also 53, Ph.D. in zoology from Johns Hopkins University. A professor of psychology and neuropsychology at Minnesota, Chicago, and Harvard, he had assumed the position of Director of the Yerkes Laboratories for Primate Biology in 1940.[31] As noted in 1946, by the anonymous writer of the internal *History of the Committee on Sensory Devices*,

> Obviously there were no scientific men already prepared by direct experience to lead work in this undeveloped and almost unheard-of field. The choice of chairman and of the specialties represented on the committee was based, presumably, on the thought that the projected studies called primarily for knowledge of the human organism combined with a high order of respect for physics and engineering."[32]

George Corner surrendered the chair in November 1948, at which time Henry Barton resigned from the committee. The chairmanship was then assumed by Dr. William E. Kappauf, Jr., a Princeton psychologist. Corner remained a member of the committee. There were no other changes in membership during CSD's ten-year lifetime.

Thus, it was the experience of global warfare which provided the stimulus, the resources, and a political rationale for government-sponsored, scientific research and development to create assistive devices for the blind. The impetus was not from individuals who were blind, nor from the established service institutions serving the blind, but from a small group of successful, middle-aged, male scientists and engineers who were in a position to foresee a successful end of the Second World War, and who perceived a post-war social obligation to provide for the needs of blinded veterans. As Lloyd Greenwood, a former B-24 pilot and a founder of the Blinded Veterans of America,[33] stated the case in 1950, "Countries which conscript their soldiery in order to wage world wars cannot morally turn their backs upon their thousands of war veterans. Thus, with the new concept of total war, came a new world group, 'the war veteran.'"[34]

Disabled veterans were not the only new group created by the war. The political act of creating of a Committee on Sensory Devices within the wartime Office for Scientific Research and Development was a foundational act. It established, in the United States, a community of scientists and engineers with interests in the creation of electronic assistive technologies for the blind, where none had existed before.

The research community and its social context

To claim that CSD established a new research community is not to say that there was no existing community with interests in aids for the blind. As documented by Frances Koestler in *The Unseen Minority*, subsequent to its establishment in 1921, the American Foundation for the Blind (AFB) had come to serve as the center of such a community whose roots were in the state schools, braille printing presses, and vocational rehabilitation programs serving blind persons, and whose leaders and innovators included many individuals who were blind. This service-oriented community was largely concerned with improving the art of braille printing and reducing its cost, improving the technology of personal braille-writing, and, increasingly in the 1930s, improving and disseminating the phonographic technology of "Talking Books."[35]

Examples of technology development and innovation within the service community include the development by AFB, and manufacture by the American Printing House for the

Blind, beginning in 1932, of a stereotyper for embossing braille on both sides of a page, thus cutting book size in half. Between 1932 and 1943, AFB and other agencies worked to improve personal braillers, resulting, in 1949, in the production of the Perkins Brailler, developed by the Howe Memorial Press of the Perkins School.[36] In 1932, AFB hired J. O. Kleber, an electrical engineer who had worked for RCA and Electrical Research Products, a Bell Telephone Laboratories subsidiary, to develop a phonographic "talking book." With support form the Carnegie Corporation, with the Library of Congress as a distributor, and, in spite of some opposition from the braille printing houses, long playing record players and their talking books were introduced in 1934.[37] The approach to the construction of "reading" and of "reading machines" by this "service community" was rather different from that of Bush's scientists and engineers, and its problems were often different problems. Reluctance by the braille press to support talking books reminds us that Barr and Stroud, in the U.K., attributed the failure of the reading optophone to the entrenchment of braille among blind readers and teachers of the blind.

At first the new research community was small, limited to the members of CSD and its contractors. None of its original members were drawn from the existing service community whose intimacy was actively discouraged. A policy of scientific detachment was set at the beginning by Vannevar Bush. According to the minutes of the first CSD meeting, in January 1944,

> Dr. Bush stressed the need for the Committee to go about its work quietly and avoid mention in the press because (1) the field is full of small concerns with inadequate scientific background. The public is likely to get misled. (2) The OSRD as a whole has managed to keep out of the public eye. The Committee could use the already existing machinery of classified contracts to protect themselves.[38]

That protection would later prove useful.

In April, Corner confirmed to Bush the wisdom of maintaining a certain distance from the service community. His choice of words indicate that he perceived the relationship to be primarily one whereby the service community would receive the products of the research community:

> There seems to be a great deal of something like jealousy between the various groups now working for the blind. There is also a great deal of resistance to new ideas and to outsiders who volunteer ideas of any sort. We must proceed with great care in approaching established agencies. I feel sure, however, that any useful device or program we may work out will be accepted in good time.[39]

CSD first contacted AFB in May 1944, some months after its research program had already begun.[40] On May 2, George Corner wrote to Robert B. Irwin, Executive Director of AFB, asking for a meeting. Corner explained, "The Committee of which I am chairman has been organized at the instance of Dr. Vannevar Bush, Director of O. S. R. D. and directed, as a wartime duty, to investigate the possibility that modern physics, engineering, biology and psychology, especially as developed during the emergency period, may have something to contribute in the way of aids to blinded soldiers."[41] Later, describing his meeting to committee member Henry Barton, Corner explained that if CSD wished to address talking book technologies, they must work with AFB.

> Perhaps these people, having an established program on their hands, are not 100 per cent open to brand-new ideas, nor can they support extensive research; but I think that after developing a little fuller contact with Kleber, his ideas and ours will stimulate each other and that we will be able to formulate a program using his practical experience with our fresh enthusiasm and our favorable position with regard to support of research and development.[42]

A year later, however, Corner declined to collaborate with AFB and the Library of Congress to address talking book technology, on the grounds that its problems were within the competence of the phonograph industry to solve.[43]

CSD records show that the new research community perceived itself as separate from the existing service community, having a fresh and separate agenda. Neither CSD nor its contractors sought to draw upon the knowledge of the service community in any significant way. The first systematic attempt by CSD to include the perspectives and the knowledge of the service community came at the end of its productive period, in 1949-1950, when Paul Zahl sought essays from both communities as contributions to his influential book, *Blindness: Modern Approaches to the Unseen Environment*, which also served as Haskins Laboratories' final report to CSD.[44] Those essays show that *Blindness* represented a starting point toward cooperation, not a milestone. As Zahl stated in his preface, "It was appreciated that there was no such compilation in existence, but moreover it was hoped that if representative specialists could express their views and describe their works between the covers of one book, perhaps any stereotyped attitudes or procedures could be reevaluated, and new ideas and technical projects and concepts examined for plausibility and usefulness."[45] George Corner's retrospective essay also underlined the separateness of the new research community, "The creation of the Committee on Sensory Devices represented a new trend in work for the blind, that is to say the volunteering of services for invention and development of aids to the blind, by the nationally organized scientific professions, impelled by general humanitarian motives rather than by direct experience with the blind."[46] As we shall see, the self-defined boundaries of the new research community had an effect on the course of its technology development and innovation.

Three observations remain to be made regarding the emerging professional social network whose creation and growth defined a new American community of technology developers of reading machines for the blind: The most notable aspect of this research community, as initially constituted, was the absence of any participants who were blind. This was an exclusion that would slowly be overcome over the next twenty-five years as the interests in innovation of the service and research communities converged. The first blind person to participate in the new community was Clifford Witcher, an exceptional man whose professional career cut across all of the group boundaries which divided the field of assistive technologies for the blind. A Ph.D. in physics from Columbia University, Witcher worked at Bell Telephone Laboratories during the war. He was recruited by Haskins Labs, where he worked on a sonic guidance device until demobilization in November 1947. He then joined AFB as a research engineer, hoping to add a scientific and engineering rigor to AFB's development program. As Koestler points out, there was irony to this match, since "years earlier the Foundation had turned him down for a scholarship on the grounds that scientific research was an unrealistic career objective for a blind person."[47] In fact, there would be few blind leaders in the field of sensory aids until the 1960s. The other notable exception was Thomas A. Benham at Haverford College, whose work was especially important in the development of guidance devices.

Second, there came into existence about the same time as CSD, a small, mostly separate, academic community with an interest in sensory aids. Based at MIT's Research

Laboratory of Electronics, this group had its origins in the development of communications theory. Its originators were Norbert Wiener and Jerome Wiesner, for whom applications related to blindness were primarily a field for the study and application of cybernetics. Wiener and Wiesner established a local project with the Perkins Institute for the Blind, to enhance tactile communications for deaf-blind children.[48] In 1950, they recruited Clifford Witcher who, according to Koestler, had been unable fully to pursue his interests within the context of a service organization.[49] Witcher found a place with Wiener and Wiesner at MIT, where he provided a focus for faculty interest in sensory aids until his death in 1956, at the age of 42. He pursued the development of guidance devices and utilized his knowledge of CSD's reading machine program to construct a simpler light probe device for reading meters and gauges, out of abandoned CSD components.[50]

Partly as a consequence of Witcher's untimely death, the MIT group, with its interests in communications theory and advanced electronics, did not play a major role in the development of sensory aids until the 1960s, when John K. Dupress, a blind WWII veteran, institutionalized a technology program with a focus on applications to blindness. Like Witcher, Dupress first worked through AFB, which he joined in 1958, as Director of Technological Research. Like Witcher, Dupress found it necessary to look beyond AFB for resources for research. But Dupress, whose degree was in psychology was a manager rather than a research scientist or an engineer, and he was professionally satisfied to work through third parties. Beginning in 1959, Dupress was instrumental in establishing a sensory research program among MIT faculty and graduate students. In 1963, he left AFB to become the founding director of MIT's Sensory Aids Evaluation and Development Center, where he remained until his death in 1967 at age 45.[51] Partly as a result of these two curtailed careers, MIT's major influence on the development of reading machines would be expressed more through its students than through its research faculty (see chapters 9 and 10).

Finally, it should be noted that the sensory aids research community comprised two related groups, one concerned with reading machines and the other with electronic travel aids. In November 1943, Bush and Haskins believed that these two technologies might be generated from a common base of scientific knowledge. Events proved otherwise, however, as technology development proceeded in different directions, in different laboratories, and from a variety of scientific premises. From the first, there was a tendency to specialize, which became greater as time went on. Only Haskins Labs and RCA received OSRD contracts in both technology areas. RCA's guidance device contract was performed by a different division in a different city, [52] and Haskins' work in guidance devices was limited to evaluation and testing. It did not include development. After wartime funding ended, Haskins continued its work in the area of reading machines alone.

By the 1950s, developers worked exclusively on one technology or the other, although program administrators at CSD and later at the Veterans Administration, typically had oversight responsibility for both. Consumers and consumer advocates, of course, were interested in both reading machines and travel aids. Consequently, professional meetings and conferences sponsored by administrative or consumer agencies might address both guidance devices and reading machines, and might assemble both communities in the same spot. But the two technologies were typically addressed in separate sessions of meetings, and reported in separate sections of review articles. The larger community for sensory aids was an aggregation of development teams working in one of two different technologies, not an aggregation of research teams with interests in both.

Although CSD was not important as a sponsor of R&D after 1947, the committee continued to play a crucial role in maintaining a community of scientists and engineers with interests in sensory aids until a federal research program was reestablished in 1957. Operating under a small grant from the Kellogg Foundation, CSD helped to sustain a sensory aids research community by, "putting inventors in touch with research literature related to their proposals, with other inventors, or with the U.S. Veterans Administration,..." and "handling mail requests for information on the status of sensory devices."[53] As CSD's correspondence files for the period 1949 - 1956 make clear, there was a continuing network of communications among a small sensory aids research community, whose center gradually shifted from CSD to the VA's newly-created Prosthetic and Sensory Aids Service (PSAS). Dr. Eugene Murphy, PSAS's first Assistant Director for Research, was a key figure in the transition. A July 1949 letter from Murphy to Dr. Wilma Donahue at the University of Michigan shows that Murphy was in already in close contact with the members of the research community established by CSD, and that he was working to establish a "well-balanced Program in aids to the blind, including the reading machine problem."[54] Bush's papers in the Library of Congress contain correspondence from Murphy provided as late as 1952, to "members, former members and friends of the Prosthetic and Sensory Aids Research Program.[55] Until Murphy was successful at reestablishing a federal research program within the Veterans Administration, CSD provided a communications network and served as an institutional symbol for the continuity of a community of scientists and engineers for the development of reading machines for the blind.

A summary

Subsequent to Vannevar Bush and Caryl Haskins' meeting in November 1943, a new American research and development community concerned with creating reading machines for the blind was established, literally from the top, down. For a complex variety of reasons, ranging from altruism to wartime duty, Bush and Haskins had the motive and the means to initiate a federal program to create sensory aids for the blind. Drawing on the elite of the scientific and engineering establishment which had been mobilized for war, they employed the resources of OSRD to establish a community to support the research program they had envisioned.

The core of the new research community was the Committee on Sensory Devices. CSD provided economic resources to the community and served as its communications hub. The committee also selected and screened potential members of the community. Two of its key decisions were to define its core membership as one of scientists and engineers, and to seek to maintain distinct boundaries between this scientific community and the established service community which had a long-standing interest in technologies for the blind. This "decision" was not the result of debate or deliberation. Rather, it was a product of consensus – a reflection of the presuppositions of the larger community of scientists from which the CSD subcommunity was formed: If science was to be brought to the aid of the blind, then only scientists could best judge how this might be accomplished. Blind people and those who provided services for the blind might provide advice on "practical" problems. They could test prototypes, but perhaps no better than sighted persons with blindfolds. They could receive the benefits of science. Individual blind scientists, like Clifford Witcher, could belong to the new research community by virtue of their being scientists. But boundaries were to be maintained between the research community and other groups which served or represented the interests of blind people. If too intimately involved in the development process, they were likely to inhibit or delay those benefits, because of their lack of understanding of science, and because of the potential interference of their "petty, political jealousies." As we shall see in the next sections, the structure of the new research community and the insulation it sought to shelter its scientific and engineering efforts were bound to affect the results of the technology development and innovation process.

Chapter 3. Haskins Laboratories: Technology Development as Applied Science

In January 1944, the Committee on Sensory Devices (CSD) proceeded to recruit and fund research teams to develop sensory aids. Three contracts were let for the development of guidance devices, while two laboratories undertook the development of reading machines. The two were Haskins Labs and RCA. Although their projects were interactive in several important ways, for the sake of narrative it is better to tell their stories separately. RCA's was an engineering development approach which sought to use advances in electronics to construct an improved optophone in order to more reliably, efficiently, and clearly convert print into sounds. Haskins Labs took a different approach, seeking to develop new scientific knowledge regarding the ability of human beings to derive information from sound, in order to define the desirable output for a reading machine of minimum complexity and maximum intelligibility. RCA started with a design concept and sought to apply engineering science to optimize the design, Haskins Labs asked what the minimum requirements for a machine might be, in order to develop a design that could satisfy those requirements. Let us examine the Haskins Labs experience first.

Some introductions

The principal investigators for Haskins Labs were Franklin S. Cooper and Paul A. Zahl. Both were close associates of Caryl Haskins from the time of their graduate student days in Boston. Zahl was a classmate of Haskins in biology at Harvard. Completing his Ph.D. a year later than Haskins, Zahl spent a year at postdoctoral research before joining Haskins Labs as staff physiologist in 1937. In 1946, he replaced Cooper as associate director of the laboratory.[1] Cooper, a cofounder of the firm, earned his doctorate in physics at MIT in 1936, and then spent three years at General Electric Research Labs before joining Haskins full time, as associate research director. Cooper was appointed an assistant liaison officer by OSRD in 1941, at the same time as Haskins, and he succeeded his colleague as Senior Liaison Officer in 1943, when Haskins became Deputy Executive Officer of NDRC.[2] Cooper's dissertation on the *Biologic Effects of Slow Electrons* complemented Caryl Haskins' work on *Genetic Mutations as Quantum Phenomena*,[3] and Haskins Laboratories was apparently founded to provide a vehicle for their continued research in biophysics.[4] As a result of his CSD experience, however, Cooper's career would take a new direction, focusing on interdisciplinary problems of human communications involving acoustics, linguistics, speech and speech perception – interests that originated in his effort to develop a machine that could read for the blind.[5]

Joining Cooper and Zahl in 1944, was Alvin Liberman, who had earned his Ph.D. in psychology from Yale University in 1943, where he continued to serve as an instructor before moving to Wesleyan College in 1946, and the University of Connecticut in 1949. Liberman and Cooper would remain research colleagues with shared interests in the acoustic basis for speech perception for more than thirty years. Zahl would return to his interests in natural history and conservation after the end of the CSD program.

Focusing on the FM-Slit System

Details on the early research of the Haskins group are scant, but Franklin Cooper's 1950 review article,[6] minutes of CSD meetings,[7] and Paul Zahl's contract report for the period February 1944 through October 1945,[8] provide a basis for reconstructing the project. In an effort to explore the conversion of print to intelligible sounds, Haskins Labs first sought to study the audible output of devices which modulate the frequency (pitch) of tones, or their amplitude (volume), as a function of the presence of black or white within areas of a printed character. As a group, these devices came to be known as *direct translation machines.* As early as June 1944, the Haskins group had prepared and filmed a simulation of several such machines, and concluded that frequency modulation was more robust than amplitude modulation. By April 1945, the group had built a simulator which could combine different types of slits, optics, and photocell circuitry to simulate the output of a variety of conceivable reading machine configurations. They used this simulator to prepare phonograph records of the performance of several types of reading machines, including the optophone, the RCA scanning device described below, and a Haskins design known as *the FM-slit system.* The recordings could then be used to test intelligibility of the different signals.

The FM-slit system produced a single-tone, sine-wave output, modulated in increments between 100 and 4,000 Hertz, according to the total amount of light incident on a photocell as reflected through a narrow, vertical slit. Thus, as the probe was moved across a letter, a characteristic, single-note "tune" would be generated which was much simpler than the six-tone optophone signal, but which bore no direct relationship to the shape of the letter. During 1944 and 1945, the research group used its simulator to test different slit configurations, the modulation of different waveforms, the provision of multiple tones (as in the optophone), and the production of consonant-like hisses and clicks based on risers and descenders of the letters, *b,d,f,g,h,j,k,l,p,q*, and *t*, but the simple FM-slit system was found to provide as intelligible a result as any. However, overall results were disappointing. After a year's research, Haskins Laboratories reported to CSD, "In a general way, none of these variations of the method of direct conversion of printed patterns letter by letter seem very hopeful, and Dr. Cooper is considering testing other possible methods involving the formation of word patterns, the recognition of printed patterns and consequent production of sound in the semblance of speech."[9]

About this time, however, the Haskins group decided to build a working model of the FM-slit device, perhaps to compare its unsimulated performance with the RCA A-2 Reader which was ready for testing at that time. The prototype consisted of a hand-held, cylindrical probe about three quarters of an inch in diameter and about six inches long. The probe was attached by a cord to a radio-sized box containing the circuitry which was in turn connected to a power supply and to a set of headphones worn by the user. The probe was held at an angle of 90 degrees to the paper, which was a photographic negative of approximately 20 point type, judging from a photograph included in a Cooper article of 1950.[10] One of Haskins Laboratories' employees was trained to use the device, with results that were astonishing.

In June 1945, Haskins Labs, in its role of central laboratory for CSD, hosted a meeting to review the reading machine project for the benefit of the Naval Medical Research Laboratories, which had expressed an interest in developing a reading machine of its own.[11] RCA's prototype was demonstrated at the meeting by a blind student from Princeton University who had been learning its use.[12] According to George Corner, who witnessed the demonstration, the student had not "fully mastered" the use of RCA's "well-engineered device." However, "unexpected progress" was demonstrated by "...one of the Haskins Laboratory employees using a device still in the laboratory stage" to "read previously unseen standard English at better than 30 words per minute."[13]

These exciting results led Corner to call a meeting of the full committee for July 18. According to the minutes of that meeting, this demonstration replicated the results of the previous month, as the test subject "...exhibited ability to read previously unseen material at a relatively high rate of speed, with considerable accuracy."[14] Corner's report to Vannevar Bush was less restrained. The subject, "a person of good but not abnormally high intelligence," had read at speeds of 170 to 220 words per minute. She could handle italics, and read in German as well as English. Corner attributed this success to Haskins' scientific approach, which subordinated the engineering aspects of the project to the psychological issues of intelligible signals.

Bush's reaction to Corner's reports was incisive. "A time comes in many developments when it becomes necessary to turn on the heat," he advised. "The results that you quote are so startling that it seems to me that we have probably arrived at a point where we need to do everything possible to expedite matters with the feeling that we at last have in sight a success that would warrant all of the effort." Corner should ensure that a patent application was filed. The necessary circuits must be added to allow the reading of positive prints. Bush asked Corner to arrange a briefing for him on the operating principles of the Haskins' device, but a handwritten postscript retracted the request while providing evidence that CSD had, in fact, constituted a community of researchers: "By chance," Bush wrote, "Zworykin [of RCA] dropped in, on another matter, after I dictated this. I now know how the device works. Also there is no doubt that his attitude toward the whole affair is exemplary."[15]

An exemplary affair

One CSD member, however, was plagued with a nagging doubt about the test. On August 1, Wallace Fenn wrote George Corner,

> I still find myself somewhat unable to believe the remarkable demonstration we saw in New York. It sounds silly, but I really would have liked to put a black hood over that girl's head and tie it under her chin just to be sure she wasn't peeking. I am sure all this has been tested by the Haskins Laboratory, but seeing is believing. It seems to me that she went over the first part of each line faster than one could understand the spoken word. I shall certainly be glad to know that some other subject has duplicated her performance.[16]

Corner responded that it was quite proper to be scientifically skeptical, and offered to arrange a test under Fenn's supervision. In any event, he would ask Zahl to apply a test the following week. While approving his skepticism, Corner also reassured Fenn, reminding him that Mary Jameson, in England, could read 60 words per minute with the optophone. The Haskins staff had watched its employee learn to use the FM-slit device, and was certain that all was well. Moreover, Dr. Zworykin had personally tested the goggles which kept the demonstrator from seeing the page she was reading, and was satisfied with the experimental set-up.[17]

But, unfortunately, Fenn's skepticism was well-founded. When Haskins Labs conducted tests using a different blindfold, their employee could not duplicate the results. As Haskins explained to Anton Carlson, "Much as I hate to do it, I have to tell you that we have ascertained by subsequent tests of a fairly exhaustive character, that the reading demonstration which [our employee] gave to the committee at its last meeting with our frequency-modulated reading machine was an entire fraud...." According to Haskins, this outcome was incredible to the entire laboratory staff. They had no suspicions of any sort. "The deception was a subtle and an ingenious one, and we were all entirely mislead [sic.] by it." Midway in her training, it seems, the employee had found a way to pry up her dark glasses and read a line ahead of the line she was scanning with the probe. "I am very, very sorry to have to report this to you, and I apologize deeply. It is clear that we were all fooled, and we are now thrown back to the point where we were in the tests before [the employee] began to show such spectacular results. We have some additional people on training now, and I hope that I may be able to report results from them before very long."[18]

This musty bit of scandal is instructive in several ways. First, the research community's apparent credulity can be understood as a testimony to their confidence that "science" could be applied to benefit the blind. Most of the research community was initially prepared to believe that the experiments showed that a simplified audible code could be interpreted at a rate of 200 words per minute, after only a few months' practice. Only Wallace Fenn suggested that a better interpretation of the Haskins' experiment might be that the subject was cheating.

A predisposition to believe in the potential benefits of applied science were manifest, for example, in a letter from CSD member K. S. Lashley to George Corner, in August 1944, reporting on his visits to Haskins Labs and to RCA:

> The RCA group did not impress me very favorably. I felt they had not demonstrated any real advance except in the obvious application of radio tubes, over the original optophone.... I was much more interested in Dr. Zahl's start toward analysis of the whole problem. As that is carried farther it should lead to a better evaluation of different principles and perhaps to a new approach.[19]

Vannevar Bush's comments on Haskins Labs' apparent success, before he learned of the deception, also illustrate how the scientists of CSD were eager to believe in the power of applied science. Bush wrote,

> I visited Haskins Laboratories a while ago and I was struck by the wisdom with which they seemed to be going about their problem. I was also convinced at that time, and so stated, that Zworykin's device, while a beautiful and ingenious piece of applied physics, nevertheless suffered under a serious handicap, inasmuch as it furnished information which was not necessary or serviceable for interpretation....[20]

Haskins Laboratories' exciting results were simply in line with Bush's expectations, and apparently those of Lashley, Haskins, Cooper, Zahl, and the research staff, as well.

The successful fraud also underlines the low level of participation of blind people or of the service community in CSD's technology development effort. Haskins Labs could have chosen to use a blind reader instead of a blindfolded one. This presumably would have prevented simple fraud, not only because of ability but because of interest of the reader. It might also have provided the research team with certain social knowledge regarding the characteristics of blind readers.

It is not as if CSD had no warning or advice: In January 1945, Corner wrote to A. C. Ellis, superintendent of the American Printing House for the Blind (APHB), informing him of CSD's interests in sensory aids. Ellis responded with a warning, "...that there are a great many people with impractical ideas on this subject," and with an offer to help CSD, by making available APHB engineers to review proposed devices.[21] In April 1945, just as Haskins Labs was beginning its testing program, Ellis told Corner that,

> [Reading machines] occupied a great deal of the time of several great scientists. I do not think any of them ever took the pains to consult a blind person or teacher of the blind about the limitations of the blind individual who must depend on either his sense of hearing or touch for his approach to literature. The advocates of these devices felt they had grasped revolutionary ideas that were thoroughly sound, and that anyone who raised a practical objection was a natural enemy. I suppose I have the largest collection of ideas and notions, devices, and gadgets suggested for the use of the blind. I

> examine every one of them patiently for some day an inventor is going to approach us with a perfectly sound idea....
>
> If I were permitted to make one suggestion, it would be as follows; All of those who would invent devices for the blind should first make a study of the blind man and his physical limitations before spending years of time and thousands of dollars in research.[22]

Corner confessed to Ellis that CSD was, in fact, pursuing research on the optophone and its variants, but, he felt that CSD was avoiding the errors of previous developers, by virtue of its scientific approach:

> We are very well aware that the instrument in its original form failed to be practically useful because of the human limitations of the user. We have therefore spent a great deal of time on the practical psychology of the signals, with trying out all sorts of variations. I make no predictions except that we can improve the Optiphone [sic.] enough to encourage further work.[23]

Members of the Committee on Sensory Devices, and the scientists at Haskins Laboratories saw the reading machine problem as one which could be informed by the science of human psychology. Indeed, their work was distinguished by its appreciation for the power of interdisciplinary science to inform engineering design. But this research community had little appreciation for the social aspects of technology, and they had no desire to obfuscate the process of scientific technology development by considering the uninformed perspectives and the petty politics of the service community.

Finally, we must consider the research community's response to the fraud, once it was revealed. The published record and all official reports lack any reference to the actual events of that summer. Subsequent to Fenn's correspondence with Corner, raising the possibility of fraud, CSD documents only allude to events by reference to personal conversations. Only a courtesy copy to Corner of Haskins' letter to Carlson, which survived in the correspondence files, makes direct mention of the fraud. If Anton Carlson had not been out of town when Caryl Haskins tried to inform him of events, there would be no written statement in CSD's files confirming that a fraud had occurred. Haskins' letter bears witness to a purposeful abridgment of the record with Corner's annotation, "Acknowledged and approved (long hand, no copy)."[24]

The reaction of the research community to this case of scientific fraud was to close ranks and to treat the event as if it had never occurred. Although it is tempting to speak of cover-up, such a characterization would be inaccurate. Rather, the effort was one to make amends, of containing the knowledge of an embarrassing incident within the family, while obscuring the event from outsiders who did not really need to know. And, in fact, the event was readily contained. Motive was not a problem. This was not a case of wartime or industrial sabotage. According to one report, it was a case of a secretarial employee trying and succeeding at pleasing her bosses with her performance.[25] According to another, the employee was reading subliminally, and was not herself aware that she was seeing the material in addition to hearing it.[26]

Knowledge of the fraud had been generally limited to insiders.[27] Nothing had been published or publicly reported. Bush's advice that "The Committee could use the already existing machinery of classified contracts to protect themselves,"[28] was an ironically accurate prediction. Because the activities of the committee had been classified as *restricted information*, knowledge of the apparent progress between April and July 1945, was limited to Committee members, contractors, Bush and Haskins. Except for Carlson, everyone who witnessed the demonstrations of June and July was personally contacted and informed of the mistake. Leslie Flory, project manager for RCA Laboratories confirms that Caryl Haskins informed Zworykin and him of the fraud, in person.[29] Both Haskins and Corner were apparently meticulous in fully accounting details of the fraud to Bush and to the members of the committee. Outsiders with some peripheral knowledge were simply informed that early indications of success had proved to be premature.

The research community apparently held its own members to be victims, not authors of events. Rather than investigating the project, or considering how its approach might have enabled the fraud, they sought to restore the *status quo ante*. This was true at the administrative level: In an August 31 supplement to the minutes of the 7th meeting of July 18, at which the ill-fated demonstration occurred, Corner wrote,

> Mailing of the attached minutes was purposefully delayed in view of the situation at Haskins Laboratories which invalidated the demonstration of the reading device given at the meeting.
>
> This matter has been explained to all members of the Committee. There is general agreement on the part of the Committee that the program of tests should be continued as planned before the disclosure. I have therefore

> requested OSRD to renew the contract with the Haskins Laboratories as unanimously voted by the Committee. Dr. Bush was fully informed and is in agreement with this action.[30]

We can only speculate as to how Caryl Haskins' dual role as President of Haskins Laboratories and Deputy Executive Director of NDRC might have influenced the way in which the issue was framed and the way the matter was administratively handled.

Subsequent to these events of the summer of 1945, Haskins Laboratories had little interest in the pursuit of direct translation reading machines. RCA Laboratories had proceeded, as directed by CSD, to engineer and build seven copies of the FM-slit device, designated the C-1, but these machines were never systematically evaluated.[31] In September 1945, with its contract renewed, Haskins Laboratories returned to the course projected in April, when initial studies with the simulator had indicated that letter-recognition machines might have disappointing limits. Research reports, books and articles by Cooper, Zahl and other members of the research community, without exception, present the decision to pursue word recognition machines as the inevitable conclusion of their scientific research. They do not mention that for four months in 1945, most of the researchers had reached quite the opposite conclusion. Because they do not mention this, they do not provide a record of how the "scientific" conclusion to reject direct translation technologies was actually reached. We shall return to this issue in the concluding section of this chapter.

In any event, after August 1945, Haskins Laboratories did not pursue the FM-slit device, and, as we shall see, they had no faith in RCA's development of the A-2 Reader. This does not mean that Haskins Laboratories lost interest in reading machines, however. The problem of generating intelligible artificial words, spelled-speech, or synthetic speech from print would occupy Haskins Laboratories for decades.

A secret but serendipitous meeting

In late July 1944, Bell Telephone Laboratories hosted an extraordinary demonstration for members of the Committee on Sensory Devices. The technology demonstration witnessed by Barton, Fenn, Guild, and Corner was classified SECRET, and the military application for the device was not revealed to them. Their host, Dr. O. E. Buckley, demonstrated a new device, called a sound spectrograph, which created a visual image from speech. Buckley believed that the sound spectrograph might have application to communications for the deaf. Bell Labs asked for CSD's approval of the concept, which would allow them to justify the use of wartime resources to develop the device as a sensory aid. They did not want CSD financial support, perhaps for the same reasons that RCA first resisted support of the A-2 Reader. CSD responded by providing the following statement:

> 1. The aim of Alexander Graham Bell to achieve complete and useful recording of speech sounds has actually been attained by these devices. Without the slightest question, they will be of vast service to the science of phonetics and linguistics. 2. Potential usefulness to totally and subtotally deafened members of the armed forces and to the civilian deaf depends on unexplored factors chiefly concerned with practical interpretation of the signals... which can only be answered by trial 3. The devices are already near the point of development which they can be used in teaching and improving speech. 4. For all these reasons, we are of the opinion that the Bell Telephone Laboratories are fully justified in carrying out experiments on the use of the apparatus, and the interpretation of the graphs, during the present war period, as a contribution to the possible relief of disability due to deafness in members of the armed forces.[32]

By November 1945, the sound spectrograph and its product of visible speech (see Figure 2), were declassified, and the *New York Times* reported that Bell Labs saw the device as providing a basis for telephone communications for the deaf. Six "girls" had been trained to read visible speech which appeared as a graph with frequency on the vertical axis, time on the horizontal axis, and intensity at a particular frequency indicated by the density of the ink, i.e., by shades of gray.

Although interpreting the graphs was hard to learn, the *Times* reported, "One congenitally deaf engineer is now able to read the patterns more easily than lips. His is probably the first case of a deaf man who talks over the telephone without the aid of a human interpreter."[33]

As late as 1963, Gale Smith, a Bell Telephone Engineer, called visible speech "the ultimate in communication for the totally deaf," but, he noted, the cost of the technology had limited its use to experimental installations.[34] In June 1964, however, AT&T unveiled the Picturephone, and the concept of visual speech as the basis of a sensory aid for telephone communication was defunct.[35]

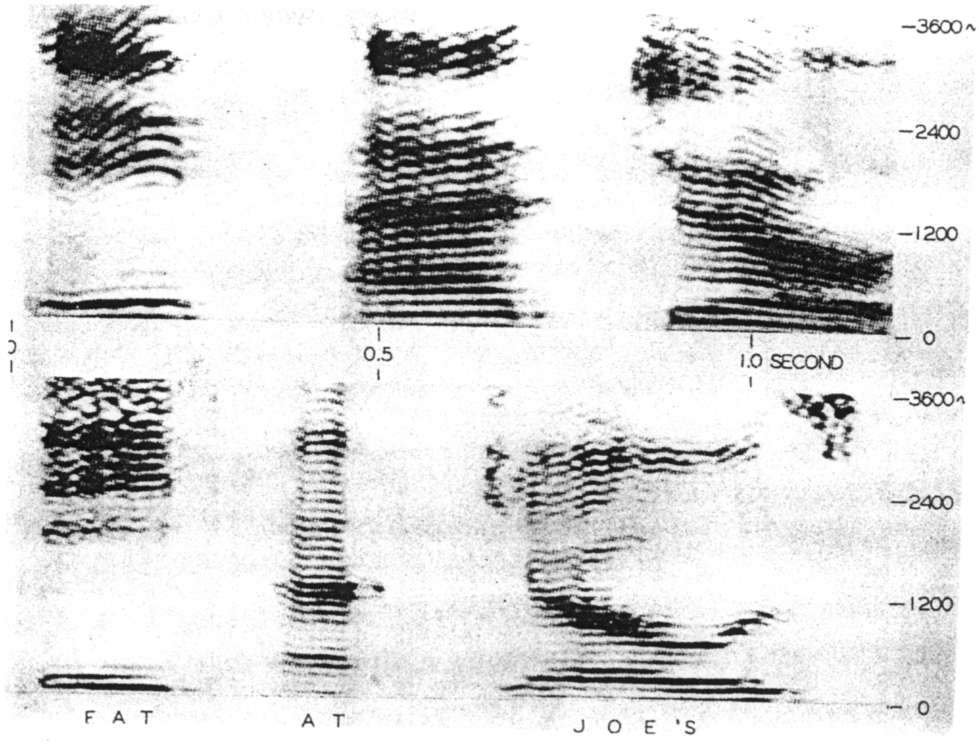

Figure 2. Spectrogram of Visible Speech[36]

Franklin S. Cooper, however, saw a different use for the sound spectrograph – as a research instrument for investigating the information content of speech. As Cooper explained in his 1950 article, a sound spectrogram provided a superior way to graphically represent speech. A comparison of spectrograms of different speakers repeating the same sentences revealed distinctive variations among words. It seemed to provide direct access to the information content of spoken language.

In a spectrogram, the number of distinctive variations per word was small – corresponding roughly to three elements per phoneme. (These elements came to be called "formants" of speech.) Therefore, Cooper reasoned, where it takes about fifteen distinct elements to depict a five-letter word in Morse code or with the simplest direct translation devices, sound spectrograms showed that spoken English reduced a short word to three to six elements (See Figure 3). Spelling out a word, Franklin reported, required about two distinct elements per letter, or ten per five-letter word. Assuming that a limit to auditory intelligibility was reached when sounds approached 750 - 1,200 separate elements per minute, Cooper concluded that direct translation devices which encoded each letter into three or more elements must have an upper limit of 50 to 80 wpm. Machines that generated speech, or sounds that resembled speech in the number of distinctive elements per word, might be intelligible at reading rates over 200 wpm. Machines that spelled out words, letter by letter should have an intelligibility limit of 75 to 120 wpm.[37] Thus, Cooper established a hierarchy for the utility of reading machines, based on their theoretical maximum reading rate. This hierarchy would define the field for thirty years.

Based on such an analysis, Cooper concluded that two types of reading machine were feasible. "The integrating type of direct translation machine" would collect all of the available information about a word from its printed letters and, integrating this information, produce a sound, corresponding to the word, that was "speech-like in character, though not reminiscent of spoken English." The recognition machine would identify letters and use this information to produce phonemes in word units which resembled spoken English as nearly as possible. The current need, Cooper maintained, was for scientific research to acquire a complete knowledge of "the physical characteristics of complex sounds which confer a speech-like character."[38]

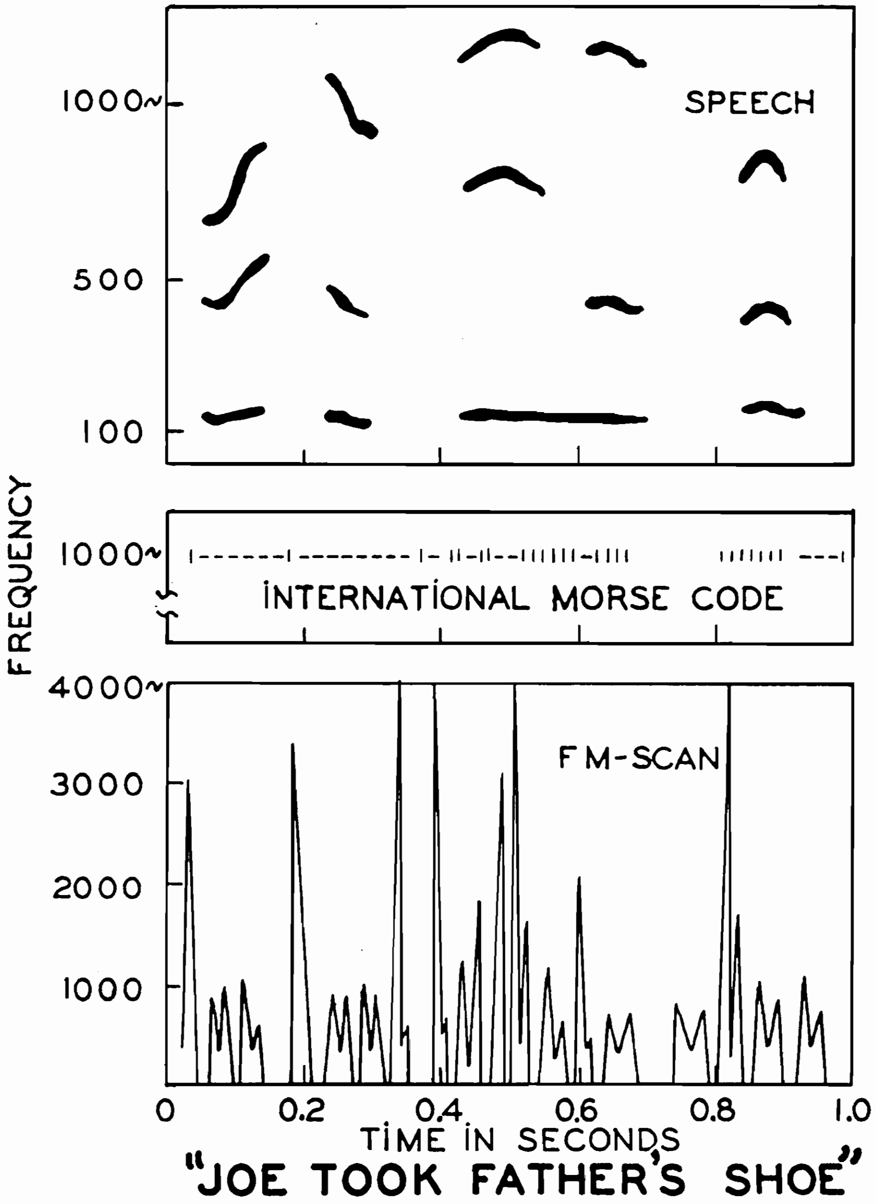

FIGURE 2. A simple sentence depicted as a stylized spectrogram (top) of speech; (middle) in Morse code; and (bottom) by the "slit-scan" type of reading machine.

Figure 3. Elements required for interpretation by type of audible signal[39]

Cooper was explicit about the basis for this research program: "The rationale for these studies is most simply stated in terms of the two principal instruments required: the *sound spectrograph* and the *pattern playback.*" Where the sound spectrograph converted speech to graphic images, the pattern playback converted graphic images to sound. An experimental method followed: The sound spectrograph could be used to generate graphic depictions of speech. Distinctive features in the graphs were to be detected by observation. The spectrogram could then be modified, by painting and erasing, and the modified image reconverted to sound by the pattern playback. Thus, research could determine the "categories of physical characteristics which the ear habitually uses for discrimination." Employing a sound spectrograph based on Bell Laboratories' design, and a playback device developed in-house, Haskins Laboratories first sought to develop scientific information to support development of a reading machine for CSD, and later secured funding from the Carnegie Corporation of New York to continue research using equipment developed under the CSD project.[40] Funding was also secured from the newly created Department of Defense (DoD).[41]

Correspondence among Cooper, Bush, and Haskins regarding this research continued into the mid-1950s. Bush's papers include at least four preprints provided by Cooper, all of which used the sound spectrograph as the basis for research.[42] A 1954 letter from Cooper to Bush reveals that DoD's interests were in the reinforcement of speech in a noisy environment, speech compression so that more information might be provided per unit of time, and in converting sound to a series of pulses which could be transmitted by wire or radio, and then reconverted to speech – that is to say, analog to digital conversion and transmission of speech.[43] Thus, when the Veterans Administration revived research into reading machines for the blind in 1957, Franklin Cooper and Haskins Laboratories were able to bring to the program current knowledge based on a continuing effort for these new research sponsors, as described in Chapter 8.

By 1946, Cooper had discounted the possibility of an effective direct translation device, and a machine to produce synthetic speech was no more than a technological idea. It might be possible, however, to build a device which would recognize the letters of the alphabet, and, based upon that recognition, activate a recording of human speech or a speech-like sound. Based upon these considerations, and his intuition that speech was a uniquely effective acoustical signal for conveying information, Cooper sought to persuade RCA to build a prototype of a recognition-type reading machine.

4. RCA Laboratories: Technology Development as Engineering Research

Although V. K. Zworykin was associated with the CSD effort from its beginning, RCA Laboratories did not reach an agreement to work with OSRD until August 1944. Negotiations began in March, when Henry Barton visited Princeton and confirmed to the committee that Zworykin would like to devise a machine which would improve upon the optophone. Corner arranged that the next CSD meeting take place at RCA Laboratories.[1]

At that meeting, Zworykin presented CSD with a smorgasbord of technological delicacies, including a benchtop model of an improved optophone, a light probe, and a partially completed supersonic obstacle detector. E. W. Engstrom, Research Director for the firm, told CSD that RCA would like to pursue these devices, but not at the cost of surrendering patent rights to the U. S. Government.[2] The problem was brought to the level of Vannevar Bush, whose first response was that CSD could provide interested firms such as RCA with public information on devices and their application, advice on project organization and direction, and services to test and evaluate prototypes, but, in the absence of a contract, could not provide information derived from other OSRD contract research.[3]

Caryl Haskins was also involved in discussions with RCA, in his role as Deputy Executive Officer of NDRC.[4] Loren Jones, RCA's negotiator, was apparently concerned about Haskins' dual role as both administrator and competing research contractor. On August 7, Corner wrote Jones to reassure him that Haskins Laboratories was serving CSD as a central laboratory for the study of "...some of the basic physical and psychological problems necessary for proper design of the kinds of devices we are interested in." Haskins Labs would not develop devices to the point of practical use, but would pass them off to other contractors, such as RCA. Zworykin's group, Corner assured him, could only benefit from such an arrangement.[5]

CSD and RCA were able to come to terms, when Bush and Haskins agreed to accept a contract form whereby patent ownership was retained by the inventor, subject to the Government's right to royalty-free use of any resulting technology.[6] RCA accepted Haskins' role as a central laboratory. An initial budget was established at $20,000 per year, and a contract was executed, effective August 15, 1944, authorizing the first six months' effort.[7]

The A-2 Reader:

For four months, Zworykin seemed to follow the CSD plan, which called for RCA to cooperate with Haskins Labs to determine the optimum output signal for a reading machine. In January 1945, however, Zworykin complained to George Corner that "The entire time up to date has been spent in cooperation with the Haskins Laboratories in the preparation of test material in the form of phonograph recordings." Zworykin continued, "We feel, however, that the success of any of these instruments will depend not only on the type of signal delivered, but also on the development of an electrical circuit and optical system which is compact and extremely simple to operate." He asked for permission to proceed to build a prototype based upon one of the several signals being tested.[8] Corner gave that permission, and by April 21, Paul Zahl and A. A. Bombe, CSD's technical aide, were able to visit Princeton and see a prototype of the A-2 Reader.

The A-2 was the improved optophone that Zworykin proposed to Vannevar Bush in late 1943. Although Zworykin asked permission to build the device in January 1945, he had, in fact, filed internal invention disclosures to RCA's patent department by October 1944.[9] Bombe reported to Corner that Zworykin felt his prototype should immediately be put to test by blind users to determine the acceptability of its "Woozy language" output, its speed, its manipulability, and the utility of its controls. RCA had already made arrangements to hire a blind student from Princeton University to conduct such tests. Zworykin proposed to assess test results and make any consequent design modifications on his return from Europe, in June. According to Bombe's report, Zahl did not want to rush things: "Dr. Zahl was only concerned that the student be cleared from a security angle, as it would not be desirable to divulge the present status of this apparatus to the Press. The thought was expressed by Dr. Zahl that RCA might be planning to stress their reading machine development as a publicity stunt, and that frankly the development had not reached the stage where that was desirable."[10] It was about this time that Haskins Labs undertook to build its own prototype of the FM-slit machine.

In July, Zworykin reported that engineering work on the RCA A-2 Reader was complete. He asked that remaining contract funds be used to produce a dozen sets for evaluation. After seeing the amazing demonstration of Haskins Laboratories' prototype, however, CSD recommended that instead of building twelve of its own A-2 design, RCA build five A-2s and seven sets of the Haskins' FM-slit device, henceforth labeled the C-1. The competing designs would then be tested by Haskins Labs.[11]

The prototypes were built, but comparative testing never took place. Interest in the C-1 quickly waned, when the fraud became known and Haskins Labs ceased to champion the FM-slit approach. CSD later authorized the fabrication of the additional A-2s. RCA reported that a total of fourteen A-2s and seven C-1s were fabricated under the CSD contract.[12] Neither the A-2 nor the C-1 were ever brought to production.

The A-2 reading machine may best be understood as a completely re-engineered optophone. It applied new electrical components and new techniques for optical scanning to re-embody the concept first stated by d'Albe, thirty years before. The Barr and Stroud optophone was the size of a sewing machine (See Figure 1, above). Its cast aluminum frame supported an optical probe and simple conversion circuitry, mounted on a two-axis tracking mechanism. A removable superstructure sat on the frame and supported a glass plate above the probe and tracker. The user placed a book or page to be read upside-down on the glass plate, while turning handles to operate a mechanical rocker which moved the probe along a line of print, and a linear tracker which moved the probe and rocker assembly down the page. Power for the lamp and electrical circuit was provided by a battery of dry cells, totaling 80 volts – large enough to be kept on the floor.[13]

The A-2, in contrast, weighed only five pounds. A box the size of a portable radio held a small storage battery and circuitry for generating the audible signal. It was connected by a cable to a probe the size of a small flashlight or a large cigar, which contained the miniature phototube, a two-stage amplifier, a 30 Hz oscillator, and all of the optical elements. The user would draw the probe along a line of print, with the guide of a movable straight edge, if desired (see Figure 4).

Where the optophone used a rotating disc to modulate six discrete beams of light, the A-2 used a continuous scanning technique. A single beam of light was directed by a vibrating mirror, up and down a line of print at a rate of 30 Hz. An oscillator, generating audible frequencies from 300 to 4,000 Hz, was magnetically coupled to the mirror vibrator so its tones were varied synchronously with the mirror, and the tone was thereby related to the vertical position of the beam of light. Where the optophone used a simple circuit with a telephone speaker which responded directly to the current generated by light incident on two selenium bridges, the A-2 used a Lucite light conductor to convey reflected light to a miniature phototube, which generated a small electric current which was amplified by vacuum tubes in three stages. The resulting current controlled the release of the synchronously generated audible signal to the earphone.

Figure 4. The A-2 Reader in use[14]

As with the optophone, black areas of print generated tones of a characteristic pitch. Upper parts of a letter generated high frequency tones and lower parts of a letter generated low pitched tones. But instead of six discrete sounds, the A-2 provided a continuous (or discontinuous, depending on the letter shape) range of frequencies over a larger frequency range. Its audio signal had a characteristic quality, commonly referred to as "chirping," or "tweeting," which was the result of scanning over a continuous spectrum. The probe was set to slightly overscan the line of print, so that the overall range of tones would vary up or down in pitch if the user began to move the stylus at an angle to the line of print.[15]

By all accounts, the A-2 was an extremely well-engineered device. Several technical problems had to be solved in order to build the device. The development team fabricated both a benchtop prototype and an A-1 version, as part of the design process. In the course of development, the design team developed a mechanical frequency modulator which generated a beat frequency necessary to obtain reliable frequency change over the output spectrum of the reader. A Lucite light collector was shaped to collect reflected light over a wide angle and, through internal reflection, deliver it to the phototube.

At first, no adequate phototube was available, and the A-1 was built using a selenium cell. Later, a developmental tube, labeled C7112 was substituted for the selenium cell. This tube, the size of a .22 caliber bullet with photosensitive material in the tip, was provided by RCA's Electron Tube Division in Lancaster, Pennsylvania, for use in the A-2 prototype. It gave superior performance due to the absence of a remnance current and sporadic bursts of noise which characterized the selenium cell.[16]

According to the recent recollection of Leslie E. Flory, the project engineer, the decision to utilize spectral scanning in the A-2 followed from the decision to use a phototube rather than a selenium bridge as the detector. The decision to use an advanced phototube supported a portable system, but eliminated the possibility of multiple photodetectors operating at different frequencies.

The C 7712 phototube later became a commercial product. Indeed, it was the possibility of this type of spin-off benefit from engineering development which provided RCA's principal motivation for participating in the reading machine program. According to Flory, in-house commercialization of the A-2 Reader was never a practical consideration. RCA was primarily interested in commercial products which could be mass produced, and the perceived market for the A-2 Reader was not large enough to attract the interest of the firm's manufacturing arms. There was some hope on the part of the development team that another firm with different business objectives might become interested in licensing the device, but marketing by the engineering team was limited to demonstrations at professional meetings. No licensee ever appeared.[17]

Evaluation of the A-2

In January 1947, CSD voted to lend three A-2 Readers to the Institute of Human Adjustment at the University of Michigan for evaluation.[18] In the 1954, Final Report of the Committee on Sensory Devices, William Kappauf stated that this evaluation project determined the device to have a maximum reading rate of 50 wpm. He then explained, "A rate of at least twice this is considered the minimum for a useful reading device. Accordingly, there has been no further engineering work on the A-2 Reader."[19]

Where did this standard came from? Kappauf provided no reference, but he was repeating a paradigmatic statement of knowledge developed by Haskins Laboratories in 1945 - 1947. Haskins Laboratories' final report was printed under the title, *Blindness: Modern Approaches to the Unseen Environment,* with support from the National Academy of Sciences in 1950, and republished in 1963 and 1973. Franklin Cooper's article on reading machine research contains a section subtitled, "The User's Requirement and the Engineer's Dilemma," which asserted that there were two "prime requirements" for a successful reading machine. The first was that a successful machine "must use the existing printed materials designed for sighted readers." The second was that a machine permit reading "at a reasonably rapid rate." In attempting to specify such a rate, Cooper suggested a "rule-of-thumb conclusion that the machine should permit a reading rate of not less than 100 words per minute for the average, well-trained user."[20]

Where did this rule of thumb come from? Was it developed from a survey of blind persons? From conversations with teachers of the blind? From studies of reading rates in braille? From a consideration of the utility of Morse Code? No, the criterion was derived from the following consideration. Lacking any "reliable a priori basis for selecting an optimum reading speed," Cooper noted that speech rates for English range from 120 to 200 words per minute. Employing an implied minor premise that a reading machine with audible output should operate within the range of rates of spoken English, he concluded, "The minimum desirable rate for a reading machine would appear therefore to be something of the order of 100 words per minute with the optimum rate at perhaps 150 to 250."[21]

This criterion was generally quoted and not actively questioned within the research community during the CSD period. Even RCA Laboratories, which had vested interests in a different criterion, accepted 100 wpm as a paradigmatic criterion. In their final report to CSD, in July 1946, for example, RCA justified its development of the A-2 as an interim step to gain knowledge of "actual equipment for reading," continuing, "It was of course realized that an ultimate reading machine should have as a goal a speed of at least one to two hundred words per minute."[22] While expressing a belief that direct translation devices warranted further testing before being rejected, RCA nonetheless agreed that future work should concentrate on technologies which could produce more speech-like sounds.[23] The 100 wpm criterion had become a standard for the research community that was repeated in reports by Haskins Labs, RCA Labs and the chairman of CSD.

There is evidence which suggests that the 100 wpm standard would have been insupportable if the boundaries of the CSD community had been differently defined, or if those boundaries had been more permeable to social knowledge from the service community. In his 1954 report, Kappauf may have dismissed the findings of the University of Michigan's evaluation project too lightly, or perhaps he did not have access to full information. A final report was never submitted, but in August 1949, Wilma Donahue, in response to a request for information from Eugene Murphy of the Veterans Administration, said that the A-2 was relatively easy to learn, although complete accuracy was hard to obtain and it was "necessary to depend on context more than is desirable." Donahue suggested that some students, reading at rates over 35 wpm, had passed beyond interpreting letter by letter, to interpreting by word patterns. She concluded, "At this time, we are of the opinion that the word and phrase method of teaching which we will study next, will produce more efficient readers."[24] In 1971, Murphy reported that Donahue's draft report had indicated that,

> Numerous subjects of various ages, periods of blindness, causes of blindness, and occupations were able to learn to decipher typewritten and printed material, even though many of them had no prior experience with printed letter shapes.
>
> Reading speeds, learning speeds and comprehensions varied greatly but some subjects attained 93 - 100 per cent comprehension of new words at 36 wpm and 53 - 90 per cent comprehension at 56 wpm....
>
> While all subjects would prefer an instrument which permits more rapid reading, they felt that an instrument with a maximum reading speed of 30 to 40 wpm would be extremely useful.[25]

There were other indications that a practical reading machine might operate more slowly than 100 wpm. In January 1948, RCA Labs demonstrated the A-2 Reader at Valley Forge General Hospital, under the auspices of Mrs. Irene Mansure of the Poor Richard Club of Philadelphia. Mrs. Mansure, who was active in volunteer service, was a Russian-born friend of V. K. Zworykin, and the wife of a Philadelphia businessman. Apparently, Zworykin hoped to interest Philadelphia businessmen in funding the production of additional A-2 Readers for rehabilitation work at Valley Forge.[26] The demonstration was attended by 15 to 20 blind veterans as well as doctors, nurses, and staff of the hospital.

Dr. Donahue was there with a colleague, in addition to the RCA group and A. A. Bombe, who reported on the demonstration. The veterans expressed a great deal of interest in the machine, and all who were not completely bedridden tried it out. According to Bombe, "Mrs. Mansure seemed very well pleased with the meeting and the interest shown by the veterans, saying that the machine exceeded her expectations. I had told her of its limitations during various telephone conversations concerning arrangements for the meeting."[27]

Corner may not have remembered Bombe's January report when, in November 1948, Mrs. Mansure asked him for permission to publicize the work of CSD as part of a campaign to raise money to provide A-2 Readers to blinded veterans. Corner began his response by noting the speed limitations of the A-2, and stating that CSD understood such a reading rate to be inadequate for effective reading by the blind. He continued,

> We have therefore not been willing to put the instruments into the hands of blind users outside a small group employed by RCA and the University of Michigan frankly as experimental subjects. We are afraid in the first place of building up hopes in the minds of blind persons which cannot be fulfilled at present, and in the second place we have not thought it advisable to burden them with the work of learning a code which will probably be altered in future designs....
>
> In a conversation with me in Philadelphia last month you told me that a number of blind veterans and civilians with whom you have been working have become deeply interested in trying the instrument and that even with its present limitations many of them feel that a rate of 25 words per minute would give them benefits justifying the labor of learning the code.
>
> These are stimulating hopes which ought to be cautiously followed up. I am sure however that I could not get the consent of the Committee on Sensory Devices to give National Research Council support... to a campaign to publicize the work in order to collect money for the construction and use of more of the instruments.[28]

Corner's attempt to discourage any campaign to purchase additional A-2 Readers was effective. Mrs. Mansure responded,

> In view of the fact that you state in your letter, and because I would not like to get into any project not supported and approved by you and the Committee of Sensory Devices [sic.], I propose to postpone our promotion of the Reader and its demonstration at the Poor Richard Club.
>
> My enthusiasm for the project has been based on my great desire to give the fellows at the hospital another constructive, helpful occupation, as well as their reception of the Reader. Having watched the various demonstration of Dr. Zworykin and Mr. Flory, I had assumed the Reader to be a practical instrument.
>
> Now I see that it may be wiser to wait until more research is done on the subject, as it would be embarrassing to get all this publicity, and put so many people to a great deal of trouble, without having a completely workable project.[29]

When the A-2 prototype was put in the hands of blind readers in 1948 and 1949, it elicited interest, even enthusiasm, and testimony to the potential utility of a device that supported reading at rates well below 100 wpm. But communications across community boundaries were weak, and the anomalous evidence from the service community was confronted by an established standard of the research community. By 1948, government funding had disappeared, and there was no interest at RCA in financing the further development of reading machines. Dr. Donahue's evaluation did not affect the fate of the A-2 reader, but, as we shall see in Chapter 5, it did play a role in reviving research into direct translation technologies under VA auspices in the mid-1950s.

Toward Recognition of the Printed Word

Zworykin and Flory were not eager to abandon the A-2 design, but in late 1946, at the urging of Cooper and Zahl and with the provision of additional funds from CSD for that purpose, RCA Laboratories turned its attention to the design of a reading machine that could produce speech-like sounds. In this way, Cooper hoped, it would be possible to overcome the rate limitations of direct translation devices like the A-2 reader.[30] This project produced a remarkable prototype device, which its designers believed to have been the world's first optical character recognition machine.[31]

In May 1946, A. A. Bombe and Franklin Cooper visited RCA Laboratories to review the status of the A-2 Reader project. Bombe reported that Zworykin and Flory wanted to continue to test the A-2 for at least six more months in order to learn if its potential of 50 wpm could in fact be reached. Cooper did not see the point. Why conduct research to establish the performance boundaries of an unworkable concept? Zworykin and Flory were not fully convinced that the A-2 was an unworkable concept, but they agreed, at Cooper's request, to design and build a machine that could recognize letters and produce speech-like sounds,* at an estimated cost of $50 to $75 thousand.[32] W. S. Pike was named RCA's chief engineer for the project.

Zworykin told Bombe that he believed solving the engineering problems of a recognition machine to be simpler than deciding on the character of the speech-like sounds to be produced.[33] But, as with the A-2 Reader, Zworykin did not wait to be informed by Haskins Labs before undertaking the design of a machine. The RCA staff did not see much value in research into system outputs. Flory and Pike felt that Haskins Laboratories' work was "only of general academic interest." As Pike put it to A. A. Bombe, "'Why bother to synthesize speech when regular speech is available?'"[34] RCA decided to build a device that could recognize a letter and then play a tape of its name, in the belief that such an approach was both simple in concept and achievable in practice. As late as June 1947, Cooper still hoped to persuade RCA to adopt a phonemic language rather than a letter-by-letter announcement as they envisioned,[35] but RCA was more interested in demonstrating their engineering concept than in testing a scientific hypothesis.

Starting with a scanning light probe and the goal of converting an optical signal into a unique sound, the engineering challenge was to develop electronic circuitry that could take the optically-generated signal and uniquely associate it with a single output. This Pike and Flory proceeded to do.

There was never any thought that a recognition-type reader would be a personal assistive device. Its expense and complexity meant that such a reading machine would be used in libraries, perhaps like a microfilm reader. Thus, the design constraints were quite different from the A-2, which was conceived as a personal reader from the beginning. The letter-reading machine was designed from the ground up.

As recognized by its developers, the letter-reading machine which they designed was a special purpose computer.[36] The computer's input device was an optical scanner driven by a cathode ray tube (CRT). Light from phosphors at the end of the eight-step CRT was

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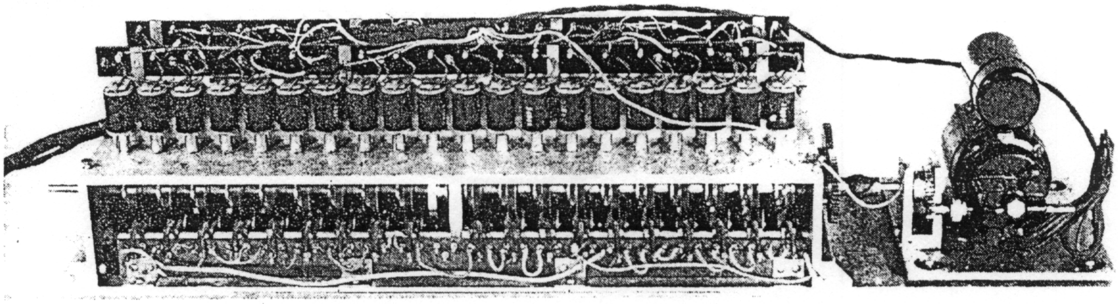
* The emphasis of this and other projects on the production of "speech-like sounds" was an expression of the problems associated with the non-phonetic pronunciation of written English.

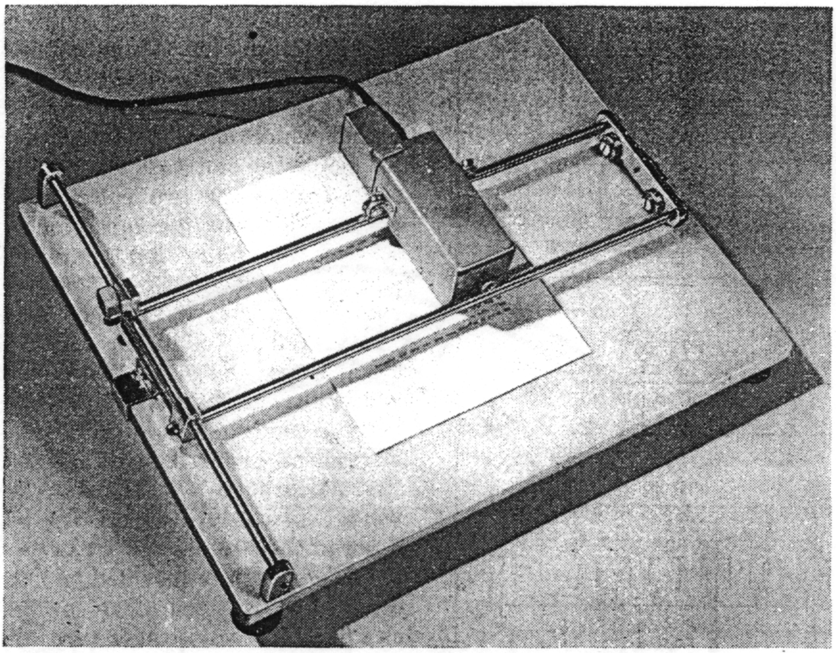
reflected off a line of print. The CRT beam was blanked except for about 100 microseconds during the middle of each of its eight sweeps. The resultant effect was that of a continuous sequence of eight vertically linear beams of light being generated every 500th of a second. Reflected light was received by a photomultiplier tube whose threshold was set so that a 500 Hz output signal was generated in each channel whenever its beam was over a white page. Since the eight beams were time sequenced by the CRT scan, the eight channels could be separated by a time gating scheme and then processed separately.

The output device was a unique magnetic tape recorder which had a capacity for 36 pre-recorded sounds. Each tape was carried on the circumference of a wooden disk, the rotation of which was activated by a solenoid switch, activated in turn by a thyratron tube. Twenty-six prerecorded tapes contained the name of a letter. The other ten tapes could be used for prerecorded words. This demonstration capability for word recognition was somewhat misleading, because practically speaking expansion of the design would require a separate disk, tape, solenoid and tube for each word. As recognized by its designers, no practical device could follow from this design. Figure 5 is a photograph of the output device for the RCA letter reading machine. Figure 6 presents a photograph of the scanner.



Letter-pronouncing section of the reader. The solenoids operate the magnetic tape recorders when tripped by the proper signals

Figure 5. RCA Letter reading machine output device[37]



Scanning device used with the reader. It contains the phototube and scanner tube

Figure 6. Letter reading machine input device[38]

The reading machine's processor employed a set of ingenious circuits which took advantage of the fact that most letters in most fonts added up to unique combinations of counts in each of the eight channels. Those few pairs that did not, like the mirror images "b" and "d" could be distinguished by the sequence of the count. Thus, the processor contained input circuitry for counting the interruptions which occurred in each of the eight channels when the scanner encountered black print under its beam. "Counting" was accomplished as each input circuit acquired a different potential according to the number of times the beam was interrupted. Two sequencer circuits were connected to four of the channels. Their state depended on which two of the four selected channels had last been interrupted. Six input channels were split into two signals. Two channels, used for descenders of consonants, provided a single channel. There were two sequencer circuits. Thus a total of 16 input signals were provided to a master selector matrix, where they were interconnected with 36 output circuits.

Each output circuit could be activated by one and only one combination of potentials across the input circuits. Whenever the scanner reached the end of a letter, all eight beams would be reflected, and all eight channels would be carrying the 500 Hz current. This condition would activate the thyratrons, allow all output channels to discharge, and reset the counters. A separate circuit reset the thyratrons. Figure 7 provides a block diagram for the letter recognition machine. Detailed circuit diagrams for many components may be found in *Electronics* for June 1949,^{39} from which this description is drawn.

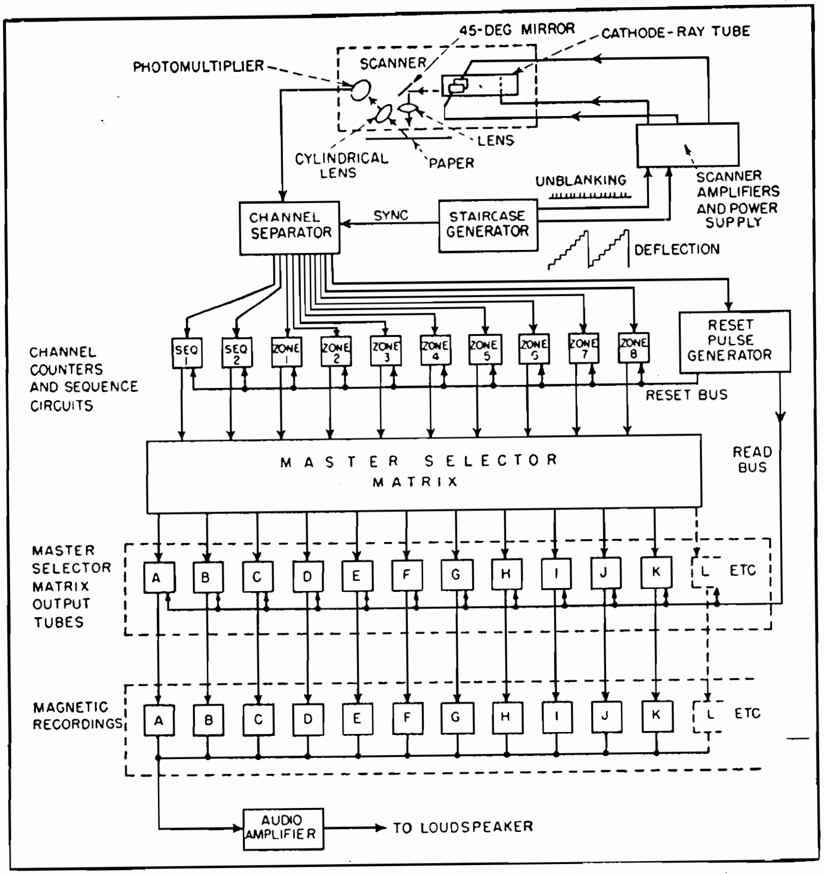


Figure 7. Block diagram of RCA letter recognition m,achine

On December 30, 1947, Zworykin, Flory and Pike demonstrated a laboratory prototype of the letter recognition machine to A. A. Bombe and George Corner, just one day before CSD funding was scheduled finally to end. Bombe reported that the prototype would recognize all of the letters of the alphabet and pronounce them, although an electrical circuit problem had required the operator to manually trip a relay between letters to reset the machine for scanning the next one.[40]

In their 1949, article, Zworykin, Flory and Pike identified several limitations of their design. The machine was very sensitive to print alignment, since incorrect counting patterns would ensue from print that was above or below the assumed alignment. Operating speed was limited by intelligibility of the recorded sounds. "The letters sound rather unnatural at speeds above about 40 words per minute, and for purposes of public demonstration a speed of around 20 words per minute has been used."[41] Ironically, the speed of the prototype recognition device was lower than that of the direct translation device which it was intended to correct.

In 1950, Cooper reported in Zahl's report, *Blindness,* that,

> In general the device operated as expected scanning and identifying successive letters in a line of type at a maximum rate of 48 to 60 words per minute, set by the magnetic tape announcing system. Some difficulties were encountered with ambiguities between letters, especially capitals, and in maintaining the alignment between type and the scanning head.... in practice it proved difficult to record natural sounding letters at speeds much above fifty words per minute.[42]

In 1954, Kappauf reported that "Nothing more has been done with the RCA recognition device since "Blindness" was written.[43] The device was apparently dismantled.

CSD efforts to develop a recognition-type reading machine came to an end when funds disappeared in 1948. Haskins Laboratories' research with the sound spectrograph did not directly contribute to the RCA prototype, although the decision to build the prototype was the result of a paradigmatic standard established by Franklin Cooper and the other researchers at Haskins Labs. That paradigm stated that a successful reading machine must be usable at a rate of at least 100 wpm – a rate that they believed could not be achieved by a direct translation device. According to Cooper's calculations, a spelled speech machine might approach that standard. A word recognition approach should do better. RCA designers believed that they could design such a letter recognition machine, drawing on their wartime experience with the scanning technologies, computers, and sound recordings, but their 1947 prototype, while a miracle of a rare device, did not exceed the reading rate of the A-2 Reader.

The Committee on Sensory Devices: A summary and some interim conclusions

In 1943, the United States government undertook a research program to develop sensory aids for the blind. This activity was unprecedented. It represented an expansion of the role of federal government that could only be justified by the needs of war and the responsibility of government for the rehabilitation of injured servicemen. Yet, it was an activity that, after a pause, survived the conditions that gave it birth and became institutionalized as an area of legitimate interest for the federal government. Federal sponsorship of the development of sensory aids for the blind has evolved, expanded and continues to this day, more than fifty years after the creation of CSD.

Because the development of sensory aids was an unprecedented activity, establishment of a research program resulted in and required the establishment of a new research community. Because the community was new, its members had to articulate, discuss, and specify their shared knowledge, objectives and interests, which might otherwise be tacit. Because the community was established under the auspices of a government program, and because its members were geographically dispersed, there is a good documentary record of these foundational events. Thus, the creation of the Committee on Sensory Devices and its activities provide an important and accessible research site for learning about government sponsorship of programs to create new technological knowledge, and in particular for exploring the relationship between the constitution of a knowledge community and the nature of its products.

The intended beneficiaries of CSD research were blind people. This fact distinguishes CSD's research from most other OSRD programs which sought to benefit the military effort. The CSD program represented government-sponsored research not for the benefit of a government agency, but for the benefit of a particular segment of the population. Its foundational documents make clear that Vannevar Bush conceived CSD as a vehicle by which the results of military research could be applied to benefit blind people in general, and blind veterans in particular, as a matter of political legitimation.

The tangible products of CSD's program to develop a reading machine for the blind were few: They included fourteen A-2 and seven C-1 Readers, together with two unique prototypes, the RCA letter recognition machine and a Facsimile Visagraph developed by Radio Inventions, Inc., which converted printed matter into a raised surface. None of these prototypes were brought to market. None were the direct progenitors of successful second generation machines. Haskins Laboratories built a simulator for direct translation machines and a prototype FM-slit device. More importantly, it built a sound spectrograph and playback device which became important tools for research concerning the psychology of sound and language. As discussed in Chapter 8, these tools would again be employed toward the development of reading machines when the Veterans Administration provided funds for a revived program in 1957. As a result of the CSD program, RCA gained experience with phototubes which were later commercialized, and with light scanners and circuits for optical character recognition that provided knowledge and experience which were generally useful to the development of other devices.[44]

The lasting products of the CSD period, however, were not prototypes, components or even research tools. They were a categoric body of scientific and engineering knowledge regarding the design and function of reading machines, as summarized in *Blindness: Modern Approaches to the Unseen Environment*, and a new research community within which that knowledge was resident. The content and structure of that knowledge and the boundaries of the new knowledge community were the products of specific historical decisions and events. To understand the direction which technology development took or did not take, to understand what that program created and what it did not create, to begin to evaluate its accomplishments, failures, and impacts, we must understand something of the details of the foundation of the new research community and of the decisions and events which shaped it.

Among the important details, were these: Individual decision makers, Vannevar Bush and Caryl Haskins and an expanding circle of associates, initiated a technology development program, and structured it to address their perception of a particular social need. They and their associates shared a conception of the role which science could and should play in meeting that need. The need identified by Bush and Haskins was one for electronic sensory aids to assist the blind, and, by extension, other assistive technologies.

Bush and Haskins articulated the need as one which pertained to blinded veterans. They went so far as to appeal to the remote possibility of returning blinded soldiers to national service, in order to justify the expenditure of federal funds on sensory aids research. But from the beginning, Bush and Haskins conceived of the need as a general societal one, and they anticipated a postwar technology development program. They assumed that postwar research would have to find philanthropic support, since they did not foresee the changes in federal polity which would legitimize government-sponsored research for the benefit of blind civilians.

Before establishing CSD, Bush and Haskins had spent three years organizing the American scientific community to create new tools for the conduct of total war. Their understanding of the success of their wartime practice gave them reason to believe that scientific knowledge could be similarly applied to solve the problems of the blind. Their wartime offices gave them access to the resources necessary to make the attempt. As temporary agents of the federal government, they had little concern for precedent, and were not subject to any effective review by Congress or any executive agency which might suppress the program due to the lack of precedent.

The approach to the development of reading machines for the blind, as articulated by Bush, administered by a committee of distinguished scientists, and implemented by Haskins Laboratories, was to underwrite multidisciplinary scientific research to determine the general capabilities of human beings to interpret information when presented through senses other than vision. Engineering a device to produce information in the specified form was taken to be a simpler task. Social questions pertaining to the proposed technology were hardly even asked. No one asked what information might be needed by which blind readers in what contexts; or how blind people learned to read braille; or how existing programs for converting printed documents into braille or talking books might define a context for technological innovation.

In constructing a research community to address the problem of reading machines for the blind, Bush and Haskins chose other scientists and medical researchers of a like mind. They did not seek participation from organizations representing blind people or the service community. In fact, they sought to insulate themselves from those communities. The principal role for blind people, according to this perspective, was as "subjects," to test the results of the scientific endeavor and, in the event of success, to receive its bounty.

CSD's attitudes toward the service community were not a reflection of simple prejudice regarding the abilities of persons with disabilities. Participation in the research community by blind scientists such as Witcher and Benham belie such a simple explanation. Rather, those attitudes were a manifestation of the research community's understanding of the role of science and of the limited ability of non-scientists to contribute to that role. As articulated by Corner, exposure to the "jealousies" of non-scientific communities and their resistance to new ideas could only degrade the ability of scientists to do their job of developing a successful reading machine. Insulation was necessary to provide an undisturbed social space where scientists could work, undisturbed, to create new technologies. Blind scientists might have special personal interests in working on these problems, but their contributions were as scientists, not as blind people.

CSD's scientists understood the practice of technology development to be one of applying science to produce new technology products. This is the research philosophy that Bush articulated to Corner in his instructions of January 1944. It is the conception described by James Phinney Baxter 3rd, in his official history of OSRD, *Scientists against Time*. Baxter portrayed a twelfth-hour mobilization of scientists who then applied their special knowledge to give the American soldier new tools by which he could win the war. It was a dramatic portrayal. But certain anomalies were apparent even in 1946. Consider this description of certain OSRD procedures as provided by Baxter,

> By January 1942, it seemed clear to Bush that it would be necessary to send scientists overseas to accompany new equipment in the field. Too frequently, if unaided, the man in the field imposed self-designed tests, misunderstood the device entrusted to him, and drew erroneous conclusions as to its potentialities and limitations. Explanation and initial training by an expert might make a world of difference.[45]

One hears in this description a very similar refrain to Bush and Corner's concern that blind people, not understanding science, should not be prematurely exposed to the process of scientific technology development, lest they misinterpret that process and threaten its success. From Baxter's account, it would appear that the beneficiaries of applied science were not even fit for the role of subjects. Without the aid of scientists to instruct them on how to understand their own practices, soldiers or blind readers might attempt self-designed tests and consequently draw erroneous conclusions regarding a technology. From OSRD's perspective, the soldier needed the scientist not only to create his technologies, but also to explain why he needed them. There is a parallel here between the soldier as subject, and the blind reader as subject that suggests how CSD could not only establish a reading rate criterion without reference to the community of blind readers, but even attribute the criterion to the community as one of scientific necessity.

Although the purpose of the CSD program was to create a reading machine for the blind, it did not do so. The policy of insulating the development process from the service community provides one explanation. Such insulation created a situation in which only a breakthrough technology could succeed at innovation – one whose utility was overwhelmingly and obviously desirable. It is hard to imagine how any less successful reading technology could be innovated without the active support of the service community with its unique institutions for education and information dissemination to blind readers. Their exclusion from the development process built into the very structure of the research community a need for technology transfer if innovation were ever to occur.

A second critical factor was that none of the development teams had a corporate interest in innovation. Haskins Laboratory was an institution for the conduct of scientific research, not a manufacturing firm. Its standard OSRD contract removed any opportunity to license or otherwise profit from innovation of the technologies it developed under federal sponsorship. RCA was a manufacturing firm, and it negotiated an exceptional contract with OSRD which would have allowed a profit from innovation. But RCA's principal business was the mass production of consumer electronics, and no reading machine for the blind was likely to be a candidate for mass production. RCA's principal interest in reading machines was in the technical knowledge to be gained through their development at another party's expense, not in their commercialization. Flory and Zworykin's efforts to promote their prototypes through demonstrations to the engineering community and elsewhere showed an interest in innovation by the immediate development team, but RCA as a firm had no significant interest in bringing a reading machine for the blind to market.

The third reason that the CSD program failed to innovate a reading machine is that none of its products could satisfy its paradigmatic standard that a successful reading machine must support a reading rate of 100 words per minute. In the published reports of the CSD program, Franklin Cooper presented the criterion as a result of scientific deduction from empirical observations of visual speech, Morse code, and the simulated and measured output of direct translation devices, but in retrospect, we can detect two other reasons that Haskins Laboratories formed a commitment to this paradigm.

The first was the discouraging and rapid reversal in their evaluation of direct translation technologies which the Haskins team was forced to make as a result of the unreported case of scientific fraud which occurred in the summer of 1945. The experience dashed the high hopes that the researchers had come to hold for their FM-slit device. Between May and July 1945, as their blindfolded test subject achieved ever-higher reading speeds, the Haskins team thought that they were witnessing an empirical verification for their theory that the most easily interpreted audible signal was the simplest one which contained some minimum amount of necessary information. Preparations were begun for incorporating that particular knowledge in a reading machine – the C-1 Reader, and for protecting the rights to that knowledge through patents. The level of excitement was high, and the level of discouragement must have been correspondingly so.

Although there can be no proof of such a statement, I think that Haskins Laboratory's rejection of direct translation technologies was, in part, an emotional rejection of the experiences of the summer of 1945 – an understandable desire to put those events behind them. Since these reasons could not be scientifically justified, or even publicly discussed, it was necessary to provide a scientifically acceptable explanation for rejecting direct translation machines. The 100 wpm criterion provided a paradigmatic standard for rejecting direct translation technologies that was consistent with the empirical data available to Haskins Labs. The criterion could be, and was, supported by a deductive argument, so there was no need to refer to experimental data from the FM-slit machine which might expose the researchers' scientific credulity. The 100 wpm criterion provided a rationale for rejecting direct translation technologies and moving on to new things that could be publicly stated and scientifically defended.

The second underlying explanation for Haskins Labs adoption of the 100 wpm criterion was that serendipity had brought them a sophisticated research technology which was perfect for studying speech recognition, and useless for investigating direct translation. The sound spectrograph and the playback machine provided Haskins Laboratories with a *means* for the empirical study of phonemes and the information content of sounds. This made for good science, and Franklin Cooper was a good scientist who recognized the potential of this research program, and applied it to launch a highly successful career. Thus, the 100 wpm criterion provided a scientific rationale for allocating disappearing resources to research employing the sound spectrograph and its derivative technologies, rather than to further development of the A-2 Reader. The 100 wpm criterion provided a rationale for Haskins Laboratories to pursue technology development through scientific research, an approach they would prefer beyond the CSD period. It is not necessarily true that good science makes for good technology development, an issue that we may explore in greater detail in Chapter 8, below.

Section II. The Veterans Administration's Prosthetic and Sensory Aids Service (PSAS): Reading Machine Development and the Problem of Innovation (1954 - 1978)

In 1948, as the Committee on Sensory Devices (CSD) was drastically curtailing its research program on reading machines, the Veterans Administration (VA) was completing its organization for the postwar provision of services to veterans with disabilities. In July 1948, the Hines VA Hospital, outside Chicago, Illinois, admitted the first group of blinded veterans into its new rehabilitation program, established under the direction of Russell C. Williams. This program, which Frances A. Koestler called "a model of excellence,"[1] trained selected veterans in a variety of skills intended to help them deal with the effects of their blindness. The veterans who passed through Hines represented the constituency of the VA's sensory aids research program, which was established that same year, in the VA's New York City offices.

Eugene F. Murphy assumed the position of Assistant Director for Research of the VA's new Prosthetic and Sensory Aids Service (PSAS) in July 1948, shortly after he completed his doctorate in mechanical engineering at the Illinois Institute of Technology (IIT). Murphy, then 35 years old, spent two years in industry after earning his master's degree from Syracuse University in 1937. He then taught two years at IIT and seven at the University of California before returning to Illinois in 1945, to join the staff of the Committee on Artificial Limbs, established at Northwestern University by the National Research Council with OSRD funding. This was part of the sister program to CSD, as discussed in Chapter 2. Murphy remained with the committee until July 1948, when, his doctorate completed, he accepted the position of Assistant Director for Research at PSAS.[2] Personal experience as well as professional interests may have played a role in Murphy's career choice. As a result of polio, he used two canes as mobility aids.

Although Congress authorized the Veterans Administration to undertake research in prosthetics and sensory aids in 1948, it failed to appropriate funds for that purpose.[3] Murphy clearly intended for PSAS to undertake reading machine research from an early date. In a 1949 letter to Wilma Donahue, who had conducted tests of RCA's A-2 reader at the University of Michigan, Murphy asked for information on her experience with the device. He explained, "We hope to develop a well-balanced program in aids to the blind, including the reading machine problem. In that connection, I should very much appreciate your views on the contribution which your past work and any future continuation might make towards development of a reading machine better than the A-2 reader."[4] But it was not until 1957 that PSAS was able to initiate a reading machine development program, when surplus funds appropriated for medical research were made available to PSAS because they had not been obligated by the end of fiscal year, and would otherwise have been lost. PSAS had the ability to write fixed price contracts for the delivery of research products without any requirement for a competitive procurement, and could thereby put the "windfall funds" to good use.[5]

In spite of its windfall origins, PSAS's reading machine development program was not to be a short-term effort. For more than twenty years, PSAS supported the development of reading machines along the general lines first established in 1957. Eugene Murphy directed the program from its beginning until its end in 1978, as part of his general responsibilities for prosthetics and sensory aid research. Howard Freiberger, an electronics engineer who joined the Research Division in 1956, oversaw sensory aids projects under Murphy's direction. A small and stable group of laboratories conducted reading machine research and development under contract to PSAS. The three principal contractors were Battelle Memorial Laboratories in Columbus, Ohio; Mauch Laboratories, in Dayton, Ohio; and Haskins Laboratories, which was located in New York City until 1970, and thereafter in New Haven, Connecticut. Professor Milton Metfessel worked for PSAS as a faculty member in psychology at the University of Southern California until 1960, and thereafter as Metfessel Laboratories, until his death in 1969. Metfessel's research into intelligible spelled speech was associated with the development efforts at Mauch Laboratories, which it was intended to inform.

After 1965, PSAS supported several projects in prototype evaluation, clinical application, and training, in support of its development projects. Internal projects were conducted at the Hines VA Hospital and, later, at the new blindness rehabilitation centers in Palo Alto, California, and West Haven, Connecticut. PSAS also supported small projects at the Hadley School for the Blind, Winnetka, Illinois, and at the American Center for Research in Blindness and Rehabilitation (ACRIBAR), in Newton, Massachusetts.

The PSAS program institutionalized the taxonomy of reading machines which was the creation of the CSD research community, as first published by Franklin Cooper in 1950.[6] According to this conceptual framework, reading machines were considered to be of two kinds: direct translation devices and character recognition devices. Direct translation devices would convert visible print into a different sensory output which had to be interpreted by the reader. Recognition machines would "recognize" letters and convert graphemes into phonemes, and thus into synthetic speech. Direct translation devices would be hard to learn and slow to use, but might be inexpensive and quickly brought to market. Recognition machines would be large. expensive, and take a long time to develop. An intermediate concept, variously labeled, envisioned the conversion of print into speech-like sounds, based on letter shape. Such a device would be easier to learn to use than a direct translation machine, and easier to develop than a full recognition machine.

Under PSAS's sponsorship, Haskins Laboratories was responsible for research to achieve recognition reading machines employing synthetic speech. Battelle Memorial Laboratories was given the task of developing a direct translation device improving on the A-2 Reader. Milton Metfessel was to conduct research into the use of spelled speech, while Mauch Laboratories was to develop an intermediate technology, using direct translation to produce speech-like sounds. The Battelle project was completed in 1965. Partly as a result of problems in achieving a spelled-speech technology, Mauch Laboratories would redirect its principal efforts, in 1966, toward development of an improved direct translation reading machine.

Each of these three efforts produced several generations of prototype reading machines, but none of them resulted in a commercial product. The spelled-speech machine pursued by Mauch and Metfessel, eventually named the Cognodictor, was abandoned in 1976. Neither the Battelle Optophone nor the Mauch Stereotoner were ever brought to market. Instead, a radically different direct translation machine, the Optacon, was commercialized in the early 1970s by Telesensory Systems, Inc. (TSI), a small business firm established to manufacture a design which was developed at Stanford Research Institute by James C. Bliss and John Linvill, beginning in 1963. A synthetic speech machine was brought to market in the mid-1970s, not by Haskins Laboratories, but by Kurzweil Computer Products, Inc., a small business venture formed in 1973, by Raymond Kurzweil. In the face of the successful innovation of these two products, the VA's systematic research and development program was abandoned in 1978. The development and innovation of the Optacon and the Kurzweil Reading Machine are the subject of Section III, below.

In addition to its support of reading machine development, PSAS conducted a smaller, but significant, program for the development of electronic travel aids. The principal contractors were Haverford College, and Bionic Instruments, Inc. Bionic Instruments was a small business firm established for the purpose of manufacturing and selling laser canes, the product of this development effort. The laser cane, currently manufactured by Nurion Industries, was the only sensory aid which achieved innovation as a direct result of PSAS support.[7]

A principal activity of PSAS's R&D Division was the sustenance of a research community through information dissemination, as illustrated in this 1971 statement of purpose:

> The work of the Division includes information dissemination (Papers in professional journals, correspondence with others in the field, maintenance of a reference collection, bibliographic activity, publication of a bulletin, arranging conferences, presenting talks), contract supervision, planning, supervision of clinical application programs, and limited in-house research."[8]

This statement of purpose provides a useful synopsis of the activities of PSAS in the area of reading machines, as explored in the following chapters. Chapter 5 describes how, after the demise of CSD, the reading machine research community was reconfigured and expanded under PSAS's wing. Chapter 6 considers the work of Battelle Memorial Institute's to develop a direct translation, optophone device. Chapter 7 presents a consideration of the work of Hans Mauch and Milton Metfessel to develop a spelled-speech reading machine, which Mauch named the Cognodictor. It then considers Mauch Laboratories' turn to a direct translation strategy and its development of the Visotoner and Stereotoner machines. Chapter 8 addresses the efforts of Haskins Laboratories toward the development of a reading machine which could recognize words in printed text and provide spoken English for a blind reader. This chapter also includes a summary of PSAS's accomplishments and begins to address some of the issues which are raised by the history of VA-sponsored research, for understanding the relationships between the processes of technology development and innovation.

Chapter 5. Establishing the PSAS Program

Reading machine conferences and an expanding knowledge community

With the termination of federal research support in 1948, the reading machine research community was largely dormant, except for the publication in 1950 of Haskins Laboratories' final report to CSD, under the title, *Blindness: Modern Approaches to the Unseen Environment.* In August 1954, two months after the formal termination of CSD by the National Research Council, PSAS sponsored a technical session on reading machines, coincident with the ninth annual meeting of the Blinded Veterans Association in Toledo, Ohio. The purpose of the session was to consider the state of the art of reading machine technologies and to provide guidance for possible future development efforts. Four additional sessions were held between 1954 and 1958.[9] They were attended by a growing number of participants. Eleven people attended the first meeting in Toledo. Twenty-four were at the second technical session in Philadelphia in April, 1955. Thirty-eight attended the third conference in New York in August 1955. Fifty participated in the fourth session in Washington, a year later, and sixty-eight were at the fifth technical session on reading machines for the blind, also held in Washington, in September 1958. The minutes of these meetings, held between 1954 and 1958, document a renaissance of the research community established in 1944, by the Committee on Sensory Devices (CSD).

PSAS's sixth technical session on reading machines was convened eight years later, in 1966, to evaluate the progress in reading machine research since 1957. In the interim, a variety of professional meetings and conferences continued to provide a forum for an expanding knowledge community. Important among these was the International Congress on Technology and Blindness, sponsored by the American Foundation for the Blind (AFB) in 1962, in New York. This conference included twelve papers on reading machines presented at a session chaired by Howard Freiberger, head of the PSAS reading machine program. A review and summary of the twelve papers was presented by Franklin Cooper of Haskins Laboratories, a major PSAS contractor. Many of the other presenters were also participants in the PSAS-sponsored conferences.[10] Four years later, a second international conference was held at St. Dunstan's, London. Among its principal presenters were Franklin Cooper, Howard Freiberger, Glendon Smith of Mauch Labs, and James C. Bliss, of Stanford Research Institute, who had also presented a paper at the 1962 meeting.[11]

In November 1971, five years after the sixth PSAS technical session on reading machines, and seventeen years after the first, the National Research Council (NRC) of the

National Academy of Sciences (NAS) held a conference on the Evaluation of Sensory Aids for the Visually Handicapped. This meeting anticipated field testing of the products of reading machine research, including the Optacon, the Visotoner, the Cognodictor, and the unnamed product of Haskins Laboratories' research into synthetic speech-by-rule. All of the American presenters in the reading machine session had participated in one or more of the previous meetings sponsored by PSAS, and the first paper in that session was delivered by Eugene F. Murphy, Chief of PSAS's Research and Development Division.

PSAS work at community building was quite intentional. Speaking at the 1971 NRC conference, Eugene Murphy told his audience that the first PSAS technical session on reading machines had been arranged seventeen years before, because, "...it became apparent that the Veterans Administration (VA) staff knew a number of people in many different related disciplines who did not yet know each other."[12] Murphy provided a more detailed explanation in a 1966 editorial in the *Bulletin of Prosthetics Research,*

> These meetings arose rather informally in 1954 because our office had found so many friends who seemed to agree that the burgeoning technology and growing understanding of psychological principles allowed hope for independent reading by blind persons, in spite of repeated past disappointments.
>
> Unhappily, in 1954, many of these more hopeful yet realistic friends of ours did not yet know each other, so we felt that some fostering of friendships and mutual widening of horizons through the conferences might be helpful. Some colleagues were pioneers in the then-visionary field of optical character recognition [Intelligent Machines Research Corp., National Bureau of Standards], others were psychologists or linguists interested in output problems [Bell Labs, Haskins Labs], some were blind engineers themselves [Benham and Witcher], or experts in rehabilitation of the blind [AFB, BVA, Perkins Inst., Industrial Home for the Blind]; all were convinced that something could reasonably be done to give blind people independent access to typed and printed information. Early conferences led to general agreement on a number of different approaches to specific goals, building on past knowledge, applying current technology and ingenious design engineering, and supporting basic and applied research in a variety of related fields.[13]

Lists of attendees are available for the second, fourth, and sixth VA technical conferences on reading machines, and for the 1971 NRC evaluation conference (see Appendix). The participation in these sessions shows the nature of the expanding research community, its continuity with the CSD era, and its departure from the CSD model. Figure 8 summarizes the attendance at the three conferences.

	Veterans Administration			**NRC**
Sector	2nd Conf 2/55	4th Conf 8/56	6th Conf 1/66	Eval Conf 11/71
Academia	2/2	4/5	12/13	8/15
Ind. Research	7/10	13/17	12/17	6/6
Service Sector	5/7	6/8	9/14	1/1
Government	3/4	8/16	6/13	7/21
Individual	na/1	na/1	na/3	na/2
Total	17/24	31/47	39/60	22/45

Figure 8. Conference Attendees (Institutions / Individuals)

There was a clear continuity in participation in the reading machine research community with the CSD period, in spite of a six-year hiatus in program funding. RCA Laboratories attended the second and fourth sessions. Haskins Laboratories was represented at the fourth and sixth meetings. Delegates included W. S. Pike and Les Flory from RCA and Franklin Cooper from Haskins Laboratories, each of whom had managed a CSD project. Clifford Witcher, who attended the second session representing AFB and the fourth session as a representative of MIT, and Thomas Benham, who chaired all six PSAS sessions, both had roots in CSD's programs, although their work had been concerned with guidance devices rather than reading machines. The Franklin Institute, which was represented at the second and fourth sessions, had also been a CSD contractor. They had developed an optical projector for low vision readers. A copy of the minutes of the second session and an invitation to attend the third session, (declined), can be found among Vannevar Bush's papers in the Library of Congress.[14] There can be no doubt that the research community represented at these conferences on reading machines was a continuation of that established by Bush and Haskins in 1944.

From the beginning, however, and by intent, the VA-sponsored reading machine conferences included a broader base of representatives, embracing four sectors with interests in issues of technology for the blind. Government agencies and industrial research centers were brought together with representatives of the technical part of the service community and with academic researchers. A convergence of the academic and industrial research communities, which were largely separate until 1955, is represented by the growing participation of academic scientists in the reading machine conferences. MIT was regularly represented, starting with the third VA session, where Clifford Witcher spoke on, "M.I.T. work on synthetic speech and on translation of foreign languages."[15] Dr. James C. Bliss, a recent MIT graduate, represented Stanford Research Institute (SRI) at the 1962 Congress sponsored by AFB, and his colleague, John Linvill of Stanford University, attended the sixth VA session in 1966. Stanford's researchers made up the largest academic contingent at the 1971 evaluation conference.

There was some movement of individuals between the academic, industrial, government, and service sectors. We have already noted Cliff Witcher's move from the American Foundation for the Blind (AFB) to MIT in the mid-1950s. Similarly, John Dupress who represented AFB at the 1962 International Congress represented MIT at the 1966 meeting. Patrick Nye represented the California Institute of Technology at the sixth technical session in 1966, and Haskins Labs at the 1971 NRC evaluation conference. Milton Metfessel was on the faculty of the University of Southern California in 1956. By 1966, he had established his own research laboratory and was a contractor to the VA. Wallace Frank moved from the Franklin Institute in 1956 to Spitz Laboratories, Inc. by 1966. Warren Bledsoe, who represented the VA in 1956, had served as editor of AFB's *New Outlook for the Blind* in the 1940s. He coordinated rehabilitation services at VA headquarters in the 1950s, before joining Mary Switzer at DHEW in 1958. He represented DHEW's Vocational Rehabilitation Administration at the 1966 conference.[16]

In contrast to the CSD period, the service community was well represented at the PSAS technical sessions. The first meeting was hosted by the Blinded Veterans Association (BVA). The American Foundation for the Blind was represented at all of the VA-sponsored meetings, as were the American Printing House for the Blind and the Perkins School for the Blind. BVA was represented at the second and fourth conferences. Perhaps the snowstorm prevented their representation at the sixth (and last) PSAS conference, which was nonetheless attended by more organizations and more individuals from the service sector than any other. One of the major functions of these sessions was to establish overall directions and goals for PSAS-sponsored research programs.

All six PSAS conferences were chaired by Professor Thomas Benham, a blind professor of physics from Haverford College. At least three other participants in the second conference were blind professionals with scientific or technical interests, a representation that continued in subsequent sessions. Blind participants were all from the academic or service sector until Harvey Lauer attended the sixth conference, representing Hines VA Hospital. Lauer, who also attended the 1971 NRC Evaluation Conference, played an important role in evaluating reading machine concepts, designs, and prototypes for the VA, starting in the mid-1960s. Their participation in the VA's technical sessions meant that blind individuals and representatives of the service community had a role in determining PSAS' research program goals. In this way, Murphy institutionalized a perspective which gave those who would particpate in the technology a role in decision making at both the beginning and the end of a development effort.

The VA always had the largest government contingent at these meetings. Its participants represented not only PSAS but also VA Headquarters and the Blind Rehabilitation Centers. The premier center was at Hines VA Hospital, outside Chicago, established in 1948. A second center was opened in Palo Alto, California, in 1967, and the third at West Haven, Connecticut, in 1969. Other government participants included the National Bureau of Standards, which had a research interest in commercial reading machines, especially for mail sorting. The Army, Navy and Air Force sponsored and published research on a variety of related topics including character recognition, speech synthesis, and tactile communication. Representatives from one or more of these projects attended each of the meetings for which attendance lists have been found. The National Institutes of Health sent delegates to the fourth and sixth sessions and to the NRC evaluation conference. In 1966, Warren Bledsoe represented the Vocational Rehabilitation Administration of the Department of Health Education and Welfare (DHEW) at the sixth conference. By 1971, DHEW had seven delegates to the VA's eight.

Industrial research representatives were largely, though not exclusively, research contractors to the VA, one of the military projects, or later, DHEW. Three institutions, MIT Lincoln Labs, Stanford Research Institute, and the Illinois Institute of Technology Research Institute represent hybrids familiar to the world of defense R&D contracting. Each of these institutions was established by a university to conduct sponsored research in response to increasing demands for defense technologies to win the Cold War. As we shall see, most of the firms engaged in developing reading machines for the blind had a defense connection and, at one time or another, relied on defense research funds to sustain the firm.

The conduct of technical conferences was one tool that PSAS used to sustain an R&D community. Another was the collation and publication of bibliographic material. Beginning in 1957, Howard Freiberger compiled a list of sixty-one articles and reports published since 1950, on topics related to reading machines. By 1963, the list had expanded to 422 references. At first, PSAS provided copies or reprints of many reports - not only its own – to interested parties. Later, the service was limited to copies of VA reports.[17] In 1964, PSAS established a journal to disseminate the results of research and clinical studies in its fields of interest. Every semiannual issue of *The Bulletin of Prosthetics Research (BPR)* (now the *Journal of Rehabilitation Research and Development)* through 1978, included a report of the previous six months' research, and contained updated bibliographic information. Many issues included articles, most written by PSAS contractors and staff, on reading machine research and development.

In summary, from 1954 and into the 1970s, the U.S. Veterans Administration sustained and nurtured a research community concerned with the development of reading machines for the blind. The Research and Development Division of the Prosthetic and Sensory Aids Service sponsored five conferences on reading machine development between 1954 and 1958. These conferences brought researchers together with members of the service community to establish directions and goals at the beginning of the PSAS research program. PSAS also conducted frequent meetings of its contractors and continued to sponsor, co-sponsor and participate in many general conferences thereafter, including major meetings in 1962, 1966, and 1971. Beginning in 1957, PSAS prepared and distributed bibliographic material on the development of reading machines, and in 1964, it established and published a scientific journal devoted to research in the fields of prosthetics and sensory aids.

The community nurtured by PSAS was a knowledge community. Its activities were all concerned with the dissemination of information and sharing of knowledge about reading machines. It would be inaccurate to describe it as a community of homogeneous shared interests. Institutions in each of the four sectors represented at the PSAS technical sessions had different, though overlapping interests in reading machines. The service sector was interested in securing and disseminating reading machines to its clients. The academic sector was interested in securing information and financial support for research in a variety of related fields including the psychology of perception and communications, pattern recognition, electronics engineering, and rehabilitation. A variety of MIT master's theses and doctoral dissertations may be found in Freiberger's bibliography. The government sector was interested in future applications for reading machine technologies as they related to the missions of the various agencies: The VA was interested in machines for rehabilitating veterans. The military departments were interested in machines for tactical communications or automated logistics handling. The latter interest was shared by the National Bureau of Standards. Beginning in the 1960s, as the federal government's role in education greatly expanded, DHEW became interested in applying reading machines to fields of special education in addition to its longstanding role in vocational rehabilitation. Industrial firms were interested in federal research contracts or in the commercial possibilities of reading machines. For manufacturing firms, reading machines for the blind were not generally the principal interest. Such devices were a potential spin-off of commercial machines for processing printed data, such as checks or mail. Thus, industrial firms attending the PSAS meetings were often associated with programs for optical character recognition sponsored by defense agencies or the National Bureau of Standards.

The achievement of PSAS, therefore, was not one of forging a community of shared interests but of supporting a community of shared knowledge. The community was not so much a network of actors with shared interests as a nodal point where actors in diverse networks came together to share information which might be of value toward the accomplishment of their several objectives. Over time, the size of the knowledge community grew, and institutions other than PSAS contributed to its support. AFB sponsored the 1962 conference and published articles on reading machine development and evaluation in *New Outlook for the Blind*, the *AFB Research Bulletin* and their successor, the *Journal of Visual Impairment and Blindness.* In 1966, Freiberger identified the Human Factors Society and the Office of Naval Research as supporting "some of the same information exchange functions," as PSAS's technical sessions on reading machines.[18] In the 1970s, DHEW became a major federal government contributor to maintenance of the knowledge community. For example, the 1977 Workshop on Sensory Deficits and Sensory Aids, was conducted by the Smith-Kettlewell Institute of Visual Sciences under the joint sponsorship of the VA and DHEW. This was the last gathering of the reading machine research community consequent to the successful innovation of the Optacon and the Kurzweil Reading Machine. It was attended by 66 participants and observers, including many veterans of previous meetings, such as James C. Bliss and Vito Proscia, now of Telesensory Systems, Inc.; Howard Freiberger and Eugene Murphy of PSAS; Patrick Nye of Haskins Labs; Glen Smith of Mauch Labs; and Edward Waterhouse of the Perkins School for the Blind.[19]

Two community-based models for evaluating reading machine development

In contrast to the PSAS-sponsored sessions and the AFB-sponsored congress, the service community was virtually excluded from the 1971 NRC evaluation conference. That conference can best be characterized as a meeting between government agencies and academic research centers, together with those industrial laboratories participating in reading machine research under federal contract.[20] The makeup of the conference was consistent with the role of the National Research Council, which acts as a liaison between government and the scientific research community, especially its academic segment. It was also reflective of a perspective on the relationship of developers to users which was embodied in the reading machine research community by CSD some twenty years before.

The roll of participants in the 1971 NRC conference underlines the fact that PSAS's inclusion of the service community in its technical sessions, beginning in 1954, represented a departure from a model which considered technology development to be the proper and exclusive domain of scientists and engineers. The contrast is heightened by the fact that the NRC meeting was devoted to the *evaluation* of sensory aids. If there were any role for the service community in technology development, surely it was in evaluating the results of the development process. But the NRC evaluation conference, by its structure and its content, reveals a polity whereby blind readers and the service community which supports them were far from central to evaluative decision making This presumption was explicit in the stated objectives of the NRC conference:

> In convening this Conference on Evaluation of Sensory Aids for the Visually Handicapped, the Subcommittee on Sensory Aids ... set the following objectives, with emphasis on the first two:
>
> - Secure presentation describing aids that are near decision points affecting relatively widespread testing and potential distribution.
> - Secure presentation by "advocates" of aids, where a "prime" advocate is the inventor, developer, or sponsor.
> - Expose several potential governmental funding agencies to the presentations.

- Encourage a "confrontation" between advocates and agencies to clarify the nature of the evaluative data to be garnered by the one side and weighted by the other.[21]

Embedded in this NRC statement of objectives is both a perception of technology development as applied science and a linear model of innovation. According to this perspective, developers who are scientists and engineers systematically bring a technology to the point where it is ready to be exposed to potential users for testing and dissemination. The active force, the "advocate" for a technology is not the person or community whose way of life is proposed for technological change, but rather the scientists and engineers who apply their knowledge to create new devices. Technology development is understood to be a practice of academic and industrial research teams, who apply their knowledge of optics, electronics, and human psychology to create new products. The outcomes of competing practitioners, then, are to be judged by disinterested scientists and engineers representing government funding agencies. Blind people might be test subjects, but the data which they generate are to be collected by one group of scientists and evaluated by another, on their behalf.

Murphy and Freiberger had instituted and attempted to pursue a more collaborative mode. Technology development was still the domain of scientists and engineers, but the community of users was important at the beginning of the process for providing direction to developers, and at the end for evaluating their success. Moreover, PSAS understood needs as arising within a social context. Understanding human psychology was not enough to fulfill a need. In order to achieve a successful reading machine for the blind, it was necessary to understand not only how people process information, but also how people – blind people – read, when, why, and under what circumstances.

Writing in 1971, the same year as the NRC evaluation conference, Freiberger articulated this understanding of the relationship between development and innovation, in an article that was retrospective with respect to technology development, and prospective with respect to innovation. The article, entitled "Deployment of reading machines for the blind," addressed the problem of innovation of the Visotoner, a direct translation reading machine whose history is considered in Chapter 7. Freiberger used the term *deployment* to mean the process of innovation, as defined in Chapter 1.

Deployment, Freiberger said, could be understood as a system with three elements: "...those desiring to introduce the device, the device itself, and the blind population meant to benefit...."[22] Barriers to innovation, "deployment problems," could arise from any of the three elements of the system. Freiberger began his consideration of barriers to innovation in this way:

> Sometimes it seems that inventors or researchers develop a device and then look for the problem it was intended to solve. The late John K. Dupress, [of AFB, then MIT], himself a blinded veteran with major upper extremity amputation, frequently spoke in such terms about the inadequate assessment of needs to be met and the ensuing premature development of sensory aids devices. Often the device alone is presented as the complete package to serve as a great boon to the disabled. Woefully neglected are real-life considerations such as production, distribution, maintenance and repair. Training plans, materials, and arrangements are also seldom considered.[23]

In other words, Freiberger had concluded, based on PSAS's experience and the influence of blind technologists such as Dupress, that developers' understanding of the process of technology development could be a barrier to innovation. Citing the first technical session on reading machines as a benchmark, Freiberger then argued that PSAS had sought to avoid this particular barrier to innovation.

PSAS had also worked to overcome those barriers to deployment which Freiberger described as adhering to "the device itself." Specifically, Freiberger said, to be capable of innovation, sensory aids must be rugged, reliable, portable, inexpensive, easy to learn and easy to use. They must avoid characteristics which draw attention to their users. They must not cause their users more problems than they solve. Drawing upon the results of six technical conferences, PSAS had learned which design specifications were important, and had, to the extent feasible, incorporated them into its development program. Working with reading rehabilitation specialists within the VA (Harvey Lauer at Hines) and without (Margaret Butow at the Hadley School for the Blind), PSAS had supported not just the design of devices, but also the development of training programs and of surveys to identify which blind people had the potential to become successful users of a particular device.[24]

There remained, according to Freiberger, those barriers to innovation which pertained to the blind population: Because that population was heterogeneous, no one device would meet everyone's needs. There would be an inertia to change among those who could afford reading machines, and there would be many who could not afford one. People must be convinced to invest the time and money needed to learn a new skill. They must be convinced in numbers large enough to create a sufficient market for the first generation of a new device, in order to create a sustainable market for the device.[25]

As we shall see in the following chapters, although they could articulate the problem of innovation, PSAS's staff lacked the resources, the skills, and the mechanisms for solving the problem. Their contractors did not necessarily see the problem in the same way Freiberger did. Nonetheless, it is noteworthy that in the seventeen years since the CSD period, and apparently as a result of participation in an expanded knowledge community, PSAS had come to articulate an understanding of technology development and innovation wherein social knowledge played such a prominent role.

Freiberger went on to describe the process of technological change in terms of technology and context. Since the time of Fournier d'Albe, Freiberger explained, scientists had been working to develop reading machine technologies. At the same time, significant social changes had been taking place which affected the innovation system for reading machines. These included, first, changes in attitudes toward blindness, in rehabilitation practices and in opportunities for higher education leading to more chances for professional or technical employment; second, the displacement of handwritten communications by typed and computer imprinted text; and third, a general increase in literacy, enhancing the social value of a reading machine. In summary, Freiberger said, "The two chains of events outlined above, showing the ever increasing need to read inkprint and the availability of comparatively practical systems for enabling the blind to do just this, leave us in 1971 with a well-defined social need and several well-engineered means to satisfy it."[26]

Freiberger's assessment of the innovation problem for reading machines reflected fifteen-years' participation in an expanded knowledge community. It demonstrated an awareness of the social diversity and complexity of the target population which was learned from interaction with the service community. His assessment linked design choices to social determinants, such as a prescription for inconspicuousness, and a contextual need for blind professionals to gain access to typewritten documents. In short, PSAS's understanding of the technology development and innovation process in 1971 represents a different and more sophisticated one than anything expressed by CSD twenty years before.

However, Freiberger's articulation of the social aspects of technology development should not be taken to represent a general shift in paradigm for technology developers –

even those concerned with reading machines for the blind. Freiberger did not put in the past tense his critique that developers often develop a device and then look for a problem which it can solve. An interesting example of different perspectives on development and innovation can be taken from two reports delivered at the 1971 NRC evaluation conference. Each was made by a reading machine developer who had participated in PSAS conferences for many years.

In their presentation of "Plans for the evaluation of a high-performance reading machine for the blind," Franklin Cooper and Patrick Nye of Haskins Laboratories described how twenty years of research had brought them to the point where they could now, "...generate synthetic speech from text in sufficient quantity to meet the needs of an evaluation study." Although not yet perfected, they argued, their technology warranted evaluation now, because it was the only approach which could provide for reading at rates over 150 wpm, because there was a gap in present services by human readers in providing text to students, because the cost of synthetic speech could be expected to fall, and because,

> The initial entry of automated techniques into any new arena can always be expected to be met by new and often unforeseen problems. These problems are usually amenable to solution, but they first need to be identified. Time then must be allowed to find ways of circumventing each difficulty. Direct contact with the user population under field-trial conditions is essential.[27]

Cooper and Nye thus described an approach to development where, after twenty years of laboratory development, the time had finally come to identify the problems of innovation through direct contact with the user population. Contrast the approach described by Jim Bliss in his presentation entitled, "Optacon evaluation considerations:"

> It is impossible to separate the development of the Optacon from the evaluation of the Optacon as its design has evolved. From the outset Optacon development has been guided by concurrent experiments with blind readers. In the last three years, the development has also been guided by the performance and experience of five Optacon readers who have used various versions of the Optacon in their everyday lives. Results of performance tests, comments, and opinions of these individual Optacon readers have played a major role in determining the directions for continued development.[28]

It is clear that these two firms practiced different approaches to technology development. Haskins Labs in 1971, as in 1941, followed a linear model of innovation. As described in Chapter 8, they followed a systematic approach which led from psychoacoustical research into the interpretation of speech and artificial speech, to the engineering design of devices capable of generating artificial speech, and only then to the field where one could learn and address problems of context. According to this concept, research precedes development which precedes innovation. Bliss described a different practice, investigated in Chapter 9, where information on a device and its application context are sought interactively over an extended period of time, where innovation and development are managed as connected processes.

We cannot ascribe this difference in approach to the direct influence of PSAS. Haskins Labs was a PSAS contractor and Stanford Research Institute was not. On the other hand, Haskins Labs established its research approach under the aegis of CSD, while Jim Bliss participated in the expanded research community sponsored by PSAS, from the time of his graduation from MIT in 1962. His mentors at MIT were also participants and active contributors to the broader conception of a research community. The expanded research community, as guided and nurtured by PSAS must have had a significant impact on Bliss and his colleagues' conception of technology development.

The knowledge community as an authority for program direction

PSAS's technical sessions provided a general forum for the exchange of information related to reading machine research. They also served a more specific purpose, providing Murphy and Freiberger with information and advice for decision making, as PSAS undertook to revive federal support to the development of reading machines for the blind. In 1971, reviewing the work of the technical sessions, Murphy stated that by the conclusion of the fourth conference in August 1956, a consensus had been reached that no single technology could meet all of the needs of blind users. Contrary to CSD's decision, a direct translation device was desirable because it could be quickly developed and manufactured at a price consistent with individual ownership, even though it would likely require extended training and achieve only a slow reading speed. At the same time, a more complex, bulky, and expensive device should be developed, which would provide synthetic speech and be appropriate for library service. An "intermediate-type" machine might combine features of both, providing a synthetic language output, where sound was related to letter shape, from a device that would be feasible for individual ownership.[29]

Murphy was describing the three-pronged approach which had been implemented by PSAS in 1957.

The minutes of the fourth session show a less orderly decision process than the one described by Murphy fifteen years later. They depict a knowledge community with diverse research interests and different understandings of the nature of technology development. It is clear from the minutes that Thomas Benham and Clifford Witcher, both blind scientists, supported further development of a direct translation device as the most rapid route to providing blind people with some capability for independent reading (see Appendix for institutional affiliations of participants).[30] A subcommittee on Direct Translation Machines, comprising Heinz Kallman, Clyde Heasly, V. K. Zworykin, Leslie Flory and Winthrop Pike also supported development of a direct translation device and recommended design specifications for an improved A-2 Reader.[31] Flory, Pike, and Zworykin represented RCA and therefore had vested interests in the A-2 design. Dr. Kallman and Dr. W. W. Thompson, of the Blinded Veterans Association expressed an interest in combining the direct translation concept with tactile output for a home reader. Mr. Ritter, Mr. Washington, Mr. Surber, Dr. Witcher, and Mr. Pike each spoke in favor of a variety of approaches to tactile displays.[32]

The most extensive presentation was made by Franklin Cooper, on the topic of "Synthetic speech and reading machines." Cooper presented a revised taxonomy of reading machines which recognized two major categories of devices (Figure 9).

According to Cooper's taxonomy, recognition machines would "recognize" printed letters and use a set of programmed rules to convert graphemes into phonemes to produce synthetic speech. Direct translation machines would convert letters into speech-like sounds where the sounds were based on the letters' shapes alone. Spelled-speech is one example of this strategy, but one which, despite its familiarity, was not optimized for rapid intelligibility. Cooper relegated direct translation devices of the type of the A-2 Reader to the category of a "research phase" of direct translation devices, so defined. Cooper argued that reading machines of both types could and should be built.[33]

The meeting addressed many other topics, most notably several devices for converting print to braille. Its principal action was to constitute five committees to pursue the issues raised at the meeting. One was concerned with terminology. Another was to prepare a brief on braille fundamentals to inform considerations of a braille output device. One was to study synthetic speech and recommend the best kind for reading machines, and one was to study and recommend an approach to tactile displays.

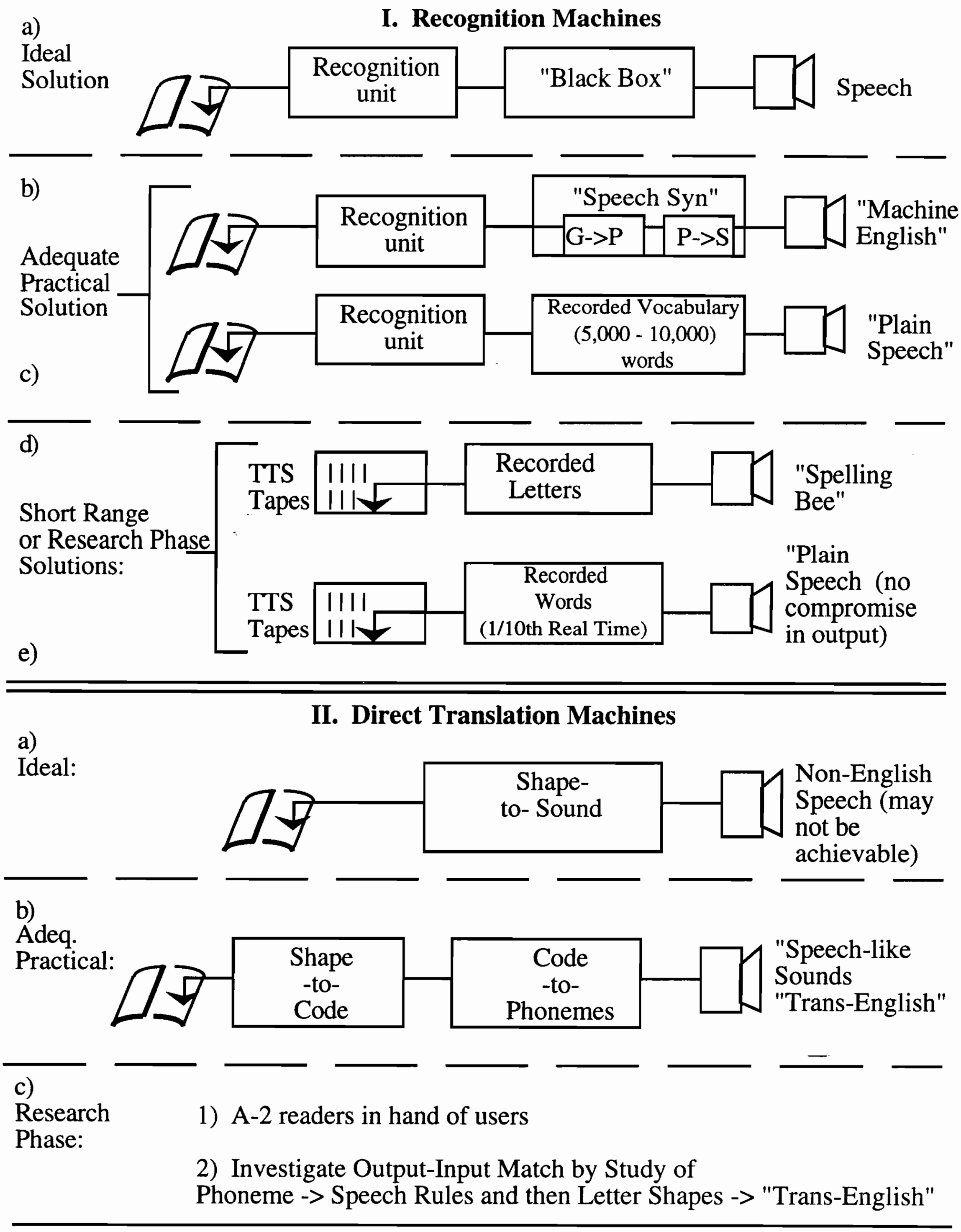


Figure 9. Reproduction of Cooper's 1956 taxonomy

The fifth committee was to summarize work to date on the A-2 reader as a starting point for further development of the concept.[34]

Somewhat out of step with the rest of the delegates was Jacob Rabinow, an independent inventor working on optical character recognition for the National Bureau of Standards. In response to a debate between Pike and Thompson on the relative merits of aural versus tactile output for a home reader, Rabinow declared that, "...actual decisions as to what to do in the future would have to come from a laboratory or a contractor, not from a committee. He felt that the function of the Conference on Reading Machines should be to evaluate instruments, after they are built, to determine which one is best."

We may take Rabinow's declaration that the proper display for a reading machine should be decided by the developer as a reminder that the notion of technology as applied science represented a robust paradigm, even in the middle of a conference which was structured according to a different conception. And, we may note that Rabinow's linear concept of the relationship between development and evaluation was the same as that expressed by Haskins Labs fifteen years later at the NRC conference.

Dr. Wildhack, of the National Bureau of Standards and Eugene Murphy disagreed with Rabinow's assertion. They argued that a committee could legitimately prepare "tentative specifications for progress of the work." Such specifications could be sent to prospective technology developers as the basis for their proposals to the VA. The minutes then record that, "Dr. Murphy thought some money could be found at the VA, depending on the type of recommendations forthcoming."[35]

In 1962, John Dupress attributed the availability of federal funding for sensory aids research to the impact of the Korean War.[36] Koestler provides evidence for this attribution, noting that the Korean toll of 500 blinded veterans represented a higher percentage of such casualties than in any previous American war.[37] Unlike the situation at the beginning of World War II, however, institutions were in place within the Veterans Administration, at Hines VA Hospital, for providing rehabilitation services to these blinded veterans. Moreover, a small research division existed within PSAS, which had a Congressional charter and the knowledge base necessary to revive a federal research program. As head of PSAS's Research Division, Eugene Murphy saw the residual funds from the medical research budget which became available in 1957, as a windfall. It was because of his efforts to sustain and expand a research community between 1948 and 1957, that PSAS was prepared to take advantage of that windfall when it occurred.

It was an exaggeration to say that the fourth technical session on reading machines reached a consensus on the direction of reading machine development. But it did negotiate a compromise which provided PSAS with the ability to cite the authority of a broadly-based knowledge community in pursuit of a reading machine development program. The very last item of the minutes recorded an agreement between Professor Benham and Dr. Cooper stressing "...the dual aspects of future work on the A-2 type reader." The conference agreed that efforts should quickly proceed to construct and test an improved direct translation device with simple aural output. At the same time, research should also be undertaken to "search for the best possible output(s) for an A-2 type reader, retaining as much as possible of the simplicity and low cost yet increasing reading speed and ease of learning."[38]

Chapter 6. Battelle Memorial Institute and the Battelle Optophone

The fourth technical conference on reading machines provided PSAS with specifications for an improved, direct translation reading machine, and a recommendation that an improved prototype be designed and fabricated for "psychological testing." The subcommittee on direct translation machines recommended that RCA's A-2 Reader be improved by the use of transistors and semiconductor photodiodes to replace the vacuum tubes and photocells employed in the twelve-year-old design. The scanning wave shape should be changed from a sine curve, which spends least time in the middle of the letter and most time at the top and bottom, to a saw tooth-shaped-scan which spends more time in the middle of a letter. This change was intended to enhance the possibility of distinguishing certain letters like a, c, e, or o, which are of similar shape, have no extenders, and which produced similar sounds in the A-2 device. Discrete, rather than continuous sounds were recommended as potentially easier to interpret. Finally, the scanning spot was to be made incrementally variable in size, allowing the reader to adjust the resolution of the device.[1]

Eugene Murphy, following the procedure he outlined to Jacob Rabinow at the fourth reading machine meeting, provided these specifications to potential contractors for the development of an improved, direct translation reading machine. He tried to interest RCA in the project, but in spite of their representation at the first four technical sessions, the RCA team decided not to submit a proposal.[2] In April 1957, PSAS placed a development contract with the Battelle Memorial Institute of Columbus, Ohio.[3]

Design of an improved optophone

Dr. Richard S. Laymon of the Systems Engineering Division was Battelle's principal investigator and D. Reagan Rice of the Electrical Engineering Division was the design engineer. Work proceeded swiftly, and by June 1958, the initial, fixed price contract was completed. Under this contract five prototype machines were built for evaluation by blind readers.

Judging from Dr. Layton's report at the 1958 PSAS contractors' meeting, his development team approached the project as an engineering design problem, in much the same way as Zworykin and Flory, a dozen years before. Like RCA's A-2 Reader, the Battelle Optophone was a new embodiment of the design concept expressed by d'Albe in the Reading Optophone. The new design incorporated advances in electrical engineering in the form of new component parts which had been developed in the intervening years.

The Battelle design satisfied three of the four specifications set by the fourth reading machine technical session. The requirements for discrete tones and for a saw tooth wave form were found to be incompatible. The design team chose to employ discrete tones, which were thought to be easier to interpret. Vertical scanning was rendered unnecessary by the use of multiple photodiodes – one for each tone to be generated. Advances in photocell design permitted the use of miniature cells, called photodiodes, in a vertical array, one per tone. The use of a single photodetector – a selenium bridge in the d'Albe Optophone, and a miniature phototube the A-2 Reader – had imposed a need either to oscillate the incident light (d'Albe) or to synchronize vertical scansion with a variable oscillator (A-2), in order to generate a pitch associated with vertical height in the line being scanned. Battelle's use of a vertical array of photodiode detectors, each linked to a transistorized oscillator, provided a simple way to associate information on vertical location with pitch, while eliminating any wave form associated with vertical scanning (see Figure 10).

By employing nine tones instead of six, Battelle hoped to meet the need for more information on the center part of a line of print which the saw tooth wave form had been intended to address. An additional two tones were added as a tracking aid – a total of eleven. If the probe began to stray from the line of print, then the highest or lowest tone would sound as a warning. Two simple lamps provided even illumination, and a commercially available lens projected light as reflected from the page onto the detector array. A simple knurled knob provided for both focusing and selection of magnification. Changes in the current generated by a photocell due to the presence or absence of reflected light changed the impedance in a switching transistor. This, in turn, would permit or inhibit oscillation by a transistor oscillator set at a selected frequency corresponding to the vertical position of the photodiode. Output from the eleven oscillators was mixed, amplified, and sent to a headset worn by the reader. The device was operated by three switches - on /off; volume; and a rheostat for lamp intensity.[4]

The Battelle report makes no reference to the involvement of blind persons in the design phase. Subsequent to fabrication of five prototypes, Battelle undertook an evaluation task which sought to train twelve blind readers in the use of the instrument and to measure the results. According to Battelle's report, the evaluation task was curtailed because of "...unexpected expenditures in the engineering department."[5]

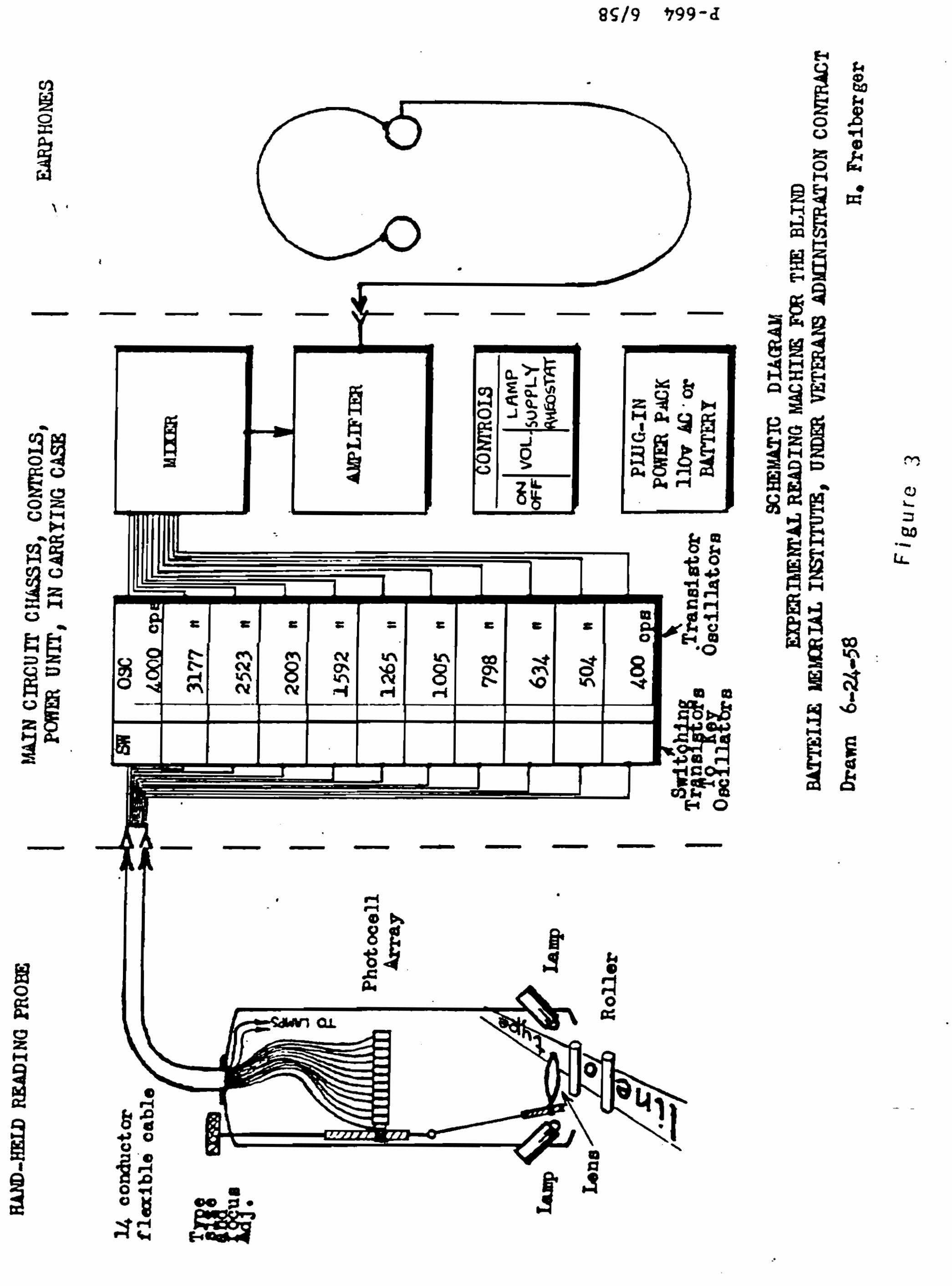


Figure 10. Schematic diagram of the Battelle Optophone[6]

Information provided by Battelle, however, suggests that the evaluation plan was not a sophisticated one. Participants were presented tape recordings of mechanically tracked letters, words, and then sentences, at rates of 15 and 30 wpm, for an unspecified period of time. Later, the students worked with hand held probes for about a month. Battelle reported results in the form of average reading rates and the ability to recognize individual letters, unrelated words, and text when presented at rates of 15 and 30 wpm, but they did not attempt to associate these measures with any independent variables nor to examine how learning rates might depend on teaching methods.

Reading rates achieved by the Battelle test group of ten students from the Ohio School for the Blind and two blind adults were disappointingly low - one to three words per minute for connected text. Nonetheless, Dr. Laymon reported, all of the participants expressed a desire to continue working with the reading machine. They expected to achieve a reading rate of about 30 words per minute, and said they would be willing to pay between $100 and $500 for the device.[7] Dr. Laymon did not attempt to explain the apparent anomaly between the disappointing quantitative results and the positive attitudes of the participants.

All of Battelle's testing under this initial contract was laboratory testing. Battelle did not try to examine how blind readers would use the reader in their daily lives. Clearly the constraints of time and a fixed price contract did not encourage field tests, but these constraints were constructed and negotiated by the parties to the contract. Funds, for example, could be carried over for up to two years under the pertinent form of contract.[8] If field testing had been considered critical to the project, it could have been accomplished. The test design seems to have reflected a conceptual framework which understood a device that works to be one which functions in an engineering sense. It also recognized that a device must work in an ergonomic sense to be physically and psychologically operable by its user within some envelope of performance. What the test plan did not represent was any notion that a technology that works is one that a user can employ to achieve a particular objective in a specific context. This question of whether or not a reading machine works in context was not construed by Battelle to be part of the design process, but something to be investigated subsequent to development. Perhaps it was the ability of the blind evaluators to imagine the device as part of their own lives that can explain the discrepancy between Battelle's discouraging test results and the optimism displayed by test participants during their exit interviews.

Evaluating the Battelle Optophone

Early in 1958, Murphy took a recording of the Battelle optophone signal to England where he played it for Mary Jameson, d'Albe's former protégé, now 59 years old. Murphy encouraged Battelle at the June 1958 contractors meeting by telling them that Miss Jameson had "high regard for the sounds of the Battelle instrument."[9] He also provided more substantial encouragement in the form of a new, continuing research contract. From July 1958 through June 1963, Battelle worked under this contract to develop their optophone, but PSAS's focus shifted from engineering development to development of a training program which might facilitate the introduction and dissemination of the technology. Project management accordingly shifted to Battelle's new Psychological Sciences Group, where John L. Coffey and Ray R. McFarland worked under the direction of Dr. William D. Hitt.

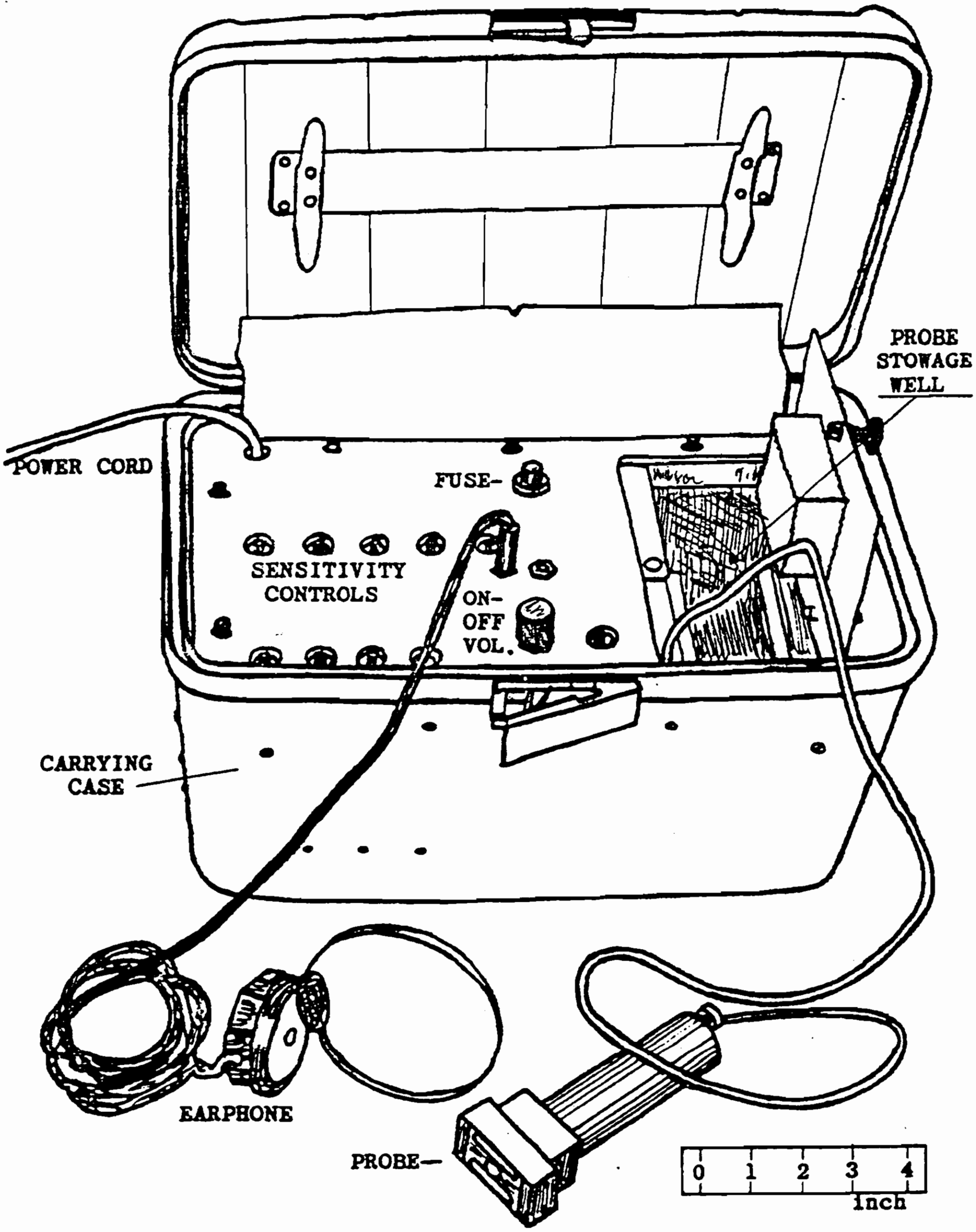
Reviewing the project in 1971, Murphy explained that the major objective of the effort was to develop a "...series of training lessons with the optophone code," although the contract did support three design reiterations. Part of Murphy's presentation to the 1971 NRC conference is worth reproducing here, because it presents a perspective on evaluation that seems markedly different from that of his engineering contractors:

> Battelle devoted its initial efforts to training two subjects with Model A. One of them, Mr. Cobb, then a church organist and now retired, was allowed to keep a device and has remained a routine user. He still has a Model-D instrument [see Figure 11], which he uses both for his own purposes and for demonstrating occasionally to other blind people.
>
> When Mr. Cobb was a student at Perkins School for the Blind in the early 1920s, the British Fournier d'Albe optophone in the production-engineered model built by Barr and Straud [sic.] was demonstrated there. At the time, most observers understandably felt that it was hopelessly slow. At that time, of course, the electronic capabilities were very limited, so the machine was noisy and produced numerous extraneous signals. After his success in learning the Battelle optophone code in the late 1950s and early 1960s, eventually reaching a stage where he was timed at 19 wpm using a probe free hand and at 38 wpm when using the probe with a rather crude mechanical tracking aid, Mr. Cobb commented wistfully that he wondered what his life might have been like had he been able to continue to use a reading machine from the time of his school days. He found the aid useful

> not only for personal correspondence but for rereading an instruction book for the church organ which he played; incidentally, he found described in the book an extra stop of which he had been unaware.
>
> A number of students at the Ohio School for the Blind were trained with the Battelle device, in its successive models, primarily to help the Battelle psychologists develop their training lessons. These subjects were paid a modest hourly rate for their services but were not allowed to keep aids after the end of the school year.[10]

The products of Battelle's research included ten prototype Model D optophones, fabricated under subcontract by Aeronca Manufacturing Corp., and a 200-hour training course on 43 reels of magnetic tape recordings, together with a lesson plan for each of the 200 hour-long lessons.[11] PSAS's interest in dissemination is evidenced by the final activity undertaken by Battelle under its contract, a one-week instructor seminar on the use of the device. Attending the session, presented by the Battelle staff with the help of five blind students, were Anna S. Drew, of the Catholic Guild for All the Blind, Marjorie Lamport of the Cleveland Society for the Blind, Vernon E. Marvel of the Virginia Commission for the Visually Handicapped, Mrs. Genevieve Miller of the Hines VA Hospital, John L. Morse, from the Perkins School for the Blind, and Mrs. Milton K. Susman of the Greater Pittsburgh Guild for the Blind Rehabilitation Center. Murphy addressed the small group of service professionals, and explained that "Title 38 U.S. Code 216(b) allows the benefits of research conducted to meet the needs of veterans to be made available to the general populace. One of the purposes of this seminar is to lay groundwork for such dissemination by acquainting non-veteran groups from geographically separated areas with details of the aural reading system, as well as for the care of veterans."[12]

Most of the week-long seminar was spent observing and then working with the Model-D Optophone and the blind students. Mr. Cobb, the organist, provided a demonstration, and told the group that strong motivation and persistence were needed to master the device. At the end of the week, Howard Freiberger and Battelle's John Coffey co-chaired a discussion session to gather the impressions of the participants. The discussion was lively. Mrs. Drew felt that research was needed to predict which blind people were most likely to successfully learn and employ the technology.



BATTELLE AURAL READING DEVICE - MODEL D
Figure 1

P-1272 8/63

Figure 11. Battelle Model D Optophone[13]

Other participants wanted to test the ability of young children to learn to use the device. Mr. Morse suggested trials could be run at the Perkins School. Mrs. Lamport identified a need for an information clearinghouse on the technology, a role that Howard Freiberger said the VA could fill. Mr. Marvel and Mrs. Susman agreed that a better tracking device would improve system performance. Questions were raised about the structure of the Battelle training course, and the best way to organize its presentation, but "Clear-cut answers were not possible because of lack of experience...." Marvel recommended that reading comprehension as well as reading speed should be a test variable.

At the close of the discussion, according to Freiberger's report, "Fully realizing the complexity of the problem with its engineering, psychological, vocational, and economic ramifications, Mr. Freiberger attempted to elicit a simplified 'thumbs up' or 'thumbs down' reaction to the device and its future from the assembled participants." He was unsuccessful at eliciting such a response. Most of the participants agreed that the device had utility for only some blind people, but they also agreed that the device deserved field trials. Several were interested in teaching the technology in their own agency, among them, Genevieve Miller of the Hines VA Hospital.[14]

Field evaluation of the optophone proved to be a difficult task. PSAS sought to sponsor a small, but systematic trial through the agency of the American Center for Research in Blindness and Rehabilitation (ACRIBAR), in Newton, Massachusetts. Dr. Leo Riley, the principal investigator, sought to select highly motivated subjects who were likely to succeed, based on tests of "physical fitness, I.Q., hearing, psychological means and musical ability." Of the six subjects, five dropped out of the program when they found employment, and one dropped out due to illness. The participant who stayed with the evaluation program the longest, completed 85 of the 200 lessons and achieved a reading rate of seven wpm.[15]

In January 1964, Howard Freiberger undertook to serve as an instructor of the Battelle course to Geneva Washington, a blind social worker employed at the VA's New York office. Originally hoping to complete three lessons per week, over the course of two years, they covered the first 80 lessons, at which time the student was reading second grade material at a rate of 3 - 4 wpm.[16]

Beginning in April 1964, Harvey Lauer, a blind braille instructor at Hines also undertook to learn the Battelle optophone, working with Genevieve Miller, who had attended the Battelle seminar in 1963. Lauer remembers the event this way:

> Thirty-five years ago [in 1959], I read in Charles Ritter's column in the Matilda Ziegler Magazine that Mary Jameson was reading her mail and checking her typing. Right then I decided to "go for it!"
>
> Five years later, in 1964, as I was teaching braille in the VA at Hines Hospital, the opportunity was offered. I learned to read with a nine-tone device the size of an overnight case. It was called the VA-Battelle Optophone.[17]

Working part time, Lauer completed the course in January 1965. His progress was reported by Freiberger in the semiannual *Bulletin of Prosthetics Research,*[18] and in January 1966, Lauer was asked to present a paper on his experience at the sixth PSAS technical session on reading machines in Washington, and to demonstrate the device. Lauer, who by then read at a speed of up to 25 wpm, reported that he had found six categories of efficient uses for the optophone. He defined an efficient use as "one which, after reasonable training, permits greater independence and also reduces the handicap of blindness to the individuals under consideration." The six were: checking typing, identifying currency, reading typed correspondence, reading bills and bank statements, identifying mail or packaged goods, and consulting reference books, such as dictionaries.

Lauer, an experienced braille instructor, said that learning to use the optophone was comparable to learning braille, and that the challenge of attaining high reading speeds was also similar. Improved teaching methods, he believed, could bring the skill within the reach of many more blind people. He concluded, "In summary, I love to use the Optophone. The pace is slow, the mileage is improving, but the payload is terrific. I would like very much to teach the skill."[19]

Later in the day, Lauer demonstrated the use of the Battelle Optophone. At that time, he also demonstrated a new device, designed by another PSAS contractor. Three days before the Washington meeting, Lauer reports, Glen Smith of Mauch Laboratories brought to Hines a new, hand-held optophone, called the *Visotoner,* and asked him to try it out, with the idea of demonstrating it at the Washington meeting. Lauer found some problems with the new machine. One of its nine channels was too sensitive, and its response was sluggish compared to the Battelle optophone, but, as Smith pointed out, there couldn't be too much wrong with the prototype if Lauer could pick it up and immediately begin to read with it.[20] A pocket-sized, hand held device, the Visotoner had some potential advantages over the Battelle optophone, and Mauch Laboratories was ready and available, under its continuing contract, to further develop the design.

From 1966, the Visotoner and its offspring, the Stereotoner, became PSAS's leading candidate for a direct translation reading machine. The Battelle optophone faded from further consideration, in part because an effective evaluation program was never formulated and in part because it was superseded by an improved Mauch design.

Chapter 7. Mauch Laboratories

Hans Mauch did not set out to design an improved optophone, nor was it Eugene Murphy's intent that he do so. Murphy knew Mauch through his work in the field of prosthetics. With PSAS's support, Mauch was codeveloper of an improved artificial knee, a project he had started in Heidelberg, Germany, at the close of the Second World War. Murphy first approached Mauch for some help in the mechanical engineering of an improved tracking device which Murphy considered to be critical to the design of an automated reading machine. Mauch responded by informing Murphy that he was just as good at electronics as mechanics, and should be asked to design the entire machine.[1]

Murphy gave Mauch Laboratories the task of developing an advanced home reading machine which was intended to be easier to learn and faster to use than the optophone being developed by Battelle. Mauch first sought to fabricate a device which would generate speech-like sounds as a function of letter shape, as recommended by Franklin S. Cooper. When this approach failed, Mauch designed a second prototype which created an artificial language by playing recorded phonemes based on the shape of the letters. This design was also rejected. Mauch's third attempt was a recognition machine to employ the spelled-speech of Milton Metfessel. Problems with the performance of this device led Mauch to fabricate a hand-held probe that would allow a blind user to precisely align the scanner and thus improve the recognition rate of the device. The probe also compensated for an inherent limitation of the spelled-speech approach, providing a means to interpret characters such as numerals and punctuation marks which were not in the spelled-speech alphabet.

Except for its tactile output, the hand-held probe, which Mauch called the Visotactor, was in effect a miniature optophone. It was a short step from the Visotactor to the Visotoner with its audible signal. This was the device which Harvey Lauer demonstrated, together with the Battelle optophone, in Washington, in 1966. Mauch, who nine years before had set out to develop an alternative device, had come by a circuitous path to fabricate the next generation optophone. By 1972, the Visotoner had been redesigned as the Stereotoner, a device which came closer to innovation than any other PSAS-sponsored reading machine. Before addressing the history of the Stereotoner in some detail, let us consider Mauch's attempts to develop an intermediate reading machine for the blind.

An intermediate reading machine

In 1957, when he asked Hans Mauch to build a tracking device for a reading machine, Eugene Murphy had just contracted with Battelle Memorial Institute to develop a new generation optophone, as described in Chapter 6. PSAS had also contracted with Haskins Laboratories to pursue research into synthetic speech machines, as described in Chapter 8, below. However, the PSAS-sponsored technical sessions on reading machines had articulated concerns that the direct translation of print to tones might be too hard to learn for many blind people. while synthetic speech machines were expected be too expensive for individual ownership. The meeting proposed that an intermediate device should also be developed which would convert letters into speech-like sounds. Such sounds, Franklin Cooper believed, would be easier to interpret than a tonal code. At the same time, such an intermediate machine would be less complex and expensive than a synthetic speech machine. When Mauch expressed his interest in undertaking the design of a complete reading machine, Murphy invited him to make a proposal to develop an intermediate device.

Murphy was sending Mauch information on sensory aids as early as August 1949.[2] It was eight years before Murphy brought him into the reading machine community, however. Mauch did not attend the first four PSAS technical sessions, where deliberations helped define the structure of PSAS' research program.

The subject of letter recognition machines was first discussed at the second technical session in April 1955. Homer Dudley of Bell Laboratories raised the topic of artificial speech. He reported that research performed at Bell Labs by Dr. Cyril Harris indicated that artificial speech in the form of phonetic pronunciation of English words was difficult to comprehend. Dr. Witcher reported that work at MIT had indicated that an artificial speech machine would be quite expensive. He then recalled the wartime work of Franklin Cooper at Haskins Labs, and suggested that the group review this work. Dudley agreed that Haskins Labs would be a good source for research on synthetic speech, at which time Murphy informed the meeting of an existing proposal to PSAS from Milton Metfessel of the Psychology Department of the University of Southern California (USC), "...to study the necessary modifications of speech to yield the most comprehensible letter-by-letter output at the fastest rate."[3] Consequent to this discussion, the conference recommended that, "A representative of the meeting should seek to obtain samples of synthetic speech from either Haskins Laboratories, The Bell Telephone Laboratories or MIT...for study and comparison with spelling bee presentation."[4]

Murphy subsequently contacted Cooper, who told him that, although Haskins Labs had no directly useful information, "...he felt far more hopeful of a successful solution than he did five years before."[5] Three months later, in June 1955, PSAS awarded a small research contract to USC for Professor Metfessel to provide a sample of spelled speech for comparison with other types of synthetic speech. In August 1956, at the fourth PSAS technical session, Haskins Laboratories, Bell Telephone Laboratories, and Dr. Metfessel all presented samples of their work.

Metfessel made the first presentation. He began by playing a tape of spelled speech. The minutes noted that, "The utterances sounded more like a foreign language than like a spelling bee." By careful selection and modification of the sounds of spelled letters, Metfessel explained, he sought to provide an output "with the characteristics of a spoken language," minimizing the impression that letters were being discretely spelled.[6] Franklin Cooper next offered a presentation entitled, "Synthetic speech and the reading machine problem," which provided a review of Haskins Labs' progress in synthetic speech research since the end of the CSD program. He began by noting the importance of synthetic speech to the problem of reading machine design, claiming, "...it would obviously be better to have the output from a recognition machine in terms of connected speech – even if a rather mechanical form of speech – than as a spelling bee."[7]

Cooper did not consider spelled-speech to be a viable output for an intermediate reading machine. He believed that any machine capable of letter recognition would also be capable of word recognition. Even in the absence of a synthetic speech capability, he thought, a recognition machine could achieve a "plain speech" output by playing back strings of words, spliced together from a prerecorded vocabulary. The principal barrier to such a design was the need for a processor capable of sorting through ten thousand words in "real time." But such a device was to be expected in five to ten years, "assuming that developments in the computer field continue at their present tempo."[8] The only reason to build a spelled-speech machine, in Cooper's opinion, was to prove the concept of a plain speech device, pending the anticipated improvement in processors.

Cooper's concept of an intermediate reading machine was not a recognition device, but a direct translation machine which converted a letter's <u>shape</u> not into tones, but into phonemes. Because this type of machine included no recognition function, the phonemes it produced would not be related to the letter's conventional pronunciation, but only to its shape. Cooper thought these speech-like sounds would be easier to interpret than pure tones or chords. Like Metfessel, Cooper played a demonstration tape. Cooper's tape included examples of state-of-the-art synthetic speech based on the playback of spectrograms, which Cooper labeled "machine-English;" and "speech-like sounds from an hypothetical direct-translation reading machine," which he called "Trans-English."[9]

Homer Dudley of Bell Telephone Laboratories then presented a tape of speech-like sounds, which he called "frozen phonemes." According to this system, under study at Bell Labs by Dr. Harris, each of the 26 letters of the alphabet was given a standard, phonemic pronunciation, so that written words were translated into a spoken language where each word has the same number of phonemes as letters. Dudley noted that in his sample recording of Mary Had a Little Lamb, "...rather wrong sounds occurred in 41% of the cases [syllables]." He suggested that a psychological study should be made of the intelligibility of different possible codes for written English, and recommended that blind people "should be principally involved in their evaluation."[10]

As described in Chapter 5, the fourth technical session on reading machines ended with an agreement between Benham and Cooper that PSAS should proceed to construct and test an improved direct translation device with simple aural output, while supporting research to develop a personal reader with an improved output for increased reading speed and ease of learning. In April 1957, the former task was given to Battelle Memorial Laboratories. In August, the core of the latter task was given to Hans Mauch.

Mauch's first prototype

Hans Mauch was an experienced and multi-talented engineering designer. Born in 1906, he joined the German Air Ministry in 1935, after six years as a member of the staff of E. Zweitusch & Co. In 1939, he was assigned to the ministry's head engineering office in Berlin, where he worked from 1939 until the end of the war, when he became associated with the Aeromedical Center of the U.S. Army Air Corps, in Heidelberg. In 1946, Mauch was transferred to the Aero Medical Laboratory at Wright Field, in Dayton, Ohio, where he established Mauch Laboratories in 1957.[11]

Murphy recalls that Mauch had been part of the German V-1 missile development team who was brought to Heidelberg under the auspices of Operation Paperclip. In Heidelberg, Mauch, together with Dr. Ulrich Henschke, pursued his interest in artificial limbs, and built a prototype hydraulic knee. Based in part on this work, Mauch and Henschke were brought by the Army to the Aero Medical Laboratory. In Dayton, Mauch built a small shop in his home, where he continued his work on artificial limbs with the help of a machinist, ultimately with PSAS's support.[12] This operation formed the basis for Mauch Laboratories.

Mauch's approach to the problem of an intermediate reading machine was not one of research, but of design – that of the talented tinkerer or skilled craftsman. Working with a few assistants, he would build bench-top models, pursuing a design concept as far as his genius could take it. When he reached an impasse, he would redesign components as necessary to find a more workable design solution. When he reached a dead end, he would salvage what he could, take what he had learned, and revise the entire design concept. If a concept failed, he would negotiate a change in design objectives, propose a new concept, or return to an old one. Over the course of twenty years, Mauch produced a variety of prototype reading machines. None of them were brought to innovation.

Mauch's first attempt to design an intermediate reading machine drew upon the concepts advocated by Franklin Cooper. During 1957 and 1958, Mauch designed and built a laboratory prototype which used the shape of letters to convert print into speech-like sounds (see Figure 12). His first bench-top model employed a scanner which resembled the simulator fabricated by Haskins Labs in 1944. It used an adjustable slit and a lens to focus projected light on five vertically aligned photocells. Current from the photocells activated a set of five mirror galvanometers which reflected light onto a segment of a rotating disc, similar to that used in the Haskins spectrograph play back machine. The playback machine was, in effect, a movie soundtrack, consisting of prerecorded frequencies from 120 to 6,000 Hz. Three different frequency bands were activated by the light from three of the mirror galvanometers.[13] Sound was generated in three frequency bands because Haskins and other researchers using the sound spectrograph described in Chapter 3, had determined that the vowel sounds in human speech were characterized by three groups of sound frequencies, called "formants." Mauch sought to enhance the speech-like character of the sounds which his device produced by producing artificial consonants, and thus creating syllables out of each two-letter pair. This was done by arbitrarily adding a hiss at the end of the sound produced by every other letter.

Mauch must have been enthusiastic about his new project. He applied for a U.S. patent on his preliminary design only a month after the start of the contract, in September 1957.[14] Although his bench-top prototype included only three complete circuits (out of five), Mauch felt confident enough of his results to present a demonstration tape recording at the PSAS contractors' meeting in June 1958.

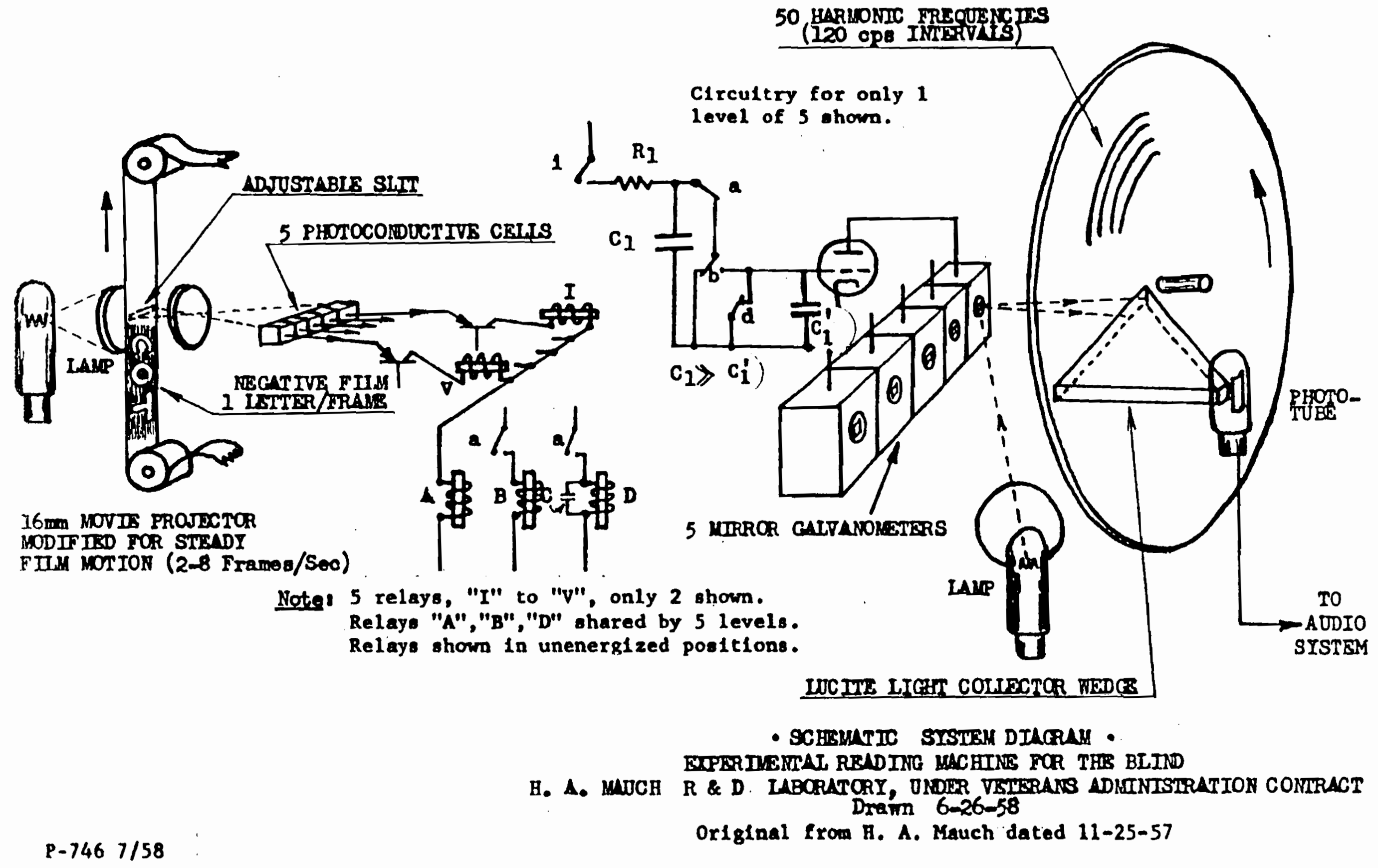


Figure 12. Schematic of the first Mauch prototype[15]

The reaction of his peers must have been disappointing. Three years afterwards, Freiberger and Murphy simply reported that, "In pursuing an ever-closer approach to speechlike sounds, Mauch found inadequate patterns of vowel sounds and hisses for sibilant consonants although confined within normal speech frequencies...."[16] Mauch's demonstration prompted an immediate discussion on whether engineering development of an intermediate device was premature, pending further research into effective, speech-like output. Mauch defended the need for engineering development, and the discussion ended with Cooper offering to help Mauch with the playback device. Mauch spent the next day at the PSAS office, suggesting ways "to improve the speech-like aspects of the sounds of his device."[17] In a summary report of September, 1958, Freiberger noted that the sound elements of the device were produced by the rotating disk method, "for the present." The report added, "It is now thought that in the future certain actual speech sounds might be recorded in some of the tone disc's channels for direct excitation into the recognizable phonemic sounds by the light spots and associated circuitry."[18]

A Second Attempt

Mauch's next prototype abandoned the tone disc in favor of a new playback component, invented by Mauch, which he called a Word Synthesizer. The Word Synthesizer consisted of a set of 160 rotating arms, radially projecting from a common shaft. Each arm carried a length of magnetic tape with a recording of a particular phoneme. In order to enhance response time, there were five arms carrying each sound, a total of 32 sounds. In response to a signal from the scanner and processor, an arm would be frictionally engaged by the shaft, and the sound it carried would be played. I have not located a detailed description of the second prototype, but a capsule description, first published in 1966, implies that it used a scanning system like that of the first. Appropriate circuitry would have converted the output signals from the five photocells into a unique activating signal to the Word Synthesizer. The capsule description states that the prototype was less than a full recognition device.[19] This is an interesting distinction, since the reading machine was clearly intended to present a unique output for each alphabetic character. It is likely that the device "recognized" 26 lower case characters in a single type font, that is to say that it played a different phoneme for each.

Whatever the detailed design of Mauch's second prototype, the overall results were still not acceptable. Well before 1962, Mauch abandoned the grapheme to phoneme approach of producing "speech-like sounds" in favor of Metfessel's concept of a spelled-speech machine. In his "Review of the major functional concepts of reading machines," presented at the AFB's June 1962, International Conference on Technology and Blindness, Mauch summarized his experience with what he now called, "integrating machines:"

> To complete this discussion, I should mention finally the so-called "integrating machines." They are fascinating to consider. They are based on the concept that it should be possible to integrate the salient features of a character into one compound signal and to use the various compound signals from all the characters as the output code of the machine. This concept places these machines between the "direct translation" and the "recognition" machines.... we ourselves tried two versions of them with an auditory output, without much success. It turned out that we had been much too optimistic in our assumptions regarding the capability of the human ear to interpret compound signals other than phonemes. We are now convinced that the concept is problematical in principle. But maybe we are now too pessimistic.[20]

Mauch was being imprecise when he blamed the failure of the design concept on the "capability of the human ear to interpret compound signals other than phonemes," since his second prototype undoubtedly had prerecorded phonemes as its output. Most likely, as described by Dudley in 1956, "frozen phonemes" were difficult to recognize when strung together. Mauch, of course, had not attended the fourth technical session where Dudley described Bell Laboratories' experience. Cooper seems to have believed that the failure lay in Mauch's approach to the problem and not in the technological concept. In his summary remarks to the reading machine presentations, Cooper responded to Mauch's presentation in this way:

> Mauch has described briefly a device that used letter features to generate sound units of word length rather than letter length. Clearly this was a step in the right direction, since one of the difficulties with the acoustic code from direct translators is that signals do not blend and flow as they do in words of speech. Might it not be possible to merge the information about successive letters to obtain syllable-like or word-like acoustic outputs and do it without losing the distinctions between different printed words or incurring the complexities of generating natural speech? Some of the features of letter

> shapes (projection above or below the line, curvature, diagonal stroke, and the like) should be comparatively easy to identify by machine and so could provide a distinctive code for the word. It would then remain only to generate distinctive "word sounds."... There has been very little work done on this possibility and one can only guess at the answer.[21]

Spelled-speech

While Mauch Laboratories was experimenting with the direct translation of graphemes to speech-like sounds, Milton Metfessel continued to construct spelled-speech alphabets with PSAS's support. His approach was largely one of trial and error. His goal was to record a set of 26 sounds - the common English name for each of the letters of the alphabet – which could be readily understood in any combination, when used to spell words rapidly.

Metfessel approached his task as one of composition. He recorded multiple sessions of many speakers repeating the alphabet in different combinations of length and pitch to find the pronunciations that worked best. He contrasted the alphabet for spelled speech with that for discrete spelling, where there were pauses between the letters:

> Obtaining an alphabet to synthesize this kind of output is vastly more complicated. In addition to being shorter, the letter sounds must be carefully balanced so they will go together smoothly in a manner approximating the phoneme flow of ordinary conversation. The problem of obtaining coalescent letters is increased by the need for enough pitch variation to avoid a monotone effect, which makes the spelled speech sound less natural. To achieve a satisfactory result it is necessary to take into account the voice used for the recording, the way in which the letter pronunciations are obtained, the characteristics of recording instruments, the relative frequency with which various letters occur in English words, and a myriad of other factors.[22]

Metfessel selected sounds on the basis of identifiability, rapid rate, sound quality, and coalescence, which he defined as "smooth transitions from letter to letter so that words and phrases rather than separate letters become the units of perception." Selecting for coalescence was a tedious task of variation and selection, where multiple recordings of each letter were tested in combination with multiple recordings of the other letters. (There are

625 possible combinations). Between 1955 and 1961, Metfessel developed more than 20 trial alphabets, before producing two which he found to be satisfactory for use at reading rates of 80 to 90 words per minute, one in a female voice, and one male.[23] Beginning in 1962, Metfessel undertook human subject studies, using these two alphabets, to investigate training methods and to test the effectiveness of spelled speech as a reading machine output. His subjects were 25 sighted college students. "Sighted rather than blind persons have been used in these pilot studies," Metfessel explained to the AFB Conference, "preparatory to training blind students during the coming year."[24]

At some time between 1959 and 1961, Hans Mauch abandoned direct translation devices and adopted a design concept which utilized letter recognition to support Metfessel's spelled-speech alphabets. In later reports, Mauch described the transition as one which was enabled by the invention of a better scanner:

> In early studies we found that speech-like aural output is necessary in order to achieve satisfying reading rates. Consequently, an electromechanical *Word Synthesizer* was designed and constructed which would play back tape recordings of individual phonemes stored in the Word Synthesizer and electromechanically selected for playback, in accordance with photoelectric scanning signals derived from the printed text. Full recognition of the entire alphabet was not intended at that time.
>
> Somewhat later [i.e., after the fabrication of the second prototype], a relatively economical scanning method was developed whereby a letter is seen simultaneously as in a 'snapshot,' by a number of photocells in a two-dimensional array (rather than by a single line of photocells which must progressively scan over a letter to establish its identity). This 'single snapshot' recognition technique was incorporated into a prototype scanner which recognized all the lower case letters of the IBM Executive typewriter alphabet.
>
> When it was realized that full recognition would be possible, the Word Synthesizer was equipped with tape recordings of 'spelled-speech' letters (developed by Professor Milton Metfessel of Metfessel Laboratories, Los Angeles, California) instead of phonemes.[25]

Like his explanation at the AFB Conference, this rationale for Mauch's switch in design concept is incomplete. If the original scanner and logic circuitry were adequate to discriminately initiate 26 phonemic sounds, then replacing 26 phoneme recordings with 26 spelled-speech recordings would be a simple substitution. If better "recognition" were required for the sake of overall system accuracy, then once a more accurate scanner and processor were designed, they could equally drive phonemic or spelled-speech output. It is hard to see how a choice between phonemic and spelled-speech output would depend on recognition rate. Most likely, there were two separate issues at stake. On the one hand, unmodulated phonemic output was no doubt hard to understand, as predicted by both Dudley and Cooper in 1956, and as implied by Freiberger and Murphy in 1961.[26] On the other, a linear, five channel scanner was too imprecise for a high accuracy rate whichever the output.

While Mauch had been building prototype machines to produce speech-like sounds, Metfessel had been proceeding with his meticulous efforts to develop intelligible spelled-speech. Mauch's new Word Synthesizer provided an obvious platform for the Metfessel alphabet, which otherwise had no primary platform within the PSAS program. It was an easy step for Mauch to attribute his second shift in design concept to the realization that spelled-speech was more intelligible than phonemic "speech-like sounds," combined with a breakthrough in scanning technology that would support the superior output, but in fact, there was no clear cause and effect relationship between the changes in output and the change in component design. Cooper's public implication that Mauch's failure was one of design rather than concept is a credible one.

On the other hand, Mauch's framing of his decision was facilitated by Cooper's taxonomy of reading machines. Mauch's first and second prototypes were patterned on Cooper's conceptual category of direct translation machines as presented at the fourth technical conference in 1956 (Figure 9, above). Mauch's third prototype, a spelled-speech system, fell clearly into Cooper's category of short range or research phase recognition machines.

There was an anomaly in Cooper's taxonomy, inherent to the concept of *machine recognition*, which was made visible by Mauch's decision to switch conceptual designs for an intermediate machine from a phonemic output of "speech-like sounds" to a spelled-speech reading machine. In 1956, Cooper had categorized spelled speech as the product of a recognition machine and speech-like sounds as the product of a direct translation type. The anomaly is found in the discrepancy between these differences in descriptive category compared to the similarity in Mauch's designs. Mauch took advantage of the anomaly to rationalize his change in design concept, claiming that spelled speech was a different approach which required a new scanning subsystem. Cooper's response was to revise his taxonomy to categorize both kinds of devices as recognition machines. Figure 13 reproduces Cooper's revised taxonomy as presented in 1962, at the AFB International Conference on Technology and Blindness.

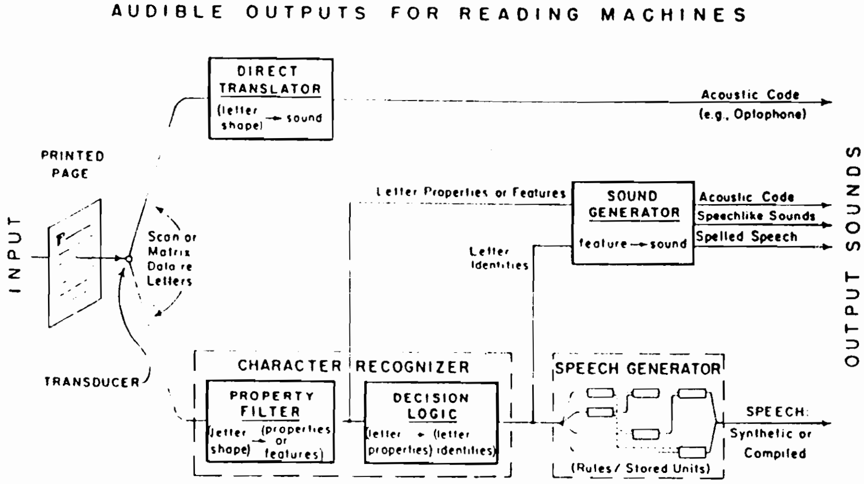


FIGURE 1 Audible Outputs for Reading Machines

Figure 13. F. S. Cooper's 1962 taxonomy of reading machines[27]

PSAS's summary report for 1963 emphasized the continuity in Mauch's work, noting that, "The existing Word Synthesizer, designed and constructed at Mauch Laboratories, accommodates the sound of the 26 letters in Metfessel spelled-speech and can include up to 32 different sounds (based on operation by a 5-unit code)." The report explained that, "While many of the details of Mr. Mauch's concepts have changed, he is still working to produce a device functionally superior to the simpler Battelle Unit, but more economically feasible for wide use by individual blind persons than the sophisticated and very expensive print recognizers even now only slowly being introduced into the day-to-day world of commerce."[28] The report also noted the resignation of the project engineer, Mr. Walter Nolte. Nolte was succeeded by Glendon C. Smith, an electrical engineer who became a key part of Mauch's project. Smith regularly shared credit with Mauch for patents and reports. He typically made the technical parts of Mauch Laboratories' presentations on reading machines. Nonetheless, it is clear that Mauch made the final decisions on system and subsystem configurations and exercised overall project management.[29] From this time until 1976, Mauch and Smith would pursue a single conceptual design, based on the generation of spelled-speech, working to develop, refine, and integrate a combination of components which could comprise a working system.

The Cognodictor

Between 1961 and 1968, Mauch's work was confined to the bench top. It was 1969, before the first prototype of a spelled-speech reading machine was delivered to the VA for evaluation.[30] This field prototype, which Mauch called the Cognodictor, was preceded by two benchtop models, built around logic and processing circuits which Mauch designated the Recognition Prototype, fabricated in late 1964, and the Recognition Prototype II, built in 1967.[31]

As of 1963, Mauch had built and experimented with an innovative scanner with a two-dimensional array, a Word Synthesizer which could carry 32 prerecorded tapes of spelled-speech sounds, and a logic circuit connecting the two. The logic circuit employed a five-bit code for activating up to 32 states of the Word Synthesizer, including "no output." In order to constrain the complexity and expense of his design and to ensure feasibility for home use, Mauch believed that it was necessary to limit the output of the device to 32 elements, and to forego automating features such as the scanner. These design constraints required that methods be provided for the user to align the page and to distinguish where on the page text might be found. The user would have to move the scanner. The reader must also have a way to interpret numerals and other printed symbols in excess of twenty-six alphabetic characters plus a maximum of five others. Moreover, the two-dimensional scanner required precise alignment to accomplish pattern recognition of the printed character. If the scanner were out of alignment with the print, then the pattern of light and dark on its photocells departed from the programmed recognition pattern.

Mauch proposed to address these needs through the development of two new system components. He envisioned a hand-held probe, which he called a Visotactor, that contained a linear array of eight photocells, in addition to the two-dimensional array which drove the logic circuits. These photocells drove eight stimulators, two on each of the fingers of the user's right hand. According to Mauch's concept, these tactile patterns could be used by the reader to scan the page and find the text upon it. The patterns could also be used to interpret numerals, punctuation marks, and other written symbols beyond the 26 letters of the alphabet. If this were so, the patterns could be used to interpret alphabetical symbols as well, since the Visotactor was, in effect, an eight-channel optophone with a tactile output. In 1964, Mauch announced that fabrication of a Visotoner was underway, substituting an optophone code for the tactile code of the Visotactor. Mauch also worked to develop a Colineator, which was a precision tracking aid to guide a blind user as he or she moved the Visotactor down a line of print and down the page. Mauch split Visotactor development into two steps: The Visotactor B, which contained only the photocells and circuitry needed for hand-held use, was built first. The Visotactor A had to perform all of the functions of the "B" model and also drive the logic circuitry of the Recognition Prototype. Its development was to be undertaken subsequent to proof of concept for the Visotactor B. The first issue of the *Bulletin of Prosthetics Research*, which appeared in Spring 1964, included photographs of a prototype Colineator and Visotactor B.

During the next two years, Mauch worked to improve the design of the scanner to support "multiple snapshots" using a more sophisticated two dimensional array. Mauch and Smith filed a patent application for the new scanner in November 1965 (U.S. Patent 3,531,770). To obtain the high quality, precision shaped photocell arrays which his design required, Mauch had to learn to manufacture them in-house. The improved scanner was incorporated into the Visotactor A. Logic circuits were redesigned to work with the new scanner and to support the recognition of multiple type faces. The logic circuitry could convert the signal generated by upper or lower case letters in nine different fonts into Baudot code which activated the Word Synthesizer. A fine adjustment was added to the Colineator, and plexiglass was substituted for glass. By November 1964,[32] these components were integrated into the prototype shown in Figure 14.

During 1965, Mauch employed the new bench top prototype as a test bed for the integration of its components. The prototype achieved a reported accuracy of 90 to 95 percent, at a presentation rate of 20 - 30 words per minute, but performance declined rapidly at higher speeds. Slow photocell response was responsible for the decline. Mauch modified the scanner circuitry to incorporate frequency compensation amplifiers. This improved recognition rates, but interfered with the tactile output of the Visotactor A. Tests were conducted to determine the effect of tracking error due to misalignment with the line of print. The system was found to require alignment within 0.008 inch to achieve 80 percent recognition accuracy of twelve point print, or within 0.005 inch to achieve 90 percent accuracy. Tests also found that the spelled speech sounds were distorted as an effect of the geometry of the Word Synthesizer's arms and its attached tape recordings. Magnetic tape wear was also a problem. As a consequence, Mauch began to consider replacing the Word Synthesizer with a commercially available rotating drum employing an optical read out. At the same time, both the scanner and the logic circuitry had to be redesigned to improve the recognition rate.[33]

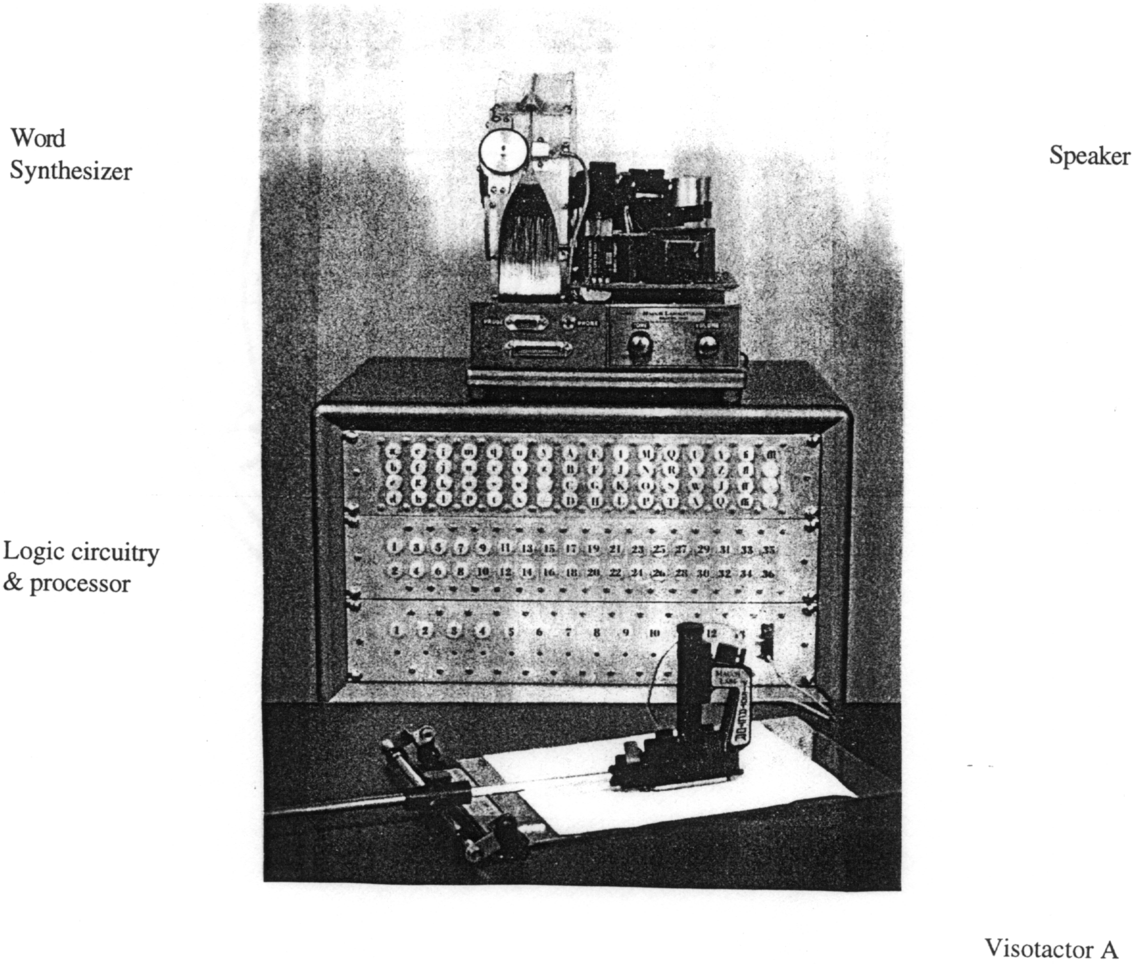


Figure 14. Mauch's Recognition Prototype (1966)[34]

At the sixth PSAS technical conference on reading machines, Mauch's presentation did not highlight these problems. According to Freiberger's summary, Mauch reported in his overview that, "Less than 100% recognition accuracy was achieved, but considering the redundancy of ordinary English text, and the powers of correcting by context, the mistakes were tolerable."[35] Glen Smith's detailed report focused on hardware development. The problems of accuracy and of tracking precision were reported this way:

> From center position where all 26 letters were correctly recognized the probe was shifted above and below in steps of 2.5% of the height of a lower case "x." The curve showed the device quite usable when misalignment was up to 10% of the "x" height. Plans are already made for a Mark II device which should be more tolerant of misalignment, and which will operate at higher speeds.[36]

By reporting alignment requirements as a percentage of the height of the letter "x," Smith obscured the fact that the prototype system would require a blind user to position a hand held probe, with the help of a mechanical tracking aid, within four one thousandths of an inch of the center of a line of print and to keep it there, line after line, in order to achieve 80 percent accuracy at low speeds. Smith did report that the proposed Mark II device would include a new photocell array and in order to allow greater tolerance for vertical mistracking.[37] A more candid report was published in the Fall issue of the *Bulletin of Prosthetics Research,* as summarized above.

When Mauch had previously faced such performance problems, he switched design concepts. Now, there was no clear alternative approach to an intermediate machine available. It was, I believe, no coincidence that at the same meeting where Mauch presented his preliminary results, Harvey Lauer was asked to demonstrate the Visotoner as an alternative to the Battelle Optophone. The Visotoner thus represented Mauch's fourth design concept for an improved home reading machine. We will return to its development in the next section, but first, let us follow the fate of the spelled-speech machine.

Mauch Laboratories worked from 1966 through 1970, to improve the Recognition Prototype's components. Their goal was a working prototype for field testing. During this time, the Word Synthesizer was replaced by a commercial device, the Cognitronics Model 632 Speechmaker, a rotating drum with 32 optical soundtracks. A Word Storage Unit was added to provide buffer storage for up to eight letters. Much of the system's electronic circuitry was redesigned to incorporate improved integrated circuits, including the electronic recognition logic. Adjustments were made to the scanner to improve performance.

In September 1967, a blind resident of Dayton, Miss Bonnie Reinecke, later Mrs. Gene Deal, began operating the Recognition Prototype II, first in the laboratory and then in her home, while Mauch's designers began a series of troubleshooting tasks and design modifications in response to her experiences. New circuit boards and redesigned components were plugged into the prototype as they were fabricated. By June 1968, Mauch reported, Miss Reinecke was able to read an entire page (23 lines) of the Battelle optophone training manual, without pausing and at a rate of 20 words per minute.

In their 1968 report, Mauch Laboratories anticipated a November delivery date for three Cognodictor prototypes,[38] but it was June 1969 before the first prototype was declared operational, and 1970 before three prototypes were in place. One was provided to Harvey Lauer at the Hines VA Hospital. One was operated by Mrs. Deal, and the third was retained by Mauch Laboratories.

As much may be learned about the Cognodictor by what was left unsaid as by what was said. Although Mauch was present at the 1971 NAS Conference on the Evaluation of Sensory Aids, there was no presentation on the Cognodictor.[39] Beginning in 1970, the *Bulletin of Prosthetics Research* reported semiannually on PSAS's new clinical application program on reading and mobility aids for the blind. The Cognodictor was acknowledged in the spring of 1971, and then left unreported. The initial report stated that three persons had tried the machine, but were handicapped by their lack of familiarity with the Visotactor probe. Lauer requested a new probe based on the Visotoner, which was delivered. Freiberger reported,

> Mr. Lauer is the only person who has had much experience with it, and after forty or more hours, he was able to read at 50 words per minute. His maximum speed with the Visotoner alone is about 40 words per minute.
>
> The estimated maximum output pace for the Cognodictor is about 75 words per minute. Reading speeds actually achieved may be lessened by four things: line change time, user errors, machine errors, and the nature of the material such as the need to read numerals.[40]

Three years later, in 1974, Lauer identified the Stereotoner and Optacon (discussed in Chapter 9, below) as current technologies, but he addressed the Cognodictor under the heading "Some Prospects for the Future." Lauer explained, "In 1971, several blind people, myself included, used a model of the Cognodictor with spelled-speech output. In my opinion, at the present rate of development, there will be a new prototype in 2 years and a production model in 4 years. Some of my colleagues feel that less time will be required."[41] Twenty years later, Lauer remembered, "[The Cognodictor] consisted of a computer and either a Visotactor or Visotoner with which the user tracked the print, adjusted magnification and read whatever the computer could not identify. Due to its crudeness, we read most items with the direct-translation component, but with luck, the body of a magazine article or book would be spelled out by the little computer which seemed so big then." These results, Lauer felt in retrospect, were simultaneously disappointing and impressive. After all, with all of its shortcomings, the Cognodictor was the first recognition machine prototype which could have been demonstrated to potential users. There may have been something to be gained by wider exposure. Lauer explained, "We didn't keep our results secret, but neither did we publicize them. The shameful reason we gave was that we did not want to raise false hopes. Publicity, however, might have brought us badly-needed pressure and support to make progress at something above a snail's pace."[42]

The Cognodictor was not exposed to testing outside the research community because its sponsor and developer believed it was not capable of innovation in its present form. It was not ready to be handed-off from developers to users. The possibility that user community could contribute to a resolution of the design impasse was not one which PSAS or Mauch Laboratories seriously considered.

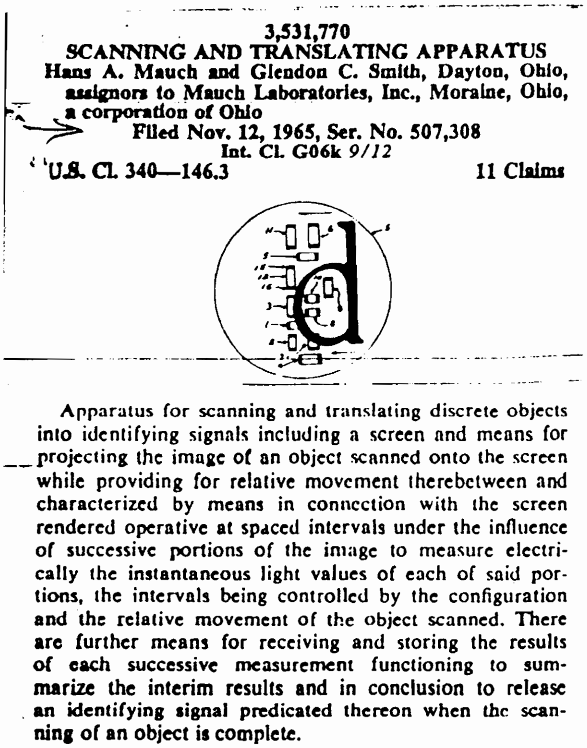
PSAS's program decisions reflected vested interests in its developers and in the conceptual framework which they shared. This framework directed PSAS to explore a direct translation machine, an institutional reader employing synthetic speech, and an intermediate device to produce speech-like sounds. There had been no departure from this tripartite approach in the fourteen-year history of the program, and there had been few changes in personnel, either within PSAS's R&D Division or among its contractors – none at the most senior levels.

Over that time, Mauch Laboratories had received nearly $1 million in PSAS support.[43] It was important that PSAS show a return on this investment. By the early 1970s, a competing design for a reading machine, the Optacon, was approaching innovation with support from the U.S. Department of Health, Education and Welfare. Mauch's Visotoner represented PSAS's best chance to achieve a commercially available reading machine to compete with the Optacon and to justify the PSAS program.

In the event, the Cognodictor was returned to the laboratory, from which it never re-emerged. As illustrated by Lauer's request for a Visotoner probe to replace the less familiar Visotactor, a major flaw in the conceptual design of the Cognodictor was that it required its user to learn to operate not one, but two reading machines. The reader had to learn to use the hand held probe in order to align the print and interpret numerals and other symbols. This implied learning the characters of the alphabet in order to distinguish them from the other symbols. Reading with the Visotoner probe was also a necessary skill for interpreting words missed by the machine, as long as its accuracy rates were on the order of 80 or 90 percent. From the limited experience of Lauer and a handful of other blind readers, it seems clear that the Cognodictor design concept had few advantages and many disadvantages over the Visotoner probe used alone.

Why the Cognodictor failed

From Mauch's engineering perspective, the principal problem with the Cognodictor was its low recognition accuracy. For five more years, he worked to improve system performance and reduce its reliance on extremely precise tracking.[44] Ironically, the major limiting factor was the innovative, two-dimensional photocell array for which Mauch had sought patent protection in 1965. The entire Cognodictor system had been built around this ingenious scanner, which relied on the irregular geometry of its photodetectors and their sequential triggering by the parts of printed letters to achieve much of the task of recognition (see Figure 15a). This scanner design simplified the problem of electronic pattern recognition and enabled the operation of the Recognition Prototype as early as 1966. However, this substitution of geometry for circuitry imposed the severe tracking constraints which Mauch once sought to obscure by using percentage of letter height as a unit of measurement. If reflected light from the print intercepted the irregular array of photoreceptors in a slightly different geometry, due to changes in alignment, then the sensors would be activated in a different pattern. The only solution was to abandon the concept for a regular sensor array (Figure 15b), where changes in tracking merely displaced the image on the array without changing the pattern of activation.

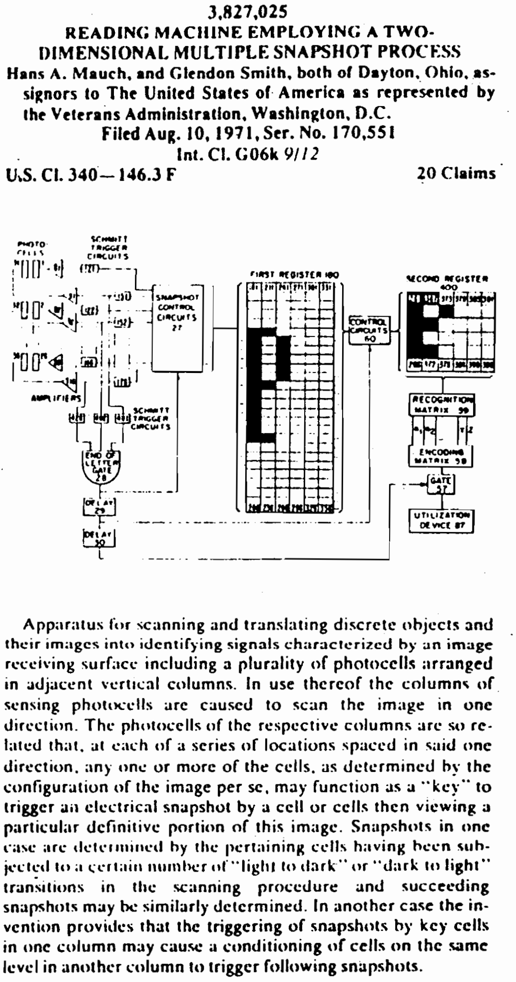


3,531,770
SCANNING AND TRANSLATING APPARATUS
Hans A. Mauch and Glendon C. Smith, Dayton, Ohio, assignors to Mauch Laboratories, Inc., Moraine, Ohio, a corporation of Ohio
Filed Nov. 12, 1965, Ser. No. 507,308
Int. Cl. G06k *9/12*
U.S. Cl. 340—146.3 **11 Claims**

Apparatus for scanning and translating discrete objects into identifying signals including a screen and means for projecting the image of an object scanned onto the screen while providing for relative movement therebetween and characterized by means in connection with the screen rendered operative at spaced intervals under the influence of successive portions of the image to measure electrically the instantaneous light values of each of said portions, the intervals being controlled by the configuration and the relative movement of the object scanned. There are further means for receiving and storing the results of each successive measurement functioning to summarize the interim results and in conclusion to release an identifying signal predicated thereon when the scanning of an object is complete.

a. Geometric scanner

b. Planar array scanner



3,827,025
READING MACHINE EMPLOYING A TWO-DIMENSIONAL MULTIPLE SNAPSHOT PROCESS
Hans A. Mauch, and Glendon Smith, both of Dayton, Ohio, assignors to The United States of America as represented by the Veterans Administration, Washington, D.C.
Filed Aug. 10, 1971, Ser. No. 170,551
Int. Cl. G06k *9/12*
U.S. Cl. 340—146.3 F **20 Claims**

Apparatus for scanning and translating discrete objects and their images into identifying signals characterized by an image receiving surface including a plurality of photocells arranged in adjacent vertical columns. In use thereof the columns of sensing photocells are caused to scan the image in one direction. The photocells of the respective columns are so related that, at each of a series of locations spaced in said one direction, any one or more of the cells, as determined by the configuration of the image per se, may function as a "key" to trigger an electrical snapshot by a cell or cells then viewing a particular definitive portion of this image. Snapshots in one case are determined by the pertaining cells having been subjected to a certain number of "light to dark" or "dark to light" transitions in the scanning procedure and succeeding snapshots may be similarly determined. In another case the invention provides that the triggering of snapshots by key cells in one column may cause a conditioning of cells on the same level in another column to trigger following snapshots.

Figure 15. Mauch scanner designs
(from U.S. Patent Gazette)

As early as June 1970, Mauch was working on a new photocell array, which in turn required a new recognition logic. He sought a patent for this new design in August 1971 (U.S. Patent 3,827,025). By 1973, he had fabricated the new scanner and part of the logic circuitry. The new design reportedly improved tracking tolerance by an order of magnitude, from ±5% of "x" height to ±50%. This new approach to character recognition required that the signal received from the scanner be compared with the signals which might be generated by all possible letters and fonts. This in turn required the preparation of recognition templates and their storage in processor memory.

In 1974 and 1975, Mauch prepared those templates, upgraded the buffer storage from 8 to 64 characters, and began the redesign of the Cognodictor's hand-held probe, based on improvements to the stand-alone version of the Visotoner. The Fall 1975 report noted that:

> Future work includes completion of the Cognodictor breadboard, design of an [new] optical probe for the Cognodictor, and construction of three Cognodictor prototypes. Other work to be undertaken, if time and resources permit, includes building improved prototypes of the Pacer and the new Colineator and designing a microprocessor-based interface between the Cognodictor and [a] Votrax speech synthesizer.[45]

But the three new Cognodictor prototypes, which Lauer had predicted would appear in 1976, were never to be built. About the time this report was being published, Kurzweil Computer Products demonstrated its computer-based reading machine for the blind which incorporated full character recognition and synthetic speech output (see Chapter 10).

Although the race had already been lost, Mauch and PSAS's immediate reaction to this unexpected competition was to accelerate their efforts to put a prototype in the field. This meant giving priority to developing an interface with the Votrax speech synthesizer. Without mentioning Kurzweil's accomplishment, Freiberger reported, "At the end of September, it was decided to forego adding further improvements to the Cognodictor breadboard and to concentrate on building parts for the Cognodictor prototypes." While Mauch Laboratories concentrated on building a hardware interface with the Votrax, PSAS made arrangements with the National Institutes of Health to borrow speech synthesis software developed there by Dr. Scott Allen.[46]

Kurzweil's achievement, however, called into question the very concept of an intermediate reading machine. Once Mauch had been forced to abandon his geometric approach to letter recognition, there was little to distinguish the conceptual design of the Cognodictor from "high end" machines like Kurzweil's, except for its spelled speech output, which was hardly an advantage. It was the 32-character limit of the spelled-speech machine which constrained the Cognodictor system now. By switching from a 5-bit Baudot code to an 8-bit ASCII code, by increasing the number of character templates stored in memory, and by increasing processor power accordingly, Mauch could accommodate 255 characters, and upgrade the Cognodictor to compete with Kurzweil. However, Kurzweil had the advantage of a working prototype. If Mauch were to rush a Cognodictor into the field, it was likely to suffer by the comparison.

Never one to give up, Mauch's response was to propose to PSAS a new design concept for a "High Performance" Cognodictor. Taking note of Kurzweil's high initial price of $50,000, and making a virtue of necessity, Mauch promised to develop a $12,000 machine which would provide, at the user's option, synthetic speech, spelled-speech, or direct translation, using a hand-held probe which would allow the user to understand the format of a document and interpret unusual symbols. PSAS agreed to this change in design concept in April 1976, and Mauch began work on a breadboard model.[47]

For a number of reasons, the project was not sustainable. Most immediately, Glendon Smith, Mauch Laboratories' senior project engineer, had lost faith in the project.[48] Smith continued to work on the High Performance Cognodictor for about a year, but in July 1977, he submitted his resignation. Mauch, who was now over 70 years old, felt that he could not continue the project without Smith. He notified PSAS that Mauch Laboratories would withdraw from the program. PSAS briefly considered recruiting a new contractor, but within a short time, closed down its reading machine development program altogether, in the light of the successful innovation of the Optacon and the Kurzweil Reading Machine.[49] According to Harvey Lauer, Smith went without work for some time trying to find a place in reading machine development. He eventually found part-time employment for Kurzweil Computer Products, but ultimately left the field.[50]

More fundamentally, the Cognodictor failed because it had lost its technological identity. Through a series of design decisions it had become a tool without a social function, a device that no one would want to use. In the 1940s, and again in the 1950s, Franklin Cooper had articulated a taxonomy which identified three categories of reading machines - those which processed visible print into audible English speech, those which converted print into tonal codes which the human mind would interpret into intelligible language, and an intermediate category whereby visible print would be converted into processed, "speech-like" sounds which could be interpreted more easily than tonal codes. It was assumed by the reading machine community as a whole that an intermediate type of machine would be easier to develop and less expensive to build than one which processed visible print into synthetic English speech.

Cooper's categorization is open to challenge on a variety of grounds, but there was no open challenge at the time by anyone in the reading machine research community. Cooper did revise his taxonomy over time, partly in response to experience with Mauch's designs. But even Mauch did not challenge the community's categories of reading machines, perhaps because his role as a technology developer could be and often was justified by reference to a particular category.

Mauch's first two prototypes fit securely within one of Cooper's categories, that of direct translation machines producing speech-like sounds. Mauch borrowed heavily from Cooper's ideas and, in the first prototype, even from his components. When Mauch's prototypes failed to convert print into an output that was acceptable to Cooper or to PSAS, he might have focused his development efforts on improving the intelligibility of the speech-like sounds. But technology development in this sense was not Mauch's practice. He was an electromechanical designer, and his firm was an institution which designed and fabricated electromechanical prototypes.

The remaining path which was open to Mauch was to design a prototype to support the spelled speech of Milton Metfessel. Cooper did not think highly of spelled speech, perhaps because it did not fit tightly into his conceptual framework which distinguished direct translation and recognition machines. From a design perspective, the distinction was not so clear. From Mauch's perspective, the difference between a machine which generated letter names and one which generated phonemes was largely a difference between which tape recordings he placed on the arms of his Word Synthesizer. In the third Mauch prototype, recognition was as much a matter of the geometry of the photodetectors on the scanner head as it was one of machine logic. In spite of these anomalies, the concept of an intermediate machine retained its power to direct technology development. Because of its simpler logic and lower processor demands, because of its hand-held scanner and its reliance on the human brain to interpret non-alphabetic symbols, because of its spelled-speech output and because of its lower price, the idea of the Cognodictor could be defended as an intermediate reading machine for personal ownership.

Unfortunately for Mauch, his innovative scanner design, around which the design of an intermediate machine had largely evolved, entailed an unanticipated, stringent requirement for tracking accuracy. Such accuracy could not be achieved within the other constraints of an intermediate device. From within his practice of engineering design, Mauch could only address this problem by a complete redesign of the scanner subsystem and consequently of the recognition circuitry as well. Mauch was not completely candid about the nature of the problem and its solution. As a consequence, while continuing to employ the rhetoric of intermediacy, Mauch embarked on the design of a scanner and processor that were no longer intermediate at all.

What's more, the time consumed by these design reiterations exhausted the margin that was available for development of an intermediate machine. The Cognodictor, if it had been fielded, would have followed a synthetic speech machine, rather than precede it. By 1976, it was impossible to classify the design of the Cognodictor or to justify its pursuit as an intermediate machine. Mauch's only chance to extend his development contract was to redefine the Cognodictor as a high performance machine. That is exactly what he did. But it was too late. The Kurzweil reader was far ahead in its development. For Mauch, it would have been a continual game of catch-up, at best. Glen Smith must have reached a similar conclusion, and he decided to concede the race. Lauer reports that sometime after Smith's resignation, "He assured me that the Cognodictor project would have been terminated or would not have produced fruitful results even if he had stayed with it." [51]

Harvey Lauer has praised Hans Mauch's abilities as a designer. Speaking of the Colineator, he has said, "Nothing better was made for tracking print by hand....Mauch was a genius; there's no doubt about that."[52] During the time he was developing the Cognodictor, the Visotoner, the Colineator, and a variety of reading machine components, Mauch also worked to improve and produce lower limb prostheses. He received patents on a ventilator cover, a jet propelled balloon, an air source apparatus and a hair dryer, a ventilating device, and a tubular structural member, in addition to seven patents related to reading machines.[53] The multiple snapshot scanner, which Mauch designed and fabricated, was a brilliant piece of engineering design for solving the immediate problem at hand. The Visotoner, as we shall see, was similarly a wonderful piece of design in terms of engineering variables such as efficiency, reliability, size, and cost. Given the input and the output of a tool or a component, Mauch was talented at solving the engineering problems at hand to produce a prototype device.

Walter Vincenti, in his 1990 book, *What Engineers Know and How they Know It,* has said:

> The criterion for retaining a variation in engineering must be, in the end, *Does it help in designing something that works in solution of some practical problem?* ....The problem may be a merely technical one – to fly in the case of an airplane, to supply lift with the least possible drag in the case of an airfoil, or to hold two pieces of metal together in the case of a rivet. It may also be contextual, that is originating outside technology.... During my career as an engineer, I have seen the scope of engineering problems also expand increasingly to include social and environmental matters. [Students of technology and culture] call for a broad method for 'integrating design characteristics with the non-technological dimensions of the cultural ambience.' For that to happen, engineers – and society – will have to define engineering problems, and hence what is meant by 'works' differently from how they do today.[54]

Hans Mauch was roughly a contemporary of Vincenti. He practiced engineering to design and build components and devices that worked in the technical sense. It was not within his realm of practice in the 1950s, 60s and 70s to redefine the nature of engineering problems to consider "what works" as a contextual issue. In the case of the Cognodictor, we can see how this understanding of the scope of engineering practice interacted with a research community's categoric understanding of reading machine technology to result in a series of bench top technical successes, that nonetheless added up to a machine that did not work.

Son of Cognodictor: Development of the Visotoner

In June 1962, Hans Mauch had the following to say about the optophone:

> This machine is unique, as I have said; and I would also venture to say that, in the area of direct translation from the visual to an auditory code, there seems hardly any other solution possible that would be comparable to the Optophone. However, there appears to be room for improvement of the latter, by selecting those frequencies that prove to be particularly adequate and this is being done.[55]

If Mauch foresaw the need for a direct translation component to his intermediate reading machine at the time, he did not mention it. But by 1963, it had become clear that a spelled-speech machine would also require a direct translation output. The only conceptual alternative was to stretch the concept of spelled-speech to include spoken numerals, punctuation marks and other printed symbols. This strategy, Metfessel explained, was impractical because the difficulty of matching sounds to achieve coalescence limited the number of characters it was possible to accommodate:

> More time is likely to be spent on the last letter than all the rest together. Each additional sound selected restricts markedly the field from which the remainder can be chosen. When the 26th letter is reached, it may be found that none of the pronunciations available will go well with the earlier selections. It is then necessary to substitute alternative pronunciations for some of these, working back and forth until the desired fit is obtained.[56]

Having previously abandoned approaches which generate artificial or recorded phonemes from print, Mauch was committed to spelled speech, if he were to undertake development of an intermediate machine as that concept was understood by the reading machine research community.

At first, Mauch proposed the Visotactor as an answer to the dilemma. The Visotactor combined the functions of a hand-held scanner and a direct translation output device. It had eight vibrating stimulators built into the handle, each linked to one of eight linear photocells in the scanner head. The user could use the vibrating signals to locate black areas on a page, and thus margins, graphics and other gross features of the item to be read. The tactile output could be decoded to interpret numerals and other symbols, or to check anomalous outputs from the spelled-speech generator.[57]

From the Visotactor sprung the Visotoner. In fall 1964, Mauch reported, "A prototype of the Visotoner is now under construction. Using the same frame, optics, and photocell arrangements as the Visotactor, the Visotoner will have a nine-channel system giving an output sound very much like that of the Battelle Optophone. The unit will have the advantage of pocket portability and battery operation."[58]

By early 1965, Mauch Laboratories had built a Visotoner prototype and provided it to the American Center for Research in Blindness and Rehabilitation (ACRIBAR). ACRIBAR was PSAS's contractor for the evaluation of the Battelle Optophone. Mauch's prototype was an elegant device. It weighed only 10 ounces, and used a 12 ounce NiCd battery which provided three hours' operation in the absence of a power outlet. The Visotoner's optics could handle print from 7 to 35 point size, by rotation of a single knurled knob. Only one hand was required to use the Visotoner, which had guide rollers to aid linear tracking. The device used off-the-shelf transistors and other electronic components.[59] However, discussed in Chapter 5, the ACRIBAR evaluation project was unraveling and Mauch did not get the exposure for the Visotoner which he probably sought.

In December 1965, therefore, Glen Smith retrieved the Visotoner prototype from ACRIBAR, and in January 1966, asked Harvey Lauer to demonstrate the device at the sixth reading machine session, together with the Battelle Optophone.[60] Mauch needed a success at this time, as the nature and severity of the tracking accuracy constraints of the Cognodictor design were becoming clear.

Mauch's strategy was successful. PSAS asked him to deliver six Visotoners and four Visotactors for further evaluation.[61] Mauch continued parallel development of the two machines. He trained Miss Reinecke to use the Visotactor by having her complete the 200-lesson Battelle optophone training program. Completing the course in eight months, she achieved reading speeds of eight words per minute (see Figure 16).[62]

The six, second generation Visotoners were delivered in early 1967. Lauer's reaction was enthusiastic. In an article published in spring 1968, Lauer, who was now assigned to the PSAS Research Division, reported,

> So I sat down with a stack of mail and the new Visotoner. Most of the return addresses were amazingly legible. While reading the table of contents in a magazine, I was so impressed with the 'fidelity' with which this machine 'sees' the print that I decided to read a whole article. I felt compelled to reach for the dictionary and sure enough it came alive. To be sure, there were times when deciphering unfamiliar diacritical marks used in the dictionary became necessary, but now I can use the dictionary when the need arises.
>
> Our faithful volunteer sighted reader could not make it through the snow that week but since then her services have not been needed regularly because I have been able to meet my urgent reading needs. For the first time I felt I had acquired a bit of synthetic eyesight.[63]

Figure 16. Miss Reinecke demonstrating the Visotactor B[64]

PSAS, Lauer continued, planned to buy 30 more Visotoners and 10 Visotactors for field testing, complete with Colineators, battery chargers and carrying cases, at an estimated unit price of $1,850. He invited interested parties to increase the order for their own trials. Meanwhile, Mauch reported that the continuing work with the prototypes by three blind users – Lauer, Reinecke, and Margaret Butow, had led him to design improvements in the rollers, lamp assemblies, controls, and printed circuits on the Visotoner and Visotactor units.[65]

The third generation Visotoner and Visotactor prototypes were delivered to PSAS in March and April, 1969. Mauch Laboratories prepared detailed drawings and specifications for the devices,[66] documentation that could support third party manufacture. Meanwhile, experience accumulated with the first ten prototypes which led to further improvements in design and methods of fabrication. The power pack was redesigned. Cables were replaced. Rollers were redesigned, and the carrying case strengthened. At Howard Freiberger's suggestion, a bumper was added to protect the top of the device when it toppled, or was knocked over. As the thirty, third-generation devices were put into service, a number of manufacturing problems were found. About half of the units were returned for repairs during the first two months.[67] Repairs and modifications were made, specifications changed, and the prototypes were returned to the VA, which now owned 36 Visotoner and 14 Visotactor prototypes.

By 1971, PSAS was actively concerned with the problem of innovation, or as Freiberger called it, deployment. Whatever the term, the problem was how to move the Visotoner out of the laboratory and into the public domain, how to convert a production prototype into a product. As Freiberger put it, "The ever increasing need to read inkprint and the availability of several well-engineered means to do just this, leave us in 1971 with a well-defined social need and several well-engineered means to satisfy it. What seems to be lacking is the deployment system to get the machines capable of satisfying the need together with the people evidencing the need."[68]

Freiberger understood the innovation problem in the classic terms of the chicken and egg: If Visotoners and teachers were available in sufficient numbers at an affordable price, then blind readers were likely to adopt the technology. If there were a sufficient number of blind readers ready to buy machines, then the market would likely provide machines and teachers at an affordable cost. The Veterans Administration's constituency, however, was too small to provide that initial market. "A period of joint operations thus seems indicated, the Veterans Administration supplying information, designs, some skilled personnel, and appropriate funds to meet the projected veteran client load, non-veteran agencies contributing commensurately with their clients' needs."[69]

Freiberger estimated that the potential market to be 5,000 readers, based on estimates of the number of legally blind Americans (500,000), the number of braille readers (12,000), and the uses reported for the Visotoner by the eight veterans and ten non-veterans who had achieved some proficiency with Visotoner prototypes. Freiberger suggested that 500 readers comprised a good target group for innovation of the Visotoner. In such quantities, he believed, Visotoners could be made for $1,500 apiece, requiring a capital investment of $750,000. Training costs he estimated to be another $500,000. PSAS had sponsored work by Margaret Butow at the Hadley School and at Hines VA Hospital which had provided screening instruments for selecting 500 readers who were likely to succeed. Lauer, Butow, and their associates could provide a base for the training of eleven teachers who would in turn train the 500 readers.[70]

From Visotoner to Stereotoner: What we have here, is a failure to innovate

PSAS took no action to implement Freiberger's plan in 1971. In part, this was because Mauch was already working on a fourth-generation Visotoner. For obvious reasons, the new device was called the Stereotoner. Mauch attributed inspiration for the new design to a 1970 research report by Sanford Fidell, who demonstrated that stereophonic tones could be generated which produced "...the sensation of signals located at various points inside the listener's head."[71] Lauer confirms that Fidell's demonstration played a role. It was Eugene Murphy, Lauer said, who learned of Fidell's study and passed the information on to the staff.[72] Lauer elaborated with a more interesting story.

> In the early seventies, [Richard] Bennett, who was wonderful to work with, felt we could make better use of our binaural hearing by dividing the channels [of the Visotoner] between the two ears. We brain stormed about it, and occluded the upper half of the window on one Visotoner and the lower half of another. I got out mending plates, threaded rods and hex nuts – things I keep handy. A shop man made us a precisely-shaped oblong plastic plate to tape between the two Colineators. We used exact duplicate pages from the Battelle course and taped them down.
>
> It took many hours for us to synchronize those machines so they sounded like one instrument. We put half the code in one ear and half in the other. It sounded impressive through earphones which was the way we normally used it. Then I slightly mixed the two channels, and liked it better. Finally, we adjusted the occluders so the three top tones were heard in the right ear almost exclusively; the three bottom ones were heard loudest in the left; and the middle ones came through in both.
>
> We liked that arrangement the best, so we made extensive tapes, shared them with people who were impressed and fully documented the results. We approached Glen Smith who suggested a taper or slope of the channels. The question was how much taper? So Glen built a jack into a Visotoner from which its nine signals could flow and made a big black box. The box had 20 lockable potentiometers. There were nine for the left ear and nine for the right, a master control for each ear and a binaural output. He sent the box to each of the three of us in turn. Each of us set the controls to suit, using other options when available. We locked them in and each sent it back to Glen who measured the results. We were in close agreement, so he had no trouble

> deciding how to set amplitudes.... Mauch's people then built a prototype stereotoner, adding a tenth channel which was welcome.[73]

The prototype Stereotoner was completed in the spring of 1972. It incorporated several technical improvements on the Visotoner. The illumination lamp consumed only one sixth the power, and its batteries were good for 8 or 9 hours of operation. Binaural operation caused Mauch to split the compact system, which weighed just over a pound, into two boxes. One, containing the power pack, sound generator, much of the circuitry and the basic controls, was worn like a necklace. It was connected to the optical probe by a shielded cable and to the ears of the user by stereophonic earphones. The other housed the optical probe, detector array, and controls for their adjustment. By early 1973, Mauch had fabricated three second-generation prototypes, and was preparing to produce 100 "production models," of which 65 were committed to a joint evaluation study by the Veterans Administration and the National Academy of Sciences.[74]

In 1971, while Mauch was redesigning the Visotoner, James Bliss was establishing Telesensory Systems, Inc. (TSI), to manufacture 50 Optacons for the U.S. Office of Education, as described in Chapter 9. By the time that Mauch Laboratories began to build the first production lot of 100 Stereotoners, in April 1973, TSI had already manufactured the 250th Optacon.[75] By choosing to further develop and improve his design for a direct translation machine, Mauch Laboratories lost the opportunity to be first in the market.

As shown in Figure 17, Mauch Laboratories and Stanford Research Institute each fabricated an initial prototype in 1965. By 1967, Mauch had fabricated six second-generation devices. A year later, Stanford had made three second-generation Optacons. In 1969, Mauch completed 30 Visotoners which were distributed for evaluation by PSAS. In 1970, Stanford made six third-generation Optacons. At this point, Jim Bliss left Stanford to form TSI for the purpose of manufacture and sale of the Optacon. In 1971, TSI made the first 50 Optacons for sale to the U.S. government. In 1972, Mauch abandoned the Visotoner to make the first prototype Stereotoner. TSI continued to make Optacons. In 1973, Mauch made three second-generation Stereotoners and in April, he prepared to produce 100 more, of which 65 were to be sold to the U.S. government. In March 1973, TSI had made its 250th Optacon. To the extent that the Stereotoner and the Optacon were competing products, TSI had achieved the advantage of initial penetration and market share, a venture outcome that is greatly to be desired.

Year	Mauch Labs	Stanford	Notes
1965	1 Visotoner	1 Optacon	
1966			
1967	6 second generation prototypes		
1968		3 second generation prototypes	
1969	30 third generation prototypes		
1970		6 third generation prototypes	TSI formed in mid-1970
1971		Begin 50 production models	
1972	1 Stereotoner prototype	↓	
1973 (May)	3 second generation Stereotoners; Begin 100 production models	Total of 250 production models	

Figure 17. Fabrication history of the Stereotoner and Optacon

By 1971, the Optacon and the Stereotoner were generally considered to be competing products. They were commonly categorized as direct translation devices within Franklin Cooper's taxonomy of reading machines. They were each intended for individual ownership and use. In 1970, Patrick Nye and James C. Bliss reviewed the field of sensory aids for the blind for the IEEE. Nye and Bliss discussed the Optacon, the Visotoner and Visotactor in a common section labeled "Current Research: Direct-Translation Reading Aids," together with a new device, the Lexiphone, under development by M. P. Beddoes at the University of British Columbia.[76] In his 1971 article on "Deployment of Reading Machines for the Blind," Howard Freiberger made the following acknowledgment of the competitive relationship between the Visotoner and the Optacon:

> While the aforementioned [PSAS-sponsored] reading-machine activities were taking place, other researchers were also developing somewhat different systems. One which has been brought to a stage of development roughly comparable to that of the Visotoner is the Optacon (Optical to Tactile Converter) built at Stanford Research Institute, Menlo Park California. This device will not be further discussed in this study however, as the aim is analysis of the deployment problems for one system, the Visotoner, and production of a plan to achieve its deployment. Some blind people for physical or physiological reasons may not be able to sense the output of the Optacon. Conversely, others will not be able to make much of the sounds of the Visotoner. For such people, the alternative machine is obviously indicated. Some blind people are thought to be tactually oriented, others favor the sound milieu – for these groups choice of system also seems straightforward. Many of the skills associated with successful use of one type of instrument are thought to be quite transferable to other kinds of instruments: if so, learning one will not be a waste of effort should a person later change to a new instrument using another sense or an improved system using the same one.[77]

By 1974, it was clear that Mauch understood the Optacon and the Stereotoner to be directly competing products. Moreover, the Optacon had become the standard for comparison. At the 1974 PSAS contractors' meeting, Mauch described the Stereotoner this way:

> The Stereotoner is noteworthy for its stereophonic output code, its 10:1 zooming range which accepts letters up to 3/4 in. high, its capability for normal operation on reversed (light and dark) letters, its very small optical probe, and a compact, lightweight control box which is suspended in front of the user's chest from an adjustable neckstrap. The Stereotoner can be used for reading printed and typewritten materials including computer (and calculator) printouts. Many other tasks may be performed with the Stereotoner such as identifying paper currency denominations, reading labels on cans and boxes, determining the lightness or darkness of clothing or other objects, and locating light sources. As compared with the Optacon, the

> Stereotoner is one-third as heavy, one-third as bulky, and less than one-third as expensive, yet training times and reading rates are comparable. With these and other advantages, including its wider range of letter sizes (the Optacon's magnification range is only 2.5:1) and its one-hand operation, the Stereotoner will be the best choice for many people, though obviously there are needs for devices with tactile *and* audible outputs.[78]

But it was already too late. Although Mauch did not yet know it, the last Stereotoner had already been built by the time this report was published. The last mention of the Stereotoner in Mauch's published research and development reports came only a year later, in Fall 1975, when he addressed the maintenance experience with the 65 Stereotoners provided the government for evaluation in 1973.[79]

An Evaluation of the Stereotoner

A Stereotoner evaluation project was initiated in December 1972, by a National Academy of Sciences Panel on Evaluation of Ink-Print Readers, attended by the PSAS headquarters staff, presumably Murphy and Freiberger, three experienced Visotoner instructors, Lauer, Bennett, and Butow, and an Optacon instructor from the Massachusetts rehabilitation agency, together with members of the National Research Council Committee on Prosthetics Research and Development (CPRD). The panel recommended a contract with the American Institutes for Research (AIR) of Palo Alto, California, to evaluate the Stereotoner. AIR was then completing a similar project evaluating the Optacon for the U.S. Office of Education. It was agreed that the VA would purchase 50 Stereotoners for testing by veterans, and CPRD would buy 15 for testing by non-veterans. The project took place at four centers: the three VA blindness rehabilitation centers and the Hadley School. Each center was to train twelve students using screening tests and new training materials developed by AIR. AIR also trained two students in the Palo Alto area.[80]

PSAS may not have been too happy with AIR's evaluation report. They published only a three-page abstract in the *Bulletin of Prosthetics Research*, in spring, 1976, while arranging to publish a thirty-page critique, prepared by the Hadley School, in the following issue. Robert A. Weisgerber, the principal investigator for AIR, reported that AIR had first adapted training materials from their Optacon evaluation project, and then developed an Auditory Selection Test to assess aptitude for Stereotoner training. Performance was measured by reading rate on selected material, and the accuracy of letter-by-letter translation of isolated words. Training consisted of 54 hours of class instruction, over two to three weeks, followed by an 87-hour curriculum of home study. Follow up observations and interviews were conducted one month after class-training and at least four months after training.

Of fifty trainees, only thirty completed the class training. Seventeen dropped out for various reasons and three were eliminated from the data set. After classroom training, the average reading rate was 4 wpm and the maximum was 13 wpm. Isolated word accuracy averaged 80%. After home study, average rates were 13 wpm and the maximum was 34, though isolated word accuracy had slipped to 66%. One of the individuals eliminated from the data set, however, was tested at 85 - 90 wpm. AIR summarized,

> Trainees found the auditory code difficult but possible to learn. They found the precise requirement of line tracking to be the most frustrating aspect of Stereotoner usage. They generally expressed pride in their modest new ability to independently perform personalized tasks such as reading of incoming mail and proofing of typing. However, their ability to read various difficult formats, typefaces, and applied numerals (prices, etc.) was quite limited.[81]

AIR concluded that "It is clear that some blind persons, but by no means all, can learn to read ink print materials with a Stereotoner. Consequently, it can be added to the repertoire of devices and aids currently available at blind rehabilitation centers." Potential users, however, should be warned that prolonged and concentrated study were required:

> Given the difficulties encountered and the slow rates attained, it was recommended that further research and development be conducted with ink print reading devices having spelled-speech output or synthetic speech output. Hopefully such efforts would lead to a simpler, more rapidly learned and more widely used aids for blind persons, whose independent access to printed materials *is* important to their personal and economic well-being.[82]

Margaret Butow, who conducted the evaluation program at the Hadley School, put a different interpretation on project results in an article that appears to have been constructed as a response to AIR's findings. Butow, who was Lauer's student and colleague, first made sure that readers knew she was equally proficient as a user and teacher of both the Stereotoner and the Optacon. Her reading rate was about 35 wpm on each.[83] The article was co-authored by Michael Carbery, vice president of the school, whose Ph.D. credentials were atypically highlighted in the byline. Butow did not choose to reproduce AIR's results or conclusions, explaining, "Since American Institutes for Research has already published their research and evaluation report of the Stereotoner, discussion here will center on students trained at the Hadley School."[84]

At Hadley twenty-one people were given the screening test developed by AIR, and all of them passed. Nineteen students participated in the study, and a twentieth started training too late to be reported to AIR. The twenty, who ranged from 18 to 54 years old, were highly educated: seventeen were college graduates. Seventeen were congenitally blind, and three were adventitiously blind and had some experience with print letters. Of the nineteen students for whom all data was collected, sixteen completed class training, three completed the home course, three partly completed the course, and fifteen continued to use the Stereotoners. Of the three who did not finish the class work, one could not hear the code well; one could not operate the equipment properly; and one dropped out from fatigue. The fourth student, who did not continue practice at home beyond eight months, had health problems.

At the end of classroom instruction, reading rates varied from 2 to 10 wpm, and, as Butow reported, "At the end of training the students could read quite independently."[85] The readers reported using their Stereotoners to screen or read personal and business mail, to check for typing errors, to read bus and train schedules, to read newsletters, to debug computer programs, to read instructions on a pay phone, and to identify currency. The Hadley school had trained four students since the project ended, and would continue to offer the course free to students who must pay their travel and support expenses.

Carbery and Butow concluded "Because of the successful Stereotoner users taught primarily at the Hadley School during the Research and Evaluation project, it would seem that the Stereotoner would have some value as a print reading aid to a number of blind people. At the present time, no concerted effort is being made to publicize and market the Stereotoner." "The Hadley School," they explained, "is a teaching center for both Stereotoner and Optacon reading aids, and is not in a position to market any sensory aid. The publicizing of the Stereotoner should be done by the manufacturer or his representative."[86] They further urged that a tracking aid be developed for the Stereotoner, which could not utilize the Colineator because of its two-box configuration.

The Hadley report took issue with AIR's suggestion that a spelled-speech or synthetic speech machine might replace the Stereotoner: These more complex devices would not be as portable as the Stereotoner. They would cost more than blind people were likely to afford. The Stereotoner was available now, and these new machines were not. In summary, "There may always be a need for a direct translation reading aid such as the Stereotoner or Optacon, which can be carried from home to office and used primarily for small reading tasks."[87]

The Hadley report made five recommendations to the VA. Two involved the improvement of the tracking system. One involved a modification to the screening protocol. One involved methods for training sighted Stereotoner instructors. The first recommendation, however, confronted the problem of innovation:

> 1. An organization should be found which is already involved in promoting sensory aids, that will publicize and market the Stereotoner.... research and evaluation of the Stereotoner has been completed. It would seem that the stereotoner is a viable reading aid for a number of blind people.... The Hadley School will continue to provide these materials and Stereotoner instruction upon request, but it is not within the province of the Hadley School to go out and look for prospective students.[88]

Two interesting issues are clearly raised by the Hadley School's report. First, it would seem that two different institutional perspectives led to two different evaluations of the Stereotoner. AIR, a contract research firm, interpreted test results forwarded from Hadley and the three VA centers to show the Stereotoner to be difficult and frustrating to learn, too slow and inaccurate in use, at best, an interim device pending replacement by advanced technology. Using part of the same data, but with an intimate knowledge of the readers and their social context, the Hadley School for the Blind concluded that the device could be independently used by a blind people after a short period of training. It was essential to the performance of small, but essential tasks in their everyday lives. The reviewers further suggested that direct translation machines like the Stereotoner are likely to be the product of choice even after high performance devices become available. The principal need was not for more research and development, but for an entrepreneur to publicize and market the device.

And that is the second issue: What kind of institution could publicize and market the Stereotoner? Not the Hadley School for the Blind, the authors made clear. Their mission was to teach blind readers. Not the Veterans Administration. The VA might buy 50 devices for test and evaluation, and then, perhaps, a dozen per year to issue to blinded veterans, but the U.S. Government was not in the business of making and marketing reading machines. Not Mauch Laboratories, either, as it turned out.

Mauch made 35 extra Stereotoners in 1973, and sought to sell them in the following years. In 1973, Mauch prepared a brochure to publicize the Stereotoner. On the front he placed a photograph of Harvey Lauer demonstrating the device. Jim Bliss of TSI objected publicly to this implied endorsement of a competing product by a government employee, and received an apology. Mauch also prepared a demonstration film, in which Lauer was featured. Rather than have the film prepared professionally, Mauch had Glen Smith do the filming and announcing. Lauer remembers that Smith was unhappy with this approach, because he felt the quality was amateur and his time was better spent on engineering.[89] Apparently two of the twenty students trained at the Hadley school bought directly from Mauch, in 1974 or 1975, as did the four students trained after the VA / CPRD-sponsored evaluation program ended. Mauch never sold all of the thirty-five units,[90] and by 1975, he must have stopped trying. Whatever tentative efforts Mauch Laboratories had made to market the Stereotoner, from Margaret Butow's perspective, they were clearly deficient.

The deficiency was more one of practice than of the quality of the product or the general will of the inventor. This explanation is suggested by the contrasting history of the Optacon, and Telesensory Systems, Inc., as discussed in Chapter 10, below. Mauch Laboratories was not a manufacturing firm, but an engineering design shop. Mauch's practice was not to stabilize a product design in order to sell it. His business was the sale of engineering services. His practice was solve problems of engineering design, including those he had created by prior design selections. Mauch did not turn to the world outside the engineering laboratory to find solutions to design problems. If a solution could not be found within the realm of engineering design, he invariably chose to abandon the concept, and, taking whatever engineering knowledge he had gained, begin to develop a new one.

It is true that Mauch could and did manufacture devices in small lots, but he had no sales organization, no distribution network, no reading machine instructors, and little direct knowledge of the market for his product. It is also true that the Stereotoner was well publicized among the service community (AFB and AAWB) and organizations of blind people (NFB and BVA) between 1967 and 1975, but as shown in Figure 18, these demonstrations were made by Lauer, Bennett and Butow, under PSAS sponsorship, not by Mauch laboratories.[91] It was PSAS that had an appreciation of the market and the "problems of deployment," not Mauch Laboratories.

Year	Month	Person	Place
1969	Aug	Lauer	AAWB Convention, Chicago
	Oct	Butow	Library of Congress, Washington
	Nov	Butow	Chicago Lighthouse for the Blind
1970	?	Lauer	Texas School for the Blind
	Jul	Lauer	Blinded Veterans Association
	Sep	Butow	Mid-Atlantic Meeting, AAWB
1971	Jul	Lauer	National Federation of the Blind, Houston
1972	May	Lauer	President's Committee on Employment of Handicapped
	Jun	Lauer	Assn for Ed. of Visually Handicapped, Miami
	Jul	Lauer Bennett	Blinded Veterans Association, Los Angeles
	Jul	Lauer	National Federation of the Blind, Chicago
1973	Jul	Lauer	National Federation of the Blind, New York
	Aug	Lauer	AAWB Convention, Cleveland
	Aug	Bennett	Blinded Veterans Association, Atlantic City
	?	Lauer	Symposium on employment of visually impaired secretaries, Houston

Figure 18. A list of known Visotoner / Stereotoner demonstrations

Like the Hadley School, the practice of the VA Hospitals was rehabilitation. Like Butow, Lauer and Bennett had both learned to use and to teach the Optacon. These three professionals saw their job to be matching the right person with the right prosthetic device. Their practice, although it welcomed and sought innovation, was ultimately that of rehabilitation, not of marketing a specific product. Although these blind professionals valued the Stereotoner as a product more highly than did AIR, they generally accepted and agreed with AIR's finding that only that fraction of blind persons whose perceptual modes were more aurally than tactually inclined were candidates for the Stereotoner as opposed to the Optacon.[92] This clinical part of the PSAS program would have considered it unethical to publicize and promote the Stereotoner in the way that Margaret Butow knew it must be promoted if it were to become a viable product.

Publicizing and marketing products was not Mauch's practice either. Hans Mauch built what he believed to be a better reading machine than the Optacon, and he waited for the world to beat a path to his door. He made a brochure and a film, to let the world know he was ready. The VA ordered 50 devices out of an initial production of 100. CPRD ordered 15 more. But the ratio was wrong. As Freiberger explained in his 1971 article on the deployment of the Visotoner, only two percent of the blind people in the U.S. were veterans. Ninety-eight percent were not. Mauch had a sympathetic market in the VA, though not a monopoly. But the VA could account for only two percent of the potential market share. If Mauch wanted the rest of that market, he would have to structure a business to go out and get it.

Mauch did not choose to do so. After all, the business of Mauch Laboratories was engineering development, and Mauch had solid development contracts to perform – contracts which it had held for nearly twenty years. Butow was right: if the Stereotoner were to succeed at innovation, it needed an organization which knew how to promote sensory aids, one that would publicize and market the device. No such organization appeared, and, like the Cognodictor, but for altogether different reasons, the Stereotoner failed at innovation.

Chapter 8. Haskins Laboratories and the Quest for Synthetic Speech

Introduction

It is hard to imagine more different approaches to technology development than those of Mauch and Haskins Laboratories. Mauch was a craftsman, an engineering designer who employed his craft to give substance to a technological idea by building a working prototype. Once a bench top prototype was built, it would be used as a working test bed for reiteratively refining the design of its components. If a prototype's performance could not be improved to the point where its performance were acceptable to Mauch or to his sponsor, then he would backtrack, build a new prototype, and start the process of refining the design over again. Mauch's practice was to design the best electromechanical prototype which he could to produce a specified output, and then, when faced with failure, as in the Cognodictor, or with success, as with the Stereotoner, to shift his efforts to a new project or a new design concept.

Franklin Cooper, by contrast, was a scientist with a scientific problem to solve. By the end of the CSD period, he had defined a problem that would occupy much of a distinguished career: What are the qualities of speech that make it an efficient acoustic vehicle for transmitting linguistic information? To answer this question, Cooper established and managed a research team that designed and built prototypes, simulators, and instruments, as they were needed to frame and address the scientific problem. This multidisciplinary team deployed concepts from psychology, physics, biology, linguistics and computer science to formulate conceptual models of speech communications and to guide research methodologies. They conducted human subject tests to gather empirical data, and they built laboratory prototypes to generate or simulate the generation of synthetic speech in order to empirically validate their theories and his models.

Unlike Mauch, Cooper was very much concerned with the output of reading machines, and most of Haskins Laboratories' technology development program was directed at research on how to generate intelligible speech with machines. Cooper's bachelor's degree was in engineering, so he was comfortable in the domain of tools and devices, but, his interests were not primarily in building a reading machine and making it work. Cooper hoped and believed that the knowledge gained in the course of his scientific research would provide a basis for new technologies, including reading machines for the blind, but his practice was multidisciplinary research to understand the acoustic basis of speech perception. His interest in technology development was derivative from that practice.

Franklin Cooper was successful as a scientist by any measure. His publications were many and often influential. He attracted capable colleagues from both natural and social science disciplines, and he facilitated their collaboration through the vehicle of Haskins Laboratories, which he led as President and Research Director from 1955 through 1975. For his work in the field of speech perception and speech generation, he was honored with the Acoustical Society of America's (ASA) first silver medal in Speech Communication, in 1975,[1] as well as special awards by the American Speech and Hearing Association, the Institute of Electrical and Electronic Engineers (IEEE), and the Society for Experimental Psychology. He was a fellow of both IEEE and ASA.[2]

Among Cooper's colleagues working at or through Haskins Laboratories, some major contributors to research related to the reading machine program were:

Alvin M. Liberman, a psychologist from Yale, who joined Haskins as a consulting scientist in 1944, and remained a Haskins associate, while progressing from assistant professor to department head in psychology at the University of Connecticut. Liberman's research area was that of speech perception.[3]

Jane H. Gaitenby, whose B.A. was in anthropology. She pursued graduate work in linguistics and anthropology at Columbia before joining the Haskins reading machine effort when it was revived, in 1957. Her principal work concerned English phrase structure and the interrelationships between morphology, syntax, stress and intonation.[4]

Ignatius G. Mattingly, a linguist from Harvard and Yale, who worked for the U.S. Department of Defense before joining the faculty at Connecticut and becoming a Haskins Labs' associate in 1966. His interest was in speech synthesis by rule.[5]

Patrick W. Nye, a British physicist with broad experience in the area of reading machines for the blind, who joined Haskins Labs in 1971. He was made Associate Director of Research in 1975, taking charge of the reading machine program.[6]

Cooper's technology development practice, conducted through this multidisciplinary team at Haskins Laboratories in New York (later in New Haven), was more notable for its differences than its similarities to the technology development practice which Hans Mauch conducted with Glen Smith in his engineering design laboratory in Dayton, Ohio. But Mauch Laboratories and Haskins Laboratories did share one important characteristic in common: After twenty years of PSAS research support, neither practice resulted in the innovation of a reading machine for the blind.

Haskins Laboratories joins the PSAS program

Haskins Laboratories was not represented at the first two PSAS reading machine conferences. Unlike the other commercial laboratories which were there, Haskins Labs was not known as a hardware developer. In the CSD period, Haskins Labs had primarily provided the committee with overall program management, a role that Eugene Murphy intended to fill for any VA research program. Haskins Laboratories did not fit into Murphy's preliminary plan for structuring a PSAS reading machine development program.

At the second technical session on reading machines, however, Homer Dudley of AT&T Bell Laboratories, inventor of the voder and vocoder, raised the topic of artificial speech as an output for reading machines. Dudley was familiar with Cooper's post-war work in the area of speech synthesis. Together with Clifford Witcher, he suggested that Haskins Labs would be a good firm to conduct research into machine-generated speech. At the close of the session, Murphy telephoned Cooper, who told him that, although he had no immediately useful information, Haskins Laboratories' postwar research had made him more confident than before of the possibility of a synthetic speech machine.[7]

Four months later, in August 1955, Cooper sent his colleague, A. M. Liberman, to represent Haskins Labs at the third technical session. Liberman staked a claim for Haskins' expertise and continuity, in a presentation entitled, "Lessons from 'Wuhzi' and progress since,"[8] which reviewed Haskins' research into the perception of speech-like sounds, initiated by its experiments with the synthetic language it called "Wuhzi," in 1944. Liberman also made the point that Haskins could build prototypes, by playing a tape of synthetic speech generated by a Haskins-designed speech synthesizer.

A year later, at the fourth technical session, Franklin Cooper presented a talk entitled, "Synthetic speech and the reading machine problem," which so impressed PSAS that it was entered in the minutes in full. The taxonomy of reading machines which Cooper presented during his talk (Figure 9, above), became the model for the structure of the PSAS' research program. Cooper recommended to PSAS that a recognition reading machine employing synthesis by rule could and should be built as a long term project. Secondly, as an interim step toward such a device, a word reading machine should be built, which would recognize words and play back prerecorded tapes of those words. Finally, Cooper conceded, a device for converting letter shapes to speech-like sounds should also be pursued as the basis for a low-cost reading machine.

Within the year, PSAS issued two research contracts to Haskins Labs – one to construct an interim word reading machine, and the other to perform research on the synthesis of speech by rules.[9] In fulfillment of Cooper's third recommendation, Mauch Laboratories was given the task of developing a machine to convert printed letters to speech-like sounds, as described in Chapter 7.

Haskins Laboratories' research program in the post-CSD period

In a sense, these contracts represented a return to its roots for Cooper's research team. Since the end of CSD funding in 1947, Haskins Labs had built a substantial research program around the spectrograph and play back machine, by which they sought to establish the acoustic qualities (frequency, intensity and duration) of speech which were perceived as information by a listener. The story was succinctly told in Cooper's 1975 citation for the ASA's silver medal, prepared by his colleagues Liberman and Mattingly:

> Cooper's interest in speech, scarcely foreshadowed by his education or early research experience, began near the end of World War II, when the Laboratories was requested by the Office of Scientific Research and Development to coordinate a program for the development of prosthetic devices for blinded veterans. Among these was a reading machine that would translate characters of the printed page into discrete discriminable sounds. It soon became apparent to Cooper that such acoustic alphabets could be perceived only very slowly by comparison with speech. Indeed, speech appeared to be a uniquely efficient acoustic vehicle for transmitting linguistic information, and Cooper determined to find out why this was so. Putting aside his earlier work in biophysics, he began the investigations that have brought him here today to receive the first silver medal in speech communication.[10]

The citation explains that Cooper designed the Pattern Playback, a research speech synthesizer, in order to systematically manipulate the elements of speech and observe the results. In contrast to other synthesizers, such as Dudley's, which were played like a musical instrument, Cooper's device was controlled by visual patterns generated from speech by a Sound Spectrograph, or prepared by a graphic artist. The citation summarized Haskins Labs' early research using the Pattern Playback in this way:

> Working intensely with the Playback in the late 1940s and early 1950s, Cooper and his associates set about identifying the acoustic cues on which the

> perception of speech rests. These cues, they found, are often less than salient in spectrograms, generally overlap in surprising ways, and are curiously scattered. However, they came to understand that this seeming disorder reflects a complex but systematic restructuring of the phonetic elements in the acoustic signal. This restructuring, because it permits simultaneous transmission of information about successive acoustic segments, accounts for the efficiency of speech that Cooper had early appreciated.

Thus, by the time CSD support ended in 1947, Cooper had already initiated "a long-range research program" initially funded by the Carnegie Corporation of New York. In 1949, Cooper presented a paper at the ASA annual meeting describing the development of the sound spectrograph and pattern playback as research instruments, and their application to study the perception of sounds.[11] Haskins Lab's modified version of the Bell Labs' spectrograph-produced photographic transparencies which could readily be reconverted to sound on the Pattern Playback.[12] At the 1950 ASA meeting, Cooper reported achieving, "a rather high order of intelligibility," in hand-produced spectrograms which were simplified and schematized versions of recorded graphs.[13] Cooper also outlined his research program to the National Academy of Science in its October, 1950 meeting.[14] By November 1952, Cooper's research team had attracted financial support from the Department of Defense, and published its first major research paper. That paper, "Some experiments on the perception of synthetic speech sounds," shows how far Haskins Labs' work had departed from any immediate concern with the development of reading machines.

In 1944, Cooper had approached reading machine development by employing a simulator to isolate, by trial and error, the simplest tonal output which could convey the information contained in printed letters and words. Cooper's application of the spectrograph and playback instruments was analogous: By hand-painting and then playing simplified spectrograms, he tried by trial and error to determine the simplest elements of the acoustical signals which were essential to intelligible speech. By 1952, based on the initial results of these experiments, Cooper's research had taken a new direction:

> The work with simplified spectrograms did not provide unequivocal answers to questions about the minimal and invariable patterns for the various sounds of speech, but it did enable us to develop our techniques and, further, it suggested certain specific problems which appeared to warrant more systematic investigation. In our research on these problems we have departed

> from the procedure of progressively simplifying the spectrograms of actual speech and have undertaken instead to study the effects on perception of variations in isolated acoustical elements or patterns. Thus we can hope to determine the separate contributions to the perception of speech of several acoustic variables, and ultimately to learn how they can be combined to the best effect.[15]

The problem, the authors explained, was that speech perception was more complex than their initial theories of the information content of speech had assumed. Certain consonants, for example, could not be identified by test subjects based on frequency content alone. Their audibly perceived identity depended not only on the acoustical signature of the consonant, as recorded on a spectrogram, but also on the consonant-vowel transition, which was characterized by frequency shifts in parts of the characteristic formants of the vowel when articulated in pair with the consonant. The information content of these transitions led Cooper to wish for a different term that emphasized their importance to speech perception:

> You have seen how the identification of a particular transition (or burst) seems to depend also on the vowel, so that apparently one is perceiving an acoustic unit having the approximate dimensions of a syllable or half-syllable. Now this is not really very surprising if spectrograms are taken at face-value, but we, and perhaps some other workers as well, had undertaken to find the 'invariants' of speech, a term which implies, at least in its simplest interpretation, a one-to-one correspondence between something half-hidden in the spectrogram and the successive phonemes of the message. It is precisely this kind of relationship that we do *not* find, at least for these stripped-down stops and nasal resonants.

It was even possible, Cooper suggested, that speech was encoded sound, such that:

> ...one may not always be able to find the phoneme in the speech wave, because it may not exist there in free form; in other words, one should not expect always to be able to find acoustic invariants for the *individual* phonemes.

> The problem of speech perception is then to describe the decoding process either in terms of the decoding mechanism or – as we are trying to do – by compiling the code book, one in which there is one column for acoustic entries and another for message units, whether these be phonemes, syllables, words, or whatever.[16]

Between 1952 and 1957, the Haskins research team presented a number of research papers at conferences on speech communications, and regularly published research reports in the *Journal of the Acoustical Society of America*, on topics pertaining to the relationship between acoustic variables and speech perception.[17, 18, 19] This research was concerned with discerning the acoustic variables (frequencies, intensities, and durations) associated with different elements of speech, as captured and measured on spectrograms, and relating those variables to the perception of speech (consonant and vowel sounds) by human subjects. This work was primarily aimed at theory generation. It was conducted at the level of consonant-vowel pairs. Together with researchers at a few other centers, the Haskins group found that there were few simple, invariant relationships between the acoustic elements of speech and the perception of speech. Basic vowel sounds could be readily characterized in terms of three formants, that is three patterns of low, medium and high frequency sounds, but when initial consonants were added, they interacted with the three formants of different vowels in complex and sometimes irregular ways. The key to perception of consonants was found to be in the "transition" of formants, that is to say frequency shifts converging on a steady acoustic pattern, which occurred when an initial consonant was added. For some consonants and some formants (the lower or first formant and the middle or second formant), the spectrograph of the transition could often be extrapolated to a common frequency of origin for the different vowel combinations, causing the Haskins researchers to propose "acoustic loci" as a theoretical element of speech perception for the voiced stops, unvoiced stops, and nasal consonants. Perceptual cues were complex, however. For example, the researchers found that changing the frequency of the third (highest frequency) formant within broad limits had no influence on perception of the vowel sound, but did have a major effect on the way transitions were heard, that is to say the frequency shift in that part of the vowel sound changed the way the listeners heard the preceding consonant.

These complexities made difficult the problem of constructing rules for the generation of words out of phonemes, which was the practical goal of the research. As the research team was acutely aware, similar problems remained to be addressed for the construction of sentences out of words. Moreover, some research results indicated that perception was not necessarily a simple matter of decoding sounds. Some consonants that are articulated identically in combination with different vowels showed different transitions and transition loci in spectrograms for different vowel combinations. In these cases, listeners invariably identified the consonant according to the articulation, not according to the acoustic signal. For example, the initial consonant "g" (hard "g") created two different kinds of spectrograms depending on the following vowel, but was universally heard as a single consonant, "g." Findings such as these led the researchers to speculate that perception might be in a sense proprioceptive – that the listener's brain somehow translated complex acoustic sounds into a mental representation of the physical act of articulation. Such considerations led the research team to further speculate that some acoustic patterns – those which could be articulated – might be capable of interpretation as language whereas other acoustically similar sounds, which could be conceived and painted as artificial spectrograms, might not be perceivable as language.[20]

We cannot explore in detail the scientific research of the Haskins group, but I have tried to provide enough information to show the perspective and the resources which Haskins Laboratories brought to its PSAS contracts in 1957. Cooper's scientific research program on the nature of speech perception had been launched by the CSD reading machine problem in the mid-1940s, but by the mid-1950s, it had departed from its origins. The spectrograph and the pattern playback machines comprised a technological basis for Cooper's scientific research, but that research was not directly concerned with reading machine design. Rather, Cooper employed these devices as research instruments for developing empirical data on the acoustic characteristics of sound and on the psychology of perception. The principal goal of this research was a theoretical explanation of how people communicated by the generation and reception of sound in the form of speech. The practical product was conceived as rules for the generation of sounds that would be perceived as speech. Those rules, once developed, could be used to control a machine generating synthetic speech, but this technological objective was, by 1957, a derivative one, no longer a motivating goal of research.

An Interim Word Reading Machine

Beginning in April 1957, Haskins Labs worked to support PSAS in two areas. One project, entitled, "Research on audible outputs of reading machines for the blind," represented general PSAS support of Haskins Labs' ongoing research program toward the generation of synthetic speech. It was clear both to Haskins Laboratories and to PSAS that this was a long range goal. It was also understood that it was a high-risk project, the value of which would depend on external events. As Eugene Murphy put it many years later, "We took an out-and-out gamble on Haskins, because their success depended on the development of optical character recognition."[21]

Murphy was willing to support long-range research, but he also wanted some more immediate results. Therefore, PSAS funded a second project which Cooper had framed, at the fourth technical session, as a "short range or research phase" solution to the problem of developing a recognition-type reading machine. This project, entitled, "Output characteristics and construction of an interim word reading machine," sought to develop a device which could recognize a vocabulary of up to 7,200 printed words, retrieve a recording of each word as it was recognized, splice the recordings together, and play them back as an audible text. PSAS funded a fixed price contract for the development of a prototype which was labeled the Interim Word Reading Machine, or IWRM. In 1956, Cooper had labeled the output of such a device "plain speech," but the term that was generally used to describe synthetic speech that was spliced word by word without further processing was "compiled speech."

In 1957, Jane Gaitenby began work on compiled speech, under Cooper's direction. At the same time, Haskins' engineering staff began work on a device to retrieve and playback the compiled words. The project did not attempt to solve the problem of optical character recognition. The interim machine was to take as its input, punched tapes of the sort used to drive printing presses. Thus, the IWRM was to accept as input a tape-generated, electrical code representing letters and spaces. It would compare the coded patterns of groups of letters between pairs of spaces with the patterns of 7,200 words stored in memory. Upon finding a match, the device would activate a recording of the spoken word, stored on a magnetic tape attached to the edge of a data processing card.

This was a time consuming process in 1957, requiring about five seconds per word. The machine, therefore, would not pronounce the word directly to the reader, but would transfer a copy of the recording to a standard reel of magnetic tape, thus compiling a text, word by word. After the entire text had been converted and stored on tape, the blind reader would receive the tape recording for playback at his or her convenience. As cumbersome as this may sound, it was not an unreasonable concept for automating the existing system of recording for the blind, which relied on the availability of volunteer readers. According to the IWRM concept, a blind reader would contact a library providing the service. The library staff would put the book of interest through the machine, and, in a matter of hours or days, instead of weeks, could provide a reader with a recorded book.

During the first year of the project, Gaitenby worked to select the best vocabulary consistent with the 7,200 word constraint, and to determine how best to record the selected words to minimize problems of intonation and stress.[22] She determined the best predictor for a word's stress to be its grammatical function. Each of the selected words was therefore assigned a word category, based on its most probable grammatical function. This was a problem for some words, such as "last" or "back" which could function as a noun, verb, adjective, or adverb in different sentences. Each category of word was assigned a specified starting pitch, pitch slope, duration and intensity. Speakers were instructed to pronounce each word for recording according to these rules. Ultimately, 7,200 such recordings were made and stored on data cards for retrieval. The intelligibility of a particular compiled text was reported to be dependent not only on these variables, but also on the speaker's skill. By 1961, Gaitenby reported the construction and test of sentence and paragraph length recordings by hand splicing prerecorded spoken words. "High intelligibility and a modicum of naturalness," were achieved by having the speaker record the words according to six types of intonational patterns based on word category.[23]

But no Interim Word Reading Machine was ever built. Funds were exhausted in 1959, after a prototype had been fully designed but only half completed.[24] This represented a problem for a fixed price contract to deliver a prototype device. PSAS carried the contract on the books until 1965, reporting semiannually that a prototype was nearly complete, but providing no clear explanation for the extended delay.[25] The contract was finally accepted as fulfilled in December 1965, when a bench top prototype, "which was not then in deliverable form as a completed device," was operated with a limited vocabulary, to demonstrate the IWRM concept.[26] No public explanation of these events was given at the time. Twenty years later, Cooper explained, "A decision to terminate the project at this point was made on the basis of a number of considerations: the most cogent were that the system was already technically obsolete and that the substantial amount of additional work needed to put it into final form and to record the dictionary tape would be largely wasted, since the same result could be obtained by computer simulation of the system (as indeed it was)."[27] By technologically obsolete, Cooper meant that by the mid-1960s, modular printed circuit cards had become available to replace the custom-designed logic circuitry of the original design, and that general purpose "computer methods," for system control and data storage had provided less expensive and more flexible approaches to system design.[28]

This retrospective explanation was incomplete, however. No doubt the IWRM design was obsolete in 1966, when it was finally abandoned, but it was not technically obsolete in 1959 - 1960, when it was put on the shelf until 1966. In his 1984 considerations, Cooper attributed this lengthy delay to an underestimation of the complexity of the device, noting that the original fixed price contract provided only half the funds needed to complete the prototype, but this explanation is still insufficient.[29]

Why did Haskins Labs draw the IWRM contract out until 1966? If the design was completed and the machine half built, why did they not simply complete a semi-functioning prototype six years earlier, as they eventually did in 1966? The answer is to be found in the nature of Haskins practice. Unlike Mauch Laboratories, Haskins Labs did not approach technology development in terms of the reiterative design and improvement of prototypes. The role of the prototype device for Haskins Labs was that of proof of concept. Research was concerned with the reiterative improvement of concepts, not devices. Once the best concept had been determined, and refined through the development and test of theories of acoustical perception, then was the time to build a prototype to demonstrate the concept. Around the time that the IWRM was shelved, Cooper had formulated a newer concept which integrated Haskins Labs' experience with the interim word recognition project and its work on the generation of synthetic speech by rule.

In a 1961 paper, entitled "Word reading device: Design considerations," Cooper described to the Acoustical Society of America his concept for an improved word reading machine, in which 7,200 data cards would be replaced by (analog) magnetic tape storage with adjacent digital addresses for each word. Cooper described how this improvement led naturally to the concept of an all-digital machine where both the location and the word could be stored in digitized form. But if the word were stored in digitized form, then it could be modified before its pronunciation by the same kind of rules for speech synthesis as published by Liberman in 1959.[30] There was a convergence of concept here which led Cooper to add a new category to his 1956 taxonomy, that of "re-formed speech."

Cooper had not yet coined this term in 1962, when he elaborated the new concept to the International Congress on Technology and Blindness. As shown in Figure 13, the concept, represented by the two middle paths in the diagram, was nonetheless well-advanced. At the time Cooper associated the new concept with synthetic speech.[31] By early 1964, Cooper was referring to the concept as a "hybrid method," reporting that, "As a result of study during the past year some modifications in emphasis have emerged. The best method of generating speech appears likely to be one that will store electronic 'instructions' for synthesizing words rather than the system of stored voice recording."[32] In 1965, Cooper reported, "It seems that the best type of synthesized audible output for a reading machine for the blind will be what has been called *re-formed* speech since the individual words are formed from stored instructions based on real speech. Next best would be compiled speech, put together from voice recordings of single spoken words."[33]

The Interim Word Reading Machine was shelved not primarily for lack of funds, but for lack of interest. Conceptual obsolescence preceded technical obsolescence. Given a digital approach to word storage, the conceptual differences between a compiled speech machine and a synthetic speech machine were reduced. One system stored digitized phonemes and the other stored digitized words. Either storage system could be used to synthesize speech by rule. In a digitized *compiled speech* machine, the stored words would simply be strung together without further processing. In a *synthetic speech* machine, the rules would operate on data stored as phonemes. In a *re-formed speech* machine, the phonemic and subphonemic elements of digitally stored words would be modified to provide enhanced stress and intonation both within and between words and phrases. Between 1960 and 1965, Cooper's interest in the re-formed speech concept superseded his commitments to build a compiled speech prototype, which in his mind would be conceptually obsolete, even if it were built. Why build a prototype to demonstrate a concept that was obsolete?

When Haskins Labs did return to the compiled speech prototype, it was not to the design which was shelved in 1959. The spring 1965, VA Contractors' Report stated that:

> Regular evaluation tests by groups of blind listeners await completion of the Word Reading Machine hardware and its control by the computer. Rapid progress is being made in putting the device into operation. The control functions for the WRM are to be exercised by the recently acquired computer. This has had to wait the inevitable shakedown of the computer itself and the training of staff in its use. Both of these have been largely accomplished. Connections between the WRM and the computer have been wired in, and programming the control functions will be comparatively straightforward. Transferring the recorded vocabulary from the cards on which it is now stored

> to the [digitized] magnetic-tape Dictionary of the WRM has as yet to be completed and will be a laborious job.[34]

The 1966 prototype was not so much a demonstration of an interim word reading machine, as a demonstration of the feasibility of the computer-based storage and retrieval of a limited vocabulary of digitally stored recordings of words. This exercise had value for the development of either a re-formed speech machine or a compiled speech machine.

Cooper's 1984 explanation was not necessarily disingenuous or intentionally misleading. It simply suffered from the advantages of hindsight. In 1967, Haskins Laboratories, with PSAS approval, merged its work on a compiled speech reading machine into its long term research program.[35] In 1966, Cooper had informed the International Conference on Sensory Devices for the Blind, held in London, England, that

> Our research to this point has led us to put aside the method of synthesis by rule, and to concentrate on generating and testing user acceptability of compiled speech as an immediate objective while we work out the remaining problems of generating reformed speech for further field tests. The present prospect is that reformed speech will be the method of choice, and that it should permit full-scale testing of a high performance reading machine within a very few years.[36]

By 1969, however, re-formed speech no longer seemed the best option, but the worst of the three, suffering the disadvantages of both. It imposed a large storage requirement, as did compiled speech; and large processing requirements as did synthetic speech.[37] From 1969 through 1971, therefore, the Haskins program returned to its original focus on two competing concepts, compiled speech and synthetic speech. By 1984, the eight-year re-formed speech excursion warranted only two paragraphs in a thirty-two page consideration. The first paragraph explained the concept. The second provided this evaluation:

> Actually, we did quite a little work on this kind of speech, and generated just enough of it to demonstrate that the process would work and that the speech would be fairly good. But the breakthrough on synthetic speech came at about this time [circa 1968], so work on the compromise method was dropped.[38]

As successes in the development of synthetic speech led to a declining interest in reformed speech, Haskins Labs was also led to reconsider the generation of compiled speech. As of 1969, the field tests anticipated in the early 1960s, had yet to be performed. An Interim Word Reading Machine had never been fully fabricated. The 7,200 data cards with their attached tapes, prepared in 1959 - 60, were truly obsolete. If compiled speech texts were to be compared with synthetic speech, it would be necessary to build a device to generate the test material.

Haskins Labs undertook this task in 1969, designing a digital-to-analog converter for converting the ten-year-old analog tapes to digital form and for driving a speaker from the digitized words. The research team wrote a program which controlled a medium-sized computer which was used to compile paragraph-length texts from punched paper tape. It was this device which Cooper, in 1984, referred to as "the IWRM ... in computer simulated form."[39] His description implied a continuity of design which was misleading.

The 1969 compiled speech generator was more an instantiation of the alternative design concept which Cooper articulated in 1961, than a direct successor of the Intermediate Word Reading Machine designed in 1957. Its retrospective construal as a simulator, rather than a prototype, may have been facilitated by the results of field tests, finally held in 1970. As a result of those tests, compiled speech was overwhelmingly rejected in favor of synthetic speech, and the last IWRM concept was abandoned. If the results had been different, the 1969 compiled speech generator might have been portrayed as the first working prototype of a word recognition machine. As it was, the device was remembered as a simulator of an obsolete concept which was finally rejected as the result of long-delayed field tests.

Synthetic speech by rule

Haskins Labs' began its post-war research program in speech perception by hiring Dr. Frances Ingemann of the University of Kansas to prepare a set of rules for speech synthesis, based upon the existing data. She compiled a set of rules in the form of instructions for painting spectrograms to "speak" a desired sentence. In PSAS's June 1958 contractors meeting, Dr. Leigh Lisker reported that he had tested Ingemann's rules with some disappointing results. Hand-painted spectrograms constructed by rule were less intelligible than those copied directly from spectrograms of speech. Based on these results, Haskins Labs set out to develop better rules.[40]

The result was an influential collaborative paper, "Minimal rules for synthesizing speech," delivered by Liberman to the fifty-sixth meeting of the Acoustical Society of America. The paper was remembered by Murphy thirty-five years later.[41] This was the first Haskins Laboratories' research report to acknowledge PSAS's support along with that of the Department of Defense and the Carnegie Corporation. It established a paradigm for later research, and for the synthesis of speech by the manipulation of its subphonemic elements.

The paper began with a discussion of two general problems of synthesizing speech by rule. First, acoustic information in speech is carried not only by phonemes but by the transitions between them. Second, speech patterns rarely break at phonemic boundaries. Conceding that rules might be written for making transitions between stored phonemes, Liberman, Ingemann and their colleagues then showed how a knowledge of the acoustic characteristics of *sub*phonemic elements, as provided by Haskins Labs' research program, could be used to generate intelligible speech using a smaller number of rules.

According to this approach, the basic unit of input for synthetic speech would be the phoneme, defined in terms of the frequency, intensity and duration of each of its formants, consonant loci or periodic sounds. Four types of rules with respect to place and manner of articulation, voicing and stress, were then applied to modify the basic units at the subphonemic level before they are used to generate sounds. The paper noted that, "This exercise may be considered to have any or all of several purposes. On the one hand, it may be practical. One thinks, for example, of the synthesizer end of a speech-recognizer band width compression system, or, perhaps of a reading machine for the blind. On the other hand, the aim might be quite academic, and, in a rather specific sense, not too different from that which motivates the linguist."[42]

A close reading of the paper reveals two practical problems inherent to its application to the development of a reading machine: It would require not only character recognition, but the conversion of text to phonemic script (grapheme to phoneme conversion). There was also a need for information regarding stress of the elements of speech – phonemes, syllables, words or phrases – according to their context. Regarding the problem of stress, the authors noted, "Now, the speech we get certainly sounds stilted if differences in stress are not provided for, but it is also markedly less intelligible than would be predicted from the levels of intelligibility achieved for its constituent vowels and consonants when these are tested in nonsense syllables." These two problems would become increasingly salient as the project continued toward one of practical application.[43]

Between 1961 and 1969, however, the thrust of Haskins Labs' research was not toward the design of a reading machine. Rather, the core of its research program was the formulation and elaboration of a *motor theory of speech perception* as an answer to Cooper's question, "What are the qualities of speech that made it an efficient acoustic vehicle for transmitting linguistic information?" The theory was presented in 1963, at the Stockholm Speech Communications Seminar, according to the following abstract:

> A theory is proposed that speech perception involves a decoding process in terms of equivalent articulatory patterns. A particular model of the brain functions allowing such an articulatory decoding is not presented, but the authors conceive of some process whereby the incoming sound stimuli could be decomposed in a sequence of motor commands that in the authors' speech would produce an equivalent auditory impression. One indirect evidence presented by the authors is the apparent distinctiveness of phonetic categories found in speech-perception experiments that in the authors' point of view is paralleled by differences in articulation that are much more distinct, simple, and invariant than the differences in the sound wave characteristics.[44]

To create empirical evidence for this theory, Haskins Labs extended its research in a new direction: In addition to the ongoing research by Liberman and others which sought to understand the decoding of acoustic information by the perceiver, Cooper initiated a new effort to examine the neuromuscular production of acoustic signals by the speaker. Cooper and his colleagues were impressed by the fact that there was not a simple relationship between the acoustical units of speech and its information content. It was the lack of a simple relationship that led him to look at the neuromuscular production of sound as a process of encoding information. If such encoding took place during articulation, then, as Cooper suggested in a 1966 paper, "one might suppose that some limited set of the neural signals to the articulatory muscles would retain a one-to-one correspondence with linguistic units of the message. Such characteristic neural signals, could then provide a most useful basis for a phonological basis of spoken language."[45]

The research reports published by Cooper's research team, during the period 1960 - 1969, fell into two major categories, in addition to those concerned with the formulation and defense of theory. The first group of papers were concerned with the encoding of acoustical information in the subphonemic elements of speech. They represent an extension of the research reported in the 1959 paper, "Minimal rules for synthesizing speech."[46] Beginning in 1961, the Haskins group also published a series of papers reporting experiments to determine the neuromuscular aspects of speech articulation. These studies employed electromyography, X-ray films, and fiberoptic camera systems to record the neurological and muscular events of speech production.[47] The rationale for these experiments was succinctly stated in a 1967 overview of the work of Haskins Laboratories:

> Current research on the production of speech is aimed at finding relations between distinctive aspects of the articulation and the linguistic units of the speaker's message. In the stages between intended speech gesture and emergent sound there is much restructuring of the message so that the stream of speech sounds no longer correspond in any simple way to the original sequence of linguistic units. Nevertheless, a fairly close correspondence might be found nearer the message source, perhaps at the level of neural signals and muscle contractions involved in articulation. The experimental procedure for testing this assumption is to record electromyographic signals from the muscles of the lips, tongue, and palate while a person is speaking; then to look for patterns of muscle activity that correspond to the units of the message.[48]

In the same article, Cooper reported experiments on the decoding of acoustic signals which indicated that speech was processed on the left side of the brain, while melodies and radar signals were processed on the right side.[49] Such a distinction would bolster Cooper's long-standing claim that an optimal reading machine should employ synthetic speech output rather than a tonal code. It would lead, over time, to further development of the Motor Theory of Speech Perception to include the claim that gestures of the articulatory organs are the ultimate constituents of language. According to this view, perceptual processes for interpreting speech operate uniquely to extract from the acoustic signal, information regarding those gestures, which are taken to be the primitive elements of human language.[50]

The impression that theory development was the focus of Haskins Lab's research was explicitly confirmed by the 1967 overview, where reading machines were addressed in this way: "A long-term objective, in addition to that of learning about the nature of speech, is the use of synthesis-by-rule, and other methods of generating speech from written text to make ordinary books available to the blind in spoken form. This work, however, is still at the trial and development stage."

Although the main thrust of Haskins Labs' research was directed toward theory development, some activities during the period 1960 - 1969 were more directly related to technology development. In 1963, the research team prepared a review paper on approaches to speech synthesis by rule for delivery at the Stockholm Speech Communications Seminar.[51] Beginning in 1964, Cooper undertook to design and build a computer-controlled formant synthesizer for the generation of synthetic speech[52] In 1967, Jane Gaitenby presented an important paper on rules for grapheme to phoneme conversion.[53]

Most important, in 1966, the Haskins team was joined by Ignatius Mattingly, who brought to the group his experience in developing computer programs for the generation of speech by rule. Mattingly, who had an M.A. in linguistics, had spent fourteen years in the Defense Department, including two years as a guest researcher at the Joint Speech Research Unit (JSRU) in Eastcote, England. At JSRU, working with J. N. Holmes and J. N. Shearme, Mattingly demonstrated a computer-driven prototype of a speech-by-rule synthesizer, as reported in 1964, in *Language and Speech.*[54] Judging from this paper's citations, Mattingly's rules were primarily derived from the published work of the Haskins group. Before joining Haskins Labs, Mattingly extended his computer program to include a limited set of prosodic features from a southern English dialect, including pauses, intonation, and prominence. Judging from the citations, this represented an addition to Haskins' work.[55]

While working for Haskins Labs, Mattingly completed a doctorate in English at Yale University. His 1968 dissertation, *Synthesis by Rule of General American English*, was accompanied by a parallel research report, entitled, "Experimental Methods for Speech Synthesis by Rule." The experimental system for speech synthesis reported by Mattingly combined a Honeywell DDP-224 digital computer with the resonance speech synthesizer designed by Cooper and Epstein. The computer supported an executive program for controlling the device and a rules program providing input to the executive from phonemic transcriptions. The rules program was an extension of the Mattingly's work on rules for the representation of phonemes and of prosodic features conducted at JSRU. By early 1968, Mattingly's synthesis program had been tested in combination with Gaitenby's rules for grapheme to phoneme conversion. According to PSAS's report, "Tests of various texts, not extensive, but probably representative of popular periodicals, indicate that at least

85 percent of the words of normal sentences are acceptably converted to sound."[56] This work represented the "breakthrough on synthetic speech" which Cooper, in 1984, gave as the reason for abandoning research on re-formed speech.

Compiled speech or synthetic speech?

Contemporary reports in the *Bulletin of Prosthetic Research* confirm Cooper's 1984 recollection that the success of Mattingly's work resulted in abandonment of the re-formed speech option. The logic for this decision had been established in 1966, when Cooper calculated that synthetic speech might cost half as much as re-formed speech, but was likely to be of much lower quality.[57] By 1969, Mattingly's work indicated that high quality synthetic speech-by-rule was achievable, whereas the preparation of digitized words from spectrograms had proven to be both difficult and expensive.[58] Consequently, re-formed speech was not pursued after 1969, and not mentioned after 1970. In the fall of 1969, Haskins Labs reported that, "not very much has been done with re-formed speech, except in the important sense that almost everything developed for synthetic speech also applies to re-formed speech," and also, "Field trials of *compiled* speech with selected individuals will start soon, and initial trials with *synthetic* speech can begin by mid-1970."[59]

In the event, tests of both compiled and synthetic speech were put off until 1970, while Haskins Labs moved from New York to New Haven.[60] During 1970, samples of compiled speech were prepared using the unnamed "simulator," and samples of synthetic speech were generated according to the most recent version of Mattingly's synthesis program. Both procedures used simulated optical character recognition. Compiled speech samples were prepared from punched tapes. The synthetic speech samples were prepared by the manual entry of phonetic symbols which simulated grapheme-to-phoneme conversion as well. In February 1969, Cooper had asked Noriko Umeda, a Bell Laboratories' researcher in linguistics, to address the problem of grapheme to phoneme conversion and to generate better rules for determining sentence stress, but with disappointing results."[61] The test material was prepared by entering phonetic symbols from a look-up table of General American phonemes, with stress symbols supplied by the human operator on two of three tapes.[62]

Somewhat informal tests of the compiled speech and synthetic speech samples were conducted at the Eastern Blind Rehabilitation Center, VA Hospital, West Haven Connecticut. Eleven blinded veterans listened to a total 27 different texts in various combinations. The veterans' candid comments were sought as the test result. An attempt was made to compare the results for different rates of speech and type of text, but the results were simple and unambiguous, in spite of the informality of the testing: Compiled speech was not acceptable because of the need to spell words not in the look-up table. "Any spelling in a text, at any of the tested rates is rejected by the listeners."[63] From the fall of 1971 onwards, Haskins Labs work on reading machines was limited to synthetic speech devices.

It is difficult to understand how Haskins Labs took fourteen years to determine that spelled-speech was unacceptable. The need to spell-out some words was known from the beginning. Word cards had been prepared by 1961, but no field tests were made until 1970. In 1965, Freiberger's summary of the contractor's report offered an explanation why field tests had not yet been carried out:

> It has not seemed either feasible or necessary to present the limited tests now available to blind subjects. At present, the sample outputs consist of relatively short passages of text, sentences of which have been laboriously compiled by manual wordcard retrieval and subsequent tape recordings. The method is too time consuming and error prone to be practical in testing of the 7,000-plus word vocabulary, especially with the handicapped subjects who are not immediately available to the laboratory location. There have, however, been numerous tests using sighted listeners. Their reactions have often been mild astonishment that the compiled speech is so comprehensible and inoffensive.[64]

The abstract does not explain why blind evaluators might be unavailable in mid-town Manhattan, nor why sighted reviewers were more tolerant of time and error than blind ones. Judging from this brief report, however, we might conclude that tapes including spelled speech had not yet been prepared.

By 1966, however, such tapes were available. One was played at the sixth technical session, in January, without negative comment recorded in the minutes.[65] In March, Gaitenby played the sample tape for the Annual Conference of the Linguistic Circle of New York. The results were known to PSAS, for they were printed in the *Bulletin of Prosthetics Research.* As Gaitenby played the tape for her audience, she commented,

> The long words which are spelled out at the end will probably surprise you (By this I mean that you may have trouble understanding them), [and

> later], "The output you have heard, and those to come, demonstrate by negative evidence, that real speech is produced not word by word, but in continuous groups of words that are compatible in respect to tempo, loudness and melody.

For readers unable to hear the tapes, Gaitenby explained,

> The most unnatural aspect of the synthetic sentences is the presently unavoidable number of spelled words, occasioned by the restriction on the size of the stored vocabulary. When in the midst of the verbal output, the listener suddenly hears a spelled word, he is more or less bewildered and his comprehension of the sentence suffers. Spelling is not typical of either conversation or of reading and actually represents a total shift from the medium of speech to the medium of writing. Spelling is therefore destructive to the intelligibility of the whole text despite the fact that it is necessary in a mere 5 percent of the words of a normal text.[66]

In June 1966, at the International Conference at St. Dunstans, Cooper may or may not have played a recording, but in Haskins Labs' presented paper, he said, "A more disturbing feature [than unnatural pronunciation] of compiled speech is the interruptions caused by words that were *not* included in the recorded vocabulary. These can be spelled from recordings of the letter sounds, but this breaks the listener's train of thought and becomes annoying if it happens too frequently." The trade off between this inconvenience and storage size for a larger vocabulary was cited as a reason for the turn to re-formed speech.[67] These concerns, expressed in 1966, were apparently forgotten, or at least ignored, as interest in re-formed speech waned. No tests with blind readers were conducted for four more years, a fact which might indicate that the problem of spelled-speech had served more as a rhetorical device for justifying the turn to re-formed speech, than as an urgent conceptual problem.

Toward a high-performance reading machine?

As of 1971, Haskins Labs had eliminated compiled speech and re-formed speech as candidates for a high performance reading machine. A total of $465,000 had been spent on the general research contract, in addition to an undetermined amount on the interim word reading machine.[68] No prototype synthetic speech reading machine had yet been built. As reported to the NAS Evaluation Conference in that year, Haskins was using the same hardware used by Mattingly for his dissertation in 1968, with an updated set of rules. Input was in the form of phonemic symbols, entered at a keyboard by an "expert phonetician," who required as long as an hour to enter a ten-minute text! Once entered, the program converted the symbols to speech at any feasible speaking rate. A working prototype would require an optical character recognizer (OCR), a grapheme-to-phoneme converter, and a program for assigning stress and intonation – all functions then being performed by the expert phonetician.[69]

For two or three years after the commitment was made to a synthetic speech system, the Haskins group contemplated the staged development of a reading service center at the University of Connecticut as a vehicle for system development At first, limited texts would be provided to students for evaluation. Then, as the grapheme-to-phoneme converter was installed, the research team could make a full evaluation of the utility of a reading center, and conduct engineering studies to select an OCR and a computer to support the center. This planning, Haskins ensured PSAS, would be directly applicable to a reading service center for veterans.[70] The initial tests consisted of 2.5 hours of synthetic speech taken from texts in psychology, psychiatry, and ancient and modern literature, reviewed by six blind students. Students agreed that the texts were intelligible, but that it was difficult to concentrate on the more complex texts. Stress and intonation were good. Polysyllabic words were readily recognized, but monosyllabic words embedded in a sentence were easily missed.[71] From this limited test, the research team drew two conclusions: More quantitative measures of performance would be needed to compare synthetic speech with natural speech. Further subsystem development would be necessary to prepare sufficient quantities of text for testing.[72]

In 1972, therefore, the laboratory purchased a commercial OCR, the Cognitronics System / 70, with funds provided by The Seeing Eye, Inc. This was a font-specific OCR system, which required that all texts be typed in a particular OCR typeface. This was understood to be impractical for a finished system, but an affordable compromise for a research prototype. Haskins Labs also secured a look-up table, or dictionary for grapheme to phoneme conversion, and wrote a program for its application. They completed a set of rules for changes in phonetic stress as a result of sentence context, and integrated the new programs with the 1971-version of Mattingly's synthesis program.[73] In spring 1973, Haskins reported that a prototype system had been built at the laboratory, but, it continued, "This system is continually undergoing refinement to increase its production capacity and to reduce the manual intervention that must now occasionally be made."[74] Actually, it seems that the OCR component had not yet been delivered. The grapheme-to-phoneme dictionary had 150,000 entries, but required an editor to intervene when a word was not found. The major rules for stress assignment had been programmed, but, "other rules, such as those depending on the capitalization of words, hyphenation, or on a context of more than two words" had not yet been included.[75]

The period from 1973 through the end of the program in 1978 did not see the emergence of a stable prototype. In 1973, Haskins Labs reported that a new OVE II serial, cascade formant synthesizer was procured to replace the parallel synthesizer designed by Cooper and Epstein a decade before. This required reprogramming of the controller and resulted in an inferior production of nasal sounds, which required tests to characterize the spectra of the output of the new synthesizer pursuant to modification of the subsystem.[76] According to a 1974 report, the OVE II was replaced by an OVE III, but system programmers had difficulties in modifying the control programs in the absence of a keyboard controlled display.[77] In 1975, Haskins procured a new PDP 11/45 computer to replace the ten-year-old DDP-224. This entailed a new interface with the OVE III synthesizer, and reprogramming of the executive program. At the same time, the research team decided to completely rewrite the rules for synthesis by speech to be less restrictive to its users. Its users were conceived as researchers, and the new algorithm was one which "will allow the researcher to define his own phonetic units, features and symbols according to his own theoretical bias; to formulate his phonological and phonetic rules in a convenient notation; and to see clearly how the synthesizer parameter values for an utterance derive from his definitions and rules."[78] At this point it would seem that Haskins' development effort, which had seemed headed for a prototype reading machine, had been converted to development of a better research tool.

The turn to research was driven not only by predilection, but also by resources. In 1973, Haskins Laboratories and the University of Connecticut submitted a proposal to the U. S. Office of Education to provide reading machine services to 20 students. Texts required by the students were to be converted to synthetic speech by Haskins Labs or to embossed braille by the university, using a text-to-braille program developed at MIT. The measure of effectiveness was to be the relative proportion of demand for the two systems. The proposal was approved, but never funded by the government.[79] In the meantime, Haskins followed-up on the results of the preliminary tests at the University of Connecticut by devising psychological tests of synthetic speech intelligibility, using a sample of about 30 sighted students at the University of Connecticut. A Modified Rhyme Test asked listeners to identify a spoken, monosyllabic word from a list of six. Synthetic speech recordings were correctly recognized 92.5 percent of the time. Naturally recorded words were recognized at a rate of 97.3 percent. A Syntactically Normal Sentence Test arranged 252 monosyllabic English words in the order, "The (adjective) (noun) (verb) the (noun)," where each word was randomly generated from a list of 126 nouns and 63 adjectives and past tense verbs. Subjects were required to write down the sentences. The error rate for natural words was 5 percent. For synthetic words it was 22 per cent. Because the sentences were nonsense sentences, however, contextual cues were absent.[80] In 1973, Haskins undertook an informal test of synthetic speech by providing transcriptions of Ann Landers' syndicated newspaper column to veterans at the Eastern Blind Rehabilitation Center. This test was disappointing in its results for several reasons: The laboratory's tape reader did not reliably read the tapes provided by the publisher. The synthesis program could not interpret the syntax of the informal English of Ann Landers' correspondents. Most of the veterans reported difficulties in understanding the synthetic speech. Afterwards, Cooper attributed these results to reticence and suspicion on the part of the veterans that the tests were of them rather than of the speech.[81]

These 1973 studies were the last to be performed by Haskins Labs in support of the PSAS reading machine program. No stable platform for the generation of synthetic speech emerged between 1974 and 1978, as Haskins Labs worked to reconsider and rewrite its rules for the generation of synthetic speech and to install them on a new computer. This was a major conversion, representing, "a significant departure from principles embodied in the earlier program by abandoning the use of a hardware synthesizer for final speech output and by placing greater emphasis on the syllable as the unit of production."[82] Haskins Labs was still working to install its new Syllable Synthesis program on the PDP-11/45, when PSAS decided to terminate its reading machine development program.[83]

The appearance of the Kurzweil Reading Machine in 1975-76, had, in effect, achieved PSAS's goals for the high performance reading machine program. The symbol of this achievement was the purchase by PSAS of a Kurzweil Reading Machine for testing at the Hines VA Hospital, as reported in the spring 1977 issue of the *Bulletin of Prosthetics Research* .

A consideration of the Haskins Laboratories' programs

Reviewing the history of reading machine research at Haskins Laboratories in 1984, Cooper wrote of the project on audible outputs, "There was not, at the beginning of the program or at any later point, the intent to design and build the device itself. This restriction on program objectives was due in part to the realization that an optical character recognizer would be an essential part of a high performance reading machine, and the belief that commercial needs would make OCR devices available by the time the output problem had been solved; furthermore, engineering development was neither a strength nor an interest of the Laboratories."[84]

It is true that the long-range research program into synthetic speech output for reading machines was undertaken with the hope and the belief that optical character recognition would be developed external to the project. We may accept Cooper's assessment that engineering development was not a strength of Haskins Laboratories, although its development of a spectrograph, the pattern playback, and a variety of other research instruments and simulators demonstrates an inventive capability of prototype development. More to the point, as the laboratories' development decisions over twenty years confirm, engineering development was simply not its primary interest.

Cooper's claim that there was never an intent to design and build a device, however, is misleading. It seems more of a rationale for failure than an explanation for a satisfactory outcome. The phrasing of the claim is ambiguous. Where was there no intent to build a device? At Haskins Labs? At PSAS? It is probably a reasonable claim that it was never particularly intended that Haskins Labs be the manufacturer of a commercial reading machine, but the innovation of such a machine was PSAS' certain goal for the program, and the criterion for its success. In 1956, Cooper had told the fourth technical session on reading machines, "It is probable that devices for synthesis-by-rule and for converting letter codes to sound can be built and as long range projects, they should be."[85] This statement was a basis for PSAS's decision to undertake the project on audible outputs of reading machines for the blind. Seventeen years later, in 1973, Freiberger's summary report on the project began, "A frequent topic of complaint from the blind and visually handicapped concerns the long delays that occur in receiving recordings of spoken texts. The alleviation of these delays by means of a High Performance Reading Machine which can provide supplementary reading services to blind people is the goal of the research being carried out at Haskins Laboratories."[86]

PSAS's goal for a new device was explicit in Haskins Labs' second project for output characteristics and construction of an Interim Word Reading Machine. Even so, the device was never built. Haskins Labs' interests were not in the engineering development of the device, but in developing the concept which the device was to instantiate. When the concept of a compiled speech machine became problematic, Haskins had little motive to fabricate a prototype to demonstrate a concept that it had rejected on other grounds.

In 1984, Cooper characterized Haskins' work on the reading machine problem as basic research. "Basic research is plainly essential to the development of devices such as reading machines for the blind," he concluded. "Only basic research could have led to speech synthesis by rule [SSBR] and to the demonstration that SSBR was the right choice for a high-performance reading machine."[87] Actually, the role of Haskins Labs was more complex than this brief passage indicates. Once it accepted PSAS' sponsorship, the Haskins Labs program was not simply a basic research project. It was also a technology development project, not just in name, but in practice.

Just as Hans Mauch constructed, tested, and reiteratively modified prototypes, so Franklin Cooper and his colleagues constructed, tested, and reiteratively modified concepts. In fact, as we have seen, some of the prototypes that were the object of Mauch's practices were based on the concepts which Cooper constructed. Mauch's failure to achieve innovation in both the cases of the Cognodictor and the Stereotoner stemmed in part from his practice of engineering development. Rather than stabilize a prototype design, such as the Visotoner, and concentrate upon its development as a product serving the needs of a particular group of users, Mauch's preference was to "improve" the design by further engineering development. Rather than stabilize a concept and seek to instantiate it in a definitive prototype, Cooper's preference was to "improve" the concept through further research. After all, that is what they were being paid to do.

The creation of technological knowledge is often described as a process of variation and selection. At the most abstract level, the variables of a technological concept are three: the input and output for the tool, the design of the tool, and the social goal which the tool is meant to fulfill. Each of these general variables can be modified, refined, and otherwise designed, in an attempt to achieve a combination that works – one that people will use, one that is capable of innovation. Both Mauch and Haskins Labs took their social goal to be basically unproblematic: Blind people wanted independent access to printed texts at an affordable cost. Mauch concentrated on the design of the tool. For him, issues of input and output were also taken as given. They were unproblematic or at least beyond his control. Input was the printed page. Output was taken as given by Cooper and then Metfessel. These outputs were assumed to be adequate to the social goal. Mauch's technology development practice centered on design of a tool which would work to convert a given input into a given output. It was an engineering development practice of the sort which, as Cooper pointed out, was neither the strength nor the interest of Haskins Labs.

Haskins Labs also took input for granted. They assumed an electronic signal representing a text string would be provided by some other firm. However, Cooper did not assume that any output was adequate to the social goal except natural human speech. Since Haskins Labs did not know how to achieve that output, the question was, how closely could the ideal be approached by a machine? Thus, Haskins Labs' technology development problem had two general variables instead of one: the output and the machine. The systematic approach to solving such a problem is to constrain one of the variables. However, the variables may be constrained reiteratively, so that outputs are improved under the constraint of a particular tool design. The tool can then be improved under the constraint of a particular output.

In general terms, this describes the technology development practice pursued by Haskins Labs over a forty year period. Between 1945 and about 1960, a commitment to the spectrogram and pattern playback constrained Haskins' design. Using these tools – which were, in effect, components of a reading machine system – as research instruments, Haskins developed a capability to produce a certain level of intelligible, synthetic speech.

About the time that PSAS support began, Haskins took its new knowledge of formant generated synthetic speech, and sought to design a new tool that could create that output by rule, rather than by graphic input. Where the tool had been taken as given to design an output, the output was now held constant while the tool was redesigned. Haskins then designed a synthesizer, procured a computer, generated the rules for speech synthesis, and wrote the software to achieve their goal. Then, from roughly 1966 through 1973, they used this new tool to further improve synthetic speech output, i.e., to design a synthetic speech output that more closely resembled natural speech, by using the tool to examine additional phonemes, then syllables, words, and phrases. As intelligibility improved, and more nearly approached the ideal of natural speech, Haskins abandoned the alternative combinations of tool and output, focusing their efforts on the use of a general purpose computer, a parallel voice synthesizer, and special purpose software to generate speech by rule. At this point, when both the tool and the output were constrained, Haskins Labs could and did turn its attention to the input problem of converting text to phonemes.

By 1973, Haskins had developed this technological concept to the point where they referred to their system as a prototype reading machine.(See Figure 19).

FIGURE 11
Operation of the Prototype Reading Machine. The system was employed to generate substantial amounts of speech synthesized by rule for use by students and in evaluation studies.

Machine will accept input in page form and will recognize OCR-A typefont. Maximum operating rates are 30 documents/min, 200 characters/sec. Output medium, digital magnetic tape. Incorporates on-line correction facility.

Computer program containing stored phonemic transliterations and grammatical categories of more than 150,000 English words. Finds phoneme equivalents of each text word and displays output for editorial checking.

Inserts stress and intonation instructions primarily on the basis of lexical rules. Output can also be checked by an editor.

Computes pitch amplitude and formant frequencies of desired acoustic output on the basis of a system of rules.

Special purpose device designed to generate larynx-like waveform or sibilant noise which is modulated by a system of three parallel formant frequency resonators to create intelligible speech. Speaking rate adjustable within wide limits.

A standard audio frequency tape recorder records synthetic speech on 1/4 inch magnetic tape which is conveyed to the researchers at the University.

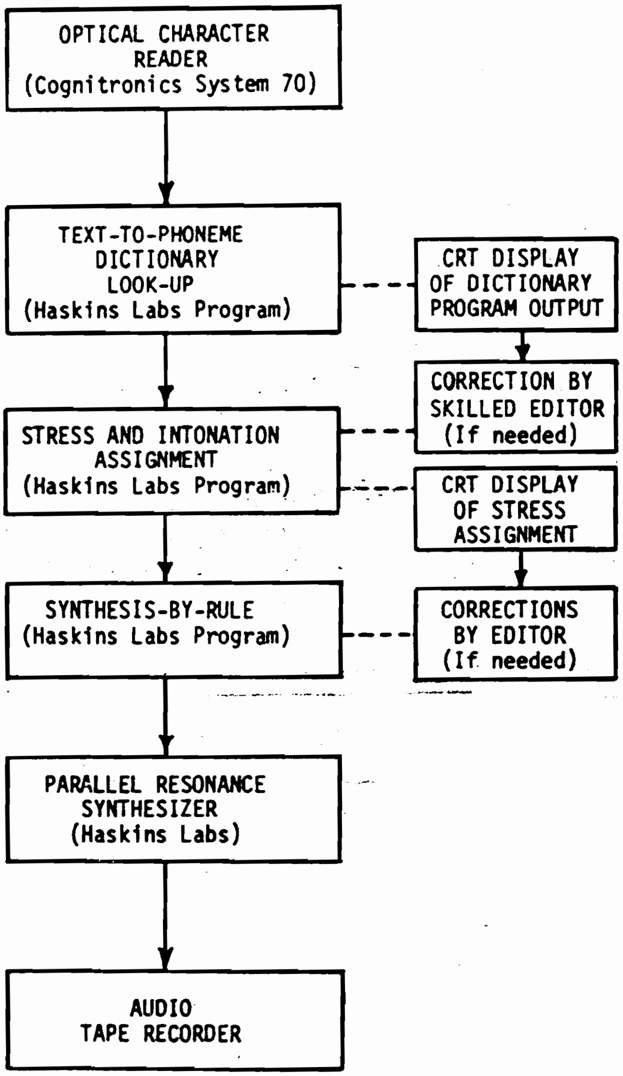


Figure 19. Haskins Labs' prototype reading machine (circa 1973)[88]

Only then did Haskins take initial steps to further develop the technology by testing the prototype against the social goal. Specifically, sample texts were reviewed by blind students at the University of Connecticut and a proposal was prepared for an extended test of a reading machine service at the university. Presumably such testing would have led to the stabilization of a design, and innovation or rejection of the technology, as occurred with the compiled speech "simulator." But funds were not made available by the Office of Education, and instead of pursuing innovation, as proposed, Haskins began a new cycle of reiterative design of the tool and its output. They bought a new computer and a series synthesizer . They started writing new rules for synthesis with the goal of better emulating natural speech. There was nothing inherently wrong with this decision, which would have led, in time, to a new opportunity for innovation. But while Haskins lab was reiteratively improving its technological concept, Kurzweil Computer Products introduced and marketed a reading machine for the blind with synthetic speech output. In the light of this commercial success, PSAS could no longer justify support of Haskins Labs.

After defending the essential role of basic research to technology development, Cooper ended his 1984 retrospective with the following question and answer:

> But is basic research sufficient to solve the entire problem? Probably not, and for a variety of reasons. For one thing, the kind of people and the kind of organizations that deal naturally and well with basic research do not usually have the temperament or skills to handle the entrepreneurial job of bringing a device to market. The Government, for its part lacks effective mechanisms for bridging the gap between the research it supports and the finished devices that embody that research; that is to say, between research and procurement – both of which the Government does do – there is much development and testing that is done only by private industry, when it is done at all. Fortunately for the users of reading machines now and in the future, there has been this kind of entrepreneurial effort.[89]

Cooper was writing with the successful innovation of the Optacon and the Kurzweil Reading Machine at hand, under the entrepreneurial guidance of Jim Bliss and Raymond Kurzweil. Let us consider their practices of development and innovation, before attempting to address, in Chapter 5, the interesting issues which Cooper raises here.

The PSAS Program: A summary and some interim conclusions

In 1957, Eugene Murphy, Chief of the Research and Development Division of the Prosthetic and Sensory Aids Service (PSAS) was able to implement a long-standing plan to revive U.S. government research on sensory aids for the blind. Murphy had prepared for the opportunity for nearly ten years, since assuming the post of Assistant Director for Research in 1948. From 1948 until 1954, he remained in contact with many of the researchers of the CSD period, and when the National Research Council terminated the Committee on Sensory Devices in 1954, he arranged a technical session on reading machines which brought together researchers from academic and industrial laboratories, government agencies with an interest in related technologies, and members of the service community for the blind with established technical interests.

Working with Sidney Friederich until 1956, and then with Howard Freiberger, Murphy made PSAS the center of a knowledge community for reading machine technology. PSAS sponsored conferences, assembled bibliographies, and, eventually, created a journal for the dissemination of information in the field of sensory aids, and specifically for reading machines, among other prosthetic devices.

Murphy drew on the knowledge of this community for structuring his research and development program. He agreed to support further development of a direct translation device, a successor to the A-2 Reader, which had been rejected by researchers in the absence of an expanded knowledge community, because of its apparent limits in reading speed. The expanded community advised Murphy that very slow reading rates would be useful to some blind readers. This project was given to Battelle Memorial Institute. Murphy also agreed to support Haskins Laboratories' research into synthetic speech outputs for reading machines, with the understanding that this was a high-risk project which depended on an external solution to the problem of optical character recognition to achieve its objective. Working within a taxonomy of reading machines elaborated by Franklin Cooper, Murphy also supported the pursuit of two intermediate concepts. Haskins Labs was asked to construct a compiled speech machine. Mauch Laboratories was asked to design and build an advanced direct translation device with speech-like output.

The PSAS research program continued for more than twenty years, and its evaluation program continued beyond the termination of research. But the devices under evaluation after 1976 were the Optacon and the Kurzweil Reading Machine, for none of the PSAS projects directly resulted in the innovation of a reading machine for the blind.

What were the products of the PSAS program? They included several prototype devices. Ten units of the Battelle Model D Optophone were delivered for testing in 1965, but the evaluation project never got off the ground, and the Battele optophone was superseded by the Mauch Visotoner. Mauch Laboratories delivered three Cognodictors in 1970, but these intermediate reading maschines imposed as many burdens on the user as the Optophone, without a discernible advantage. In 1976, Mauch turned to the development of a High Performance Cognodictor, but Kurzweil had preceded Mauch Laboratories in this market, as TSI's Optacon preceded Mauch's Stereotoner in the direct translation arena. The project was abandoned later that year.

In 1969, Mauch Laboratories delivered thirty prototype Visotoners. Howard Freiberger outlined a plan for their "deployment" or innovation with an initial fabrication of 500 machines, but Mauch turned to a redesign of the device, and it was 1973 before he undertook production of 100 Stereotoners. By that time, Telesensory Sytems, Inc. had already sold 250 Optacons. By the accounts of Harvey Lauer and Margaret Butow, who learned to use both machines, the Stereotoner was as useful a product as the Optacon. It worked, in an engineering sense, to deliver a useful signal from a lightweight and portable device that was reliable and easy to use. It worked, in a technological sense, to allow a blind reader to sort, read, and proofread typed or printed material. The VA bought 50 machines but that was more than enough to meet its internal needs, and too few to establish a market. No more Stereotoners were ever made.

In 1959, Haskins Laboratories almost completed a prototype Interim Word Reading Machine which generated compiled speech. But funds ran out, and the research team chose to pursue the concept of re-formed speech instead. The contract was deemed fulfilled after Haskins demonstrated the concept with an undeliverable model in 1965. In 1969, Haskins completed a compiled speech "simulator," which might have been considered a new generation prototype. But when compiled speech was finally tested in 1970, it was found to be unacceptable by its blind users because of the distractive necessity to spell-out words which were not in its limited vocabulary. The concept was then abandoned. By 1973, Haskins publicly claimed it had constructed a prototype reading machine for synthetic speech by rule, but only a few hours of speech were ever produced, and the design was never stabilized. The system was undergoing a complete redesign when Kurzweil Computer Products introduced the Kurzweil Reader. The redesign was incomplete when PSAS's research program was terminated, two years later.

A greater product than these prototypes was the creation of a knowledge community for reading machines. By 1962, the community established by PSAS had assumed a life of its own, as symbolized by the reading machine sessions at the International Conference on Technology and Blindness, held in New York under the sponsorship of AFB, and the International Conference on Sensory Devices for the Blind held at St. Dunstan's, London in 1966. John Linvill and Jim Bliss, developers of the Optacon, were early and active participants in that community. The complex professional relationships which the community supported can be represented by Patrick Nye who, after leaving St. Dunstan's in 1964, joined the faculty at California Institute of Technology, where he collaborated on an important review paper with James Bliss, shortly before joining Cooper at Haskins Laboratories. As to be expected, the nature of this community changed after the innovation of the Optacon and Kurzweil Reader, but continuous chains of professional relations may be readily traced from the conferences of the 1950s and 1960s to the Sensory Aids group of the Rehabilitation Engineering Society of North America and the Assistive Devices Division of the Electronic Industries Association, established in the 1980s. The founding members of these modern groups included Telesensory Systems, Inc. and Kurzweil Computer Products, Inc.

The case histories in this chapter have concentrated on the PSAS program and its efforts to develop a reading machine for the conversion of print to an audible output. We should also note that beyween 1954 and 1956, PSAS devoted significant attention to the conversion of print to braille. Sidney Friedrich designed and built a prototype device for the conversion of text on punched data tape into Grade I braille. After he left PSAS, in-house development was discontinued. Members of the MIT faculty were well-represented at the PSAS-sponsored conferences, however, and during the early 1960s, Dr. Robert Mann, at MIT, led a project which developed a high speed translator (Dotsys) and a braille embosser (Braillemboss), for the production of Grade II braille from tapes. The Dotsys system was installed at the American Printing House for the Blind in 1964, and Dotsys II was developed for commercialization by the Mitre Corporation.[90] Other researchers at MIT, led by Frances Lee, fabricated a computer-based demonstration system for the synthesis of speech from text, which adopted the methods published by Mattingly and his colleagues in 1964 and 1966.[91] A third group including Ingham, Lee, Mason and Troxel, built an optical character recognition module which was intended to interface with either the braille or synthetic speech device.[92] Unlike the braille translator and embosser, however, no effort was made at MIT to develop a product from the demonstration reading machine.

The PSAS research program was ended because its objectives were achieved. Disappointingly to those involved in the program, the innovation of reading machines for the blind was achieved by others. Because of this circumstance, an assessment of why the VA-sponsored projects failed to achieve innovation can benefit from a comparison with the case histories of the successful innovators, and we shall therefore leave that task to the concluding chapter. We may, at this point, benefit from a brief consideration of certain aspects of the VA program which do not depend on the comparison.

First, we should note that the PSAS research program had a constituency and a Congressional mandate. Its constituents were blinded veterans and its mandate derived from Public Law 729, approved in 1948, authorizing the VA to conduct research and to generally disseminate its results. The mandate made the program, once established, less vulnerable than CSD to termination for reasons of policy. The existence of a clear constituency provided a possible source of reference and authority for establishing objectives and judging program results beyond that of the scientific community. Eugene Murphy specifically sought to involve the service community in the process of establishing program objectives, and to include the staff of the VA Blind Rehabilitation Centers in the evaluation of its products. During the early 1960s, it was against VA policy to conduct research on veterans.[93] After this policy was changed, patients at the VA Blindness Rehabilitation Centers were also employed in the evaluation of reading machines. The participation of VA staff and patients in product evaluation continued after the research program was ended.

Second, the VA program lasted 20 years, where the CSD project was effectively terminated after only three years. This introduced the possibility of technical obsolescence during the course of development, a phenomenon which had an impact on all of the PSAS projects. The Battelle Optophone was made obsolete by Mauch's Visotoner before it could be fully tested. Vacuum tubes were replaced by transistors and transistors by integrated circuits. Hand-wired logic circuits were replaced by customized integrated circuits which in turn were replaced by general purpose computers. One of the reasons – or at least a rationale for – why prototype designs did not stabilize was a continuing desire on the part of the developers to incorporate improved components into their latest design or prototype. By the time one component was updated, the opportunity or need was there to update another. Based on the case of the Interim Word Reading Machine, we might reason that this phenomenon had an interactive effect with the rate of research funding. If a complex project were drawn out, due to a low rate of funding, it became more likely that the design would fail to stabilize, as the development of one component proceeded while another was frozen, awaiting funding for further development. Such an extended development cycle was possible where the pace of research depended on federal budgets rather than on product sales to recover investment capital.

Third is the related fact, identified by Carbery and Butow in 1976, that none of PSAS's contractors had a corporate interest in innovation. This was the same situation as applied in the CSD period. Battelle Memorial Institute, Mauch Laboratories, and Haskins Laboratories all earned their principal income by providing research and development services. After the first round of contracts in 1957 - 58, they were all supported on cost reimbursement-type contracts. The best way for these firms to ensure an income was not to achieve innovation, but to identify additional research opportunities and persuade the sponsor of its value.

Fourth, as in the CSD period, a particular technological paradigm prevailed, as embodied in the PSAS program structure and within the reading machine community as a whole. The paradigm was the one articulated by Franklin Cooper, in 1956. It provided a heuristic for development decisions by each of the project teams, which sought to shape their devices in conformance with the structure of the paradigm. It may be that one reason braille output machines were not generally considered as "reading machines," was their omission from Cooper's audiocentric taxonomy. In the 1962 International Congress on Technology and Blindness, for example, audible output issues, with one exception, were considered under the heading "Reading Machines," while braille output devices were considered in a separate session labelled, "Indirect Access to the Printed Page."[94] There is no reason to think that Cooper ever intended his analytical categories to be so definitive, but, once articulated and employed by a research community, they appear to have operated in such a fashion.

Finally, we may note that although PSAS involved blind persons and their advocates at the beginning of development in setting program objectives and at the end of development in evaluating prototypes, their absence during the development process was conspicuous. When blind users were finally involved, the immediate results sometimes devalued years of research. Most notably, Haskins Laboratories' tests of compiled speech, conducted in 1970, led to the immediate rejection of the results of twelve years of (off-and-on) effort. These tests could have been undertaken nine years earlier. All of the developers ultimately put products or simulated products in the hands of blind evaluators, but they did so at the end of the process, after a myriad of design decisions had been made, each constraining the field for the next decision. Participation by blind users was solicited after a design had stabilized to confirm its success or identify its problems. No one seemed to consider the participation of blind readers in the intermediate steps of variation and selection as a design was slowly evolved.

We will return to these issues in Chapter 11, but first let us examine, for comparison, the development and innovation of the Optacon and the Kurzweil Reading Machine.

Section III. The Optacon and the Kurzweil Reading Machine: Innovation Achieved (1962 - 1990)

During the time that OSRD (Section I), and then PSAS (Section II), were sponsoring the development of reading machines for the blind, social and political changes were occurring in the United States which would affect the further course of development and innovation in the 1970s and beyond. The full exploration of these changes is beyond the scope of this study, but their outline is well known. A brief consideration here will provide a background for better understanding the context for the development and innovation of reading machines.

For most of the twentieth century, and especially since in the post-WWII era, American society has been characterized by an increasing, positive valuation of social access and participation by persons with disabilities. The ethic of inclusion has been institutionalized politically – first through legislation providing social services to persons with disabilities, then through further laws ensuring their access to federal government facilities and programs, and most recently, in 1990, through passage of the Americans with Disabilities Act, which provided for access to participation in most aspects of American Society by persons with disabilities as a matter of civil right.

Advances in the ethic and polity of inclusion have been accompanied by the establishment or expansion of government institutions for the development and dissemination of assistive technologies which support those values and norms. Figure 20 identifies the milestones of American policy evolution with respect to social participation and federal support to assistive technology development in the twentieth century.

Both accessibility and assistive technology development are rooted in longer-standing policies regarding governmental support to vocational rehabilitation.[1] A continuous national policy toward vocational rehabilitation was first articulated as part of the progressive response to the First World War. The Smith-Sears Veterans' Rehabilitation Act of 1918 established a program of vocational training for disabled veterans. In 1920, the Smith-Fess Act established a general vocational rehabilitation program. These programs were highly federal in structure, providing for national government subsidies to counseling, training, and job placement programs established by the individual states. They were directed at members of the workforce who lost their ability to work as the result of an injury or illness. Their justification was one of economic return to society. These vocational rehabilitation programs were directed at the least handicapped persons who could be rapidly trained and employed.

1918	Smith-Sears Veterans Rehabilitation Act: Vocational trainng for disabled vets
1920	Smith -Fess Act: General vocational rehab program
1935	Social Security Act: Permanent rehab program
1943	Barden-LaFollette amendments to Rehab Act adds physical rehab services to vocational training
1944	OSRD Committees on Sensory Devices and on Prosthetic Devices
1946	Demobilized rehab specialists form first rehab clinics NAS Board for Prosthetic and Sensory Devices VA Prosthetic Appliances Service
1954	Amendments to Vocational Rehabilitation Act authorize civil sector assistive technology R&D for vocational rehabilitation
1967	Amendments to Elementary and Secondary Education Act establish a technology R&D component of 1966 special education program.
1973	Rehabilitation Act outlaws exclusion from participation in activities receiving federal government assistance on basis of disability
1978	Establishment of National Institute of Handicapped Research
1988	Technology-Related Assistance for Individuals with Disabilities Act authorizes provision of technology for greater participation in home, school, work and communities.
1990	Americans with Disabilities Act. Accessibility as a civil right. Employers and service providers to provide assistive technologies

Figure 20. Policy milestones in social participation and assistive technologies for persons with disabilities

During the New Deal, disability policies became solidly institutionalized and more broadly defined. In 1933, the vocational rehabilitation program was transferred to the Office of Education in the Department of the Interior. The Department of Education and its predecessor agencies have been the institutional locus for civilian programs related to vocational rehabilitation ever since. In 1935, the Social Security Act permanently authorized the vocational rehabilitation program, and implicitly recognized that persons with disabilities, like other Americans in the Depression, might be unemployed for reasons unrelated to their ability to perform a job. In 1943, the Barden-LaFollette amendments to the Rehabilitation Act expanded federal support to include general physical rehabilitation services in addition to vocational training. This law resulted in the establishment, in the immediate postwar years, of the first modern rehabilitation centers in the U.S. As many as thirty general rehabilitation clinics were opened in the early 1950s, many by professionals who received their training or experience as part of the wartime effort.[2]

As we have seen (Section I), federal programs for the development of assistive technologies also had their origin in World War II. In 1944, the Office of Scientific Research and Development (OSRD), established a Committee on Prosthetic Devices through a contract with the National Academy of Sciences (NAS), as well as its Committee on Sensory Devices which reported directly to Vannevar Bush (Chapter 2). On demobilization, both activities were combined under a single Board for Prosthetic and Sensory Devices, within NAS, reporting to the Surgeon General of the Army. At the same time, the Veterans Administration (VA) created a Prosthetic Appliances Service, "...to provide the best available prosthetic and sensory devices, and foster research and development to improve these important aids."[3]

Gradually, these policies and programs to serve veterans were extended to the general population. During the 1950s and 60s, the Veterans Administration assumed a federal leadership role in the development, testing and dissemination of assistive technologies. As Robert Stewart, Director of the VA's Prosthetic and Sensory Aid Service explained in the first issue of the *Bulletin of Prosthetics Research*,

> It was not realized that the total number of civilians with disabilities requiring prosthetic and sensory aids was many times greater than the corresponding roster of disabled veterans. Consequently, research, development, and education in these aids were sporadic, uncoordinated and generally ineffective.... Since World War II, there has been a determined and

> continuing effort to improve this situation. The Veterans Administration has been a major participant in this work, alone, and in cooperation with other agencies of the government. and private enterprise.[4]

As a social policy of inclusion expanded the constituencies for rehabilitation technology programs, however, the institutional locus for those programs changed. Federal sponsorship of assistive technology R&D in the civil sector was first authorized by the 1954 amendments to the Vocational Rehabilitation Act. Under the stimulus of rehabilitation professionals such as Mary Switzer and Howard Rusk, many of whom became involved in the rehabilitation field during the war, the Office of Vocational Rehabilitation, later the Rehabilitation Services Administration (RSA), established a research program which included both engineering and social research into the "vocational and social functioning of disabled people."[5]

Beginning in the mid-1960s, the federal government also assumed a role in assisting and ensuring the education of children with disabilities, as part of a general expansion of federal government interests in elementary and secondary education. The 1966 amendments to the Elementary and Secondary Education Act of 1965 (PL80-10) authorized funding state programs to educate handicapped children. The 1967 amendments provided for a research and demonstration component of this program in the Bureau of Education for the Handicapped (BEH).[6] At about the same time, the Rehabilitation Act was amended to increase federal support for rehabilitation research, and to establish the first Rehabilitation Research and Training Centers at New York University and the University of Minnesota.[7]

By the 1970s, the federal government sponsored three significant research and development programs concerned with assistive technologies, directed at the needs of veterans (through PSAS), the special education of children (through BEH), and vocational rehabilitation (through RSA). The underlying national policy, to invest national resources in assistive technologies for the general welfare, was given an explicit expression in 1978, through the establishment of a National Institute of Handicapped Research (NIHR), renamed the National Institute on Disability and Rehabilitation Research (NIDRR), in 1986. According to Dr. Rusk's 1981 testimony to Congress, the consensus for such an institute was broad: "When the Rehabilitation Act came up for renewal in the late 1970s, most all of the research community and professional associations involved in research proposed that a national institute be created to deal with research in the field of rehabilitation for the handicapped." An important purpose of the new institution was "...to expand the areas into which rehabilitation research should go including research regarding rehabilitation of the aged and of children and including research regarding the development and utilization of technology for the handicapped."[8]

As symbolized by the establishment of NIHR, there have been three interrelated, generally continuous trends in post-World War II national policy regarding technology and disability: The federal government has come to assume a leadership role in the development of assistive technologies. The circle of intended beneficiaries has expanded from veterans to disabled workers, to school children, and, specifically since 1973, to include the most severely disabled Americans of all ages. At the same time, the underlying rationale of policy formulation has shifted from a narrow one of the vocational role of the individual, to the broader economic and social perception of the individual with a disability as a general actor in society. The term *rehabilitation technology* has gradually been subsumed under the newer and more general term of *assistive technologies.*

National policies regarding accessibility and disability have a shorter history than that of technology policies, though the two are interrelated.[9] Percy identified the movement to eliminate architectural barriers, beginning in the 1960s, as the "forerunner" of national policies to enhance the entry of persons with disabilities into the mainstream of American society, and labeled Section 504 of the Rehabilitation Act of 1973, a major piece of civil rights legislation.[10] The language and perspective of ADA, passed in 1990, confirms this interpretation of the events of the last thirty years as the emergence of a national policy and consensus regarding the participation in government and society by persons with disabilities.

Both conceptual and legislative continuity can be traced from the Architectural Barriers Act of 1968, through the Rehabilitation Act of 1973, and its subsequent amendments, to the Americans with Disabilities Act (ADA) of 1990. In the late 1950s, a guide for access to public buildings was prepared by an ad hoc group including rehabilitation professionals of the Veterans Administration. In 1965 the Vocational Rehabilitation Act amendments mandated a study of accessibility by a national commission. Their report provided a stimulus to the Architectural Barriers Act of 1968, which was supported by the Commissioner of the Vocational Rehabilitation Administration. That act provided that all federal and federally funded facilities be both accessible and useful to persons with disabilities. Percy concludes, "With this legislation, public policy of a rights-oriented nature ... was enacted, moving policy away from a service orientation."[11]

Section 504 of the Rehabilitation Act of 1973 (PL93-112) states:

> No otherwise qualified handicapped individual in the United States, as defined in section 7(6) shall, solely by reason of his handicap, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving federal financial assistance *or under any program or activity conducted by any executive agency or by the United States Postal Service.*[12]

The italicized words were added in the 1978 amendment. Political continuity with the Architectural Barriers Act was provided by Section 502, which created an Architectural and Transportation Barriers Compliance Board (ATBCB) to oversee compliance with the 1968 act, and to establish minimum guidelines for accessible design.

The Rehabilitation Act's pivotal relationship with the traditional federal focus on vocational rehabilitation is found in its original definition in section 7(6) of a handicapped person, as one who

> (A) has a physical or mental disability which for such individual constitutes or results in a substantial handicap to employment and (B) can reasonably be expected to benefit in terms of employability from vocational rehabilitation services provided pursuant to Titles I and III of this Act.[13]

Clearly this definition was inappropriate to the emerging policy of accessibility as a civil right, articulated in Section 504 of the act. The following year, the definition was amended to read,

> For the purposes of Title IV and V of this Act, such term (handicapped individual) means any person who (A) has a physical or mental impairment which substantially limits one or more of such person's major life activities, (B) has a record of such impairment, or (C) is regarded as having such an impairment.[14]

In 1973, the Department of Health, Education and Welfare assigned the implementation of Section 504 to its Civil Rights Division. In 1980, President Carter, through Executive Order 12250, transferred lead agency authority from DHEW to the Department of Justice. Although agency and judicial interpretations of the scope of requirements under Section 504 have differed, the basic policy statement has not been challenged. More importantly, the passage of the Americans with Disabilities Act of 1990 (ADA) confirmed the political meaning of Section 504 of the Rehabilitation Act of 1973.

ADA's restatement of national policy, following more than 15 years' experience with Section 504, was both considered and explicit:

> "It is the purpose of this Act –
>
> (1) to provide a clear and comprehensive national mandate for the elimination of discrimination against individuals with disabilities;
>
> (2) to provide clear, strong, consistent, enforceable standards addressing discrimination against individuals with disabilities;
>
> (3) to ensure that the Federal Government plays a central role in enforcing the standards established in this Act on behalf of individuals with disabilities; and
>
> (4) to invoke the sweep of congressional authority, including the power to enforce the fourteenth amendment and to regulate commerce, in order to address the major areas of discrimination faced day-to-day by people with disabilities.

ADA retained the 1974 definition of disability as articulated by Section 504. ADA incorporated Section 504, by reference, and required that executive agencies implementing Title II, pertaining to state and local governments, be consistent with the body of executive regulations implementing Section 504, as pertains to federal executive agencies and recipients of federal funds. Section 509 of ADA applies the rights and provisions of the Act to the U.S. Congress and its instrumentalities. The Department of Justice has regulatory responsibility for both ADA and Section 504. The Architectural and Transportation Barriers Compliance Board has the responsibility for establishing guidelines for accessible design under both acts. Thus, between 1973 and 1992, a network of legislation and regulatory implementation articulated a policy of accessibility by virtue of civil right.

In summary, two robust trends in national disability policy converged during the 1970s to provide a social and political setting for considering the innovation of reading machines for the blind. The new institutions would have their most significant impacts in the 1980s and 1990s, that is to say subsequent to the innovation of reading machines. But in the late-1960s, the new Bureau of Education for the Handicapped (BEH) in the Office of Education provided support to Stanford University's development of the Optacon, as one of its first major projects (Chapter 9). Equally or more important to the innovation of reading machines, BEH, like PSAS for veterans and RSA for disabled adults, became involved in an expanding role of providing assistive technologies to its constituents, in this case, students with disabilities. As social services to persons with disabilities expanded beyond vocational rehabilitation and the return of injured soldiers and workers to the work place, the expanded role of the federal government helped create a market for assistive technologies far larger than the direct purchase of prosthetic devices for disabled veterans.

Expanded social participation by persons with disabilities meant a growing number of individuals of all ages with the education, skills, and interests for participating in the development of assistive technologies. At the same time as federal institutions expanded their roles in the face of such social change, so did organizations of persons with disabilities. These issues were important to the development of the Optacon (Chapter 9) and the Kurzweil Reading Machine (Chapter 10). They are discussed in some detail as they pertain to reading machine development and innovation in the following chapters.

Chapter 9. Stanford, Telesensory Systems, and the Optacon

Jim Bliss wanted to build a reading machine for the blind. So did John Linvill. Working separately at first, and then together, these electronic engineering scientists sought research funding, conducted human factors research, designed electronic circuits, built engineering prototypes, learned to utilize federal funding as a form of venture capital, established a manufacturing firm, solved the problem of dissemination and training, and achieved innovation of the first successful reading machine for the blind.

In his 1984 retrospective (See Chapter 8), Cooper suggested that entrepreneurs were a different breed from researchers and that the government lacked effective mechanisms for bridging the gap between the two. This model will not fit Bliss and Linvill, who were researchers who took up entrepreneurship in order to turn their technological ideas into a product.

Like Cooper, Linvill and Bliss both earned their doctorates from MIT – in electrical engineering rather than physics. Whereas Cooper's initial research in 1944 involved tests of the human perception of acoustic signals, Bliss's early research involved the human perception of tactile signals. Cooper and his research team sought and combined funds from several government sources to support their work on speech perception. They initially relied on defense funding, before expanding their base of research support to include the Veterans Administration. Bliss, working at Stanford Research Institute (SRI), also sought funds from any available source to pursue his research on tactile communications. He relied heavily on defense funding before securing support from the Office of Education.

Cooper's initial research centered on the use of the Spectrograph and Pattern Playback as research tools for the generation of acoustic signals. Later, he replaced these instruments with a new generation of devices for the control and generation of synthetic speech. Bliss followed a similar strategy, designing or modifying a series of devices for generating and producing tactile signals, before adopting Linvill's piezoelectric vibrator technique as the basis for a tactile reading machine. Both Cooper and Bliss became presidents of private firms which supported their development practices. Cooper was named president of Haskins Labs in 1955. Bliss became founding president of Telesensory Systems, Inc. (TSI), in 1970. Cooper drew upon colleagues and graduate students at the University of Connecticut as collaborators in his work. Bliss and Linvill drew upon the faculty and students of Stanford University.

There are also some interesting contrasts between the careers of the two researchers. Cooper's first reading machine project involved investigation of a direct translation device for the conversion of letter shapes into corresponding sounds (the FM Slit Device, see Chapter 3). Bliss began by investigating a recognition system which would convert a letter into a unique tactile signal. Cooper rejected the direct translation device because he believed it would be too slow, and turned his attention to long-term research to develop a synthetic speech machine. Bliss rejected the recognition approach because it depended on optical character recognition and would take too long to develop into a product.[15] The first user of the FM-slit device was a sighted employee of Haskins Labs, whose astonishing success at reading over 100 words per minute (wpm), and subsequent discovery as a fraud influenced Cooper to reject direct translation devices (See Chapter 3). The first user of the Optacon was Candace (Candy) Linvill, John Linvill's blind daughter, whose modest success at attaining reading rates of 30 wpm, encouraged Bliss and Linvill to develop a direct translation reading machine.[16] Ultimately, Miss Linvill achieved a reading rate of over 60 wpm, and employed the Optacon as an essential device as she pursued her education to the Ph.D. level in clinical psychology.[17]

Bliss and Linvill's reading machine research before their collaboration

John Linvill, a native of Missouri, came to MIT in 1941, with a bachelor's degree in mathematics. Changing fields to electrical engineering, he completed his doctorate in 1949, and upon graduation was appointed assistant professor in his department. In 1951, Linvill joined AT&T Bell Laboratories as a researcher in the field of transistor circuits. In 1955, he assumed his career position on the faculty in electrical engineering at Stanford University, where his research was concerned with integrated circuit design.[18] In 1952, Candy Linvill was born. In infancy she lost her sight to a rare cancer of the retina. As she grew, the Linvills wanted Candy to attend school locally, so they agreed to braille all of her textbooks in order to support her studies. This was a time-consuming task for the Linvills. It was around 1962, when, according to Koestler, "On a visit to an IBM research center in Germany, Linvill saw a high speed computer which used vibrating pins as hammers to produce its printout. 'If you could print with vibratory pins, you could surely feel them' was his first thought. He went on to develop this idea, using piezoelectric reeds as vibrators."[19]

Linvill developed his concept for a vibrating display which emulated a dot-matrix printer with the support of the Office of Naval Research. The initial design work was accomplished by G. J. Alonzo, a graduate student, whose thesis, "Development of Piezoelectric Dynamic Embosser for Use as a Reading Machine,"[20] was published as a research report in March 1964. Under the title, "Photomechanical Dynamic Embosser," Linvill was granted U.S. Patent 3,229,387 for the device, in January 1966.

Jim Bliss was Linvill's junior by 14 years. He completed his doctorate at MIT in 1961, subsequent to work at Northwestern (B.S.E.E., 1956), and Stanford (M.S.E.E., 1958). While Bliss was a student at Stanford, Linvill was a member of the faculty and director of the solid-state electronics laboratory.[21] Apparently Bliss and Linvill did not work together at this time.[22] While a graduate student, Bliss worked at Stanford Research Institute, conducting research on alphanumeric reading systems.[23]

Bliss's initial involvement in the field of sensory aids was serendipitous. He went to MIT intending to study circuit theory with Professor Guillimen, who, as it turned out, was not taking students when Bliss arrived. Directed toward Samuel Mason as an alternative, Bliss was told that Professor Mason was changing his research interests from circuit theory to sensory aids for the blind. Mason's shift in research interests was influenced by John Dupress, the Director of Technological Research for the American Foundation for the Blind (AFB), who was working to promote research interest in sensory aids at MIT (see Chapter 2). Under the influence of Mason and Dupress, Bliss, like several other students, decided to undertake dissertation research in the area of tactile communications. From that time on, Bliss has said, "I was only really interested in developing systems for blind people."[24]

Bliss's dissertation, entitled *Communication via the Kinesthetic and Tactile Senses,* submitted in 1961, is not readily available, but an article entitled, "Kinesthetic-Tactile Communications," submitted in July 1961 to the *IRE Transactions on Information Theory,* provides a window on his research, which was supported by the Army Signal Corps, the Air Force Office of Scientific Research, and the Office of Naval Research.[25] Although Bliss's paper recognized possible military applications, it is clear from the paper's examples and citations that his primary interest was in developing a tactile output for a reading machine.

Bliss's early research was built around a device with the cumbersome label of "kinesthetic-tactile communication system." This pneumatic device had eight finger rests which could be moved in each of three dimensions by a push-pull bellows assembly. Each rest had three positions in each of three dimensions, a total of twenty-seven positions. The user placed four fingers of each hand on the rests. Thumb switches were used to control the device. The rests and the fingers placed upon them were moved among the twenty-seven positions under the control of a punched paper tape which caused air to be valved to the twenty-four bellows which moved the eight finger rests. The bellows-control tapes were prepared by a small computer which implemented a simple translation program driven by punched paper tapes of the same sort used by Haskins Labs to simulate optical character recognition. The device may be pictured as a typewriter whose keys move in three dimensions.

Bliss's research, like Cooper's, was concerned with the information content of an alternative mode of language perception. Bliss's article reported tests on two modes of tactile communication among the several which were the subject of his dissertation. One mode moved the reader's fingers just as they would move during touch typing, with special codes for the shift key, space bar, and the fourth row symbols. The other mode used a "traveling wave," signal, by which a positional code for each letter was sequentially presented to each finger. The hypothesis was that this approach would increase the communication rate and support the recognition of word patterns.

Tests showed the traveling wave to be confusing, providing a slower rate of information transfer than the typing method. Bliss felt that the measured reading rate of fifteen wpm for the typing method was limited by the pneumatics of the machine rather than the perceptual abilities of the readers. Ironically, given his next project and his later commitment to the Optacon design, Bliss concluded his report by speculating that the kinesthetic-tactile communication system was successful because it encoded information into roughly equal units (i.e., finger positions). He anticipated inferior results from alternative tactile systems which presented variable temporal or spatial displays, leaving the processing of that information into equal units (e.g., letters or syllables), to the user.

Bliss continued his research into tactile outputs for sensory aids when he returned to Stanford Research Institute (SRI) as Head of the Bio-Information Systems Program in 1962. He was able to secure a small grant from the Rehabilitation Services Administration of the Office of Education, supplemented by another from Seeing Eye, Inc., to investigate the use of tactile arrays in obstacle detectors and to communicate a "picture" of the environment,[26] an idea which Vannevar Bush had discussed with Caryl Haskins in 1943 (see Chapter 2). Otherwise, the only funding Bliss could find for his research was from the aerospace sector. In 1962 and 1963, Bliss worked with other SRI researchers on a joint project of NASA and the U.S. Air Force which tested the ability of human subjects to distinguish spatial and temporal patterns presented tactually, by the air jets, to different parts of the body.[27] Bliss and his colleagues fabricated a tactile stimulator with 96 computer-controlled air jets in a 12 x 8 array, and conducted a series of experiments to determine subjects' abilities to resolve tactile stimuli that were close together in space or time. They investigated the phenomenon of apparent location – where two jets of air are perceived as a single stimulus located somewhere in between; and that of apparent motion – where temporal patterns of stimuli are perceived as spatial patterns.

Bliss sought to apply the knowledge of tactile perception gained through these projects to the design of reading machines for the blind. Building on friendships established as a student at MIT, he maintained a close relationship with the reading machine research community. At the 1962 International Conference on Technology and Blindness, for example, Bliss presented a paper entitled "Tactual-Kinesthetic Perception of Information" which drew upon both his dissertation research and his work at SRI to consider different approaches to tactile reading machines.[28] There were three types of mechanical stimulators which might be used in a reading machine, Bliss explained: poke probes, vibrators, and air jets. Poke probes had the advantage over vibrators of a smaller two-point limen, that is to say, two stimuli could be distinguished closer together. The skin adapted more quickly to poke probe stimuli, however, that is to say that the sense of touch became used to the stimulus and subjects' ability to perceive such stimuli faded more quickly. Air jets as built for NASA and the Air Force, Bliss hoped, might have superior qualities of resolution and adaptation. Moreover, air jets did not require direct contact with the skin, and were easy to build and to control. Bliss's paper concluded with a conceptual design for a recognition-type reading machine which employed air jet stimulators, controlled by punched tape, to provide tactile alphanumeric characters.

Using an air jet stimulator, Bliss and his colleagues at SRI conducted a variety of studies investigating spatial acuity, dynamic effects, and the ability of subjects to extract information on tactile spatial displays which might be used for aerospace tracking.[29] Air jets made for a fairly large stimulator, however. In 1962, the area of the body Bliss used for testing the air jet stimulators was the chest – one of the few parts of the body with sufficient area to accommodate an 8 by 12 array, given the air jet dimensions.[30] In 1963, Bliss sought and received funds from NASA Ames Research Center to fabricate a smaller air jet array which could deliver stimuli to the palm of the hand. It was shortly thereafter that Bliss and Linvill began their collaboration.

While working with Linvill to develop a reading machine, Bliss continued to pursue research into aerospace applications for tactile communications, until 1967, when major support from the U. S. Office of Education allowed him to devote full time to reading machine applications. In the period between 1964 and 1967, like Franklin Cooper at Haskins Labs, Bliss, working with Linvill, garnered funds from a variety of sponsors for both basic and applied research in non-visual communications. These included NASA, the Systems Division of the U.S. Air Force, the Office of Naval Research, the National Institute of Neurological Diseases and Blindness of the National Institutes of Health,[31] and the Rehabilitation Services Administration (RSA) of the Office of Education.[32] During this period, Bliss freely applied concepts developed with Linvill for the reading machine to his aerospace work, and also drew upon his aerospace research to address sensory aids issues.

Collaboration and community

Sometime in late 1963 or early 1964, Bliss and Linvill became aware of their mutual interests. Koestler reports that "Linvill discovered that a colleague working at Stanford Research Institute, Dr. James C. Bliss, was also working on tactual reading."[33] Bliss remembers that, "While doing research on tactual communication at SRI, I heard that Prof. Linvill had conceived a tactual reading aid for blind people. I approached him, and described my research at MIT and SRI to him. We decided to join forces to try to develop his reading aid conception."[34] Whoever took the initiative, Bliss and Linvill's meeting was a fruitful one.

Bliss gives all the credit for the Optacon concept to Linvill, but the subsequent development of the Optacon was collaborative in the broadest sense. Linvill provided the conceptual design and a patent for an effective output device. As head of Stanford's Department of Electrical Engineering, he secured a part-time faculty position for Bliss, creating an institutional base for coordinating research at the university and at SRI. Bliss provided a computer program capable of driving a rectangular tactile display together with his experience in building and testing such arrays with air jet stimulators. Bliss undertook the human factors research toward the Optacon interface, and was responsible for managing the overall system development effort.[35]

Much of the electronic circuitry for the Optacon was designed in the Electrical Engineering Department by Stanford graduate students. Between 1964 and 1972, three masters theses and thirteen doctoral dissertations in electrical engineering were generated by the Optacon project, as was an M.A. thesis in education. Most of these efforts involved some aspect of circuit design. Four were concerned with the psychology of perception and the man-machine interface. For projects completed through 1968, the Office of Naval Research was the principal funding agency.[36] After receipt of a major grant from the

Bureau of Education for the Handicapped, the Office of Education was the principal source of funds.

Between 1964 and 1967, Bliss and Linvill were active members in the reading machine research community. Bliss had become a participant while a student at MIT. Linvill attended PSAS's sixth technical session on reading machines for the blind, in January 1966, where he presented a synopsis of research at Stanford and SRI, and showed a film which included a demonstration of a prototype reading machine by his daughter, Candy Linvill. Later that year, Linvill and Bliss sent their colleague, Kenneth Gardiner of SRI, to London, where he presented two papers to the St. Dunstans' conference. Also in 1966, one of the Stanford group presented their film to the annual conference of the American Association of Instructors for the Blind.[37]

One benefit of Bliss and Linvill's participation in the reading machine community was access to its knowledge base. According to Bliss, research at SRI was influenced by both Franklin Cooper and Patrick Nye. One SRI research project made use of Haskins Labs' version of compiled speech, and later, when TSI explored the possibility of adding a speech output to the Optacon, Cooper helped Bliss to secure a license to MIT's version of synthetic speech.[38] Bliss reports that the Stanford group did not benefit technically from the work of Mauch Laboratories, but they became familiar enough with Mauch's design of the Stereotoner that they were persuaded the device would fail because of the low resolution of its optical system. This was potentially valuable information to a competing technology, though, according to Bliss, he was unsuccessful at persuading PSAS that his evaluation was correct.

Another motive for participation in the reading machine research community was to establish those professional relationships which are conducive to securing funding for research. Bliss sought and received help from John Dupress in securing a small research grant from RSA.[39] The Stanford group was unsuccessful in securing any support from PSAS, however. Bliss later recalled, "At first we sought support from the VA but we soon discovered that they were totally committed to Mauch and it was hopeless to get any funding from them."[40] Between 1964 and 1967, therefore, Bliss and Linvill financed their reading machine research from a pastiche of military and civil sector sponsors. The big breakthrough in funding came in 1967, not from the established reading machine research community, but from a new agency, the Bureau of Education for the Handicapped (BEH).

Linvill and Bliss were successful in obtaining major research support in the same way as Cooper and Mauch before them: They got in at the beginning of a new federal government program. In 1943, Caryl Haskins persuaded Vannevar Bush to conduct OSRD's new reading machine research program at Haskins Labs (see Chapter 2). In 1957, Hans Mauch persuaded Eugene Murphy to give Mauch Labs the task of developing an intermediate reading machine as part of PSAS's new program in reading machine research (see Chapter 7). In 1967, Linvill persuaded James W. Moss of the Bureau of Education for the Handicapped to support the development of an optical to tactile conversion device.[41]

Between 1963 and 1968, under Presidents Kennedy and Johnson there was an unprecedented growth of federal support to the education of children with disabilities. This support was manifested in an expansion of the organization and resources of the Office of Education to support special education programs in the states, teacher training, and research. Among the major pieces of legislation which were passed during the period were the 1965 Elementary and Secondary Education Act and its 1966 amendments (P.L. 89-750). Title VI of those amendments established a Bureau of Education for the Handicapped within the Office of Education. In 1967, Congress provided the bureau $8 million for research.[42] From these funds, Stanford University ultimately received $1.3 million, for a four-year project to develop a tactile facsimile reading aid for the blind.[43]

Linvill and Bliss adopted the research community's reigning taxonomy of reading machines which categorized devices as recognition or direct translation machines. The first major report of the Optacon design, (as yet unnamed), was submitted to the *Proceedings of the IEEE,* with the title, "A direct translation reading aid for the blind." The third paragraph of that report placed the Stanford project firmly in the community context:

> Cooper, in his review of reading machines for the blind, suggests the classification 'direct translation' be given devices of this type that perform a one-to-one transformation of an optical image to a corresponding tactile or auditory image. At the more complex end of this classification system is the 'recognition' machine which would identify each printed letter or word and present an output such as Braille, spelled speech, or spoken words. Two major advantages of the 'direct translation' approach as a personal reading aid over the 'recognition' approach are versatility and simplicity of implementation. Not only has the complexity and cost of 'recognition' machines made them prohibitive for this application, but it is clear that their range of input material would always be more restrictive that that of a direct translation device.[44]

The second major research report, published in 1969, took as its theme the proposition that previous direct translation designs had failed to achieve their potential utility in terms of reading speed, because their optical resolution was insufficient to the task of distinguishing the differences in letter shape.[45] Later, in their influential 1970 review, Bliss and Nye also organized their consideration of reading machines according to the traditional taxonomy.[46] Bliss and Linvill's acceptance and further elaboration of this technological paradigm is interesting, because their unique tactile design could readily have been cast in terms which would have challenged the paradigm as an anomalous case. Instead, Linvill and Bliss used the established framework to position their research within the research community and to defend its virtues relative to other designs.

Bliss and Linvill's participation in the reading machine research community were ultimately important to expanding and redefining that community. For example, their 1966 report in *Proceedings of the IEEE,* acknowledged research support from the American Foundation for the Blind as well as the Office of Naval Research and the National Institutes of Health. Haskins Laboratories had previously combined defense and NIH support, but this is the first case where service sector support of reading machine research was acknowledged and combined with federal funds. In 1967, Bliss published a synopsis of the Stanford project's progress in the *Archives of Physical Medicine and Rehabilitation,* [47] extending information dissemination regarding reading machine research beyond the VA-sponsored *Bulletin of Prosthetics Research* to the general rehabilitation community. After 1967, participation in reading machine conferences by the Department of Health, Education, and Welfare also increased because of the department's expanding mission in rehabilitation and special education research, and in particular because of its investment in Linvill and Bliss's research. Beginning in the mid-1970s, AFB's *Journal of Visual Impairment and Blindness* became a major forum reporting on field testing of the Optacon.

In the late 1970s and early 1980s, as the Optacon and the Kurzweil Reading Machine became commercial products, the research community's focus shifted toward reading machine evaluation, before it disappeared as a distinct knowledge community, subsequent to the innovation of these two products. The last gathering of the group occurred in 1977, when Haskins Labs, Mauch Labs, Telesensory Systems, Inc., and Kurzweil Computer Products were all participants in the Smith-Kettlewell Institute's Workshop on Sensory Deficits and Sensory Aids, jointly sponsored by the VA and DHEW.[48] The make-up of the workshop closely resembled that of the PSAS sessions of the 1950s and 1960s, with the addition of representatives interested in parallel sessions on sensory aids for the deaf (see Appendix).

This 1977 conference provided an explicit acknowledgment of Bliss and Linvill's success. According to the workshop report, direct translation aids were no longer considered to be "priority items for further development." At this time, TSI had sold more than 3,000 Optacons (out of an eventual 12,000, by 1990). Mauch, Haskins, and Kurzweil were all working on recognition-type machines, and, "Telesensory Systems, Inc., under National Science Foundation (NSF) sponsorship, [was] working on adapting the Optacon to function as an OCR device with synthesized speech output."[49]

Kurzweil would be the first in this field. As he told the session on reading aids, Kurzweil Computer Products had already built six reading machines and had sixteen more in production.[50] Like Mauch (Chapter 7) and Haskins (Chapter 8), TSI ultimately chose not to compete with Kurzweil for the synthetic speech reading machine market after Kurzweil's initial success at innovation. But all of this lay ahead in 1964, when Linvill and Bliss met and decided to collaborate on the development of a reading machine for the blind with a tactile output. Having considered the Optacon's place within the structure of Stanford University's Electrical Engineering Department and the reading machine research community, let us return to examine the course of that research.

Technical Collaboration: Piezoelectric bimorphs

A tactile array which stimulated the chest by means of air jets was an adequate research tool, but hardly a viable basis for a reading machine. About the time that Bliss and Linvill discovered their common interests, Bliss's team at SRI was designing a small, computer-driven, 8 x 12, 96-unit air jet array, using funds provided by NASA's Ames Research Center. This new device could be used on the palmar side of a reader's fingers, where nerve endings are closer together, and tactile sensations can be discriminated with higher resolution than on the chest (Figure 21). Later tests used only half the array, reducing the array size from 96 units (8 x 12) to 48 (6 x 8), so that the active area could be covered by a reader's index and middle fingers alone.[51]

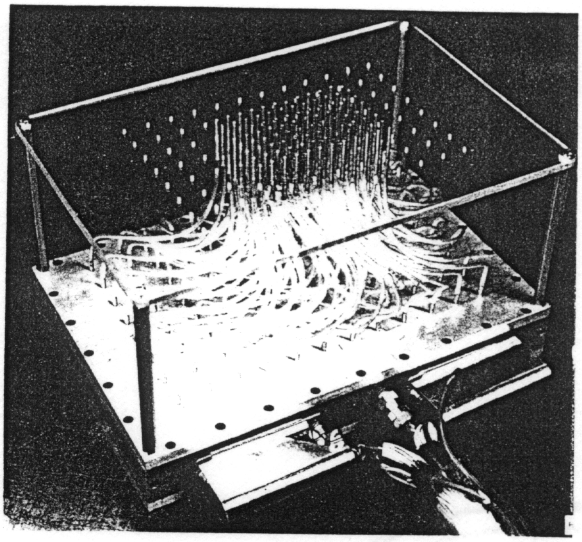


Fig. 2. Tactile stimulator array.

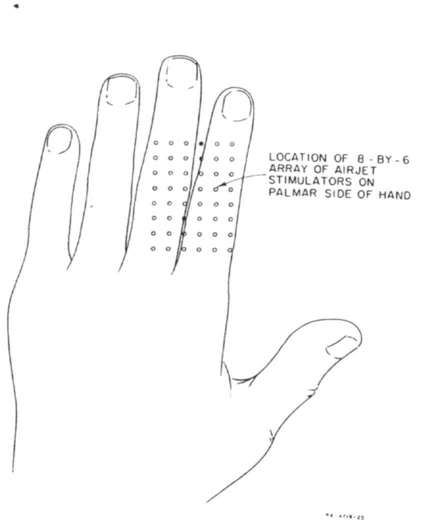


Fig. 5. Position of airjet array. The airjets were positioned about $\frac{1}{8}$ in. below the palmar side of the hand.

a. Air Jet Array and Tactile Pattern

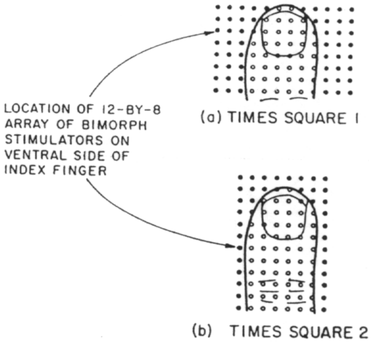


Fig. 11. Location of finger stimulation with the bimorph array.

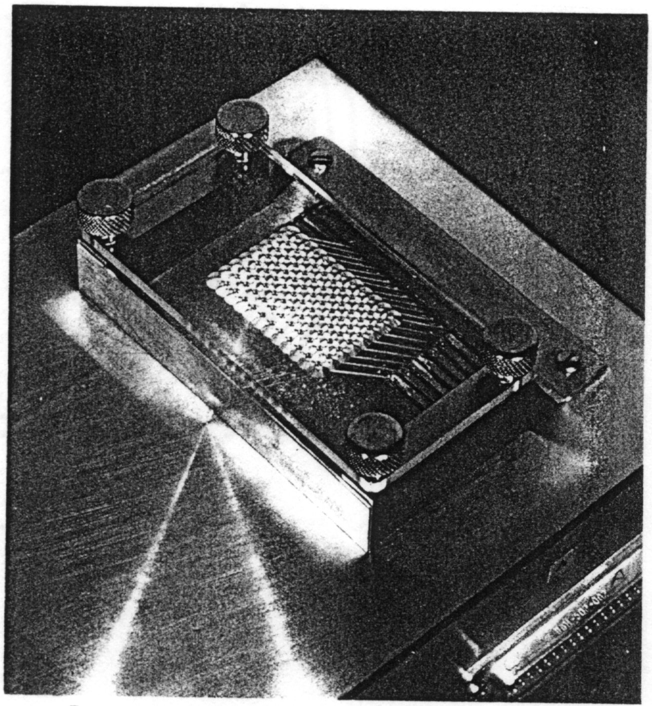


Fig. 3. A 12 × 8 array of piezo-electric bimorph tactile stimulators

b. Piezoelectric Bimorph Array and Tactile Pattern

Figure 21. Tactile arrays (circa 1965)[52]

Bliss and his colleagues used the prototype device to continue their studies of human tactile perception. Like Cooper at Haskins Labs, who ten years earlier had investigated human responses to the frequency and duration of sounds over time, Bliss and his colleagues at SRI were concerned with the spatial arrangement and duration of pressure stimuli over time. Between 1964 and 1966, with funding from the Air Force and the National Institute of Neurological Diseases and Blindness, they investigated subjects' abilities to recognize alphabetic characters and other symbols under a variety of conditions. A series of research papers in the new journal, *Perception and Psychophysics,* presented their results which sought to characterize the attributes of tactile perception and cognition.[53]

Beginning in 1964, Bliss applied his air jet prototype for preliminary tests of Linvill's tactile reading machine concept. The piezoelectric stimulator constructed by Alonzo in 1963 was not capable of supporting definitive reading tests,[54] so Bliss and Linvill tested the general concept of a tactile reader using the air jet display. As Kenneth Gardiner described events to the St. Dunstan's conference in 1966,

> ...Dr. Bliss and Dr. Linvill realized that the SRI computer-controlled air jet array could be programmed to provide a tactile pattern of moving letters that would be similar to the tactile pattern of the device envisioned by Dr. Linvill but would not require a miniaturized photoelectric matrix for scanning an actual line of print. Experiments were immediately conducted on the feasibility of reading with such a tactile output.
>
> Candy Linvill was the first subject and was soon reading text, programmed into the computer from her school books, at a rate of about 20 words / minute with less than 20 hours of practice.
>
> This very encouraging beginning with the air jet array led to the immediate construction of an 8-by-12 array of 96 bimorphs that could be driven by the same computer output circuitry used to drive the array of air jets. Candy found the bimorphs as readable as the air jets and with practice reached a reading speed of 35 words / minute.[55]

As shown in Figure 21, above, an array of piezoelectric bimorphs could be designed to present a smaller field of vibrators which could be covered by a single finger tip. The 8 x 12 array pictured in the figure was constructed in 1964 by a graduate student, D. Sorenson, to be driven by the same computer which controlled the air jet array.

A piezoelectric bimorph is a crystalline material that changes its shape due to physical stress induced in the material when subjected to an electric potential. Linvill and his students used small reeds made of lead zirconate. The upper and lower surfaces of the reeds were coated with silver, which served as an electrical ground. A thin brass sheet in the middle provided a conductor. When voltage of one polarity was applied to the conductor, the reed would flex upward. When polarity was reversed, it would flex downward. The reeds were designed to vibrate through a distance of 10 microns at a rate of 200 Hz. The reeds, which were 1.5 inches long, 0.032 inches wide, and 0.020 inches thick, were used to drive an array of pins with separations of an eighth of an inch, by setting the reeds at a 45 degree angle from the sensing plate which held the pins in place.[56] The vibrating reeds pushed the pins up from under the touch pad.

These design details were published in January 1966, in a major research report in the *Proceedings of the IEEE.* That report described the piezoelectric array and discussed design considerations for an electrically matched scanner which could drive it. The article also reported reading tests conducted with computer controlled arrays as pictured in Figure 21. The readers were three blind students, aged 12 (Candy Linvill), 16, and 18. All three read braille at rates of 100 - 130 wpm. They all achieved reading rates of 20 wpm after 17 hours' training, Two readers who received 50 hours of training achieved a rate of about 30 wpm, using block capital letters. The block capital letters were five-columns wide, but Candy Linvill's index finger covered only four columns of the array. (Words flowed across the array like a Times Square sign). This observation led Bliss to test the effect of word recognition as a function of the number of columns of vibrators, when words were presented at a constant rate (24 wpm). Bliss found that recognition rates declined to about 20% when a single column was used. Two vibrating columns increased the recognition rates 77%. Three or four columns supported a recognition rate of about 90%.[57]

The introductory section of this article drew upon Cooper's 1962 taxonomy to locate the proposed device within the reigning technological paradigm[58] – indeed the title of the report was "A direct translation reading aid for the blind." The concluding section of the report drew on Freiberger and Murphy's 1961 review in the *IRE Transactions on Human Factors in Electronics*, to provide a positive comparison between their results and those achieved by previous direct translation devices which employed an audible signal. The report quoted Murphy and Freiberger's statement that blind readers would find useful reading rates as low as 15 - 20 wpm, and concluded, "Thus, the rates already demonstrated with a tactile direct translation reading aid appear to be within the range of usefulness."[59]

This was a bit of an exaggeration, since those "demonstrated" rates were achieved with a computer-driven array using block capital letters.

During the same month that the Stanford group's first major research report was published in *Proceedings of the IEEE*, Linvill shared a platform with Battelle and Mauch Labs at PSAS's sixth technical session on reading machines, where he presented a summary of the information contained in the published report. After Harvey Lauer demonstrated the Battelle and Mauch devices, Linvill showed a film of his daughter reading with the computer-driven prototype, and announced that work was underway at Stanford to produce a new model.[60] Clearly, by 1966, Bliss and Linvill were striving to take a leading place in the reading machine research community, and to challenge the Battelle Optophone and Mauch Visotoner with an alternative direct translation reading machine.

A reading machine needs not only an effective output device, but also a scanner which can convert print to an encoded electrical signal, and logic circuitry for converting the electrical signal to the desired output. While Bliss and his colleagues at SRI were conducting perceptual research using the air jet device, Linvill and his graduate students at Stanford worked to develop the other components of a prototype reading machine and to integrate them into a working system. The first working prototype of what was later known as the Optacon was built by a doctoral student, Richard C. Joy, sometime in 1965. The optical system was crude, fabricated from a section of a microscope. A 6 x 8 array of phototransistors at the end of the microscope tube were individually linked by 48 circuits to a 6 x 8 array of piezoelectric stimulators, so that the vibratory pattern of the array corresponded to the letter image. This 1965 prototype demonstrated Linvill's concept, but it was large and cumbersome to operate. The material to be read was inverted and moved over the one-letter-sized aperture of the microscope. Also, Linvill reported, "The 'first-generation' reading aid... presented some difficulties in letter recognition which it was thought might be lessened by increasing the number of image points."[61]

It was at this point that John Dupress was instrumental in securing support for Bliss and Linvill from the Vocational Rehabilitation Administration. The researchers used these funds to improve the tactile screen. They designed a 144-element array of six columns, each with twenty-four stimulators, as the basis for a new, high resolution prototype which was completed in 1967. This prototype incorporated an optical probe with 144 fiberoptic cables, connected at the other end to 144 phototransistors in an electronics box. This second-generation prototype was tested by four blind subjects who achieved reading rates from 10 to 20 words per minute.[62]

Thus, by 1967, Bliss and Linvill had established a recognized position in the reading machine research community as developers of a direct translation device with a tactile output. Bliss, who maintained strong relationships with members of the service community, had secured financial support from AFB and, with Dupress's help, from RSA. He combined that support with contracts from the Air Force and from NASA, which were concerned with aerospace applications of tactile communications, to maintain his research into human factors related to a tactile reading machine.

Bliss's principal subjects for reading machine research were blind readers. Unlike other researchers in the field, Bliss never reported research using sighted subjects. John Linvill was also disposed to employ blind readers, including his daughter, in the development of an effective reading machine.

By recruiting doctoral candidates in electrical engineering to work on the problem, and by deploying general resources available to his laboratory from the National Institutes of Health and the Office of Naval Research, Linvill was able to provide major financial and intellectual support to sustain the reading machine project. Working together, Bliss and Linvill proved the concept of a tactile reading aid through fabrication and demonstration of a second-generation prototype device. When the Bureau of Education for the Handicapped was established in the Office of Education in 1967, and Congress appropriated significant funds for a research program in the new bureau, Bliss and Linvill were in a position to take advantage of this new source of research support.

The Optacon

In 1967, Bliss and Linvill applied to the Bureau of Education for the Handicapped (BEH) for a two-year grant to construct five reading devices, "of sufficient simplicity and effectiveness to give meaningful reading tests."[63] The grant, awarded in February 1968, eventually totaled more than $1.3 million.[64] It was extended each year through 1972, by which time Telesensory Systems, Inc. (TSI) had manufactured its first production run of Optacons.

The "Optacon" label may have first appeared in a *Time* magazine article of September, 1969, where the device was called "Linvill's 'Opticon.'"[65] Articles prepared earlier in the year for publication in *Machine Design* and the *IEEE Transactions on Audio and Electroacoustics* did not use the term.[66] Bliss used the name, in its final spelling, in the 1970 survey of sensory aids for the blind which he co-authored with Patrick Nye.[67]

As explained in Linvill's 1973 final report to the Bureau of Education for the Handicapped, the name was a contraction of the words Optical to Tactile Converter.[68]

The BEH grant to Stanford University was used to buy equipment for the Integrated Circuit Facility within the Stanford Electronics Laboratory and to support electronics research, primarily by doctoral candidates in the Department of Electrical Engineering. These students utilized the new equipment to fabricate circuits for test and integration into the Optacon. They prepared doctoral dissertations as reports of their research. A subcontract from Stanford University to the Stanford Research Institute supported Bliss's work on human factors and tactual perception. All of these lines of research supported the design and fabrication of a series of prototype reading machines.[69]

The first prototype fabricated under BEH support was completed in the autumn of 1968. Known as the "pancake" prototype, this device incorporated new, multiplex circuits and a smaller power supply than the second-generation device (See Figure 22). The pancake prototype was never intended to be more than an interim design, however. The Integrated Circuits Laboratory was already working to develop a monolithic photodetector array to replace the 144 commercial phototransistors which comprised the sensor for both the second generation Optacon and the third-generation pancake prototype. The pancake prototype was taken to Washington in November 1968, where it was demonstrated to three of its underwriters, the Bureau of Education for the Handicapped and the Office of Social and Rehabilitation Services within DHEW, and the Office of Naval Research. Three improved versions of the pancake prototype were completed in April 1969. They were used for reading experiments with blind students, while work continued on the development of a fourth-generation, portable device.[70]

Meanwhile, Bliss conducted an analysis of reading machine resolution requirements with respect to the characteristics of printed letters. He concluded that twenty-four parallel channels were required to obtain a faithful reproduction of letter patterns. A minimum of twelve photosensors were needed to scan the 160 vertical mils (0.16 in.) of letter space just to ensure the detection of all the horizontal lines in a letter of pica type. As Bliss pointed out in his 1969 article, previous direct translation devices did not meet this requirement.[71] The Battelle Optophone and the Visotoner each employed nine detectors. The Stereotoner later employed ten, in order to provide an equal number of channels to each ear. In 1993, Bliss repeated his belief that inadequate resolution was a primary contributing factor to the failure of the Stereotoner: "We knew that the Mauch designs would be unsuccessful because they made a fatal error in not having enough resolution in their camera," he explained, "But we couldn't convince the VA of this fact."[72]

Name	Pancake	Portable	Hybrid	Modified Hybrid
Generation	Third	Fourth	Fifth	Fifth
First Made	1968	1969	1971	1971
Number Made	4	8	1	1
Dimensions (in.)	8.5 x 15 x 4? plus pad & tracker	8 x 13.5 x 2.3	6 x 8 x 2	6 x 8 x 2
Weight		9 lbs	4 lbs	4 lbs(?)
Sensor	144 commercial phototransistors	Bipolar monolithic retina. Folded optics. Variable magnification.	Improved bipolar retina	Smaller camera, fewer parts, lower machining cost retina design
Circuitry	Multiplexed circuits	Improved bimorph drive circuitry, low power rqts.	12 metal oxide semiconductor chips replace 144 transistors & resistors	Printed circuit cards
Touch pad			Smaller, denser array, user-regulated, easier to make.	Return to prior sized array. Retaining other features.
Comments	Demonstrated in DC in November 1968.	Used for field testing and development of training methods		Easily fabricated chassis. Manufacturing prototype for TSI.

Figure 22. Summary of Optacon prototypes fabricated with BEH support

Bliss used the second generation Optacon, constructed before the initiation of BEH funding, to test his analysis of resolution. In an intriguing experiment, two blind readers identified letters presented tactually by the prototype, while two sighted readers identified letters presented visually by an array of lights driven by the device, as letter height was systematically altered to simulate the use of ten, fifteen, twenty-four and thirty-six detectors within a vertical letter space of 160 mils. The results were taken to confirm Bliss's analysis, as all four subjects achieved asymptotic recognition rates of 92 to 100% at a space height corresponding to 24 detectors over a vertical space of 160 mills. The blind readers' performance at lower resolutions was worse than that of the sighted readers. At a letter space height corresponding to ten detectors per 160 mils, the blind readers' recognition accuracies were 10% and 60% vs. 80% and 90% for the sighted readers. At a height corresponding to 15 detectors per 160 mils, the recognition rates were 75% and 82% vs. 95 and 98%. At full resolution, the scores were 92% and 93% vs. 95%. Bliss interpreted these results to "verify" the resolution hypothesis. He argued that the differences in performance at lower resolution could be attributed to the differential effects of smaller letter size on tactile vs. visual acuity.[73] Because the experiment simulated sensor density by varying letter size across a constant array, in place of varying the density of sensors in the array across a constant letter size, this interpretation of results might be taken as less than positive proof of Bliss's hypothesis.

Bliss also used the second-generation prototype to determine that a 24-element vertical array was within the capabilities of human tactile perception. He tested readers' abilities to interpret letters presented at different vibration frequencies of the piezoelectric bimorphs, and determined that recognition accuracy rates were greatest at frequencies above 160 Hz.

Three new blind readers were introduced to the second-generation Optacon, joining Candy Linvill as contributors to the technology design. Two of these, Bliss later recalled, made special contributions to the project: They were Lorin Schoof, a Stanford sophomore in 1968, who demonstrated the value of the Optacon for reading formulae in higher mathematics; and Bob Stearns, a computer programmer who used the machine to read and debug computer programs.[74] Bliss used the results of reading machine tests with these participants to directly challenge his competitors, noting that these new readers attained reading speeds of at least ten wpm after 20 hours of instruction:

> However, it appears from the literature that the Battelle students required 65 hours to obtain a reading rate of about nine words / min., and that the subject with the Mauch Visotactor required 130 hours to obtain a reading rate of about eight words / min. The more rapid progress of our subjects may be because of the simplicity of the direct correspondence between the printed letter shape and the two-dimensional tactile pattern, and because of the relatively greater resolution of our reading aid.[75]

Improved prototypes, Bliss predicted, would lead to improved performance. Performance might also be improved by enhancing the output of the technology, for example, to design the array to present more than one letter at a time.[76]

Advanced prototypes were soon to follow. The third-generation, pancake prototype was in fabrication as Bliss conducted his research. It had been built in four copies by the time research results were published in March 1969. The first portable Optacon, the fourth generation prototype, was completed in November 1969. Eight of these machines were built by early 1970, of which seven were provided to blind users. It was this model, generally referred to as "the 1969 Optacon," which was principally used to gather information from the using community. The fifth-generation Optacon was built in a single prototype model in March 1971. Designated the "Hybrid Optacon," this device was intended to be a production prototype for Telesensory Systems, Inc., but before production began in the summer of 1971, a "modified hybrid Optacon," had been built. This prototype served as the model for Telesensory Systems' Model R-1, commonly called "the 1971 Optacon."[77]

In addition to these mainstream prototypes, two experimental Optacons were built at the Stanford Electronics Laboratory in 1970. One was a laboratory model which supported the development of metal-oxide semiconductor (MOS) chips, custom integrated circuits which were later incorporated into the 1971 Optacon.[78] The second experimental prototype was fabricated under a $75,000 grant from DHEW's Social and Rehabilitation Services.[79] This "Jumbo Optacon" included a double camera width and touch pads for each of two fingers. The Jumbo Optacon could thus present the equivalent of two letters at a time. It was used by Bliss to investigate his theory that increasing the amount of available information would enhance reading speeds. Bliss and a graduate student, Jon C. Taenzer, performed a variety of tests using the prototype and computer-driven displays. Results indicated that the simultaneous presentation of two letters typically resulted in decreased reading speeds, and at best did nothing to enhance reading rates. A high-density array was built so that the two letters could be presented to a single finger, with no positive effect on results. Comparative tests with sighted readers indicated that, with Times Square-type presentations, visual reading performance improved in proportion to the width of the reading window up to a size of five to seven letter spaces. In contrast, tactile reading performance improved only up to a size of one letter space, and then decreased or leveled off. This was a disappointing result, which Bliss was slow to accept.[80]

At the same time as perceptual research and systems development were being conducted in laboratories at Stanford and SRI, field testing was being undertaken by Carolyn Weihl, a research associate in SRI's Information Science and Engineering Division. In 1972, Weihl joined TSI with the title of Training Manager. Linvill's 1973 final report includes this summary of her work:

> In the spring of 1970 Miss Carolyn Weihl of SRI conducted a successful experiment in Optacon reader training of six blind students of different ages at the Monroe Elementary School in Campbell, California. By summer five of the people who had been assigned Optacons for home use were able to read easily at more than 40 wpm. (Candy Linvill, who had been using the reading aid since the first prototype was built, had achieved a reading speed of 65 wpm). One of the people with an Optacon, Miss Susan Melrose, a Stanford student, taught beginning Optacon reading to a group of blind high school students in a seven-week summer institute in San Diego, California. As more people were trained, a collection of text material for building reading skill was gradually being assembled and revised. For beginners the alphabet was divided into groups of letters beginning with the five letters chosen by experienced readers as the easiest to recognize. With the second group of letters, simple words using the ten letters learned thus far were presented. As the letters became more difficult, only three or four at a time were added; words and sentences containing the cumulative alphabet at each point formed a major part of the exercise.[81]

As indicated by this summary description, blind readers played an important role in the development and dissemination of the Optacon. Five blind readers, Candy Linvill, Sue Melrose, Loren Schoof, Tracy Reynolds, and Bob Stearns participated in a variety of formal and informal tests of prototypes prior to the foundation of TSI. Linvill, Melrose and Schoof were, or became, students at Stanford. Melrose, as we have seen, taught the Optacon to a group of high school students, fondly known to the research team as "The San Diego Five." An unidentified blind Optacon user, perhaps Melrose, also taught the use of the Optacon to Richard Joy, a blind and deaf student. Bliss reported that Mr. Joy "learned letter recognition well, but language deficiency hampered continued development in [the] time available." Loren Schoof who learned the Optacon as a high school student, later joined the research team at Stanford University where he earned an M.S. in Operations Research and served as a research associate in the Stanford Engineering Laboratory. Schoof prepared a set of introductory lessons for teaching Optacon students to read mathematical symbols and notations used by computer programmers.[82]

Bliss kept the service community informed of Optacon progress in a variety of ways. The project at the Monroe School, conducted by Carolyn Weihl, for example, was reported in AFB's journal, *New Outlook for the Blind.*[83] In April 1970, James Bliss participated as a panel member in an AFB forum on "The Blind in an Age of Technology." In May, Bliss and Weihl demonstrated the Optacon at the California section of the Council for Exceptional Children;. In June, Bliss addressed the Institute for Parents of Young Visually Handicapped Children at the California State School for the Blind. In July, John and Candy Linvill demonstrated the Optacon to the national conference of the Association for Education of the Visually Handicapped and the national convention of the American Council of the Blind. In August they presented the Optacon to groups in Australia, and in September to conferences and laboratories in Japan.

The promotional schedule was similar in 1971, with an international focus on Europe, including Britain, Germany, Italy, Poland, and France. In the United States, presentations were made to a wide variety of audiences interested in sensory aids or education for the blind.[84] In November 1970, as the new president of TSI, Bliss issued an *Optacon Newsletter* which he mailed to 250 people with an interest in the progress of the Optacon. In November of 1971, TSI mailed the second newsletter to 350 addresses. This bulletin announced the commercial availability of the Optacon at a price of $5,000 (see Figure 23).[85]

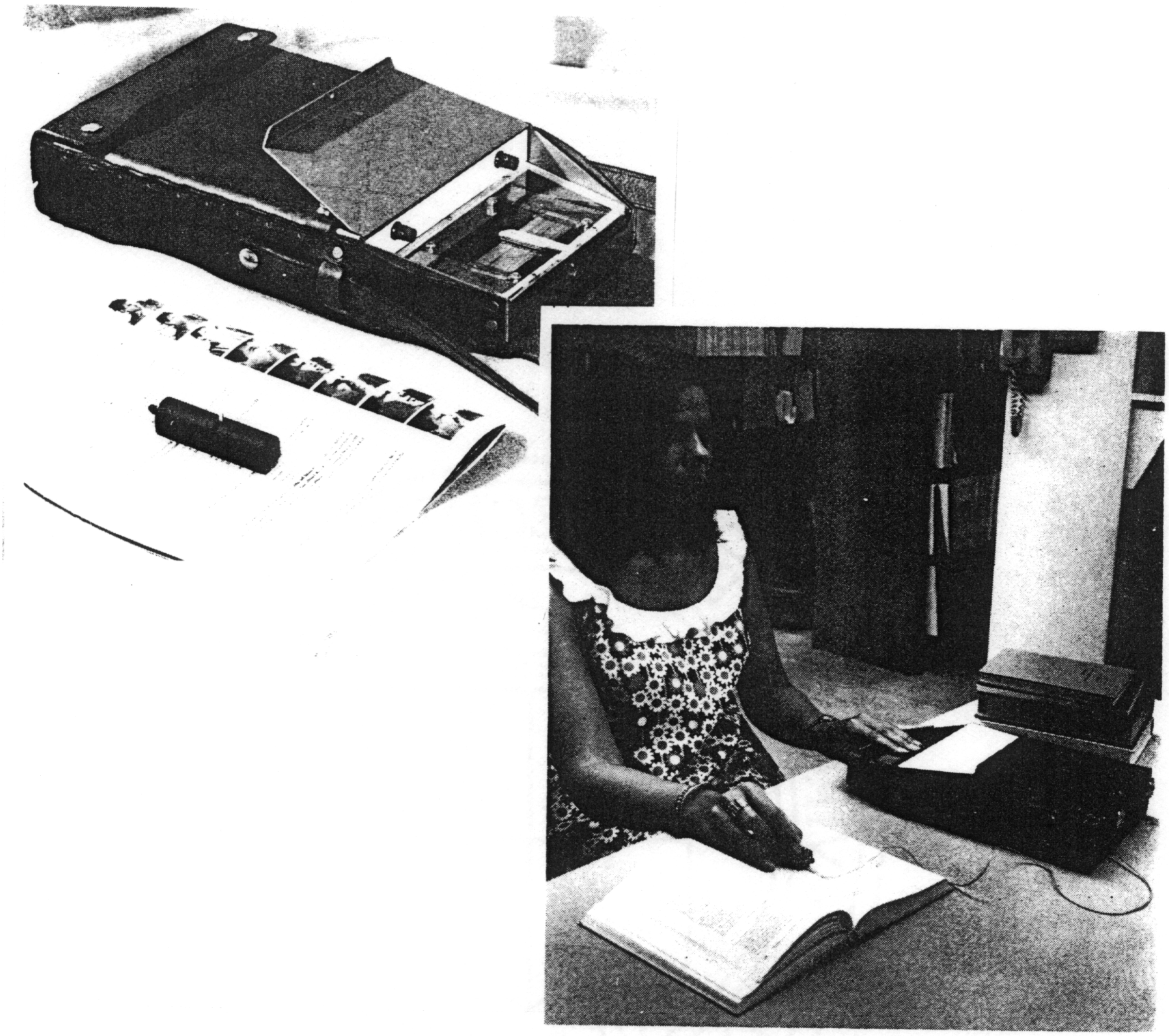


Figure 23. The Optacon[86]

Telesensory Systems, Inc.

Bliss carried his philosophy of inclusion and networking with the service community into Telesensory Systems, Inc., which was established in 1970 to manufacture and market the Optacon. Among the first recipients of an Optacon were Vito Proscia and Robert Whitstock.[87] Proscia, a blind engineer who directed MIT's Sensory Aids Evaluation and Development Center, joined TSI as its first marketing vice president in 1972.[88] Whitstock provided funds for the first Optacon training course, and later for an Optacon loan fund which was established to help finance purchases of the Optacon. (At an initial price of

$5,000, the Optacon cost as much or more than a new automobile.) Other early blind customers also became advocates of the technology or employees of the firm. Nils Nilson, the first Swedish Optacon user, made numerous presentations in Sweden. Alain Lequeux, the first French Optacon reader, became TSI's French distributor for twenty years. Jim Storer, another early Optacon user, funded Optacon programs at the Cleveland Society for the Blind. Such projects, Bliss reports, were important factors to the success of the Optacon and of TSI.[89]

A number of Stanford associates accompanied Bliss to the new firm, among them Carolyn Weihl, William T. Young, an electronics technician at Stanford Electronics Laboratories since 1958, and Stephen Brugler, whom Bliss credits with much of the design of Optacon electronics. Brugler's 1968 doctoral research was concerned with photodetector design. A research associate at Stanford Electronics Laboratories after he graduated in 1968, Brugler became TSI's Vice President for Research in 1972.[90]

A new business venture requires capital. In spite of Linvill and Bliss's technical success in fabricating a prototype, their commercial success was hardly guaranteed. A commercial reading machine was regarded to be a high-risk venture by the Stanford Business School and the executives of business firms whom Bliss consulted prior to establishing TSI. These experts advised Bliss that the potential market for his product was too small, that blind people could not afford to buy the Optacon at a price consistent with its cost of manufacture and distribution, and that the absence of any existing high technology company in the blindness field would discourage investors. Bliss cites three reasons for his decision to establish a commercial firm in the face of such advice: First, he and his colleagues were determined to see the Optacon made available to blind people and could find no other practical way to achieve that goal. Second, in Bliss's judgment, the likelihood for continued research funding in the area of technology and blindness was low, and he had no wish to return to work on defense projects. Finally, Bliss, who turned 37 the year TSI was founded, reported, "I was ready for a career change and the challenge of running a company instead of being a scientist or university professor appealed to me."[91]

Bliss became president and the chief executive officer of TSI, while John Linvill was made chairman of the board of directors. Professor James D. Meindl, Director of the Stanford Electronics Laboratory also became a member of the board.[92] TSI's initial capitalization was $75,000, provided by Stanford University and two other investors.[93] But more important, and critical to the success of the firm, was a contract from DHEW to purchase fifty Optacons.[94] At a calculated price of $250,000 plus the cost of support services, this contract, in effect, provided collateral for the working capital of the start-up firm, and provided significant leverage to the firm's relatively small capitalization. One method of managing these meager capital assets was to subcontract those manufacturing steps which depended on expensive tooling and capital equipment. TSI contracted with the Qualidyne Corporation, and later with Teledyne Semiconductors, for production of the Optacon's bipolar retina. Nortec Corporation produced the metal oxide semiconductor drive circuits which were packaged and bonded by American Micro-Systems.[95]

Between 1970 and 1973, TSI remained in many ways a child of Stanford University. While TSI manufactured and sold Optacons, and provided training in their use, Stanford Engineering Laboratories continued research on new models, new components, and new circuitry, while providing technical services to TSI and its contractors for the design and production of Optacon circuitry.[96] At the same time, John and Candy Linvill and members of the laboratory staff were active in promoting the Optacon, not only to the benefit of Stanford, which maintained a research contract with BEH until 1973, but unavoidably and intentionally to the benefit of TSI. Linvill's 1973 report to BEH freely mixed activities of the two institutions, often without distinguishing which was the sponsor of a particular activity. For example, the "First appearance of advertisement (Scientific American) showing Mr. Schoof using the Optacon with the HP-35 calculator," in November 1972, was presumably a TSI activity, whereas, "Demonstration by Mr. Schoof at Association for Computing Machinery Conference, Anaheim, California, of use of a modified Optacon to read video computer printouts," and an accompanying Stanford University News Release, in December, were presumably activities sponsored by Stanford Electronics Laboratories.[97]

Stanford and SRI provided a safety net against the risks of the business enterprise for some of the employees of the new venture. Brugler maintained a professional relationship with both TSI and Stanford Electronics Labs until 1973.[98] Bliss did not sever his relationship with Stanford Research Institute until 1976, and he retained his appointment on the university faculty for some time thereafter.[99] The failure of TSI would not necessarily result in a personal catastrophe for its principals.

Writing in 1973, in his final report to the Bureau of Education for the Handicapped, Linvill maintained that this consortium of academia, government and industry represented a robust, new model for the realization of national social goals through federal support to research and development. Linvill wrote:

> The Office of Education is the first government agency in the education and welfare sector which has made an investment in advanced technology to produce developments not directly obtainable as fallout from earlier defense or space research. It is only through such support that productive projects of the nature of the one described here can be carried out.

"Government, university, and industry," Linvill continued, "are symbiotic in attacking blindness with technology." The university contributed unique facilities, equipment, and a pool of talented doctoral candidates. Using BEH funds, the Stanford faculty and students "have developed the most able IC [integrated circuit] activity in any university." At the same time, Stanford Electronics Laboratory provided a locus for involvement of the semiconductor industry, which Linvill thought was crucial to the project's success. Through its scientific publications in professional journals, Stanford made the industry aware of opportunities for the "application of this advanced technology to the problem of blindness." These firms, in turn, hired Stanford's newly minted Ph.D.s in electrical engineering. Because of BEH's prior support to Stanford, TSI was able to manufacture and sell Optacons without a need to recover the capital cost of research. Finally, Linvill concluded,

> The necessary and mutually desired openness of the OE [Office of Education] – Stanford – TSI relationship implicitly provides insurance to the blindness system and to the public that good value will be received for its financial support. The only insurance the commercial enterprise, TSI, has against competition is its own effectiveness. When other enterprises find manufacture and distribution in competition attractive, they are free to enter competition for the government market. At the same time, in the best sense of American free enterprise, TSI can reward employees, managers, and engineers for their effective contributions. The whole system benefits as these components of development, production, and distribution are provided suitable incentive.[100]

Innovation

As of the date of Linvill's report, March 1973, TSI had manufactured and sold 250 Optacons. In addition to the Office of Education, Optacons had been sold to the Library of

Congress, and to the Department of Agriculture and the Internal Revenue Service, for the use of employees. PSAS had purchased several Optacons for evaluation. Optacons had been placed in two schools for the blind and in six mainstream schools or school districts. Twelve state rehabilitation agencies had bought Optacons, as had eight research institutes. Thanks partly to an extended trip to Europe by John and Candy Linvill in 1972, institutions in Germany, Italy, England, Denmark, and Sweden had purchased Optacons, as had the Victoria Institute for the blind in Australia, and the Jewish Institute for the Blind in Jerusalem. As many as thirty-five individual purchases accounted for about fifteen percent of total sales.[101] By 1973, the unit price had been reduced to $3,450, but the cost of accessories and training brought the total cost of a useful Optacon to about $5,000.[102]

In 1973, Linvill welcomed competition for the Optacon, but in the event, direct competition never appeared. That is not to say that TSI faced clear sailing. The most viable competitor was the Mauch Visotoner and its offspring, the Stereotoner, as described in Chapter 7, above. Like the Optacon these direct translation devices had the advantage of prepaid research and development costs – the VA and DHEW had invested comparable amounts to bring these two technologies to the production prototype stage. From 1971 through 1973, it seemed likely that the Mauch designs would provide stiff competition, and as late as 1976, Carberry and Butow urged that, "An organization should be found which is already involved in promoting sensory aids, that will publicize and market the Stereotoner."[103] But the last of 100 Stereotoners was made in 1973, and not all of those were put into service. In 1973, there were 250 Optacons in service. By 1977, 3,000 had been sold.[104] A 1978 advertisement by TSI put total sales at "almost 5,000."[105] A 1981 advertisement claims more than 8,000 sold.[106] By 1990, more than 12,000 Optacons had been sold at a value of over $50 million,[107] with peak sales occurring around 1980.

Perhaps the single major factor in the Optacon's success was TSI's approach to marketing. Bliss and his colleagues had the knowledge of the service community and the insight to realize that the lack of a marketplace for reading aids was a major constraint to innovation. They also had the entrepreneurial creativity to find a solution to the problem. Writing in 1993, Bliss said, "The Optacon was such an innovative approach to a major problem of blind people that the entire system, including university educators, teachers, students, rehabilitation counselors, employers, and blind users needed to be changed."[108] This concept of technological innovation as social change is emphasized by Bliss's comment regarding the blind people who were instrumental to the success of the Optacon: "It is interesting to note that few, if any of the blind people were leaders in the blindness field at the time. The reason for that is that the Optacon is much more easily mastered by young people because learning is easier, they have the time and the motivation to learn a difficult skill, and they do not have alternative support, such as secretaries, assistants, etc. Most of the list became successful professional people outside the blindness field."[109]

How would one go about selling reading machines for the blind? Door-to door? Through retailers? Through newsletters and conferences of organizations of blind people or of advocacy groups? We have seen in the case of the Hadley School and the Hines VA Medical Center (Chapter 7) that institutions serving blind people shared an ingrained reluctance to market a particular product. Bliss's breakthrough idea was to work through the educational system to train teachers of the blind to teach reading with the Optacon. The training course would itself provide a demand for a small number of machines. As teachers returned to their schools and rehabilitation institutions, there would be a need for machines to support them and their students. As blind persons were taught to read with the Optacon, an expanding market would be created. Thus, in 1973, Bliss proceeded to modify the blindness system through the agency of the Richard King Mellon Foundation, which provided seed money, followed by major resources from the Office of Education.

The Mellon Foundation project entitled, "Professional Preparation of Teachers of Reading with the Optacon," was initiated in the summer of 1973, by Professor Mary Moore at the University of Pittsburgh's Department of Special Education and Rehabilitation. The project comprised three special study institutes which trained 27 teachers and 10 graduate students to teach the use of the Optacon.[110] Subsequent to their evaluation of the summer project, the U.S. Office of Education agreed to expand the effort as the Optacon Dissemination Project. Between 1974 and 1979, the University of Pittsburgh trained nearly 700 teachers who worked with more than 800 blind students. Writing in 1985, Susan Spungin, Associate Executive Director of Program Services for AFB held the project up as a paradigm for "the training-and-dissemination component of technological development." It would be hard to improve upon her summary:

> When Dr. Edwin Martin was director of the Bureau of Education for the Handicapped, a very large dissemination grant was given to TSI and the University of Pittsburgh under the direction of Dr. Mary Moore to ensure that the Optacon would become a common device, available to every blind child in the United States. The University of Pittsburgh trained all the teacher educators from some 35 universities, in order that they in turn could teach

> their teachers in training not only in how to use the Optacon, but more importantly, how to teach blind children using it. Millions of dollars were spent on this program, so that virtually every eligible blind child had an Optacon of his or her own in high school.
>
> This model – stressing the training of teachers as well as the development of training materials specific to the needs of the population to be served – is paramount to insure the life and utility of any device. And indeed it used the blindness system in a very effective way. For without these two components – professional training and software development – we will continue to see the shelves of all programs servicing blind persons buckle under the weight of unused devices.[111]

In co-opting the Office of Education to establish a market for the Optacon, Bliss and TSI took advantage of the political and social movement which James J. Cremins called "the revolution in special education." The Kennedy and Johnson administrations in the 1960s had reorganized and strengthened the Office of Education's programs in special education, and, through the power of the purse, expanded the federal government's role in education. In 1968, Linvill and Bliss were among the first to tap this new resource for the research funds which had supported the development of the Optacon. In 1971, they secured funds for the evaluation of their reading machine as an educational tool. They in effect converted those funds into venture capital for the establishment of a new manufacturing firm, and applied them not just to fabricate the first fifty Optacons, but to build a small business capable of sustained production and marketing of its initial product. Between 1973 and 1979, during which time Congress continued to strengthen programs for the education of handicapped children, TSI worked to see that significant federal funds were directed toward programs which entailed the purchase of their product and the training and maintenance services which they provided to support the product. It is true that Bliss and TSI exploited the winds of social change to power and promote technological innovation of their Optacon. But it is also true that these opportunities were generally available to those with the technical and political skills and the desire to take advantage of them. They were available to Bliss and Linvill. They were available to Mauch and Haskins. Bliss took advantage of them. The other technology developers did not.

Competing technologies

Bliss suggested that young blind people were more likely to grasp the Optacon's potential for technological innovation and personal achievement than were older blind people who had established different relationships and different reading practices – in short, different technologies – for gaining access to print. In 1971, Hans Mauch was 65 years old. Franklin Cooper was 63. Jim Bliss was 38. Mauch had been president of his own firm since 1957. Cooper had been president of Haskins Laboratories since 1955. Bliss was the new president of a firm whose business was to make and sell Optacons. Mauch Laboratories and Haskins Laboratories had each been pursuing their particular practices of technology development, under VA sponsorship, for fourteen years. TSI was a new venture in a new context.

Bliss and Linvill, who had initially sought VA sponsorship, had been forced to look elsewhere. Like the young blind people who embraced the Optacon, Bliss was free to innovate by virtue of the absence of prior commitments. He recognized the new programs established in the Office of Education to be a resource which could be exploited to establish an innovative firm and then to secure its initial growth and success.

Bliss believed that the Optacon Dissemination Project was critical to the success of the Optacon.[112] But TSI did not invest all of its energies in a single marketing strategy - or even a single product. As Bliss put it, "We tried every approach we could think of. Other approaches that were successful included selling internationally to England, Sweden, Germany and Japan, establishing a pilot program in the San Diego School System, establishing an Optacon loan fund with a grant from the Seeing Eye Foundation, and establishing a Palo Alto training system whereby blind people could come from anywhere around the world for an excellent two week training course."[113] To secure the success and stability of TSI, Bliss continually sought new products. He expanded TSI's product line to include a talking calculator, an electronic brailler, a closed circuit television for low vision readers, and a variety of other assistive devices for people with vision impairments. Still other products were tried and rejected by TSI at different stages of development, including the Mowat Sensor, an electronic travel aid manufactured in New Zealand.[114]

Among the new products considered by TSI in the early 1980s, was a "talking Optacon," whose development was supported by PSAS in collaboration with BEH and RSA.[115] TSI never brought the talking Optacon to market. Harvey Lauer interpreted this result as a failure in engineering development, based on the wrong approach to camera design and a consequent low rate of recognition accuracy.[116] By the 1980s, however, Bliss was concerned less with technology development and more with developing a product which would be marketable at a certain price as part of an existing product line. Use of the existing Optacon's camera was more a constraint imposed by a business strategy than a question of technical feasibility. Bliss saw no benefit in competing with Kurzweil Computer Products for the high end market which Kurzweil by then controlled. On the other hand, a low cost, personal synthetic speech machine was a potentially viable product worth considering. In the early 1980s, however, it was product idea that proved to be out of TSI's reach.

In spite of its primary support to Mauch Laboratories, the VA's interest in the Optacon was strong and long-standing. It is true that Murphy was unwilling to drop his support of Mauch in favor of Stanford, but PSAS's evaluation program purchased Optacons as soon as they were available, and TSI was regularly acknowledged and included in PSAS's information dissemination activities. Among those who took the two-week Optacon training course were Harvey Lauer and Richard Bennett, of the VA's blindness rehabilitation centers. Shortly after the first Optacons were produced, the VA announced that initial plans had been developed for teaching the Optacon. Bennett, with Murphy's permission, and apparently at VA expense, participated as a research subject at SRI testing "Optacon-like displays," in the spring of 1972, and undertook formal Optacon training in the summer of that year.[117] Lauer undertook Optacon instruction in October, when it was offered in Cleveland.[118] Both Bennett and Lauer taught the Optacon to blinded veterans, even as they provided training in the use of the Visotoner and participated in the development of the Stereotoner, as described in Chapter 7. If the VA was too committed to Mauch Laboratories to sponsor Optacon research, as Bliss believed them to be,[119] they were not so committed as to ignore the technology or its utility to blind veterans.

Realistically, the PSAS research budget could not be stretched to provide significant support to Bliss without terminating support to Mauch or Haskins. As it was, PSAS's resources were stretched too thin (see Chapters 7 and 8). Bliss apparently understood this constraint, and argued that Mauch should be abandoned on technical grounds. Murphy chose not to follow this recommendation. Although their research products never competed for customers in the commercial marketplace, the relationship between the Stanford group and the VA's organization for research long predated the production of the Optacon. Underlying the overt competition for research funds, were significant differences in practice which distinguished TSI from PSAS's contractors.

We have already learned how Bliss was a regular participant in the PSAS-sponsored knowledge community from the early 1960s. From 1962, there was hardly a professional platform that Bliss did not share with Cooper, Mauch, and Murphy or their colleagues. The way in which Bliss defined his role in the existing knowledge community helped to foster a sense of competition. His adoption and use of Cooper's taxonomy placed the Optacon squarely in the same category as the Battelle Optophone and the Visotoner, although it is not obvious to one outside the paradigm that auditory and tactile communication devices have more in common than in distinction. It is not even intuitively clear what it means to attribute "recognition" to a machine, yet PSAS, under the influence of the reading machine research community had selected concepts for technology development based upon a distinction between machines which recognize and those which do not. Nor is it clear that the psychology of tactile perception of letter shapes is analogous to the auditory perception of tones and sounds in a way which strongly supports the inclusion of both modalities in a single category.

Clearly there was an element of convention involved in assigning conceptual designs to a particular category of reading machine. This is evidenced by the shift in Cooper's framework which occurred in 1962, reassigning Mauch's prototype from one category to another. At any rate, the acceptance of the young MIT graduate, Bliss, into the reading machine research community in 1962, included his tacit acceptance of the conventional categorization. This had the ultimate effect of placing Bliss and Mauch's designs in competition for funds within a common category of "direct translation reading machines."

This competition was not inevitable in 1962. Mauch had just abandoned prototypes which produced speech-like sounds in favor of a letter recognition device which produced spelled-speech. Bliss's research was just beginning to move away from proprioceptive kinesthetic models which also required letter recognition, toward air jet stimulation which did not. By the time of the sixth PSAS technical conference in January 1966, however, Mauch's Visotoner and Bliss and Linvill's Direct Translation Tactile Facsimile Reading Aid represented competing technological ideas within the research community's taxonomy of reading machines. What might have been perceived as very different audible and tactile reading machine concepts, were primarily understood and discussed as competing, direct translation technologies.

When the Stanford group finally secured substantial research support from BEH in 1968, the Optacon and the Stereotoner became competing prototypes sponsored by different federal government agencies with different constituencies and different missions.

PSAS's mission, dating from 1948, represented an earlier, more limited vision of the role of federal government, which allowed federal expenditures to support research and services on behalf of veterans, but which left most matters of education to the individual states. When PSAS's Research Division was created in 1948, no civil executive agency had the explicit authority to expend funds on rehabilitation research. This situation gradually changed during the 1950s, with respect to vocational rehabilitation, but the creation of BEH in 1967, and the passage of the Architectural Barriers Act in 1968, represented a political vision of a Great Society where the federal government had an acknowledged role in ensuring persons with disabilities access to education and a broader participation in society.

Competing Interests

The members of the existing research community did not reject the emerging political changes. To the contrary, they welcomed them and the resulting expansion in their professional opportunities. But, in a sense, they were institutionally bypassed by them. Between 1957 and 1967, the Veterans Administration, whose constituents comprised only two percent of all blind Americans, had been the major federal sponsor of reading machine research. Beginning in 1968, the budget made available to the Office of Education was many times that available to the VA, and its base of constituents potentially extended to the other ninety-eight percent of blind Americans, although in practice its concerns still focused on youth and working-age adults. During a transitional period, from 1968 through about 1978, when the Office of Education replaced the Veterans Administration as the major federal sponsor of rehabilitation research, it was perhaps inevitable that emerging perspectives and interests would reinforce competing technological ideas.

There can be little doubt that Jim Bliss was an aggressively competitive corporate manager. He intended for TSI to be a success. As a commercial vendor of products and related services, the firm's success depended on profitability, market share, and an evolving product line that could keep up with the market. These interests, while normal for business, were quite alien to the context of altruistic service to people with disabilities, and conflicted with the presumably "disinterested" objectives of the research community. Bliss was a successful businessman who built TSI into a firm with more than $30 million in annual revenues by the 1980s. He was competitive in the sense that he promoted his product and his firm. For example, when asked about his relationship with Kurzweil in the 1970s, Bliss framed his answer in competitive terms. "In general Kurzweil's promotions were detrimental to Optacon sales and vice versa,"[120] Bliss remembered, although it is not clear to what extent the $5,000 Optacon was in fact competing for the same customers as the $50,000 Kurzweil Reading Machine.

Harvey Lauer remembers the relationship between the VA and the Office of Education as destructively competitive, often characterized by mutual suspicion over motives and tactics. Describing a visit to Stanford in 1970, for a review of Optacon research by representatives of both the Office of Education and the VA, Lauer reports,

> I was enthusiastic and encouraging to the visitors, so I was surprised later when we were speaking privately. Jim said that he felt Mauch should get no support, and that the Stanford project should get it all. When I disagreed with him, he seemed displeased. I was really disappointed and a bit uneasy about future cooperation since he felt he should get all the support, but I did no more than disagree.
>
> He thanked me for giving good advice on handling the review. We parted amicably, but I have a feeling he was disappointed – that he wanted to "win me over completely" instead of what he had done which was to strengthen my conviction of the value of the concept he championed. He seemed dissatisfied with my enthusiasm for both methods of reading. He kept that attitude up for years – perhaps to the present.[121]

Lauer was accurate in his guess that Bliss's attitude extended to the present. In 1993, in response to the question, "In retrospect, what were the key factors that contributed to the successful dissemination of the Optacon? Can you contrast these with any other system that failed at innovation?" Bliss replied in this way:

> I think the key factors were; [1] Project leaders that were committed to seeing the Optacon reach blind users, not result in just another research report. After TSI was founded and the early employees left their secure university and research institute jobs, dissemination was essential or the company would fail. There was total focus on making the dissemination succeed. [2] The Optacon design was excellent and well thought out to fulfill the needs of intended users. The design was based on sound research in physics, engineering, psychophysics and human factors. [3] The training program was essential to the successful dissemination. The Optacon without the training program would have been a failure. [4] The Optacon accessories

> (visual display, typing lens, CRT lens, automatic training system, automatic page scanner, tracking aid, etc.) did much to ensure the success. [5] Imaginative people at the Office of Education [and] Mellon Foundation. [6] Prof. Mary Moore at the University of Pittsburgh played a key role in the successful dissemination of the Optacon by organizing the system of training university professors and student teachers.
>
> A system that failed at innovation was the Stereotoner from Mauch Labs. Some of the reasons were: [1] The Stereotoner design was not based on sound physical principals. [2] As long as the VA continued to fund Mauch Labs, they were content. [3] The VA leadership was motivated politically and once they had committed significant funds to Mauch, they were afraid to change because it would indicate they might have made a mistake. [4] Mauch Labs was isolated from the major technological developments taking place at the time in integrated circuits. [5] No comprehensive dissemination plan was devised outside the VA system.[122]

Many of these points of difference center on the commitment and organizational relationships of the people involved. The competition between the Optacon and the Stereotoner was, in retrospect, partly one of design, and partly one of differing practices in technology development. Differences in practice included different relationships among developers, manufacturers, blind readers, and sponsors of research. The competition was also a product of a social construct, of the conceptual categories by which the research community understood and compared reading machine conceptual designs.

Comparing the Optacon and the Stereotoner

The successful innovation of the Optacon was the result of some rather complex factors which were highly and inextricably "social," because they involved relationships between and among individuals and communities of people. Among these factors were Jim Bliss's role as a doctoral student at MIT and the relationships which he established with the service community while a student working in the field of tactile communications. John Linvill's relationship with his blind daughter, Candy, was important as a motivating factor for research, and for patterning the relationship between researchers and blind readers which characterized the Stanford group. Far more than any other research team we have investigated, the Stanford group sought the assistance of blind readers and participated in the activities of the service community, worked to keep them informed of their progress, and courted their interest and support.

Collaborative relations between Linvill and Bliss were sustained by institutional relations between the Stanford Electronics Lab and Stanford Research Institute. These two organizations' continuing support from the Navy, Air Force, NASA, and National Institutes of Health provided resources which sustained Optacon development until a major grant was secured. The facilities, equipment, and knowledge of electronic circuit development resident in the Stanford Electronics Lab were deployed to support Optacon development through a series of doctoral dissertations, while human factors research at SRI provided information regarding design goals and constraints. Even as SRI pursued basic research into tactile perception, however, Candy Linvill and other blind students were being provided simulated versions of tactile readers, and soon actual prototypes. Their reading material was typically text books, and their objective was to gain access to the mainstream classroom.

Relations between researchers and research sponsors were important to the success of the Optacon as well. Linvill and Bliss were unable to secure support from the only existing sponsor of reading machine research, whether for technical or fiscal reasons, or simply for reasons of habit and loyalty. As a consequence, they were looking for alternatives and were ready and able to take advantage of the creation of a new research program by the Bureau of Education for the Handicapped. The fact that their patron was an educational agency later provided an opportunity for innovation through persuading the special education community to learn to teach the Optacon. Since each teacher could influence many students over a teaching career, this route to innovation provided significant leverage of time and resources to TSI. Moreover, the number of potential reading machine users passing through the educational system was a hundred times greater than the number of veterans passing through the VA's blindness centers.

Finally, there was the creation of Telesensory Systems, Inc. a commercial firm for the fabrication and sale of reading machines and, later, of other electronic products for people with vision impairments. This step transformed the Optacon from a prototype to a product, and within the context of the American and global marketplace, this was surely a critical step toward successful innovation.

Bliss has acknowledged the importance of these kinds of factors to the Optacon's success, and he attributed the failure of the Stereotoner, in part, to Hans Mauch's lack of interest in entrepreneurship. But Bliss also maintains that the Optacon was a superior design based on sound research. The Stereotoner, he asserts, was a design which was based on a bad understanding of physics, and which failed to incorporate contemporary research on printed circuits. The Optacon, succeeded, in part, because it was a better design, one design which incorporated superior scientific knowledge.

Was the Optacon a better design in any recoverable sense? Since the Stereotoner failed to achieve innovation, the question cannot be answered by reference to the marketplace, the numbers and kinds of people who use it, or by a survey of its applications. Bliss maintains that the Optacon was a superior design because of its use of printed circuits and its higher resolution based on 24 vertical elements. The Stereotoner, or any other device with only ten vertical elements across a standard letter height, he believes, can be shown to lack the resolution to ensure the capture of all of the information in the printed letters - and in particular to risk a failure to detect narrow horizontal bars such as distinguish the letters "e" and "c."

To the extent that reading rate is an appropriate measure of effectiveness, there is little to distinguish the Optacon as a superior design. In a 1977 report, specialists at the VA's Eastern Blind Rehabilitation Center summarized the results of Optacon reading tests conducted to date: After fifty hours' instruction, nine veterans averaged just over 2 wpm using the Optacon. Thirty-five teenagers trained and tested by the American Institutes for Research (AIR) averaged 7 wpm. After extended training, five veterans averaged 6 wpm, and the teenagers averaged 11 wpm. A group of seven British professionals averaged 19 wpm. The range for all these readers was from 4 to 37 wpm.[123] A 1982 study of methods to improve Optacon reading rates reported an unpublished study of 500 naive Optacon readers that found average reading rates of 12 wpm after 50 hours' training. TSI reported that a sample of 22 blind students after a year's experience with the Optacon had an average reading rate of 22 wpm.[124] Candy Linvill achieved rates of over 60 wpm.

Far fewer tests were made of Stereotoner readers, but in 1976, AIR reported an average reading rate of 4 wpm for thirty veterans and students at the Hadley School, after initial training, and 13 wpm after extended home training (see Chapter 7) - somewhat faster reading speeds than reported for a similar population learning Optacon. One reader's scores were eliminated from the data set, because he achieved reading rates of nearly 90 wpm. Margaret Butow and Harvey Lauer, who learned to use both the Stereotoner and the Optacon, each read at between 30 and 40 wpm with both devices. According to the best available information, blind readers achieved similar performance with the Optacon and the Stereotoner: Reading rates of ten wpm or less after initial training for most students and an ability to read about 20 wpm with practice. Some individuals can achieve rates of 30 - 40 wpm in time, and a few experts learn to read at rates over 60 wpm.

Whatever the benefits of the Optacon's printed circuitry and superior calculated resolution, they did not unambiguously result in higher reader performance. They did contribute to a higher cost, however. Hans Mauch sold the first (and only) production run of Stereotoners for $1,850, less than 40% of the price of the first Optacon. The Stereotoner was mechanically and electrically a much simpler design. Nonetheless, it was at least as portable as the Optacon without the need for more sophisticated electronics.

Moreover, it is unclear that the lower resolution of the Stereotoner resulted in lower utility. It was not the machine that distinguished letters and words, after all, it was readers using the machine. Readers could often distinguish a "c" from an "e," by context. More important, they could adjust the position of the Stereotoner probe so the horizontal bar did not fall between the photosensors. Readers could repeat a word as often as necessary to clarify its identity. While Bliss's critique of the Stereotoner's resolution may be factual, technical facts do not necessarily add up to an inadequate reading machine.

Margaret Butow thought there was a place for both machines. Harvey Lauer, who used and taught the use of both the Optacon and the Stereotoner, provided this comparison:

> Were it not for adaptation, vibro-tactile signals would doubtless be superior to the tonal modality for most people.... With the Optacon alone, using soap-washed hands, it's easy to feel the patterns at first. Then, if the stimulator intensity control isn't at the top, you can raise it and go on for up to half an hour before legibility fades away. Then you must rest to recover sensitivity. Eventually, if learners persist, at least some of them develop high tolerance for the vibrations and high skill.... As with the tonal code, you need to give people plenty of practice to build up tolerance, tracking skill and get the process of reading flowing and working within mental processing below the level of conscious awareness....
>
> With the audible code, adaptation is a far lesser factor because humans are used to hearing sounds all day. We are less accustomed to feeling vibrations on the skin. The tactile code is best for tracking because of the wider window, but the audible one is more legible for horizontally dense characters, especially "m" and "w." The tactile code is better when, hopefully only occasionally, you must decipher or verify complex or broken characters by moving the camera vertically as well as horizontally so as to use

> the most sensitive area--the ball of the first joint of the finger. When the audible code is being used by itself, vertical movement rarely helps.
>
> For most people, descenders are hard to feel with the Optacon but easy to hear with the audible code. Some people have a hump on their finger which renders part of the tactile array unusable. If you press down to flatten the hump, the stimulators quit. That's where the audible code “fills in.”
>
> Uneven hearing losses within the frequency range of the audible code adversely effect perception of it. Fortunately, the top tone of the Stereotoner code is 3,500 Hz which most people can hear pretty well, even as they age and high-frequency hearing drops off.
>
> Ironically, many people without experience believe they could tolerate the vibrators but the audible code would "drive them up the wall." After careful observation, I can assure you that people don't "climb walls" until what they hear or feel ceases to be meaningful to them. And that happens soonest with Optacon beginners and with those few people who are really tone deaf. It happens at the point of fatigue or diminishing return in all the rest.[125]

The Optacon's Success

The Optacon was a reading machine that worked. It worked as a machine which produced a tactile code from print that could be read by many blind people at speeds from 10 to 40 wpm and at higher speeds by some. It worked as a technology - as a tool for reading in a variety of contexts, providing many blind readers with access to printed and typewritten material. Most especially, the Optacon was useful for such tasks as sorting and reading mail, interpreting bills and bank statements, proofreading typing, scanning tables of contents, and reading key passages. It may not have worked significantly better than the Stereotoner, but it worked well enough to become a successful product, generating over $50 million in revenues for its manufacturer.

The creation of Telesensory Systems, Inc., was a key factor in the Optacon's success. TSI's mission was the fabrication and sale of electronic products for the blind. The success or failure of the firm depended on whether or not it sold products profitably, and for several years, its only product was the Optacon. Bliss believed in his product and he marketed it aggressively, emphasizing its uniqueness as a window on the world for the blind, and focusing on its strengths and its utility. Such enthusiasm for the Optacon had its drawbacks. Lauer explained,

> At first, the practical uses to which the Optacon could be put were overrated. Training requirements were played down. Only after several years was a thorough training course developed and regularly offered. Some machines were given to, and bought by people who couldn't use them. There was even unfounded hope that it would replace braille transcribing. Some said we didn't need to continue development of talking reading machines. Exaggeration ignited flames of suspicion in consumer groups. Unrealistic optimism thus gave rise to both a backlash and a lack of motivation to progress.[126]

Later, Lauer explained, the limitations of the Optacon became more generally known and appreciated among the blind community, and TSI, among others, developed better training courses and manuals. The structure and type of training were critical, Lauer believes, not only for teaching new skills but also for activating students' motivation for sticking with a long and often tedious learning process.[127]

Whatever his enthusiasm or excesses as a marketer, Bliss was quite aware of the limitations of the Optacon. At the 1977 Smith Kettlewell Conference he described TSI's research into a synthetic speech machine in this way, "Dr. Bliss explained that the Optacon had broad applicability but permits only slow processing and is difficult to learn. If the output were speech the problem would be reduced. The superiority of speech has long been appreciated by the Optacon developers and all Optacons... have an input-output (IO) connector to facilitate conversion to an OCR-synthesized speech system."[128]

One important factor to the Optacon's success was the absence of a competing product. If a blind person wanted a reading machine, there was only the $5,000 Optacon or, after 1978, the $30,000 Kurzweil Reading Machine (KRM). Although prices came down somewhat, until the mid-1980s, synthetic speech machines cost five to ten times as much as an Optacon. For this reason, the Kurzweil machine was more a competing concept than a competing product. Its price generally limited the KRM to institutional purchases, mostly libraries and schools.

Bliss did not know this would be the shape of the market when he formed TSI. To the contrary, he had every reason to think there would be competition from the Stereotoner, although Bliss believed he had the superior product which would win the competition. The shift in rhetoric which Lauer noted from "overrating" the Optacon toward a more accurate representation of its value and limitations was likely a reflection of TSI's emerging understanding that the Optacon would stand alone in the marketplace for personal reading machines for the decade of the 1970s and beyond. Without access to the financial records of a closely-held private firm, we may nonetheless conclude that the ability to maintain a substantial profit margin without sacrificing market share was a positive factor to TSI's success. It is possible that a competitive market for personal reading machines would have stimulated more sales at lower prices to the benefit of blind readers and the vendors of reading machines. But it is not clear that lower price would in fact have resulted in correspondingly larger sales, and it is possible that lower revenues would have threatened the viability of TSI as a business.

The Optacon was a success in that it worked as a machine, it worked as a technology, and it worked as a profitable product, but its total dissemination was, nonetheless, rather small. In 1977, according to Louis Goldish, there were 1.7 million Americans who were legally blind, and 500,000 with no useful vision. Of these, only 25,000 actively used braille, of whom 13,000 found the use of braille a necessity. This group comprised 9,000 students and 4,000 adults who used braille in their employment.[129] 175,000 people were estimated to use library and book services, principally recorded material for the blind. Approximately 90,000 blind people were served by agencies for the blind, and 40,000 people had purchased aids and appliances from AFB over a three-year period.[130] By the time Optacon sales peaked in the early 1980s, about 8,000 Optacons had been sold, including international sales. By 1990, this number had increased to only about 12,000.

These statistics can be read in at least two different ways. On the one hand, the number of Optacons sold during its first decade was equal to less than two percent of the totally blind population of the U.S. From this perspective, its market penetration was minimal. On the other hand, nearly a third as many people used Optacons (assuming only one reader per machine), as read braille, and braille required no capital expenditure on the part of the blind reader or a sponsor. Based on my acquaintances who are blind, there was probably a large overlap between the 13,000 readers who found braille a necessity and the 10,000 or more who became Optacon users. The 9,000 braille readers who were students were also the principal target of the Office of Education's Optacon dissemination program. In other words, the Optacon's market penetration and impact was high among the young and upwardly mobile blind population which was the primary constituency of the Bureau of Education for the Handicapped, the same population whom Bliss described as most able to adopt a new technology. It was this group, as opposed to the much larger population of persons losing their vision to pathologies associated with aging, which could be reached through the dissemination program implemented at the University of Pittsburgh. It is probably no coincidence that the blind readers who contributed to the development of the Optacon from the mid-1960s were all college-bound students who were also adept at reading braille. Certainly the technology that emerged from that development process was one which best met the needs of a similar group of independent, mostly young, blind readers.

When asked to characterize its impact on persons with vision impairments, Bliss replied that the Optacon expanded educational opportunities, created new employment opportunities, fostered greater independence in personal life, and stimulated engineers to undertake other technological innovation for blind consumers. “Many blind people said that they couldn’t have gotten their jobs if it were not for the Optacon. An interesting documentation of this is that when Optacon II was introduced, [1988], the major market was as a replacement for people who had obtained Optacons ten or fifteen years previously. While their original Optacons had been provided to them by some social service, they were now able to purchase Optacon II with their own funds due to a successful career.”[131] Informal discussions by the author with adult blind readers indicate that college students and people who live alone or with family members who are also blind are the most likely to be Optacon users. Least likely to use the Optacon are people who lost their sight late in life, who are retired, and who live with a sighted family member capable of reading to the blind person or performing those household tasks which require reading.

Summary and some preliminary conclusions

Innovation is a thoroughly social phenomenon. The adoption of a new technology is a process which characteristically involves the establishment of new relationships among groups of people – users, vendors, and institutions supporting the dissemination and use of a new tool. In the case of the Optacon, we can see that the forging of relationships among individuals and institutions which were essential to the reading machine’s success began quite early in the development process. In some cases, social relations that were important to the course of innovation were formed during the research phase, before the formulation of the Optacon concept.

We are fortunate to have for comparison the cases of the Stereotoner and the other reading machines which were developed in the decades after World War II, because their rather different histories of development and their failure at innovation make apparent some of the social factors which were important to the development and innovation of the Optacon. Their histories point to a conclusion that the Optacon's success at innovation cannot be understood in terms of the device alone. The Optacon was a reading machine that worked, in that it converted visible print into a signal that was accessible by a different sensory mode, but so was the Stereotoner, and the Stereotoner was not a success.

What were the factors that contributed to the Optacon's success? The most visible fact was the formation of Telesensory Systems, Inc., as a business firm which would succeed or fail with the innovation of the Optacon. As we shall see in Chapter 10, the establishment of Kurzweil Computer Products, Inc., served a similar role in the innovation of a synthetic speech reading machine. Certainly the success of the Optacon was a consequence of the formation of TSI, but the story is more interesting and complex than that. The formation of a firm to fabricate and market the Optacon was just one step in a longer social process. It was a step that was available to other reading machine developers as well as to Bliss and Linvill.

Three different categories of social relationships appear to have been factors in the Optacon's success. The first were those personal and professional relationships which helped shape the developers' interest in and approach to reading machines. The second were the institutional relationships which supported technology development. The third were those relationships which characterized the course of innovation and dissemination, including the formation of TSI. By way of summary and interim conclusion, let us review the social history of the Optacon, and identify those relations which appear to have contributed to its form and its success.

Among the social factors which shaped the developers' approach to the Optacon were Bliss and Linvill's relationships with the service community, their place within the reading machine research community, and the role of blind individuals in system development. Both Bliss and Linvill had strong ties with the service community which predated the concept of the Optacon. Linvill's initial participation in organizations of and for the blind was in the role of a parent of a blind daughter. Bliss became familiar with the technical part of the service community while a doctoral student at MIT, where his research was stimulated and guided by John Dupress of the American Foundation for the Blind and the MIT faculty members who were influenced by him. Bliss's initial research in tactile communications were fostered in this environment. Later, during the development of the Optacon, Bliss received modest support from such agencies as AFB, Seeing Eye, Inc., and the Rehabilitation Services Administration. Throughout the 1960s, Bliss and Linvill were active participants in meetings and conferences sponsored by organizations of blind people and by the service sector. As a consequence, in the 1970s, the service community, including rehabilitation specialists and teachers of the blind, represented an informed group of advocates and customers for the Optacon.

As a protégé of Mason and Dupress, Bliss was a second generation member of the reading machine research community. When he completed his doctorate, Bliss assumed an active role in that research community, employing its paradigms in his descriptions and analyses of his own research and that of others. Under the reigning taxonomy, the Stereotoner and the Optacon were grouped together and understood as competing designs of a similar type. Bliss hoped to capitalize on his membership in the research community to secure research funding from PSAS, the long-standing sponsor of reading machine research. He failed to do so, Bliss believed, because of PSAS's commitment to the Stereotoner, which both PSAS and Bliss perceived to be a competing design. On the other hand, as a consequence of his standing in the research community and his association with Linvill, Bliss was in a position literally to capitalize on the new research role assigned the Bureau of Education for the Handicapped in 1967. Because of his failure to secure funding from PSAS, Bliss was attuned to the opportunity as it arose.

An important social factor contributing to the development and innovation of the Optacon was the way in which its developers sought and assimilated the contribution of blind readers. At the 1971 NRC Conference on the evaluation of reading machines, Bliss maintained that it was difficult to differentiate the development and the evaluation of the Optacon, because blind people had been involved with its reiterative design at every step. First Candy Linvill and then a small group of blind high school and college students were active users of Optacon simulators and prototypes beginning with the air jet experiments performed in 1962. In 1970, an expanding circle of blind readers, mostly students, were exposed to Optacon prototypes, beginning with the San Diego Five. The results of these formal and informal tests were important to the design choices that were made as the Optacon evolved. Perhaps for this reason, TSI's product design was remarkably stable. The modified hybrid design of 1971 was developed within three years of the initiation of major research support from DHEW. It became the first production prototype and the basic Optacon design for over ten years.

Other developers did not ignore blind readers, but they did tend to involve them at the end of the development process. Haskins Labs used sighted subjects in interim tests of synthetic speech recognition, under the assumption that the psychology of perception was no different for blind or sighted readers. That assumption was probably a valid one, but it ignored the idea that a technology comprises social behavior as well as individual perceptual response. Haskins Labs' delay in involving blind readers in the evaluation of compiled speech resulted in nine years' investment of time and effort in a technology which nobody wanted. Mauch used the services of a single blind reader to check out prototype devices toward the end of their development process, but he did not expand on this base. Unlike TSI, Mauch Laboratories' published reports did not credit their blind reader with any active role in the evolution of reading machine design. Harvey Lauer and Richard Bennett contributed to the design of the Stereotoner, but their help was not solicited by Mauch, and it came so late in the development process that it represented a redesign of the Visotoner, more than a contribution to its development.

Isolating the precise influence of blind readers on the Optacon design process is not possible, but it is noteworthy that the contributors were principally blind students, pre-professionals, who wanted to use the Optacon to gain independent access to texts and printed materials that were not available in braille. The major market for the Optacon also appears to have been students, white collar workers and professionals who read braille, but who desired access to printed texts not readily available in braille. In short, the user of the technology was an extension of the group that contributed to its development. We can speculate that if John Linvill had been motivated by the needs of an elderly blind mother, a rather different device would have emerged. The social knowledge which was incorporated into the Optacon design was not about blind readers in general, but knowledge of the ways of life of a certain group of blind readers with the motivation, the skills, and the ability to benefit from the design which emerged from the development process.

These high-achieving blind students differed in many ways from the middle-aged blind veterans served by the VA's blind rehabilitation centers. According to a 1964 study of 851 blind veterans, this overwhelmingly male population was, on average, forty-six years old. Only 15% were college graduates. Their income was primarily from disability compensation. Thirty-five percent did not read at all. Of the 550 veterans who did read, 56% relied primarily on a sighted reader, and only 4% used braille as their primary mode of reading.[132] These social differences between groups of blind readers provide an additional explanation for Bliss's overwhelmingly positive conception and optimistic claims for the

Optacon – claims which Lauer and others may have attributed to his vested interest in the machine. The blind readers most familiar to Bliss, those who had participated in Optacon design and evaluation, were hardly a representative sample of all blind people. Based on their experiences with this group, the developers of the Optacon may have reached quite different perceptions of the technology than Lauer and others who were most familiar with a different group of blind readers.

Finally, we know from their testimony and their deeds that Linvill and Bliss were determined to put Optacons in the hands of blind readers. This determination must have been based, in part, on an extension of their personal relationships with blind persons including Candy Linvill and the other students who were involved throughout the course of Optacon development. If we believe their testimony, Linvill and Bliss's principal motivation in developing the Optacon was not to increase scientific knowledge nor to develop a theory of cognition and tactile perception. It was not the demonstration of an engineering design or proof of concept. It was not the maintenance of a research laboratory through the winning of research contracts, although their research involved all of these activities and met all of these goals. The formation of TSI as a business venture which would succeed or fail with the innovation of the Optacon was a commitment and an event which symbolized that determination in a way which distinguished the Stanford group from Mauch, Cooper or any of their predecessors.

In developing the Optacon and in establishing TSI, Bliss and Linvill took sound advantage of the federal Office of Education. From the start of their collaboration in 1962 until 1968, Bliss and Linvill pieced together a reading machine development program by managing resources provided to the Stanford Electronics Laboratories by the Office of Naval Research and the National Institutes of Health, combining them with funding to SRI from NASA and the Air Force. These various research projects advanced not only the individual interests of their patrons, but also contributed to the development of a reading machine for the blind, thus achieving good leverage of small grants from the Rehabilitation Services Administration and Seeing Eye, Inc. Up to this point, the patchwork approach followed by Linvill and Bliss to fund reading machine research was similar to that followed by Haskins Laboratories, which similarly combined funds from a number of sponsors to advance their research into the perceptual basis of speech recognition.

When major support was secured from the Bureau of Education for the Handicapped in 1968, however, Bliss and Linvill took action to ensure that those research funds were converted into a capital asset. BEH funds were strategically invested in a combination of capital improvements at Stanford Electronics Laboratory, studies of perception and cognition at SRI, and engineering development at both institutions so that by the end of the grant, Bliss and Linvill were in a position to establish a commercial venture whose research costs were fully amortized. According to Linvill's 1973 report to the Office of Education, this was a deliberate strategy, worthy of emulation. "The R&D work supported by the Office of Education at Stanford University made it possible for Telesensory Systems to be established to produce and sell Optacons,"[133] he explained. For more than two years, between mid-1970 and early 1973, TSI continued to benefit from projects carried out at Stanford and SRI, including electronics research, prototype fabrication, the development of training materials, system testing, and representation at national and international conferences, as funded by the BEH grant. At the same time, the Office of Education became TSI's first customer, purchasing fifty Optacons for evaluation, and thus underwriting start-up capital for production of the Optacon in 1971. The success of the Optacon and of TSI owed a great deal to this successful brand of academic entrepreneurship and institution building, which had learned to convert federal research dollars into venture capital.

More innovative still was TSI's co-option of the blindness system through the Mellon Foundation's summer project to train Optacon teachers, followed by the Office of Education's Optacon Dissemination project. By training dozens, then hundreds of teachers in the service community to teach blind students to read with the Optacon, TSI was not only able to further capitalize the firm through the sale of a thousand Optacons, they were able to build a nationwide market through a single, centralized project. At the same time they created a continuing demand for Optacons as the newly trained teachers proceeded to teach new students. Meanwhile, TSI, individual blind persons, and the service community cooperated to create local and national programs for the purchase or finance of Optacons for individuals and institutions that could not readily afford them. As Susan Spungin recognized, the achievement of TSI was not merely the engineering development of a device, but the development of a model for modifying the blindness system to ensure the life and utility of a device.

The innovation of the Optacon was more than a success in engineering development, it was a success in the creation of new relationships between developers and users on the one hand, and between developers and institutions in the blindness system, on the other. The Optacon was successful because it was a product which worked to convert print to an accessible tactile signal. It was successful because its design was responsive to a particular social need of a particular group of blind readers, a result which followed from its developers' approach to their development practice. The Optacon was successful because Linvill and Bliss established a firm whose principal purpose was innovation of the Optacon as a commercial product. It was successful because Bliss and his colleagues worked to design not only a new device but also new institutional relationships within the blindness system, thus creating a marketplace and a market for their product where none existed before.

The Optacon was also successful because the changing role of the Federal Government and its Office of Education during the decades of the 1960s and 70s created new opportunities for researchers and developers of assistive technologies, and the possibility of a new marketplace for the products of their research. This was an opportunity which Bliss and Linvill were in a position to take, by virtue of their acknowledged position in the reading machine research community without the benefits or the commitments of PSAS's support. It was an opportunity which Bliss and Linvill helped create and shape by the series of relationships they created between Stanford, TSI and the Office of Education during the process of technology development and innovation.

In 1973, the same year that the Mellon Foundation undertook seed funding of the project for the Professional Preparation of Teachers of Reading with the Optacon at the University of Pittsburgh, another company was established for the purpose of developing and manufacturing a reading machine for the blind. This was Kurzweil Computer Products, a small business venture which exhibited surprising differences and similarities with TSI. The crucial similarity was its success at innovation of a reading machine for the blind. The next chapter considers the development and innovation of the Kurzweil Reading Machine which was the first successful recognition machine, converting print to synthetic speech.

Chapter 10. Raymond Kurzweil, Kurzweil Computer Products, and the Kurzweil Reading Machine

> ...the kind of people and the kind of organizations that deal naturally and well with basic research do not usually have the temperament or skills to handle the entrepreneurial job of bringing a device to market. The Government, for its part lacks effective mechanisms for bridging the gap between the research it supports and the finished devices that embody that research; that is to say, between research and procurement – both of which the Government does do – there is much development and testing that is done only by private industry, when it is done at all. Fortunately for the users of reading machines now and in the future, there has been this kind of entrepreneurial effort.[1]
>
> --- Franklin Cooper, Haskins Laboratories, 1984

Raymond Kurzweil and Kurzweil Computer Products, Inc., were the second group of developers to achieve innovation of a reading machine for the blind. In 1978, about seven years after Jim Bliss and TSI introduced the Optacon, Kurzweil brought to market a synthetic speech reading machine such as Haskins Laboratories had worked to develop for forty years. Unlike the developers of the Optacon, Kurzweil and his firm seem to fit the picture painted by Cooper, which draws a firm distinction between the "temperament" and practices of entrepreneurial firms and research laboratories, entrepreneurs and scientists.

Kurzweil's career and practice appear to have been exceptional in many ways: Unlike Bush, Haskins, Cooper, Linvill or Bliss, Kurzweil left MIT with only a bachelors degree. His field was computer science, not physics or electrical engineering. He was not sustained by the reading machine research community, and he did not participate in its meetings until after he had produced a prototype. He did not publish papers in scientific or engineering journals. Kurzweil's first step, not his last, was to form a corporation to support his reading machine development. Unlike any of his competitors, who remained central to their firms for decades, Kurzweil quickly moved on to new ventures, selling Kurzweil Computer Products to Xerox Corporation in 1980, just seven years after its establishment and two years after the introduction of its first commercial product.

It is easy to draw a picture of Kurzweil as an outsider, a task made easier by Kurzweil's personality and the generational differences which contribute to his cultivated image of a slightly counter-culture, highly inventive genius. Although he is less well-known to the general public, Ray Kurzweil is more readily compared to Steve Wozniak and Steven Jobs of Apple Computer or Bill Gates of Microsoft, than to Franklin Cooper or even Jim Bliss. Like his contemporaries, Kurzweil built a successful, computer-related business while abjuring the conservative image of a corporate executive, and cultivating the image of a "whiz kid," as he was dubbed by the business press. Just as the anti-establishment style and image of Apple Computer under Wozniak and Jobs contrasted with that of IBM, so did Kurzweil's style and image contrast with that of the distinguished and well-connected scientists at Haskins Laboratories. Kurzweil's brashness, self promotion, and eagerness for personal recognition did not sit well with some of his older colleagues in the field of reading machine research.[2]

And yet, underneath the visible differences between Kurzweil and his competitors, one may also find many similarities. Hans Mauch, like Kurzweil, lacked the Ph.D., and did not publish in scientific or engineering journals. Lacking an academic base Mauch, like Kurzweil, formed a business enterprise, Mauch Laboratories, to support his engineering development projects. Bliss and Kurzweil shared the experience of successful innovation. Their relationships to their firms were not as different as it might appear. Although Kurzweil sold a controlling interest in Kurzweil Computer Products in 1980, he remained active in the subsidiary's direction for another decade.[3] Bliss, while maintaining TSI's independence, nonetheless diluted his ownership over time by a series of acquisitions and mergers, ultimately leaving the firm in 1990 to pursue his interests through consulting and other new ventures.

In one way or another, most of the technologists considered here were successful entrepreneurs. Cooper was a founder and then president of Haskins Laboratories. Mauch was the founder and president of Mauch Laboratories. Bliss and Linvill founded and led TSI. Kurzweil was founder and chairman of Kurzweil Computer Products. As of January 1995, all four firms or their successors were still in business, although only two (TSI and Kurzweil's successor, Xerox Imaging Systems) were in the business of selling reading machines for the blind. In short, all of these technology developers were successful entrepreneurs, although they were not all successful at innovation of reading machines. A model which relies upon a strict dichotomy between researchers and entrepreneurs is ultimately insufficient to explain Kurzweil's success and Haskins Laboratories' failure, as it was insufficient to explain the history of the development and innovation of the Optacon by Linvill and Bliss.

Introduction

Raymond Kurzweil and his college roommate, Aaron Kleiner, established Kurzweil Computer Products in 1973 with the purpose of developing a reading machine based on optical character recognition. The Kurzweil Reading Machine (KRM) was a synthetic voice reading machine of the type envisioned by Franklin Cooper in 1945. As anticipated by Cooper, the Kurzweil reader was expensive, with a price tag of $30,000. Its principal purchasers for many years were therefore institutional customers.

Compared to his predecessors, Kurzweil's path from inception to innovation was a short one: Kurzweil Computer Products was established in 1973. A prototype reading machine was demonstrated in 1975. The technology was brought to market in 1977. In 1980, Kurzweil sold a controlling interest in his firm to Xerox Corporation for a sum reported to be $6 million.[4] After selling his firm in 1982, Kurzweil created two new businesses – Kurzweil Music Systems, which developed a computer-based music synthesizer, and Kurzweil Speech Systems, later Kurzweil Applied Intelligence, which has worked to develop voice-controlled business machines.

Before its sale, Kurzweil Computer Products was a closely-held corporation which did not use government research funds, and therefore did not prepare progress reports to a sponsoring agency. To the contrary, the firm's technical know-how represented a capital asset, valued by Xerox Corporation in the millions of dollars – a circumstance which inhibited the publishing of technical reports in the scholarly or engineering press.

The swiftness of the development process at Kurzweil was such that by the time the firm became known to the research community, it was on the verge of success, and that success soon resulted in the demise of the community. Only one article describing the Kurzweil Reading Machine (KRM) appeared in the *Bulletin of Prosthetics Research*, in spring 1977. The article, co-authored by Kleiner and Kurzweil, was apparently extracted by Eugene Murphy as part of the price for his support for a VA purchase of three KRMs. Also in the spring of 1977, Kurzweil attended the Smith-Kettlewell Sensory Aids Workshop in San Francisco, co-sponsored by the VA and the Department of Health, Education and Welfare, which was also a customer for KRMs.

This one article and these published proceedings comprise the contemporary literature from the reading machine research community on the development of the Kurzweil reader. In 1978, largely as a result of Kurzweil's success, PSAS terminated its reading machine research program. No further reading machine research conferences were held. As a consequence, the research reports, technical articles and conference proceedings which document the development of other reading machines do not exist to support a history of the Kurzweil reader. In contrast to the case for Haskins Labs, Mauch Labs, and even TSI, published sources for the development of the Kurzweil reader are found almost exclusively in the general business press and the emerging popular press devoted to personal computers. An important additional source is Kurzweil's speech to the 1975 annual conference of the National Federation of the Blind, which was published in the September 1975 volume of *The Braille Monitor.*

Within these limitations, this chapter seeks first to explore certain social aspects of the development of the Kurzweil Reading Machine, with special attention to the similarities and differences in the practices of Kurzweil and his predecessors. It next describes the design of the Kurzweil reader and the factors which influenced that design, insofar as they can be recovered. Then, it addresses how the Kurzweil Reading Machine was brought to market, and its evaluation by the expanding service community. The final section considers the reasons for Kurzweil's success where other developers failed to achieve innovation of a synthetic speech reading machine.

Origins

In part, the differences between Kurzweil's approach to technology development and that of his "peers" were generational. Kurzweil was a baby-boomer who embraced the interests of his generation. Jim Bliss, the next youngest of the developers, was born in 1933. He completed his doctorate in 1961, five years before Kurzweil enrolled as an undergraduate at MIT. Franklin Cooper was born in 1908, and completed his doctorate in 1936. Any of the other members of the reading machine research community could have been Kurzweil's teachers, although Kurzweil, by temperament, was not one to play the role of humble student or apprentice. Born in 1947, Kurzweil was of a generation with Steven Wozniak and Steven Jobs and like them, he was an icon of the computer age, a status acknowledged by the IEEE's Association for Computing Machinery (ACM) when it awarded Kurzweil its Grace Murray Hopper Award in 1978. This award is made to "the outstanding young computer professional of the year," on the basis of a "single recent major technical or service contribution," made before the age of thirty.[5]

During the 1980s, the business and popular science press carried a series of articles on Kurzweil, dubbing him, "Chipmaster,"[6] "Mister Impossible," "Boy Genius,"[7] and of course, "Whiz Kid."[8] From these articles, we learn that in 1960, at the age of 12, Kurzweil developed computer software for statistical analysis which was distributed by

IBM Corporation. At age 16, he won first prize in the International Science Fair for his computer program that analyzed the patterns in musical compositions and then composed new melodies according to the pattern. The popular press was amazed by a machine that "composed like Mozart," though Kurzweil demurred, saying his program was no better than a second-rate 18th century composer. Later, as a sophomore at MIT, Kurzweil developed a computer program that matched students to colleges, which he sold to Harcourt Brace Jovanovitch for more than $100,000.[9]

The picture which these biographical articles sketch is that of a talented and ambitious young man, as yet undisciplined and lacking a clear sense of direction, who, through youthful exposure and zeal, in some ways knew more about computers and programming than did his teachers. His early successes were individual achievements. As a largely self-taught member of the first generation to grow up with computers, Kurzweil felt ready to take on the world armed with his own talent and a bachelor's degree.

For two years, Kurzweil drifted, working as a computer consultant, and looking for the right opportunity to apply his skills and interests in pattern recognition, formed before high school and reinforced at MIT. When he decided to undertake the development of a reading machine, sometime in 1972 or 1973, Kurzweil was not interested in a basic research objective, such as understanding the ways that articulation encodes information in spoken language. Nor was he primarily seeking some way to improve the lives of blind people. Kurzweil's principal goal was to find a rewarding way to apply his knowledge of computer-based pattern recognition.

In 1972, multi-font optical character recognition represented an outstanding problem in the emerging field of artificial intelligence. It was a problem posed by Professor Marvin Minsky to his class in artificial intelligence at MIT, when Kurzweil was a student.[10] After graduation, Kurzweil returned to the problem, convinced that he could solve it. Kurzweil acknowledged Minsky's influence in several interviews,[11] but apparently he was not influenced by or even aware of the work on reading machines being conducted by Samuel Mason, Robert Mann and others at MIT. When, two years after graduating from MIT, Kurzweil decided that he could solve the problem posed to his class by Professor Minsky, he did not seek a government grant. Rather, he sought venture capital from his family, friends and associates, including Aaron Kleiner, his former college roommate.

In the 1970s, venture capital was available to those who could take advantage of it. Kurzweil was on the leading edge of a generation of bright, young people who would turn their knowledge of and love for computers into high-technology, small-business ventures, using other people's money. Like Kurzweil Computer Products, many small, computer-related firms were founded on venture capital and later sold to a larger company or, through a stock offering, to the public. But whatever his temperament or preference, Kurzweil's pursuit of an entrepreneurial approach must be attributed, in part, to the fact that government research grants were not realistically available to him. He lacked the primary credential for such a grant, namely a Ph.D. from an accredited university. Lacking the credential or any professional association with a university or industrial research laboratory, Kurzweil had no credible basis or standing for seeking a federal research grant or contract. Later, in the mid-1980s, partly because of the successes of small business technology developers such as Kurzweil, the U.S. government would establish a small business innovation research (SBIR) program to encourage and benefit from the capabilities of small business firms. But in 1972, no such program existed.

At any rate, Kurzweil did not yet have a small business firm. Having decided to attack the problem of text-to-speech conversion as an area of personal interest, Kurzweil first formed a corporation to serve as a vehicle for raising capital and supporting a team to work on the problem. Because of the need to show potential investors a return on investment, Kurzweil's firm had to be product-oriented from the start. Where Professors Linvill and Bliss could develop a prototype reading machine and then capitalize on the design to establish a firm to produce it, Kurzweil capitalized a firm in order to assemble the resources necessary to develop a design and build a prototype reading machine.

Kurzweil Computer Products, Inc.

All of the other American developers of reading machines for the blind depended upon federal government research funds for their technology development programs. In the 1940s, Haskins Laboratories and RCA were funded by the Office of Scientific Research and Development (OSRD). Beginning in the 1950s, the VA's Prosthetic and Sensory Aids Service (PSAS) funded the projects undertaken by Battelle Memorial Institute, Mauch Laboratories, and Haskins Laboratories. There is no reason to believe that any of these firms would have pursued reading machine development in the absence of federal funding. In fact all of them stopped their research when federal funds disappeared. It is possible to believe that Bliss and Linvill would have pursued their development of the Optacon in the absence of federal funding, but federal support to research was their familiar way and they followed it. For the pair from Stanford, federal grants were a well-known path to securing research and development support. It was the path of least resistance.

In contrast, Raymond Kurzweil's reading machine project received no federal research support during the initial development phase. That path was not realistically available to him. Kurzweil was unknown to the research and development community. He lacked the proper credentials to survive a peer review. He had no prior experience on successful projects in support of federal agencies. His firm, Kurzweil Computer Products, was formed for the purpose of developing a reading machine, and had yet to produce anything. In short, if Kurzweil was to secure funds for developing a reading machine, they would have to come from some source other than the federal government, until such time as he could demonstrate a working prototype.

Kurzweil first sought financing for his project from family and friends. Key among these was Aaron Kleiner, his former roommate at MIT. Kleiner, who was working for Johnson & Johnson Corporation in 1973, not only made a personal investment in his former roommate's idea and talents, he also approached the development arm of Johnson & Johnson, seeking their investment. In the event, Johnson & Johnson provided $33,000 in seed money toward the building of a prototype reading machine.[12] According to Kleiner, Kurzweil's total capitalization was $200,000, most of which came from the principals, their parents, and other relatives and friends.[13]

Kurzweil's initial efforts were not aimed specifically at a machine for blind readers, but at a general proof of concept for a computer-based machine which could convert print to text. One use for such a machine might be as an aid to blind readers. Another application was the commercial sorting of printed documents such as checks or mail. Few details are available, but it was the conclusion of the firm's corporate backer, in 1974, that the initial Kurzweil prototype failed to prove the concept. It was Johnson & Johnson's decision to withdraw its support that led Kurzweil to narrow his effort and direct it toward a reading machine for the blind.

Kurzweil's decision depended on two factors: First, unlike their corporate sponsor, Kurzweil's technical staff were themselves persuaded of the soundness of their concept and of their ability to demonstrate it in a prototype device. Second, the members of that development team were willing to forego immediate compensation with the goal of developing a reading machine that could help blind people, where they were unwilling to do so for the goal of financial return alone. Aaron Kleiner told the story this way:

> There was a moment when we had to give one or the other a priority. What happened is that J&J in its initial evaluation gave us money to build a

> prototype. We built a very crude prototype. They thought it was too crude and didn't feel we were going to get anywhere with it. So they stopped funding us. At that point we had no money, and we looked at the people in the company, and we said, "What are we going to do with this thing?" Some of them said they were willing to sign on. The consensus was that the willingness of the people in the company to go forward had a lot to do with the reading machine for the blind. That was something [for which] people were willing to give up pursuing other careers and so on, understanding the financial risks to themselves in this enterprise. This was a very important fact. At that moment, it was more important that we were doing something for the blind than that it was going to be a huge financial success. I would say that that was the compelling argument at that moment.[14]

An approach to the National Federation of the Blind

In late 1974, after losing Johnson & Johnson's support, Kurzweil initiated conversations with staff members of the National Federation of the Blind (NFB) regarding their participation in the development of a reading machine.[15] This was a new experience for Kurzweil and also for NFB, which had not previously taken an active role in new technology development. Kurzweil valued NFB's participation for the information it could provide on user needs in a variety of application contexts. Some NFB staff members, in turn, saw an opportunity to practice NFB's philosophy of blindness to the benefit of its members, and perhaps an opportunity to compete with the service community as well.

Kurzweil's described his overt motives for an association with NFB in an address to its annual convention in 1975:

> There are many questions to be answered, for example: what kinds of controls should the machine have; what is the ideal configuration of the controls; how should controls be marked; what kinds of special page formats are most important; should there be special auditory cues for punctuation and what should these cues be; and there are many other questions like these. It's my firm belief that the people who can best answer these questions and who can best guide the continuation of these research efforts, are the blind people themselves who would be using the machine. [Shouts of approval and applause] I can think of no organization better suited to provide this guidance and to answer these questions than the NFB. [Applause][16]

Working with staffers Mike Hingson and Jim Gashel, Kurzweil Computer Products and NFB defined a relationship whereby the federation worked with its membership to develop and provide consumer information to the Kurzweil design team. As Hingson wrote to the membership, in 1976,

> During the course of the project we want to evaluate fully the strengths and weaknesses of this new technology. If there are limitations which can be overcome, we must know about them. The results will be compiled in a final project report to Kurzweil Computer Products, where our findings will be incorporated into future models of the machine. The study will also be available for review by others, since this type of substantive consumer participation in scientific development is truly a pioneering concept. The possibilities are exciting, and again the NFB is leading the way.[17]

But NFB brought more than a perspective of blind users to the project. They also brought money in the form of grants from philanthropic foundations for the purchase of the Kurzweil machines. At least four foundations, including the Pure Memorial Trust ($50,000), the Hearst Foundation ($30,000), and the Max Fleishmann Foundation ($100,000),[18] provided funds for the NFB to purchase five Kurzweil Reading Machines for their test and evaluation, at a cost of about $250,000.[19] It was highly unlikely that a business firm such as Kurzweil's could have secured such philanthropic funds by itself. Participation of an organization representing or serving blind people was a necessary element to persuade the foundations that their funds were well spent.

NFB was also of help in persuading federal government agencies to purchase the Kurzweil reader for evaluation. Subsequent to an endorsement of the Kurzweil machine by NFB, in 1975, the Rehabilitation Services Administration (RSA) and the Bureau of Education for the Handicapped (BEH) purchased eleven machines and services to support field testing under a contract worth $655,000.[20] Following this success, Kurzweil approached the Blinded Veterans Association to secure their advocacy to the Veterans Administration. In February 1976, BVA's Board of Directors urged the VA to purchase, "...without delay," three prototype Kurzweil Reading Machines – one for each blind center – to aid in the research and development of the machine."[21] In 1977, the first KRM was delivered to Hines VA Hospital for testing by Harvey Lauer. According to Kurzweil, Jerry

Monroe, national President of the Blinded Veterans Association had been "particularly helpful in providing guidance, enthusiasm, and insightful user input" for the VA project.[22]

The National Federation of the Blind and the service community

Previous chapters have shown how reading machine developers met and exchanged information as a research community, and how that community and its members interacted with the service community, a term which has been used to signify those organizations which deliver services (and sometimes products) to blind persons. The focus has been on those persons and institutions within the service community which had an interest in the use of new technology products as assistive devices.

Among the technology-oriented organizations which comprised the service community were the American Foundation for the Blind, the American Printing House for the Blind, the Perkins School and the Hadley School, and organizations representing workers in the blindness field, such as the American Association of Workers for the Blind. The Committee on Sensory Devices followed a policy of keeping the service community at arms length (Chapter 2). Eugene Murphy reversed that policy, and sought to include representatives of the service community in the establishment of goals for the research community and in the evaluation of their results (Chapter 5). He supported reading machine research conferences which brought together members of the research and service communities. Working through the VA Blindness Centers, he encouraged the service community's evaluation of finished prototypes. Linvill and Bliss, developers of the Optacon, sought a deeper level of collaboration (Chapter 9). They involved blind readers at all stages of their development efforts, and sought opportunities to present their work in progress not only at technical conferences but also to general conferences of organizations in the service community and groups of blind individuals.

Like Bliss, Kurzweil sought to include blind readers in the development of a reading machine. Unlike Bliss, Kurzweil came to the reading machine problem with no prior experience with what has been called, "the blindness system."[23] When, in 1974, Kurzweil decided that the best course for his firm was to pursue a reading machine for the blind, he quickly sought to make contacts with organizations which represented or served blind people. According to Aaron Kleiner, the organization which expressed the greatest interest in their project was the National Federation of the Blind.[24]

It was during the 1940s and 1950s that blind persons in the United States first organized into advocacy groups at the national level. The Blinded Veterans Association, which was established in 1945, with assistance from the American Foundation for the Blind,[25] played a supporting role in the direction and validation of the VA's research programs, as described in Chapter 5. Although it was slower to take a role in technology-related fields, the National Federation of the Blind (NFB) was, in fact, a predecessor to BVA. It was formed in 1940, by the merger of six state organizations, under the leadership of the California Council of the Blind, and its president, Jacobus tenBroek.

NFB's agenda, and the impetus for its formation, was a demand for social reform in the perception and treatment of blind citizens. TenBroek, a blind scholar in the field of constitutional law, articulated a general discontent with the social status of blind persons in the United States. A common theme in the statements of tenBroek and other NFB leaders was the idea that the physical condition of blindness is less a handicap to blind persons than society's perception of blindness and the dependent roles which society ascribes to them.[26] The theme was succinctly expressed by Mary Ellen Anderson in a 1982 statement:

> The biggest problem faced by the blind today has nothing to do with vision or not seeing. The physical lack of eyesight is a nuisance – no more than that. The real problem facing the blind in the 1980s is an attitudinal one. We (all of us, blind and sighted alike) have been taught since early childhood that blindness is one of the worst things that can possibly befall a person.[27]

In addition to their general concern with the impact on blind people of common social attitudes toward blindness, NFB was directly concerned with the specific attitudes of the service sector, of what tenBroek called, "...the oppression of the social worker and the arrogance of the government administrator."[28] As might be expected, NFB was often at odds with agencies or individuals in the blindness system, including blind individuals who served as spokesmen for the service community. Matson quotes tenBroek as follows:

> For if we cannot say that "bad men" have combined against us, we can and do say that men of bad philosophy and little faith have done so – sighted and sightless men whose vision is short, whose ears are stopped, and whose minds are closed by institutional and occupational self-interest, whose banner is the wretched patchwork of medieval charity and poor relief.[29]

In 1971, three years before he committed NFB to collaboration with the Kurzweil organization, tenBroek's successor, Kenneth Jernigan addressed the service community with these words,

> If you tell us that you are important and necessary to our lives, we reply: It is true. But tear down every agency for the blind in the nation, destroy every workshop, and burn every professional journal; and we can build them all back if they are needed. But take away the blind, and your journals will go dusty on the shelves. Your counselors will walk the streets for work, and your broomcorn will mold and rot in your sheltered shops. Yes, we need you; but you need us too. We intend to have a voice in your operation and your decisions since what you do affects our lives. We intend to have representation on your boards, and we intend for you to recognize our organizations and treat us as equals. We are not your wards and there is no way for you to make us your wards. The only question left to be answered is whether you will accept the new conditions and work with us in peace and partnership or whether we must drag you kicking and screaming into the new era.[30]

As indicated by the rhetorical tone of NFB's presidents, the organization's style has often been confrontational. As a consequence, individuals and groups who were not sympathetic with its style split off from NFB in 1961, to form the American Council of the Blind (ACB), an organization that has worked more intimately with the service community.[31]

Thus, in 1974, when Kurzweil decided to concentrate his efforts on a reading machine for the blind, and therefore to seek collaboration with an organization representing blind consumers, his choices were limited. The Blinded Veterans Association was national in scope, but it represented only a small fraction of blind Americans. Although BVA had a history of advocacy for social justice and technological change for veterans, it also had associations with the Veterans Administration, and thus with Kurzweil's potential competitors. The American Council of the Blind (ACB) was a smaller organization than NFB, its parent. In 1971, ACB lacked affiliates in a third of the states.[32] Moreover, by contrast with NFB, ACB was a conservative organization, associated with AFB and the established service community, which had existing relationships with the reading machine research community and thus with Kurzweil's competitors. The National Federation of the

Blind, which claimed 50,000 members in 1974,[33] was the oldest and largest national consumer group representing blind Americans. As an organization with an anti-establishment stance, NFB had no precommitments to any reading machine developer. In fact, before 1974, NFB showed little or no interest in technology-related issues.

NFB's counterculture and activist style probably appealed to Kurzweil, who also cultivated the image and the role of the outsider. It would not have taken long for Gashel and Hingson to instruct Kurzweil in NFB's philosophy. In his 1975 address to the NFB, Kurzweil showed his audience that he was a fellow traveler:

> As an inventor, I can say that it is a real privilege and a pleasure to work with the organization of people for whom this invention is intended, especially an organization with the dedication, not to mention the enthusiasm of the Federation. [Applause] I was reading an interview with Edwin Land of Polaroid, inventor of instant photography, two days ago, and he mentioned that an inventor has two important jobs to do. The first is to make the thing work, and the second is to convince the people for whom the invention is intended that they really want the invention. Well, for my part, I've got the thing working but it is quite clear to me that no one is going to tell the National Federation of the Blind what blind people want. [Applause] Through this program, the National Federation of the Blind will tell us what blind people want. I pledge to you that I will do everything in my power to see to it that the reading machine fulfills the needs and desires of blind people as expressed by their national organization, the National Federation of the Blind. [Cheers and to applause] And that's why I've come here today. It should be our mutual goal that this program serve as a model of that kind of relationship that should exist, but rarely does, between professionals and the clients they serve.[34]

Three years later, addressing NFB's panel on technology and communications, Kurzweil showed that he was prepared to render more than lip service to these ideals. *The Braille Monitor* observed, "Mr. Kurzweil discussed the progress his company has made in hiring blind persons and in familiarizing his staff with the philosophy of the Federation. Ten Kurzweil employees were present at the convention."[35]

It probably would have been impossible for Kurzweil to work closely with both NFB and ACB as he sought to develop his reading machine in the mid-1970s. At the time, the two organizations were in open conflict. In June 1972, a group of eighteen blind Iowans had filed suit against NFB President, Kenneth Jernigan, who was Director of the Iowa Commission for the Blind. The litigants, all ACB members, claimed that Jernigan misused state and federal funds by promoting the activities of NFB.[36] The attorney for the group was the Washington representative of ACB.[37] This circumstance so angered Jernigan that he published correspondence in *The Braille Monitor* stating that it had become a moral issue that NFB members not hold simultaneous membership in ACB. Jernigan compared the struggle between the two organizations to the Cold War between the United States and the Soviet Union, and to the hot war between the U.S. and Nazi Germany,[38] leaving no doubt as to which side he equated to the Nazis. Ultimately, the suit was dismissed by its judge, who ruled that Jernigan's participation in NFB activities were discretionary and consistent with his duties according to the charter of the Iowa State Commission on the Blind.[39]

During this period of high antipathy, NFB leaders characterized ACB as an agency by which the service community controlled blind people – a sort of a house union, so to speak. The focus of conflict was often the ongoing debate over the legitimacy of the National Accreditation Council for Agencies Serving the Blind and Visually Handicapped (NAC), which was established in 1967, under joint sponsorship of AFB and the Rehabilitation Services Administration to provide and enforce standards for agencies within the service community. For example, an unsigned editorial in the October 1977, issue of the *Braille Monitor* made this claim:

> For 15 years, the council has depended on the support of AFB for its survival. The price for this support has been its soul. The ACB now may only speak on issues which do not threaten the stability of work with the blind as a professional field – the stability of the field as perceived by AFB. The ACB will always speak out in support of agencies accredited by NAC. Indeed it will speak in favor of any agency whose clients are seeking to reform it, and whose directors maintain close ties with AFB.
>
> This was a bargain of the conscience, and although there is no contract available for our inspection, the terms of the contract have become obvious as they have been played out again and again, at the Chicago Lighthouse, at NAC meetings, at repressive agencies across the land.[40]

This general atmosphere of competition may have been partly responsible for stimulating NFB's interest in technology-related projects. Not only did the NFB leadership decide to cooperate with Kurzweil, in 1974, but, in the same year, they also initiated an aids and appliance service to provide NFB members with assistive devices by mail order.[41] This service, in effect, meant that NFB was competing with a longstanding program of AFB, which was a $560,000 annual business in 1972.[42]

NFB discontinued its aids and appliances service after only a year. According to NFB, the service was terminated because of its popularity! According to the announcement in the *Braille Monitor*,

> The prime purpose of the Federation must continue to be what it has always been: To provide a means for concerted action by the blind in expressing their views and solving their problems. The Federation should work with agencies and strive to help them give better service, but it must not become an agency itself. This would deprive it of its unique character as the voice of the blind of the nation. As long as the sale of aids and appliances was a sideline, an incidental part of the larger operation, the result was constructive. However, events of the past few months make it clear that the sale of aids and appliances (if permitted to go unchecked) could become the principal focus of the national office of the Federation. This cannot be allowed to happen. The consequences to the blind would be disastrous.[43]

If we take this explanation at its face value, it would appear that the NFB leadership valued its role of social and political criticism to the point that it would forego the provision of a valuable service to its membership in order to focus on that role. At any rate, NFB leaders believed such a rationale would be persuasive and acceptable to its members.[44]

It is impossible to conclude that NFB undertook the Kurzweil project as part of a new agenda to recruit technology to the service of social change. Such a conclusion is not supported by its other activities or the decisions which NFB made at the time, nor was it part of the rhetoric of the day. On the occasion of the formal announcement of the Kurzweil Reading Machine to the press, in January 1976, Jim Gashel made the point clearly, in a statement to a reporter from the *New York Times:*

> James Gashel, head of the federation's office in Washington, said that reading machines merely attacked one of the physical problems of blindness and called them "just one of the breakthroughs we need for equal opportunity."
>
> The extra opportunity provided by such machines, Mr. Gashel said, must be "coupled with a new social attitude."
>
> He added, "We don't believe the primary problem of blindness will be solved by technology. The real problem of blindness is not the blindness itself but the misunderstanding of other people."[45]

Later, in an interim progress report, the NFB staff described the value of the Kurzweil project in a way which emphasized not the value of the technology to the blind user, but the proper relationship between the blind community and the rest of society with regards to technological issues:

> Although the Kurzweil testing project will end this June, the experience gained by the Federation in this area will not go to waste. The value of large-scale consumer testing has not been lost on other producers of technical devices for the blind. We have been approached by several companies interested in setting up formal testing projects for their machines; and we are prepared to work with any firm that wants the input of its consumers. Particularly in the area of technical advances, it is far more productive to solicit the input of consumers in the development stage than to work without their input and then wonder why the result is rejected by them. We are the ones, after all, who have to use the devices.[46]

In short, NFB's approach to technology development was a reflection of its approach to service delivery, as articulated by Kenneth Jernigan in 1971: Your success and viability depends on us, the consumers. You must find ways to take our needs and perspectives into account. If you do not, you will ultimately fail. In spite of NFB's radical rhetoric and its confrontational style, this was essentially a consumerist approach which sought to establish democratic participation in the development and delivery both of services and of products.

The course of development, 1973-1976

The principal sources for tracing the development of the Kurzweil Reading Machine are two: Kurzweil's 1975 address to the National Federation of the Blind,[47] which was delivered as part of his effort to establish the NFB program which purchased five reading machines, and an article by Kleiner and Kurzweil published in the *Bulletin of Prosthetics Research* in 1977,[48] when Kurzweil was seeking to sell three machines to the Veterans Administration, which published the journal.[49] These two articles contain substantial, contemporary summaries of development efforts. They can be augmented by retrospective information from interviews which took place in later years, after Kurzweil's success. The following account draws upon the two principal documentary sources, except where indicated by other citations.

One remarkable aspect of the Kurzweil development program was its duration. Under the pressure of limited capital resources and the need to achieve a working prototype in order to attract any additional funds, Kurzweil produced a working prototype in a little over two years after he established the firm in 1973.

There is little information available on Kurzweil's 1974 prototype, beyond the fact that Johnson & Johnson's evaluation of the device caused the firm to withdraw its support from the project. As can best be determined, after a three-to-four month effort,[50] Kurzweil was able to demonstrate the separate operation of the components of a reading machine, but he was not yet able to integrate them into a system. In his address to NFB, in July 1975, Kurzweil recalled:

> About one year ago, and about one year after our organization was formed, we developed initial prototypes of both the character recognition system and the speech system. After considerable refining, last January, we integrated these two systems into a single laboratory model of the reading machine. We were able at that time to go directly from a printed page to full word synthetic speech. We have continued to refine the system since that time. On April 8, we gave a demonstration to the National Federation of the Blind, represented by Jim Gashel and Al Schlank. We are currently implementing two final features: capability to track from one line to the next automatically; and an algorithm which will separate letters that physically touch one another on the page. We hope to place test models of the reading machine in the field around the end of this calendar year....

> After the successful completion of these testing programs, which we hope will be in about two years, we hope to introduce a reading machine with a moderate production level of several hundred units.[51]

Kurzweil was a visionary and an engineering entrepreneur. The image of the prototype reading machine as he described it to the NFB convention in 1975, was partly a description of the prototype as it existed at the time and partly a description of the Kurzweil Reading Machine as Raymond Kurzweil envisioned it:

> I would like to describe the machine to you briefly. The reading machine comprises two physical units – a desk-top reading unit and an electronic control unit. The two units are connected by a flexible cable. The desk-top reading unit, which is the only unit the user interacts with, is about eighteen inches high, two feet wide, and two feet long. The electronic control unit is plugged into an ordinary 117-volt electric outlet and requires no special wiring. To use the machine the user places the printed material face down on a glass plate which forms the top surface of the desk-top reading unit and presses the start button that indicates that he is ready to start reading. After the start button is pressed, the rest is automatic.[52]

Two years later, in 1977, an NFB progress report described the 1975 device from a different perspective:

> This marks the end of a long period beginning with the first demonstration of the device by the inventor, Ray Kurzweil, to the media in early 1976, and ending with the installation of a model in roughly its finished form. It is a milestone worth noting that the original machine which occupied half a room and could only read print typed on Ray Kurzweil's personal typewriter, has now been transformed into a compact unit which can handle complicated formats and read nearly 200 typestyles. It now has the capacity to read slowly or fast and at various pitches [i.e. voices]; it will repeat words, spell words, back up a line at a time or jump back to the top of the page; it can manage pages with two or more columns; it will read or omit punctuation. The speech is easy to understand almost immediately; it can read almost any typestyle used in books or typewriters (not handwriting); and

> a capacity for skimming (skipping ahead a paragraph at a time or ahead to the next bold-print heading) is hoped to be made part of its talents.[53]

Between 1975 and 1977, Kurzweil Computer Products worked to maintain an image of a going concern selling a commercial product. Kleiner and Kurzweil's 1977 article in the *Bulletin of Prosthetics Research* (*BPR*) was vague about the number of reading machines that the firm had sold. The *BPR* article refers to a machine which was demonstrated at NFB, BVA, and BEH, in 1976, as "the fifth version of the Print-to-Speech system," and identifies the 1975-prototype described by Kurzweil to the NFB convention as the first.[54] An article in the March 1977 issue of the *Braille Forum*, reporting an earlier demonstration of the Kurzweil reader to the ACB, stated that "ten to fifteen machines" had been sold, but in a conference held at the Smith-Kettlewell Institute in March 1977, Kurzweil stated that six machines had been completed and sixteen more were in production.[55] The "fifth version" described in the *BPR* article was apparently the fifth machine to be built.

It appears that the small Kurzweil organization – about seven people at the beginning of the period and fifteen at the end[56] – was assembling its first products one-at-a-time, incorporating design improvements in each new device as it was built, and retrofitting improvements, as possible and as necessary, to the older devices in the field. Later publications grouped the reading machines produced between 1975 and 1977 into two types, the Model I and Model II, depending on the computer platform – the Model II used a newer version of Data General NOVA computer which was the system platform.[57]

By selling each of these sequential prototypes as a product, for a price of about $50,000, Kurzweil was able to convert federal funds for test and evaluation into a form of venture capital, while avoiding the loss of intellectual property rights which would have occurred under a federal research and development contract or grant. Income from the sale of each machine was applied to a set of incremental improvements to the next.

Kurzweil Computer Products sold a total of nineteen reading machines between 1975 and 1977, including eleven to the Department of Health Education and Welfare, three to the Veterans Administration, and five to the National Federation of the Blind, raising a total of about a million dollars. Thus, about three-quarters of the revenues came from federal government funds. The rest came from foundation grants to NFB. For this two-year period, Kurzweil worked to improve his design in two ways. He used information from NFB and the federal agencies to improve the KRM's human interface and its utility as a reading tool. At the same time, he continually upgraded system components, including the computer platform and the speech synthesizer, to enhance technical performance.

At the end of this phase of development, in mid-1978, Kurzweil stabilized the design of the Kurzweil Reading Machine with a new model, labeled the Model III KRM, which incorporated these improvements. At that time, Kurzweil lowered the unit cost from $50,000 to $20,000.[58] This large price reduction may be taken as evidence of a transition from development to a production stage. The Model III may thus be seen as the first production model of the Kurzweil Reading Machine. The nineteen "Model I and II" devices sold to NFB and to federal government agencies can be characterized in today's terms as beta prototypes, that is to say a preliminary design which is exposed to field testing for the purpose of learning what improvements are necessary to realize a fully-functional product. By selling these beta prototypes outright, to institutions with an interest in achieving a working reading machine for the blind, Kurzweil was able to secure the capital he needed to complete system development without incurring any obligation to dilute or surrender his intellectual property rights to a sponsoring agency. He also avoided any requirement to reveal the details of his technical successes to potential competitors through public reports to a federal research sponsor.

Kurzweil's successful business strategy can be seen as a further extension of the one employed by Jim Bliss: Bliss and Linvill developed the Optacon at Stanford University with funds provided by the Bureau of Education for the Handicapped. Based on a successful prototype, Bliss raised most of the funds necessary to capitalize a manufacturing firm, Telesensory Systems, Inc., through an advance sale of the first run of production models to the federal government for training teachers of the blind. Kurzweil extended this approach to an earlier stage of the development process, raising most of the funds to capitalize development of a manufacturing prototype KRM through the sale of machines which were labeled and sold as products, but were, in effect, beta prototypes for field testing. It should not be thought that Kurzweil sought to obscure this strategy from his clients. To the contrary, they were active participants in the strategy. As Harvey Lauer put it in 1994, "It was understood that the price included some development costs."[59]

Figure 24 presents a photograph of one of the prototype units (Model 1), as illustrated in the *Bulletin of Prosthetics Research.* The reading machine comprised two large boxes, the scanner and the minicomputer, and two smaller boxes, the controls and a speaker. The following section discusses the design of these early Kurzweil prototypes.

We then consider the role of NFB testing and that of the federal government agencies in advancing system design as manifest in 1978, with the introduction of the Model III.

Figure 24. Kurzweil Reading Machine, 1977.[60]

The Kurzweil Reading Machine: System concept and component engineering

When Johnson & Johnson withdrew its support of his reading machine project in 1974, Kurzweil decided to focus his firm's efforts on a reading machine for the blind. The result was the fabrication, in 1975, of the first "Print to Speech System," the prototype device, which Kurzweil demonstrated to NFB in order to secure its support. The 1975 prototype embodied a particular reading machine concept which guided Kurzweil's development efforts. As he described it to the NFB convention in 1975, Kurzweil drew upon his layman's knowledge of reading and of blindness to establish four criteria for a reading machine for blind readers: It must read ordinary inkprint as found in common printed material such as books, magazines and correspondence. It must be easy to use so that a reader could concentrate on the book, not the machine. It should require minimal training so that any blind person could use it. It must provide rapid reading rates.[61]

These criteria which directed Kurzweil's design of the 1975 prototype were essentially the same as those identified by Franklin Cooper and Haskins Laboratories thirty years before. What had changed were the technology base and the social context within which development and innovation might take place.

The most important change in the technology base was the commercial availability of general purpose minicomputers, such as the Data General NOVA computer, introduced in 1969, used by Kurzweil as a platform for his prototype reading machine.[62] In 1947, in order to build a spelled-speech machine, Les Flory and his colleagues at RCA had to design and fabricate electronic circuitry which functioned, in effect, as a special-purpose computer (Chapter 3). Thirty years later, Raymond Kurzweil could write character recognition software for a multipurpose computer which could be purchased off-the-shelf. The need for circuit design was largely limited to the interface between the computer and its input and output devices, and even here standard interfaces had been established by the engineering community. The Votrax Voice Synthesizer used by Kurzweil, for example, could be connected to a minicomputer via a standard RS-232 interface.[63]

An emphasis on the development of software instead of hardware distinguishes Kurzweil's technology development practices from those of Mauch and Haskins Laboratories. Mauch, as we saw in Chapter 7, had to design integrated circuitry for the Cognodictor and arrange to have them custom-manufactured. Kurzweil's ability to fabricate a prototype reading machine in only two years, for a total cost of less than \$260,000,[64] must be attributed, in part, to his ability to purchase off-the-shelf processing circuitry in the form of a minicomputer. Not only were general purpose minicomputers more affordable than custom-built components, they could be programmed and reprogrammed without the need to rewire, redesign, or replace single-purpose circuits, as prototypes were modified and improved.

Mauch, it will be recalled, hired a young electrical engineer, Glendon Smith, in 1963, in order to secure technical expertise in the design of integrated circuitry, as the electrical engineering design skills learned by Mauch during his pre-war education and apprenticeship became obsolete. Ten years later, Kurzweil brought to the task of reading machine development a new set of skills in computer programming and a new set of concepts and techniques from the new field of artificial intelligence, just as the technology base was providing the new electronic components which could support a software-centered approach to the development of a reading machine.

During the 1960s and 1970s, Mauch and Haskins repeatedly faced situations where their latest design for a reading machine was obsolete by the time it could be built and tested, or where their state-of-the-art design for one component required a redesign of the other parts of the system. This kind of experience contributed to these developers' failure to stabilize a system design. Kurzweil clearly understood the advantages of software-based design for avoiding system obsolescence, and he consciously exploited this insight in his approach to system development and innovation. In his 1977 article for the *Bulletin of Prosthetics Research*, in a section headed, "Anti-obsolescence strategy," Kurzweil explained:

> An important design goal was to produce a high-performance (rapid, easy to use) reading machine for the blind which would not become obsolete. With continuing rapid advances in digital component fabrication techniques, the problem of design becoming obsolete by the time it is completed is a serious one. Therefore, we have implemented any information-handling process likely to change, in software. The software can and will be modified over time as the system continues to be shaken down, and as further improvements are implemented. Software changes, as they are developed, can be distributed to units in the field in the form of software update tapes, which can be loaded into each reading machine using the digital cassette tape drive provided with each unit....A final advantage is that for future production runs we can take advantage of more efficient components – new microCPUs, new memory chips – as they are introduced, without having to redesign the heart of our technology, which is primarily in software.[65]

From the perspective of 1995, Kurzweil's design philosophy may seem unexceptional, but in 1977, his insight was fresh, and its clear expression was unique among the developers of reading machines for the blind.

Kurzweil understood his reading machine design to comprise four subsystems: the scanner, the character recognition system, the speech generation system, and user controls.[66] The following subsections consider each of these subsystems as they were developed and implemented in the nineteen Kurzweil Reading Machines deployed for field testing during the period 1976 - 1977.

Character Recognition. According to Kurzweil's 1975 address to the NFB, his first focus for research and development was that of optical character recognition (OCR). In the thirty years since Les Flory at RCA designed and demonstrated the first functional letter recognition machine, OCR devices had become generally available as a component for large-scale, commercial, computer-based scanning and sorting of coded information. PSAS's reading machine research program had been predicated on the assumption that an effective OCR device would be developed in the commercial sector (see chapter 8), and in 1972, Haskins Laboratories bought a Cognitronics System / 70, for use as a front end component for their text-to-speech reading machine. But such devices were still very expensive and could process only a limited number of pre-programmed type fonts.

In late 1973, the electronics press reported a "dramatic" decline in the cost of OCR devices from over $200,000, to a lower price range of $30 - $100,000.[67] Clearly this component cost was still too high to support the development of a reading machine with an initial price in the range of $20 - 50,000, as proposed by Kurzweil.

Kurzweil questioned PSAS's assumption that the commercial sector would provide a suitable or cost effective OCR component for a reading machine for the blind. As he told the NFB convention,

> There have been for many years commercial character recognition machines on the market that are capable of scanning and recognizing printed letters. A number of researchers in the blind reading machine area have been waiting for a commercial character recognition machine to come along that would be suitable for blind persons. It has been apparent to us, ever since we started this project, that such a device is not going to come along and that a specific research effort would have to be launched to develop a character recognition system for the specifications needed for a reading machine for blind persons.[68]

Commercial applications for optical character recognition, Kurzweil explained, required ultra-high speed machines and extraordinary accuracy. The OCR component for a reading machine must satisfy different criteria: It must work with all standard type styles in a way which did not require the user to identify the font; and it must be reasonably inexpensive. This was the kind of OCR device which Kurzweil set out to develop.

Little detailed information is available on the workings of Kurzweil's proprietary OCR program. It was the rights to this element of the Kurzweil reader which led Xerox Corporation to pay $6 million for a controlling interest in the firm. A general description of the OCR system was provided in Kurzweil's 1977 article.

According to Kurzweil, the pattern recognition program took as its input a signal from the scanner, representing a two-dimensional matrix of black and white points. The program was based on the assumption that each contiguous area of black points represented a single character. A set of "feature extraction" routines searched for patterns that are relatively invariant from font to font, such as the fact that a capital "C" always includes the property of an east-facing cavity. A set of such properties, extracted from each character was then compared to a look-up table. This step provided either final identification of the character or an "ambiguity code" indicating several possible identifications to be resolved by comparison to context. A special module, called a "disambiguator," analyzed positional and contextual cues to select a final identification of ambiguous characters. As a final step, characters were collated into words and punctuation, in the form of a text string which was sent electronically to the speech generation system.[69]

Speech Generation. Kurzweil's second research focus was that of speech output. While Kurzweil concentrated on pattern recognition problems, two colleagues, Richard Brown and Steve Pelletier appear to have done much of the work on speech generation.[70] Brown, like Kurzweil, was a student in artificial intelligence at MIT. Unlike Kurzweil, he continued work toward his Ph.D., which he completed in 1980,[71] about the time Kurzweil sold his firm to Xerox Corporation.

Kurzweil rarely acknowledged his colleagues. Whether for reasons of ego or corporate image, Kurzweil kept his name at the front of all his endeavors. He encouraged, or at least accepted, a growing media myth that the Kurzweil Reading Machine was the product of the inventive boy-genius. The myth began to crumble in the late 1980s, when Kurzweil Music Systems and Kurzweil Applied Intelligence failed to replicate the astonishingly rapid success of Kurzweil Computer Products. In 1988, *Business Week* tracked down and interviewed Richard Brown as part of a debunking article entitled, "This whiz kid isn't such a whiz at business." In an attempt at journalistic balance, *Business*

Week acknowledged Kurzweil's success in securing investors for his firms and his talent as an "idea man," before reporting that:

> ...critics accuse Kurzweil of taking credit for inventions that are not his alone. The reading machine, heralded as the greatest breakthrough for the blind since the invention of Braille, was Kurzweil's idea, but its creation required considerable technical and scientific help from others. "His contribution was to say it could be done at an affordable price," says Richard H. Brown, who headed the team that built the machine and is now principal scientist at Mitre Corp.
>
> Kurzweil denies taking any undue credit.[72]

Uncovering the relative contributions of different Kurzweil staff members would be a difficult and uncertain task. Little contemporary information is available on the roles of individual members of the Kurzweil team. With rare exception, the public record does not mention Kurzweil's colleagues by name, except for Aaron Kleiner who has been Kurzweil's spokesman and advocate for over twenty years. In a recent interview, Kleiner remembered that in the period 1974-5, there were about seven employees, and that, "Ray was the primary software person at the moment. I can't think if there was another. There might have been one other. But Ray was the software guy. There was a hardware guy. There was a kind-of a manufacturing-oriented person. There was somebody that was going to try to help us get government contracts."[73]

The next available benchmark is 1979, by which time Kurzweil Computer Products had expanded to more than 100 employees, including 32 in research and development, 47 in manufacturing, and 32 in marketing and administration.[74] By this time, the scope of the firm and its product had clearly moved beyond the technical breadth of a single inventor, however talented. In 1981, the first article to appear in the popular science press reporting on the development of the Kurzweil reader credits Kurzweil with solving the character recognition problem, and Brown and Pelletier with solving the grapheme to phoneme conversion problem. The article, which was clearly based on a personal interview with Kurzweil, is the best available source providing a window on the technical role of persons other than Kurzweil.[75]

In his address to the NFB convention in 1975, Kurzweil concentrated on a description of the optical character recognition problem, before turning to the issue of speech output, explaining, "I'll only touch upon this lightly because of the time constraint." This comment might be taken as evidence that his knowledge of this area, or at least his interest in it, was secondary. Kurzweil told his audience that he had rejected spelled speech or phonetic speech, as described in the literature, as outputs for his reading machine because of the training demands they imposed on the user. Kurzweil continued,

> In this area, we have developed a system which converts letter sequences into phonetic sequences with a high degree of accuracy using only a small amount of computer memory and a minicomputer. Conversion systems centers are in a set of one thousand linguistic rules which we devised as a result of the pronunciation of English. There was, incidentally, very little of value that we were able to use in this effort in the linguistic literature. Our best source document was our *Random House Dictionary.* In addition to the phonetic rules, we have also programmed the exceptions to the rules. One last point about the speech output is that the machine does perform a relatively simple analysis of sentence structure to assign a stress contour over each sentence. We do not by any means compute full sentence parsing, that is we do not determine the part of speech for each word in the sentence but we do analyze certain syntactic features to determine the assigning of stress. The result is an intonation pattern that is more pleasing to listen to than the monotone.[76]

The absence of formal research reports and the lack of any direct reference by Kurzweil to the work of Haskins or other laboratories involved in the development of synthetic speech make it difficult to evaluate Kurzweil's claim that his research team considered and dismissed the value of "the linguistic literature" for constructing its text-to-speech algorithms. It may be that Kurzweil failed to appreciate the amount of research that was embodied in the Votrax phonetic voice synthesizer which, like the NOVA minicomputer, he employed as an off-the-shelf component.

In his 1977 article for the *Bulletin of Prosthetics Research,* Kurzweil explained that the speech synthesis component of the Kurzweil Reading Machine consisted of a set of 1,000 phonetic rules for the conversion of textual words to phonemes, supplemented by a dictionary for exceptional roots and common affixes. Stress contours for words were augmented by a set of primitive syntactical rules and a separate dictionary of syntactic types. This program for the conversion of graphemes to phonemes applied its rules to the text string delivered by the character recognition module, and then sent a phoneme string to "a hardware synthesizer, which is essentially a set of variable electronic filters designed to model the human vocal tract."[77]

The hardware synthesizer to which Kurzweil referred was a Votrax voice synthesizer,[78] probably the model VS-6 phonetic-input formant synthesizer.[79] Votrax synthesizers received U.S. patent protection in 1974 and 1975, just at the time that Kurzweil was fabricating his first and second prototypes.[80]

More than just a set of electronic filters, the Votrax synthesizer was, literally, a black box which accepted as input codes an eight-bit digital word and produced as output sounds similar to the human voice. Six of the eight bits in each input word defined one of sixty-four allophone symbols stored in read-only-memory (ROM) in the synthesizer. The other two bits carried one of four inflection codes. Sounds were generated according to a set of fourteen electronic outputs, controlled by an internal look-up table corresponding to the sixty-four allophone codes, as modified by the four inflection codes.[81]

The noteworthy achievement of the Kurzweil organization was to create and program a set of algorithms that operated quickly and effectively to convert a text string into a set of phonetic and inflection codes which drove the Votrax voice synthesizer, and to do so in a way that resulted in speech which could be readily understood. This was a task that Jane Gaitenby and others in the Haskins organization had pursued for many years as part of their reading machine research. It was the problem of modulating a raw phoneme string so that it was comprehended as intelligible speech. This was a difficult problem that had caused Haskins Laboratories to explore alternative approaches such as compiled or reformed speech (Chapter 8). During the period 1971-1973, Haskins Labs settled on an approach which depended on a look-up table of 150,000 words to generate a phoneme string, but their prototype required an editor to intervene when, as frequently occurred, a word was not found. Haskins Labs never did complete its work to modify phoneme stress based on sentence context. Kurzweil solved this problem at a time and in a way which made his firm one of the first to provide computers with a voice.

Kurzweil's entry into the field of speech synthesis was timely. The availability of the Votrax synthesizer simplified his design task and focused his attention on writing a program to produce phoneme strings from text, a practice which was not, in fact, well documented in the prior scientific literature, which had been more concerned with the acoustic properties of phonemes themselves.

The Votrax embodied much of this prior research in the way it generated speech-like sounds from an allophone code. As can be seen from Figure 25, reproduced from a description of the Votrax VS-6,[82] the Votrax generated audible frequencies corresponding to the formants of speech, according to the codes it received from the computer which drove it. Knowledge of the relationships between articulation and the perception of sounds as speech was a product of research conducted by Haskins Labs, Bell Labs, and other researchers in the field of synthetic speech. For example, it was Franklin Cooper and other Haskins' researchers who used the Sound Spectrograph and Pattern Playback to determine the relationships among the formant frequencies of vowels and human perceptions of consonant sounds. It was work like this which informed the makers of the Votrax what formant frequencies to send to the synthesizer's vocal tract model in order to produce sounds that listeners would perceive as a particular phoneme.

Table.... Parameters output by phoneme parameter ROM of the VS6 synthesizer

Parameter	Destination
First formant frequency	Vocal-tract model, F1 stage
Second formant frequency	Vocal-tract model, F2 stage
Third formant frequency	Vocal-tract model, F3 stage
Nasal closure	Vocal-tract model, nasal resonator
Nasal frequency	Vocal-tract model, nasal resonator
Fricative frequency	Fricative source bandpass filter
Fricative low-pass	Fricative source low-pass filter
Phoneme timing	Phoneme timer
Vocal amplitude	Vocal-source injection
Vocal delay	Vocal amplitude parameter delay
Vocal spectral contour	Vocal spectral contour filter
Closure	Vocal and fricative injection
Second formant bandwidth	Vocal-tract model, F2 stage
Fricative amplitude	Fricative source injection
Closure delay	Closure parameter delay circuit
Transition rate	Articulation and timing circuits

Figure 25. Facsimile of a descriptive table of Votrax outputs[83]

There can be no question that the Votrax synthesizer depended on the work of Haskins Laboratories, among other researchers. In Bristow's 1984 text, *Electronic Speech Synthesis,* Gagnon, Fons and Gargagliano state that the proprietary speech synthesis model employed by Votrax, Inc. of Troy, Michigan was an adaptation of the formant synthesis method described elsewhere in the text by James Flanagan, Head of the

Acoustics Research Department of Bell Laboratories.[84] Gagnon was a consultant to Votrax, who published the first description of the Votrax synthesizer in 1978. Flanagan was author of the canonical text, *Speech Analysis: Synthesis and Perception*, published in 1965, and revised in 1972.[85] Both Flanagan's 1972 text, and Bristow's 1984 text contain references to many Haskins Laboratories' technical papers and conference presentations as discussed in Chapter 8, above.

The importance of Haskins Labs' research is also clear from Flanagan and Rabiner's 1973 volume in the series *Benchmark Papers in Acoustics*. Two of six papers representing the "History and fundamentals of speech synthesis" were authored by Cooper, Liberman, and their colleagues.[86] Among the ten benchmark papers on "Speech synthesis by rule" were Liberman's 1959 paper, "Minimal rules for synthesizing speech," and Holmes, Mattingly and Shearme's 1964 paper, "Speech synthesis by rule,[87] " published just prior to Mattingly's joining the Haskins' group. Wittingly or not, Kurzweil's speech generation system incorporated in its operation the results of twenty years' research at Haskins Laboratories and that of the linguistics research establishment whose literature he belittled.

The Scanner. Although commercial scanners were readily available, the Kurzweil development team at first fabricated their own input device. The scanner was a flat-bed type, which the user operated much like a copy machine, placing the material to be read face down on a glass plate. A camera, mounted on an X-Y mover, focused an image on a linear photosensor array.[88] The scanner was housed in a box which sat atop the minicomputer, as illustrated in Figure 24, above.

The most remarkable thing about the scanner was that its developers believe it to have been the first to use charge-coupled devices (CCDs) as the photosensor. In 1945, Les Flory of RCA took advantage of a new, miniature photomultiplier tube developed for military applications to enable his design of a portable A-2 Reader (See Chapter IV). In 1975, Kurzweil employed a Fairchild CCD which was probably developed for Air Force overhead reconnaissance applications, as part of his scanner design. Kleiner recalled,

> "We used this very strange CCD, that Fairchild couldn't even believe anybody was using, because it was so flaky. But we needed extremely high resolution – much higher than anything else at the time to do this because of all grades of print that we were trying to deal with. So we designed our own scanning device, along with our own X-Y mover.[89]

In short, the scanner design was driven by the need for high resolution optics which could support a character recognition program that would work with all fonts. Jim Bliss believed that the degree of optical resolution was a serious technical problem in Mauch's Stereotoner, a technology in which the human reader could compensate for some lack of resolution. In a synthetic voice machine, no user compensation was possible, and sufficiently high resolution was a prerequisite for a highly flexible and precise pattern recognition program. Working from a systems perspective, driven by the needs of the OCR component, Kurzweil chose a sensor with the highest available resolution. This was a design choice which was unnecessary for single-font commercial machines which need to discriminate among fewer than 75 different characters (upper and lower case, punctuation and numerals).

User controls. User controls were the part of the Kurzweil reader which could most directly benefit from a knowledge of users' behavior and needs. Kurzweil understood his collaboration with NFB to be directed primarily toward the design of the user interface. Addressing the NFB convention in 1975, he emphasized that information to support the selection of controls, their configuration and markings, was the first objective of the "human engineering study," to be conducted by NFB.[90] Kurzweil described a machine that could be operated by a single control:

> To use the machine the user places the printed material face down on a glass plate which forms the top surface of the desk-top reading unit and presses the start button that indicates he is ready to start reading. After the start button is pressed, the rest is automatic...[91]

Kurzweil knew the operation of the reader would not be as simple as that. He went on to describe how, using optional controls, the user could "...assume an active role in controlling the sequence of his reading while leaving the tiresome task of tracking the individual text lines to the machine."[92]

In 1975, Kurzweil apparently envisioned a control panel with as few as six controls. He may not have foreseen that by 1978, the keyboard controlling the Kurzweil Reading Machine would include more than thirty buttons (see Figure 26).[93]

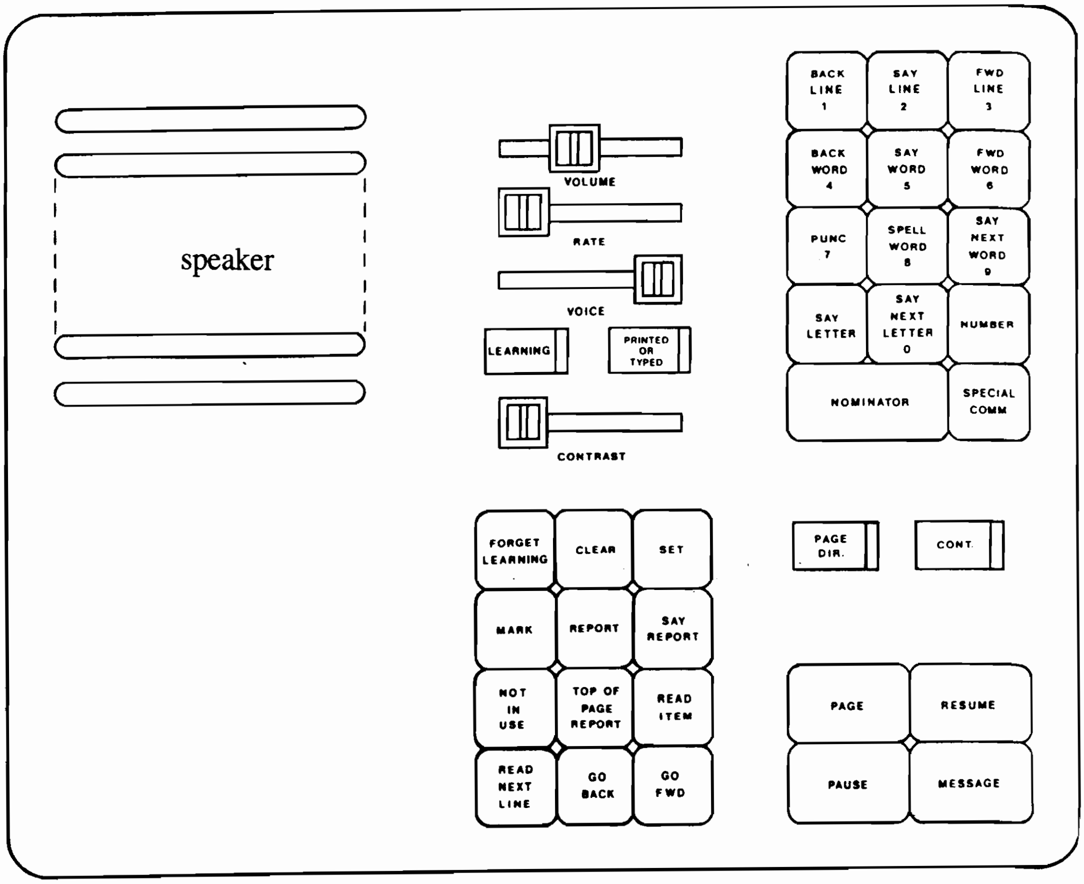


Figure 26. Keyboard layout for the Model III KRM[94]

The design of a control system presented a trade-off between functionality and ease of use. From this perspective, the proliferation of controls was a potential problem. In his discussions with Kurzweil during the period of prototype testing, Harvey Lauer of the Veterans Administrations advised that Kurzweil strive for simplicity in the controls, or at least familiarity. Writing in 1994, Lauer remembered,

> Raymond Kurzweil paid us a visit in which he described his efforts. I wanted to hear about the controls; he said they started out with six, but now felt thirteen would be needed. When they ended up with 39 keys and knobs on their keyboard, I pleaded for a Qwerty [standard typewriter] keyboard, but they never considered it, alleging that it would be intimidating.[95]

Between 1975 and 1977, Kurzweil's concept and design of a control system for the KRM changed from one of simplicity – ideally a single button – to one of enhanced functionality. This progression is counter-intuitive. It's occurrence might lead us to suppose that technical constraints or a technologist's delight in a machine's capabilities led Kurzweil to minimize the interests of potential users. Apparently this was not the case. To the contrary, the proliferation of controls between 1975 and 1977, represented, at least in part, a perspective provided by the NFB members who tested the Kurzweil prototypes.

NFB's evaluation of the Kurzweil Reading Machine

The National Federation of the Blind (NFB) claimed a large degree of ownership in the Kurzweil technology. In June 1977, for example, the NFB staff reported to its members,

> It is also worth noting that the final development of this machine has been coordinated by the National Federation of the Blind. We obtained the grants to support the project, and we have provided constant liaison to Kurzweil Computer Products, the inventor's company in Cambridge, Massachusetts. It is proper that the organized blind should be in the forefront in this way, for this project will benefit all of the blind, and the blind of future generations.[96]

This interim report provided some details on the ways NFB participation influenced the design of the Kurzweil reader. Noting the wide press coverage given the Kurzweil reader in January 1977, including a demonstration on NBC's Today Show and syndicated reports by the Associated Press and United Press International, the NFB article continued:

> What the press often missed, but which is an essential point to the blind, is that the Kurzweil machine has been developed with the active involvement of the blind. Its usability has increased immensely as a result of this immediate and direct feedback from blind persons associated with the project. It was this involvement, for example, which led to the realization that straight reading was nowhere near sufficient, that the ability to stop, back up, spell, and pronounce punctuation were necessary to scholarly work, and many other kinds of work. It was discovered that the machine could not read photocopies – a major problem since at least half of all business reading is copied material.

> The machine can now read photocopies. A drawback to other print-translation devices, developed without active consumer involvement, has been their limited number of uses. As hundreds of blind people put in hours with this machine, its capabilities will undoubtedly expand greatly.[97]

Judging from this report, the proliferation of controls for the KRM was largely a response to advice from NFB regarding a desire for enhanced functionality on the part of blind readers, together with user control of the additional functions. The report's reference to scholars and businessmen as readers serves as a reminder that the members and staff of NFB who participated in the field test may not have represented a cross section of all blind Americans, or even a cross section of NFB members.

Harvey Lauer's preference for simple controls may represent demographic differences in the characteristics and reading needs of the blinded veterans which were his primary constituency. Some evidence for this interpretation is provided by the VA's 1964 study of 851 blinded veterans, which found that 60% of blind veterans were out of the labor force, and only 4% were college graduates.[98] NFB's report of the reading needs of businessmen and scholars may have had little relevance to this group. This is not to say that the veterans were not readers. To the contrary, their reading rate (65%) was about the same as that of the general American population.[99] However, their choice of reading material and the context for their reading may have been quite different from the office environments tested by NFB. The VA survey assumed a bias toward home reading among its subjects, since it only asked if they had recently read newspapers, magazines or books. It did not ask if participants had read texts, journals, or business materials.[100]

Additional details of NFB's contributions to the KRM were provided in a final report to the membership, published in *The Braille Monitor* ten months later, in April 1978. This report is worth quoting at length, both for its content and its interpretation of NFB's role and interests in the technology development.

> The Federation's testing and evaluation of the Kurzweil Reading Machine is nearing its conclusion, and the results have been well worth the effort. The project has taken longer than expected, and this has been due to the emergence of small but difficult to correct problems with many parts of the system. Yet this is the most valuable aspect of the testing. For instance, the design of the book holder has been changed a number of times. In early

models of the machine, either the book holder would break or it would damage the books being read. It was the sort of problem not likely to concern computer engineers working in isolation in their laboratories, but it is important to blind people using the machine.

The Federation purchased five of the reading machines; and as of February 1978, 75 blind persons have used them for a total of more than 1,100 hours of reading. Heavy day-in-and-day-out use like this has enabled the Kurzweil engineers to locate problems before the machine is on the market in its final form. The difference is between a machine that startles the public with its technical sophistication and a machine that is actually useful to blind people. It is a difference that the blind know well in an age when every laboratory of advanced research in the country seems intent on producing some miracle for the blind.

The basic technology for turning print into speech has been around for several years, and a number of companies have demonstrated the use of it. What emerged as the Kurzweil machines were spread around the country and used for routine reading chores was just the beginning. As reported in the June 1977 *Monitor*, Kurzweil Computer Products had made great progress in dealing with the enormous variety of typestyles used in printed matter. Originally restricted to a single typewriter type, the machine now comprehends more than 200 different styles.

Yet it turned out that this was just the first step. The traditions of book formatting have been developing since the middle ages, and the innovators in the field never worried about what sense a machine would make of their work. Multiple columns, headings at the left or right margins, page numbers in a dozen places, pictures, graphs, and the paraphernalia of scholarly texts – all of these have proved a nightmare for the engineers. Beyond this, the mechanics of the machine have come in for extensive comment. The placement of keyboard buttons, the pressure it should take to press one down, the spoken commands, even the kinds of screws and handles that will permit easy maintenance and replacement – all of these have been tested and altered and tested and altered again.

It has been an eye-opening experience for everyone involved, but the result will be a machine that is not just a technical breakthrough but a useful tool.[101]

Later, in October 1978, after the appearance of the Kurzweil Model III, Raymond Kurzweil acknowledged NFB's contribution:

> The new desktop model of the Kurzweil Reading Machine is the result of the guidance and very detailed input of the Federation program. Mike [Hingson] and the many others who participated worked with us on a daily basis. Mike probably knows our technical staff as well as I do. The result of this intense involvement was over 100 specific recommendations for making the machine as responsive as possible to the real reading needs of blind consumers. The new model has implemented all of this input from NFB.[102]

NFB did not prepare a formal, summary report of its evaluation of the Kurzweil Reading Machine. There is no reference to such a report in either *The Braille Monitor* or in the published literature. Apparently NFB's evaluation was continuous, ad hoc, and experiential, aimed more at providing guidance to Kurzweil's designers than data for a formal report. The NFB staff did prepare a training manual which was used by the Rehabilitation Services Administration in the course of their evaluation project. Writing in 1978, Lawrence Scadden, Director of the Smith-Kettlewell Institute's Rehabilitation Engineering Center, which conducted the evaluation of the Kurzweil Reading Machine for RSA, said, "The training manual developed by the National Federation of the Blind is considered currently the best training manual in existence. This manual, practice sheets, and taped instruction should be made available to all new KRM users."[103]

NFB worked closely with RSA and the VA during the period that all three organizations were evaluating Kurzweil prototypes. In addition to frequent, informal consultations by telephone and occasional personal meetings, staff members of the three organizations met in a two-day workshop and review, held in Chicago, in February 1978.[104]

The reports from NFB's staff to its members struck a very positive tone regarding the KRM and NFB's role in its development. The final report, quoted above, gives the impression that reiterative tests and improvements to a crude prototype resulted in a vastly improved reading machine which could meet the needs of blind readers. The evaluations of RSA and the Veterans Administration were more guarded.

Other evaluations of the Kurzweil Reading Machine, Models I and II

Both the Veterans Administration (VA) and the Rehabilitation Services Administration (RSA) adopted a cautious approach to their public statements about the Kurzweil Reading Machine. Their unspoken dilemma was the same as that faced by George Corner in 1945: How could the agencies communicate their positive hopes for the technology without creating unrealistic expectations among blind readers? At the same time, how could they express their concerns for the problems they found with the Kurzweil reader, without discouraging or even killing the precarious development program that had come closest to realizing their hopes for a general-purpose reading machine for the blind? Corner had recourse to wartime secrecy. He did not have a constituency of blind people to which he had to answer. The postwar emergence of public agencies such as PSAS and BEH which supported technology development for their constituents required communication, if not democratization of technology development efforts. The specific involvement of an advocacy group such as NFB in the development of the Kurzweil reader made the need for communication more explicit.

Like the NFB staff, many of the persons responsible for federal agencies' evaluation programs were blind. By the mid-1970s, blind professionals were increasingly in positions to serve not only as evaluators, but as administrators and spokesmen for federal agencies and the institutions supported by federal research grants. Harvey Lauer and Richard Bennett had assumed increasingly responsible roles in technology evaluation for the Veterans Administration, and their names frequently appeared as principal authors on VA reports. Dr. Lawrence Scadden, a blind scientist, was named director of the Smith-Kettlewell Rehabilitation Engineering Center (REC). Established in 1975, Smith-Kettlewell was the first of the new RECs, authorized by the Rehabilitation Act Amendments of 1973, to be devoted to sensory disabilities.[105] Scadden's institute was contracted by RSA to conduct its evaluation of the Kurzweil Reading Machine.

In his published report of the RSA evaluation, Scadden adopted a "good news / bad news" approach to the dilemma. He first reported that the evaluators agreed that most readers could achieve good comprehension of the KRM's synthetic speech without difficulty. On the other hand, he continued, RSA's vocational trainees "frequently had disappointing results," when trying to read work-related materials. Scadden explained, "Although an individual can tolerate reading errors in recreational reading materials whether produced by a sighted reader or the KRM, the blind reader cannot tolerate the same errors when required to read necessary work related material."[106]

RSA's study included a quantitative measure of the performance of twelve blind readers using a comprehension test prepared by the Educational Testing Service. Two of seven readers who completed 40 hours' practice with the Kurzweil reader achieved scores of 100% at reading rates of about 150 wpm – higher scores than they achieved after listening to taped speech. Three other readers scored as well or better on comprehension of synthetic speech as compared with taped speech, with scores in the range of 75 - 88% on the standard test. Two readers scored less than 50% on their comprehension of synthetic speech, scores which did not equal those for their comprehension of taped speech.[107]

Scadden's article also presented a summary report of the Chicago meeting of the RSA, VA and NFB evaluators of the Kurzweil Reading Machine. Again, he started with the good news: "In general, all users and trainers are very encouraged with the early model of the KRM," Scadden reported. "It is strongly believed that most individuals can and do learn to use the system effectively with optimal materials." Difficulties arose, however, when the material to be read was less than optimal, that is to say when the print quality was less than excellent and formats were other than single column, uniform text.

In particular, Scadden identified two major, systemic problems: First, effective reading speed was much lower than the 150 word per minute capacity of the Votrax synthesizer. Character recognition errors, an unreliable scanner, and problems in reading formatted material resulted in an effective reading speed of only 85 - 100 words per minute, under the best of circumstances. Moreover,

> ...technical manuals, duplicated memoranda, textbooks and other materials commonly printed with more than one column, magazines and journals, are not read with high accuracy, if at all. Unfortunately, it is these kinds of materials that are not readily available to blind readers in any other format.[108]

The second systemic problem, which interacted negatively with the first, involved the contrast control. Good performance at character recognition depended on proper adjustment of the contrast control. Too little or too much contrast reduced the OCR program's ability to discriminate among characters. Not only did a blind reader find it difficult to adjust for contrast differences which he or she could not see, low quality print and some artistic fonts could present contrast which varied across a page or even within a character. In the absence of assistance from a sighted person, a blind reader had no resources to diagnose this kind of problem.[109]

The RSA evaluation offered eleven specific recommendations for improving the Kurzweil reader, and predicted that "many of the problems identified in the evaluation process can be overcome with further research and development of the KRM." Overall, however, the report was cautious, concluding that the utility of the Kurzweil reader for vocational rehabilitation would depend on the solution of those problems and also on a reduction in the cost of the machine to the point where it could be reasonably provided to individual blind employees at their work place.[110]

The VA's evaluation was spearheaded by Gregory Goodrich, a research psychologist at the Western Blind Rehabilitation Center in Palo Alto, California. It provided a statistical analysis of OCR error rates for the three machines – a Model I and two Model IIs – tested by the VA. The VA study utilized an analysis of variance where the dependent variable was character recognition error rate. There was a matrix of independent variables which included three machines, reading each of three fonts (Elite, Pica Legal and Dual Gothic), using five reproduction methods (Carbon ribbon, cloth ribbon, carbon copy, and good and bad photocopies), with the learning feature turned on and off. The learning feature was an optional module of the character recognition program, enabled by the reader. It was meant to improve recognition accuracy by using contextual cues to "learn" the characteristics of a particular font. Use of the learning feature required additional time to expose the machine to a large sample of text before starting to read the passage of interest.

Goodrich and his colleagues found that there was no significant difference in character recognition rates between Model I and Model II machines. Differences in character recognition rates for different type styles were small, but significant, i.e., the Kurzweil OCR program dealt with some fonts better than others, but not a lot better. The quality of print had an effect which was both large and significant. Low quality print was very hard to read. In most cases, the learning feature significantly decreased error rates. The VA study found there were significant interactions between type style and reproduction method, i.e., some type styles were easier to read in low quality reproductions. There were also significant interactions between the learning feature and type style, i.e., some type styles were easier to learn than others.

These results give substance to Scadden's observation that problems in reading arose in less than optimal situations. Character recognition error rates for one-strike carbon ribbons and good quality photocopies in Dual Gothic type, with the learning feature turned on, averaged less than 1%. In contrast, the use of cloth ribbons or poor quality photocopies resulted in error rates on the order of 10%.[111] A character error rate of 1% percent would result in a word recognition rate of about 95% assuming words to be composed of five random letters, but a character error rate of 10% would lead to a word recognition rate of only 60%. Nearly half of all words would contain some error in pronunciation under these circumstances. Most errors occurred for common, lower case letters, thus increasing the problem of word recognition. The VA report noted, "Some of these errors had little effect upon intelligibility of the samples read; others noticeably decreased intelligibility."

An internal VA report from the same period provides further insight as to the effects of character errors on intelligibility. Writing in 1979, Harvey Lauer reported,

> We had often wondered why the intelligibility rate of the synthetic-speech output drops as rapidly as it does as the accuracy rate drops (or the error rate rises). For instance, at very high accuracy rates, the intelligibility rate drops proportionately as the accuracy rate drops. A point is reached, however, at which intelligibility falls almost to zero while accuracy falls only slightly. The exact rate has not yet been measured.[112]

Based on these results, the public VA report carefully concluded that the KRM could read high quality original print documents "...with an accuracy acceptable for many reading needs." With high quality copied material, "The KRM OCR error rates approached (but did not attain) an error rate judged to be sufficiently accurate for high accuracy reading...." The VA concluded that the KRM was acceptable for casual reading of high quality print, but the device could not be used with low quality print such as carbon copies or low-quality photocopies, even for casual reading.[113]

The VA's internal reports were more candid, and provided the Kurzweil organization with detailed critiques of the prototype reading machine and recommendations for improving its design. Internal VA reports also show that the VA and RSA were in close contact with one another, and with NFB and the Kurzweil organization, during the evaluation period. Harvey Lauer, for example, talked frequently with RSA and NFB researchers over the telephone. He attended the 1977 NFB convention, where he checked the performance of one of the NFB machines against that at the Hines VA Hospital.[114]

Evaluation of the Kurzweil Reading Machine by the Bureau of Education for the Handicapped lagged behind that of the other two federal agencies. A synopsis published in early 1979 reported that seven blind middle school students had each received no more than three hours exposure to the reading machine. Preliminary tests of word recognition and comprehension using standard test instruments indicated that the students quickly learned to comprehend synthetic speech on a level comparable to natural human speech. The report noted that these preliminary results "... agree with the experience of nearly everyone who has practiced with the reading machine."[115]

Like NFB, the other evaluators brought their own particular perspectives to their assessment of the Kurzweil reader. The VA, which had sponsored reading machine research for thirty years, tended to comparative evaluation. Lauer, for example, commented in one internal report that he was able to read low quality copies with the Mauch Stereotoner which he could not read with the Kurzweil reader.[116] As a result of his suggestion, a simple optical probe with audible output was added as an optional feature in later versions of the KRM.[117] The Rehabilitation Services Administration, which was responsible for vocational training of blind adults, was especially concerned with the KRM's utility in the work place and its affordability for such applications.

In summary, between 1975 and 1977, Kurzweil Computer Products developed a reading machine that could convert high quality printed text, in a variety of type styles, into highly intelligible synthetic speech. During the development process, Kurzweil worked more closely with more blind readers than any other developer of reading machines. Only the developers of the Optacon could compare in their inclusion of blind readers during the development process. Like the other developers, Kurzweil's work relied heavily on support from the federal government, although this reliance was somewhat covert in order to protect Kurzweil Computer Products' intellectual property rights in the face of government funding. Kurzweil's strategy was to sell beta prototypes to federal customers and to NFB in order that they might evaluate the technology. In this way, Kurzweil raised a million dollars in venture capital, and provided an unprecedented opportunity for user contributions to the development process. The participation of blind readers, most notably through the agency of the National Federation of the Blind, led to numerous modifications in reading machine design, especially in design of the user interface. At the same time, evaluations by important intermediary institutions, RSA and the VA, raised serious questions about the technology, based upon its utility to blind readers within particular social contexts: Given the format and print quality of documents commonly used by readers in the general society, and considering the likely social contexts wherein blind readers might wish to read a particular document, the role for a tool such as the Kurzweil reader was not clear.

Evaluators within RSA and the VA believed that reading tasks with the highest social value involved those documents which were least accessible to the KRM. These included technical publications which were highly formatted with graphs, tables, formulas and charts; and business correspondence, which typically comprised typewritten documents prepared with cloth ribbons, low quality carbon or photo-copies and hand-written memos. Recreational reading was possible with the Kurzweil reader, but even so, most magazines were not accessible since they were highly formatted. Newspapers were not accessible because they were printed on pulp paper with low quality print. Only hardcover books in a standard page format could be assumed by a reader to be readily accessible. These documents were those which were most readily available in other forms – either in braille or as a recording. It was not at all clear to these federal evaluators that the technology represented by the Kurzweil Reading Machine could be made practical and available at a cost consistent with its value to blind readers, or to the service agencies which might purchase reading machines on their behalf. This was a delicate issue, which was addressed only circumspectly as Kurzweil sought to bring a reading machine to market.

The Model III Kurzweil Reading Machine

In 1978, Kurzweil Computer Products introduced the Model III Kurzweil Reading Machine (Figure 27). Known as the Desk Top KRM, the first series of the Model III combined the scanner and computer into a single box which would fit on a large desktop. The speaker and control panel were housed in a smaller console connected to the computer by a cable.

According to a 1979 report, the Desk Top KRM was initially priced at $19,400, a substantial reduction from the $50,000 price of the Models I and II.[118] However, two 1981 reports show that the price was up to $29,800.[119] This higher price included installation, training for one person in Cambridge, Massachusetts, and maintenance of the KRM for one year. A maintenance agreement cost $210 per month thereafter. Apparently the $19,400 figure did not include these services – in 1979, the State of New York paid $25,000 apiece for 22 machines, including installation and training.[120] Assuming Kurzweil provided the State of New York with a discount for the large purchase, it is likely that any price increase was apparent rather than actual.

Figure 27. The Desk Top KRM (circa 1979)[121]

A 200-series Model III KRM was introduced in 1982, to be replaced, in turn, by the 400 series in 1984. The 200 series closely resembled the Desk Top reader, although the scanner and computer were separated into two stackable boxes. The 400-series departed from the desktop format. It incorporated a disk drive for updating software, implemented automatic contrast control, and could be connected to certain microcomputers to provide text-to-speech conversion of computer files.[122] As the Model III KRM was improved, its price remained at $29,800 until the fall of 1986, when the price of the 400 series machine was reduced to $19,800.[123] In 1988, the Kurzweil reading system redesigned as the Kurzweil Personal Reader at a cost of about $12,000. According to Harvey Lauer and Lawrence Scadden, performance was much improved. This was the first KRM which was purchased in any appreciable number by indivudual readers. Later that year, in response to competition from Arkenstone, the KRM was transferred to a microcomputer platform, at a system price of to about $7,000.[124]

Details on the sales history of the KRM are hard to come by, but it is possible to construct a general outline (Figure 28).

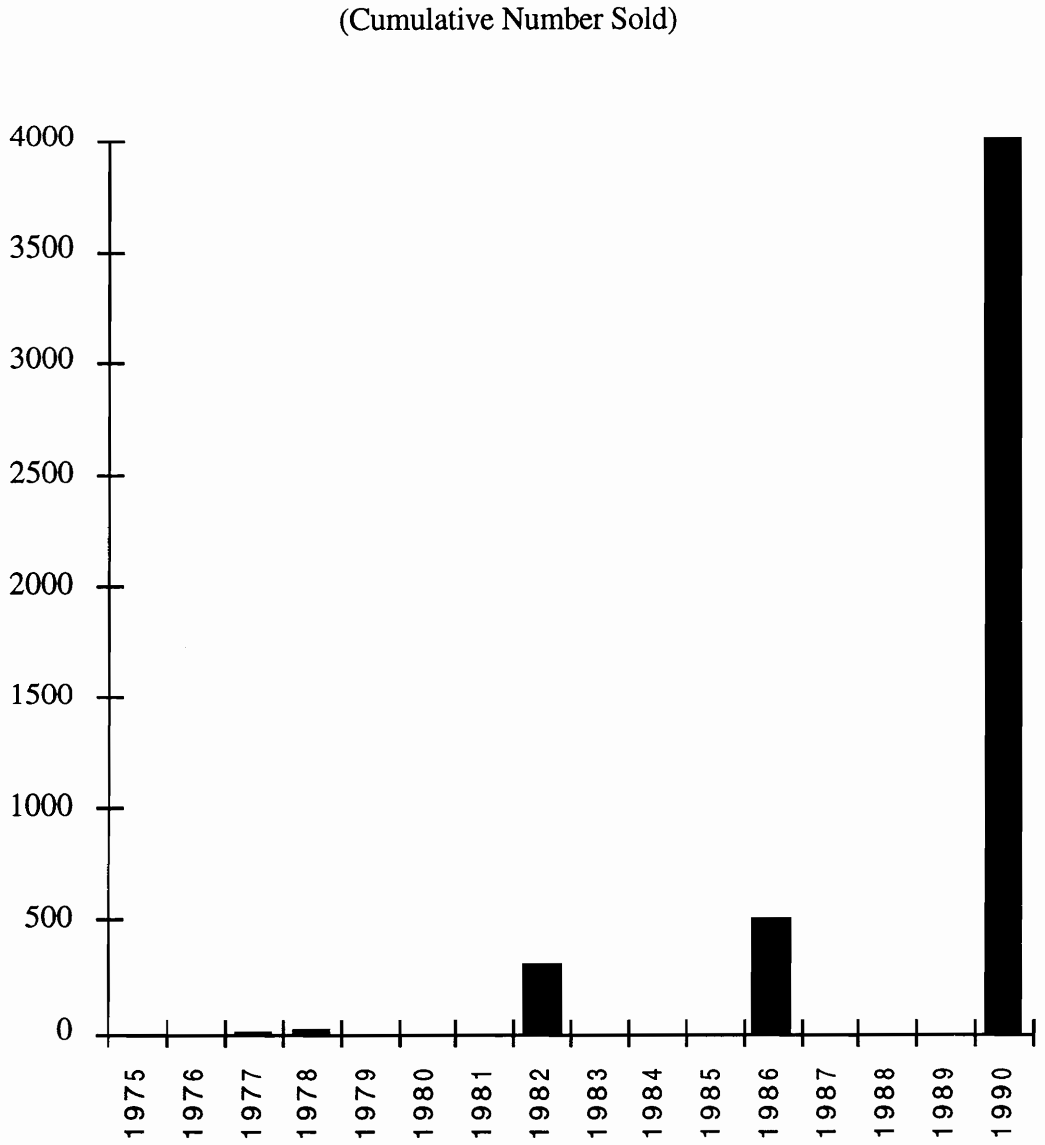


Figure 28. KRM production history

Among the earliest customers for the KRM was the New York City Public Library. In April 1978, the library purchased three machines. Later that year, the New York State legislature appropriated $550,000 to purchase and install a KRM in each of the state's twenty-two library systems.[125] Britain's Royal National Institute for the Blind and St. Dunstan's jointly acquired a machine in 1979.[126] Stevie Wonder, a popular singer who was blind, bought two machines. He was the first individual to buy a Kurzweil Reading Machine. Several years later, Xerox Corporation featured the entertainer using his

Kurzweil reader in their corporate advertising.[127] By the end of 1981, at least 92 public and university libraries in the United States had installed KRMs.[128]

In a May 1982 letter, Kurzweil put total production to date at "close to 300 machines."[129] It is unclear whether this figure included any of the 200 machines which Xerox Chairman David Kearnes had announced, in October 1981, that his firm would donate to college and university libraries across the country.[130] That announcement was made at the Helen Keller Symposium celebrating the diamond jubilee of the American Foundation for the Blind.[131] As of 1986, when prices were reduced from $29,800 to $19,800, Kurzweil Computer Products reported that, "The KRM is in use by thousands of people in over 500 locations worldwide."[132] By 1990, subsequent to another major price reduction and the release of a microcomputer-based reader in 1988, sales of Kurzweil Reading Machines totaled approximately 4,000 units.

Kurzweil did not face effective competition until the late 1980s, when other firms, including TSI, Arkenstone, and Adhoc Reading Systems, entered the market for personal computer-based reading machines. This situation was hardly a foregone conclusion. In March 1977, at the Smith-Kettlewell conference, both Mauch Labs and TSI discussed near-term plans for introducing synthetic speech reading machines. This was a year before Kurzweil brought the Model III to market, and at a time when Kurzweil had built only six prototype machines. Mauch Laboratories had been a successful business for more than twenty years, and TSI was being funded by the National Science Foundation to adapt the Optacon to include character recognition and synthetic speech.[133] Kurzweil had every reason to consider himself in a race to market the first synthetic speech reading machine.

We should not underestimate the KRM's success based on the relatively small number of sales compared to the Optacon. Five hundred machines at $30,000 equates to $15 million in sales. Xerox Corporation apparently bought 200 of these machines from its subsidiary at some discounted price,[134] but the remaining 300 sales alone would have accounted for about $9 million in external revenues during the first six years of commercial sales, exclusive of the sale of maintenance services. Total revenues generated by sales of the Kurzweil Reading Machine and the Optacon must have been similar, on the order of $10 million in the first seven years.

It cannot be said that the Model III was a success because it solved the problems identified by NFB in its evaluation project. In spite of the influence of NFB on the design of the KRM, evaluations of the Model III resembled earlier evaluations of the Model I and II prototypes. In 1981, Harvey Lauer and Leonard Mowinski, blind reading instructors with the VA, compared their new Desk Top Model III with the prototype Model I. The new keyboard, they reported, was practical and usable by blind veterans. Scanning, reading, and rereading by line, word, or letter were easily accomplished, as were adjustments to the speech output. Automatic contrast adjustment was still needed, however, and the control sequence for reading columnar material was such, that readers typically sought help from a sighted person.

The Model III was 50% faster than the prototypes, with a top speed of more than 200 wpm and an effective speed of about 140 wpm. Readers judged the speech of the new machine to be more intelligible – Kurzweil Computer Products had switched from a Votrax to a Computalker speech synthesizer. (They would later employ a Prose 5000 from SpeechPlus, Inc., a firm spun off from TSI, whose product was derived from the work at MIT.)[135] However, OCR error rates caused readers to operate the KRM at low speeds in order to facilitate their interpretation of mispronounced words based on context. Highly formatted material remained inaccessible. Reading headings and text at the top and bottom of pages presented problems. Sometimes lines were repeated or skipped. In one test, two skilled readers took an average of 55 minutes to read a single page where illustrated text was formatted in three columns, compared to 9 minutes for a comparable, single-column text. Even so, subsidiary use of a direct translation device was required. "There is no other way now for the user to independently determine which column is being read and when material is being skipped."[136]

Most important, the Model III remained unable to interpret low quality print. Nine veterans and three staff members reported that the Model III:

> ...performs satisfactorily (99 percent accuracy) on high quality text in many common fonts. However, experienced users are able to read with the machine approximately 25 percent of work-related materials they wish to read. This is an average, and means that the machine would serve well only on jobs where high-quality print and simple page formats are typical. This performance is due to the unsolved problems in optical character recognition and in the machine's handling of page formats. One hundred print samples were tested, rated, and saved. Other experience with work-related items was also logged for making the above estimate.[137]

In an internal update to this published report, Lauer added, "In our opinion, the performance has not reached the level claimed by its manufacturer which is also the level which we project would make it a useful tool for more than a handful of blind people. It would them constitute a prosthetic device to be considered for selective issuance by the VA."[138] Two years later, in 1984, the VA did approve the 400 series KRM as a prosthetic device, and purchased 85 machines between 1984 and 1986 for issue to blind veterans who needed a reader for study or at work. The first veteran to receive a KRM under this program was Ron Miller, Executive Director of the Blinded Veterans Association. As quoted by the Kurzweil organization, "Mr. Miller concedes that while it may initially be easier and faster to use the services of a reader, he says that he prefers the independence that the KRM allows."[139]

In the meantime, a growing number of libraries and blind readers were gaining experience with the Model III KRM. Their evaluations often paralleled those of Lauer and Mowinski, and their ambiguous response to the technology often reflected that of Larry Scadden's report on the prototype models. In 1981, for example, Hanan C. Selvin, a professor of sociology at the State University of New York, Stony Brook, published a comment in the AFB's *Journal of Visual Impairment and Blindness.* Selvin noted that he first learned of the Kurzweil reader in the *Braille Monitor's* transcription of Raymond Kurzweil's 1975 speech to the NFB convention. He first used a KRM during a sabbatical at St. Dunstan's in 1979, and then at the Suffolk Cooperative Library, on his return to the United States in 1980. The library had leased three machines in addition to the one purchased by the State of New York.

Dr. Selvin reported that newspapers were not readable, and that carbon copies, letters typed with a cloth ribbon, and "less-than-optimum xerographic copies" would be read badly. He experienced problems with paperback books and books printed on thin paper. It took as long as five minutes to find the first line of text in multi-column encyclopedias. The machine could not read italics, Greek symbols, diagrams, graphs, or pictures, which were common to the technical material in sociology which he most wished to read. Its mechanical voice took the pleasure out of reading fiction, when compared to talking books recorded by trained readers. And yet, Selvin asked,

> Does this mean that the KRM is at best an expensive toy, without any real value to the blind reader? *Not at all!* My point here is simply that the

> KRM should be used where the above shortcomings and difficulties are of little matter.

The Kurzweil reader, Selvin continued, could be used by scholars and students to independently scan new books, reviews and academic journals, freeing them from the need to wait until the documents were recorded for the blind. Interesting items found with the KRM could be recorded by volunteer readers. The KRM was also useful for editing a blind author's own writings. Dr. Selvin, therefore, was urging his university library to buy one, and he intended to buy a personal machine as soon as he could afford one. He concluded,

> The lesson I want to draw for the blind person about to use the machine for the first time or for those members of the "blindness system," such as teachers, counselors, and even the personnel of the Kurzweil Company, is not to exaggerate the capabilities of the KRM as the machine now exists and also not to minimize the time it takes to learn to use the KRM effectively. Ignorance of these realities has led some potential users to become disillusioned before giving the machine a fair trial. Contrariwise, I hope that providing potential users with realistic expectations will enable them to benefit as they should from the use of this wonderful device.[140]

Harvey Lauer may have disagreed with Selvin's overall assessment. Writing in 1993, he reported,

> In the eighties, the VA bought a lot of Models III and IV KRMs, well over 100, I believe. Most were bought at the end of the fiscal years. Most were issued to vets; they didn't do much good. An occasional client used his to read documents useful to him.... Our center didn't issue many Models III and IV KRM's because we showed them realistically, so most vets didn't want them. Some other centers did better at issuing them, so there were complaints about their usefulness.[141]

Libraries were the major purchasers and users of Kurzweil Desk Top readers, and, like blind users, librarians reviewed the technology for their colleagues. In 1980, Belle Weinberg of the New York Public Library noted her institution's early experience with a prototype KRM, and described how the library subsequently sought foundation grants to purchase three KRM Desk Top machines. Weinberg described how the acquisition of the KRM changed the way the library did business. "A reading machine brings an entirely new type of user into the library and involves librarians in concerns they never considered before. It has caused changes in the staff at the Mid-Manhattan and made us think about library services in a different way," she explained. Among the differences: training blind readers to use the machine (a six to ten hour job), scheduling appointments to use the machine in advance, ensuring the requested materials were on hand, and coping with diagnosis and repair of equipment problems. In addition to the 37 people trained on the prototype, which included 9 regular users, the Mid-Manhattan trained 26 readers on the Model III in a year-and-a-half, including 12 who used the machine regularly. "Fewer patrons are asking for leisure reading;" she noted, "more are students or professionals."[142]

In 1983, Eithne Cotter, a librarian at Fordham University and Emily McCarty, a colleague at Queens Borough Public Library, teamed up to describe the Kurzweil reader to other librarians in the first volume of a new journal, *Library Hi Tech.* In contrast to other evaluators, these librarians reported that the sound of synthetic speech was "in some ways...the most difficult obstacle in people's acceptance of the Kurzweil machine." "Most people," they reported, expected something closer to the human voice of talking books. Nonetheless, librarians should work through this barrier, because "Neither Braille nor talking books could ever cover the amount of material that the Kurzweil can." They suggested starting with a familiar text such as the Gettysburg Address. Eventually, it becomes clear that the authors were concerned more with the perceptions of librarians than with those of blind readers. "It is helpful," they explain, "for sighted people to close their eyes while listening since this helps avoid distractions. Many visually handicapped people have developed the ability to listen carefully and find the synthetic voice relatively easy to comprehend." Most of the article describes the operation of the control panel. The only systemic problem noted by the authors was that the keys which enable the machine to read double columns of print, "are not totally reliable." They expressed satisfaction with Kurzweil Computer Products' service, and confidence in the KRM's improvement by way of periodic software upgrades.

In 1985, Gerald Jahoda and Elizabeth Johnson, of Florida State University's School of Library and Information Studies surveyed the 103 academic members of the Association of Research Libraries to characterize the use of Kurzweil Reading Machines. Of eighty-eight libraries responding, fifty had KRMs. The survey found low use rates for the reading machines. Nine libraries reported that they had no readers. Thirty-nine schools averaged one to five readers per week, while two libraries had between six and ten blind readers per week. The authors determined that the principal explanation for these results was the small number of blind students enrolled at these institutions, combined with a preference by students for personal readers, when available. They suggested that use rates could be increased if libraries would facilitate the use of the Kurzweil machines by assisting in the identification and retrieval of documents for their blind readers.[143]

Summary and some preliminary conclusions

Raymond Kurzweil succeeded at the development and innovation of a synthetic speech reading machine where others had failed. Beginning in 1973, with the incorporation of Kurzweil Computer Products, he first obtained venture capital and then built prototypes of the optical character recognition and speech synthesis components of a general purpose reading machine. When his corporate sponsor withdrew support, Kurzweil held his small company together through appeals to their belief in the technology, and its potential to benefit blind people. This necessity caused him to refine and articulate his conceptual design for that particular application, and to build a complete system prototype of a reading machine for the blind. In 1975, Kurzweil took that prototype to the National Federation of the Blind, asking their participation in its further development and their help in securing funds for the venture.

Kurzweil's appeal was attractive to several young staffers at NFB, including Jim Gashel and Mike Hingson. These young men found the technology to be appealing in its potential to support independence among blind readers. They were eager to participate in technology development, and they saw how that participation could be framed in terms of NFB's social philosophy. They brought an aggressive, consumerist approach to the project. Kurzweil recognized the benefits of this approach to a system developer. In an intriguing way, NFB's outsider's relationship to the established service community paralleled Kurzweil's outsider's relationship to the research community. NFB and Kurzweil Computer Products were natural allies.

NFB's purchase of five machines was not sufficient to capitalize the development of the Kurzweil reader. As he established relations with NFB, Kurzweil also worked to sell prototypes to three federal government agencies. During the 1950s and 1960s, the Veterans Administration (VA), the Rehabilitation Services Administration (RSA), and more recently, the Bureau of Education for the Handicapped (BEH) had come to support both technology development and technological innovation to meet the needs of Americans with disabilities. In order to maintain intellectual property rights to his technology, Kurzweil could not seek research contracts with the development arms of these agencies. Rather, he sought sales contracts with their service-providing elements. This was the same strategy which Jim Bliss employed to establish TSI as a manufacturing firm, subsequent to development of the Optacon at Stanford. But Kurzweil escalated the approach to an earlier stage in system development. He did so with the knowledge and collaboration of the federal agencies which wanted both to encourage innovation, and to satisfy their constituents. Among these constituents were members of NFB and BVA, whom Kurzweil had sought as allies to his development strategy and proponents of his technology.

With a million dollars in revenues provided by the sale of nineteen KRMs, Kurzweil refined his design, using lessons learned from each prototype to incrementally improve the next. Insofar as possible, he worked to incorporate the advice provided by blind readers through NFB, the VA, and RSA. Experience with the KRM at BEH may have come too late to have had much impact. Both Kurzweil and NFB agreed that NFB's involvement with reading machine development was intimate and important to the design of the KRM Model III which was the first production model. Both Kurzweil and NFB were enthusiastic about the technology and positive about the results of their collaboration.

The federal agencies evaluated the KRM more rigorously. They were publicly ambiguous and privately concerned about the technology. They praised the KRM prototypes (Models I and II) for their ability to read high quality print in simple formats, and in many fonts. However, they were concerned that the business and academic contexts within which independent reading had the highest value were the least likely to present a reader with high quality, simply formatted documents. Although Kurzweil designed and redesigned the control panel, the book holder, and other elements of the user interface to meet the needs of blind readers, he did not and could not do much to solve this basic problem. The first production model, the Desk Top KRM, did little or nothing to solve the problems identified by the VA and RSA, although it did provide a faster reading speed, an improved user interface, and a more intelligible version of synthetic speech.

Kurzweil's design concept for a reading machine incorporated an appreciation for the advantages of a software-based approach. During prototype evaluation, systems in the field were continuously updated as improvements were made by providing new software which was loaded into the minicomputer using cassette tape recorders. Later, Kurzweil provided annual software updates as part of a maintenance contract, switching to a floppy disk drive in the 400 series KRM. KRM model and series changes denoted a change in computer platform. With each model change, system software was transported to a new computer platform, until 1988, when Kurzweil successfully transferred his software-based reading machine to a personal computer. By this time, the sum of incremental improvements to the KRM came close to providing the utility envisioned by Kurzweil ten years before. Meanwhile, changes in office printing technology – first daisy wheel printers with single-strike ribbons and then high resolution laser writers – worked to enhance the utility of the KRM, as its price was decreasing.

Subsequent to the introduction of the Model III, and prior to the sale of a controlling interest in the firm to Xerox Corporation, Kurzweil Computer Products turned its attention to the design and manufacture of a data-entry OCR machine.[144] It is unclear to what extent, if any, the success of the Kurzweil reader depended on subsidies from the data entry part of the business. We know that Kurzweil Computer Products never showed a net profit prior to its acquisition.[145] We know that the parent corporation donated up to 200 KRMs to university libraries. We do not know whether the sale of reading machines for the blind was ultimately a self-supporting business.

Even if the Kurzweil reader's success depended on external support, the meaning of such a fact would remain ambiguous. TSI did not have a parent company to subsidize sales of the Optacon, but it did have external benefactors, including foundations and the AFB which subsidized the purchase of Optacons by blind readers in the pursuit of their own missions and interests. If Xerox subsidized its reading machine operations in order to enhance its other business and public relations, there would seem to be little difference that would detract from Kurzweil's success. In any event, the KRM has been a successful product, showing an exponential growth curve from the fabrication of the first prototype in 1975 to a total of 4,000 sales by 1990.

Kurzweil brought to reading machine development a combination of technical skills, small-business enterprise, and a consumerist approach which distinguished his practice from that of other developers. Subsequent to his success, he was pictured by the media as an outsider, a brash and talented "whiz kid" who converted his individual genius into a personal fortune, at the expense of established firms like Xerox Corporation. Kurzweil was an outsider to the established reading machine research community until his success brought him to the attention of other developers, in early 1976. He was an outsider to the service community by lack of previous experience and by virtue of his alliance with NFB.

Kurzweil's choice of an institutional base was constrained by his lack of an advanced degree, as was his opportunity to gain entree to the reading machine research community. No academic or industrial laboratory was likely to give him the responsibility or resources to pursue a major project like the development of a reading machine. But there was also an important generational issue involved. Kurzweil was one of several talented young people of his generation who were fascinated by and became expert in computer programming, and who pursued their interests outside of the academic / industrial research establishment.

Kurzweil's place in time was an important factor to his success. He began his work in 1973, thirty years after Cooper, fifteen years after Mauch and ten years after Bliss. This temporal advantage was not a simple matter of Kurzweil's drawing upon the progress of prior researchers. Indeed, insofar as Kurzweil was aware or admitted, he did not draw upon their experience in any important, positive way. He typically acknowledged his competitors only to point out the mistakes which they had made and he had avoided. He specifically claimed that prior work in linguistics was not useful to his development effort.

Nevertheless, Kurzweil did benefit directly from the work of Franklin Cooper, Alvin Liberman and their colleagues at Haskins Laboratories. The Votrax speech synthesizer which Kurzweil used as an off-the-shelf component depended on their research. The availability of the Votrax reduced Kurzweil's text-to-speech conversion problem to one of creating and writing a computer program to convert text into an allophone code.

Similarly, the introduction of the minicomputer transformed the problem of grapheme-to-text conversion from one of electrical engineering to one of computer programming. Where Mauch Laboratories spent much of the 1960s designing dedicated integrated circuits to support his Cognodictor, Kurzweil faced no such task. The speed and flexibility of the minicomputer and its newly affordable cost made it possible to develop a reading machine by writing computer codes for multi-font character recognition, instead of designing and building expensive, custom circuits.

The use of a CCD device for an optical sensor represents a third example of Kurzweil's exploitation of emerging technologies, but this device was not, as it turned out, essential. Kurzweil selected this component to achieve the highest possible grapheme resolution, to facilitate multi-font character recognition. The limiting factor, however, proved not to be the quality of the KRM's optics, but the precision of the print being scanned. High resolution of low quality print was of no help to the problem of optical character recognition.

The availability of these new tools and his use off them in no way diminishes Kurzweil's accomplishment. After all, such tools were available to all of the reading machine developers and to anyone else who might choose to enter the field. It might be argued that their greater experience and access to funding should have given Mauch, Haskins and Bliss the advantage in exploiting these new components. But they did not.

The essential nature of any temporal advantage enjoyed by Kurzweil had two parts: First, unlike those development teams with entrenched interests in prior research, Kurzweil did not have to go through a process of abandoning an existing approach in order to embrace a new one. Secondly, Kurzweil, by virtue of his youthful interests in computer programming and his subsequent education in artificial intelligence was in some ways a more experienced practitioner than his distinguished competitors. He had, in fact, brought several pattern recognition-based programs to fruition, where his competitors had brought none. Although literally true, it is not so much the case that Kurzweil succeeded at developing a reading machine where Mauch and Haskins failed. Rather, Kurzweil mastered and pursued a different kind of practice, one which he proved, by virtue of his success, to be more adequate to the task of designing a functional reading machine.

The notion of functionality, however, is one that warrants further consideration. It would be wrong to conclude that Kurzweil succeeded at reading machine innovation simply because he developed a reading machine that worked well. As we have seen, the prototype KRM (Models I and II) did not work very well to accomplish the tasks faced by blind readers in many social contexts. Newspapers, magazines, formatted textbooks, paperback books, carbon copies and most typewritten documents were difficult or impossible to read. Nor did the Model III KRM significantly improve on the prototype in these applications. It could be argued that, at the time of its commercial debut, the KRM had some functional problems that were as severe as those faced by prototype under development at Haskins Laboratories. One important difference is that Kurzweil did not choose to work out those problems in the laboratory. Given his business constraints and need for capital, he could not. Rather, Kurzweil sought to expose a minimally functional prototype to a large number of blind readers in the field. Based on that experience, he made what improvements he could, stabilized a design, and brought it to market with the intention and the built-in capability to improve the product subsequent to its innovation.

This innovation strategy carried its own risks. As noted by Hanan Selvin and Harvey Lauer, Kurzweil was prone to oversell his product. As Lauer put it, "Company people, even its blind people, seemed to constantly overestimate the usefulness of the machines.

They fell into the habit of judging the value by what they hoped the next software release would do."[146] Lauer believed that Kurzweil's technology did not achieve a reasonable balance of function and cost before the introduction of the microcomputer-based Kurzweil Personal Reader, in 1988.[147] This judgment and the overall ambiguity of blind readers' response to the KRM was also reflected in a 1990 review of reading technologies by Judith Dixon and Jane Mandelbaum of the Library of Congress:

> During the same period [that saw the introduction of the Optacon] Raymond Kurzweil, of the Massachusetts Institute of Technology [sic.], was developing a machine that could perform the same tasks that the human brain performs when it sees print letters. In the mid-1970s, the first reading machine that could actually scan text, recognize the patterns as letters, and then speak that text was released. Expensive, slow, and inaccurate, the first Kurzweil Reading Machine nonetheless represented a major advance in the accessibility of print for blind persons.
>
> Throughout the 1970s and early 1980s, little progress was made in the evolution of machines that could read. The Optacon remained unchanged except for some minor upgrading of models. Although the price of the Kurzweil Reading Machine was reduced, the machine was still too expensive for most people....

Finally, major breakthroughs were made by both Kurzweil Computer Products and Calera Recognition Systems. Kurzweil now sells its Kurzweil Personal Reader for under $12,000. Both Kurzweil and Calera market special computer-based scanners for blind people that can read both typeset and typewritten material.[148]

The Kurzweil Reading Machine was a success because it was good enough. It was a success because of its potential value to blind readers. The KRM's limited capabilities, together with the appeal of its potential capabilities, were sufficient to persuade librarians, legislators, foundations, Xerox corporate executives, and VA service providers, among others, to buy or install a small, but exponentially growing number of machines. Although the KRM was a disappointment to some, it also attracted sufficient endorsement from blind readers to justify or defend their institutional procurement. Those readers included Hanan Selvin, Stevie Wonder, and those exceptional readers who regularly used the machines at some of the university and public libraries which installed them, There was no doubt that the KRM could read. Provide clean print in single column format, without fancy graphics or tables, and the KRM performed quite well. Thanks, in part to the participation of many blind readers in the development phase, it was easy to learn and in many ways easy to use. It produced highly intelligible synthetic speech from a large variety of type fonts. Some blind readers found it to be useful some of the time. Over the course of ten years, the price-to-performance ratio of the Kurzweil Reading Machine dramatically improved, until, thanks to Kurzweil's software-based design strategy and the emergence of the microcomputer industry, Xerox Imaging Systems could introduce the PC-based Kurzweil Personal Reader in 1988. The Kurzweil Personal Reader achieved thousands of sales and stimulated competition from other manufacturers. This convergence of the synthetic speech reading machine and the personal computer marks the beginning of a new phase of assistive technology development and the end of this historical study.

Chapter 11. Practices of Technology Development and Innovation

> What all the successful entrepreneurs I have met have in common is not a certain kind of personality but a commitment to the systematic process of innovation.[1]
>
> --- Peter Drucker, "The discipline of innovation"

The history of reading machines for the blind in the United States provides a rich domain for investigating issues of technology development and innovation. The reading machine research community was large enough to include diverse practices and a variety of competing technical approaches. Yet it was small enough to be comprehensible within the scope of a single study. Spanning more than four decades from the 1940s through the 1980s, the development of electronic reading machines occurred within an ever-changing technological context. It was a time in which transistors replaced vacuum tubes, integrated circuits replaced simple transistors, and general purpose computers came to provide an alternative to special purpose integrated circuitry.

The social context was also dynamic. The post-war United States saw a vast expansion in the legitimate roles of the federal government. Federal support, through the states, to persons with disabilities extended beyond vocational rehabilitation for injured veterans and workers to include general rehabilitation services to adults, and the education of children and youths with disabilities. The federal government established research and development programs for rehabilitation and assistive technologies in the 1940s – first as a wartime emergency action, then as a continuing program in the Veterans Administration. Congress authorized civil sector research programs in the 1950s, established technology development programs in special education in the 1960s, and, in the 1970s, created a National Institute for Handicapped Research (NIHR).

During the same time, communities of persons with disabilities organized and expanded their membership, sometimes challenging the authority of the older, service community to speak for blind consumers or citizens, and sometimes collaborating with the service community to enhance opportunities or services for disabled persons. Ultimately, this combination of social and political empowerment of persons with disabilities, programs on their behalf within the service community, the growing role of the federal government as a provider of social services and a guarantor of social access, and the emergence of innovative technologies for personal assistance and environmental access would culminate in the passage of the Americans with Disabilities Act of 1990.

Reading machines for the blind were just one kind of assistive technology to achieve innovation during this period. Powered wheelchairs, lift vans, telecommunications devices for the deaf, augmentative communications aids, and electronic travel aids, such as the laser cane, are a few of the more important innovations to be made by groups of persons with disabilities between 1960 and 1980. A consideration of the development and innovation of reading machines alone is admittedly concerned with only a part of a broader social phenomenon. And yet, broad studies must be composed of particulars, and an emerging understanding of the general themes in science, technology, and society must be grounded in historical evidence. In the field of technology and disability, there have been few historical studies of development or innovation. The nine historical studies presented here include seven case studies of technology development and two of the structure of reading machine programs. They provide a resource for beginning to address issues of society and technological change. In particular, they provide a resource for addressing issues of development and innovation within one sector of the field of assistive technologies.

The following section provides a reprise of the history presented in Chapters 2 - 10. It is meant both to summarize and to interpret that history by focusing on decisions by and relationships among individuals, organizations and institutions concerned with the development and innovation of reading machines to the end of achieving a better understanding of how the two processes were historically related.

Reprise: The development and innovation of reading machines for the blind

OSRD. Six teams of scientists and engineers worked to develop reading machines in the United States in the period from the 1940s to the 1980s. In 1943, Vannevar Bush and Caryl Haskins decided to apply the resources of the wartime Office of Scientific Research and Development (OSRD) to develop sensory aids for the blind. They justified their decision in terms of the rehabilitation of blinded soldiers, but they intended to use the combination of federal funds and scientific knowledge available to OSRD to develop technological solutions to the problems of blind people. Bush and Haskins kept close control over the program, assigning its technical management to Haskins Laboratories, appointing Bush's subordinate at the Carnegie Institution, George Corner, to head OSRD's Committee on Sensory Devices (CSD), and having him report directly to Bush.

It is apparent that Bush, Corner and the members of CSD viewed the problems of technology development as primarily technical problems to be solved by scientists and engineers. A linear model of innovation was implicit in their actions, and occasionally explicit in their discussions. Good science was to provide solutions to be captured in design by good engineering, resulting in a useful new product to be adopted by the intended beneficiaries (see Figure 29a, below).

Haskins Labs. The ways in which CSD scientists interpreted the incredible achievements of a blindfolded reader who tested the FM-slit device are especially revealing (see pp. 36 - 37). This prototype embodied Haskins Labs' initial findings that simple audible codes carried as much useful information as complex ones. The success of a single, blindfolded reader at reading print, italics, and even German texts at high speeds using the prototype device was taken at face value by these distinguished scientists because it was consistent with their understanding of the power of applied science and its role in technology development. CSD's intentional exclusion of agencies serving blind people, from its projects because of their "small concerns" and "inadequate scientific background," (p. 26) further defined their understanding of the practice of technology development.

When it was revealed that test results were fraudulent, the result of the blindfolded reader peering beneath her mask, CSD's scientists did not reconsider their understanding of technology development. Rather, they reconsidered the meaning of their scientific results. The finding that a simple tonal code carried as much useful information as a complex one was no longer taken to mean that a simple reading machine was the best. It was now interpreted to mean that no tonal code could provide a basis for a useful reading machine, and that direct translation reading machines were not a viable concept. Adopting Bell Laboratories' Sound Spectrograph as a research tool, Franklin Cooper redirected Haskins Laboratories' research toward the information content of articulated speech, abandoning any interest in direct translation machines

RCA. Meanwhile, V. K. Zworykin and Les Flory of RCA were working to design and build an improved optophone. Theirs was an engineering approach which took print as the input, a polytonal code as the given output. They applied their knowledge of radio tube and telephone circuitry to update d'Albe's WWI-era concept for reliability, portability, and ease of use. RCA's A-2 Reader worked to generate a polyphonic code from print which was more complex than that of the FM-slit device. A prototype was completed just as tests at Haskins Labs seemed to indicate an inherent superiority of the FM-slit approach. Work on the A-2 was shelved, and RCA was asked to design a C-1 Reader, based on the FM-slit prototype. The C-1 design was near completion when the fraudulent basis for its priority became known. Rather than return to the A-2, however, Haskins Labs pressured RCA to drop the design on conceptual grounds, and to turn their energies to the design of a recognition device. With some initial reluctance, Flory, Zworykin, and W. S. Pike designed and built a unique letter recognition machine. This special purpose computer may have been the first optical character recognition machine. It was completed in 1947, just as CSD funds were exhausted. The single prototype served to demonstrate the concept, but, ironically, the prototype seemed to support reading rates which were no faster than those achieved with the simpler A-2 design.

In the absence of continued federal funding, neither Haskins Labs nor RCA were interested in the business of developing reading machines for the blind. Vannevar Bush tried to secure federal support for CSD programs from the defense sector, but was able to extend the committee's funds only for a demobilization period. As anticipated by Bush, the civil sector of the federal government lacked the institutions or the authority to pursue sensory aids research. A small foundation grant kept CSD in existence as an information center until 1954, but did not provide funds for research and development projects. Zworykin and Flory wanted to pursue the A-2 design. Preliminary tests showed that blind readers could use the portable device to read at rates of 10 to 35 wpm. A few blind veterans who saw it thought that the A-2 might be a worthwhile product. But CSD discouraged Zworykin and his associates from exposing the A-2 to blind readers on the grounds that they lacked a proper perspective for judging it. Their firm, RCA, was not interested in pursuing the A-2 as a product because it was neither a mass market item nor one which could be sold at high prices in small quantities. From 1948 through the mid-1950s, reading machine development came to a standstill.

PSAS. Throughout the hiatus, Eugene Murphy, research director for the Veterans Administration's Prosthetic and Sensory Aids Service (PSAS), worked to revitalize a reading machine research program. When the National Academy of Sciences finally terminated CSD in 1954, he sought the support of the Blinded Veterans Association to provide a forum for reading machine research with an expanded membership. He brought together former reading machine researchers, academic scientists and engineers, and technically-oriented members of the service community in a series of five meetings which provided a forum for discussing the needs of blind readers and technical approaches to reading machines. Based upon a conceptual framework in the form of a reading machine taxonomy developed by Franklin Cooper, these meetings negotiated the goals and structure of a reading machine research program which Murphy was able to fund beginning in 1957. The initial availability of funds was the result of increased appropriations toward the rehabilitation of wounded Korean War veterans. The legitimacy of the continuing program, which extended for twenty-one years, was a reflection of a more fundamental policy shift, also expressed in the 1954 amendments to the Vocational Rehabilitation Act which first authorized the expenditure of federal funds for civil sector rehabilitation research.

Murphy departed from the CSD model when he sought the involvement of blind individuals and the service community in the setting of program goals. His implicit model of innovation was still a linear one, however. Once goals were established, it was the job of technical specialists to develop prototypes which satisfied the negotiated program objectives. Informed users were then to be engaged in the evaluation of the developers' success. Developers were to consider training issues and to ensure that materials and procedures were prepared to teach blind readers to use the tool which was the product of development – another advance on the CSD model. Once he had established program goals through the course of five meetings in 1954-58, Murphy did not call another for eight years. In the sixth technical session, held in 1966, Harvey Lauer demonstrated the Battelle Optophone and the Mauch Visotoner, developed under VA auspices, to the sixty attendees. It was not until this time that Howard Freiberger, who supervised the VA's reading machine program, began to address the problem of innovation in earnest, resulting in his analysis of the "deployment" of the Stereotoner in 1971.

The Stereotoner was a redesign of the 1966 Visotoner, which was an unanticipated product of Hans Mauch's project to develop an "intermediate" reading machine. Actually, Cooper's taxonomy, universally adopted by the reading machine research community, recognized two major categories of reading machines: recognition machines and direct translation devices (Figure 9, p. 84). Cooper believed the development of direct translation devices to be futile because of psychological limits to their intelligibility. But Murphy disagreed, based on the advice of Thomas Benham, and the limited experience of Wilma Donahue in training blind readers with the A-2. When RCA chose not to participate in the revived development program, PSAS contracted with Battelle Memorial Institute to redesign the A-2 Reader. Murphy asked Haskins Labs to pursue a recognition-type reading machine.

Mauch Laboratories was brought on to develop a machine which was intermediate, according to Cooper's scientific taxonomy. The concept was intermediate in the sense that its "speech-like" output should be more intelligible and easier to learn than a direct translation device, while its development path would be shorter and its cost lower than that of a recognition machine producing synthetic speech. The concept of "speech-like" sounds was a broad one, primarily made necessary by the fact that English spelling is not phonetic. According to the theory which emerged from Haskins Labs' research, partly as an explanation of the performance of the C-1 and A-2 Readers, the high level of comprehensibility of articulated sounds is a product of human evolution. Therefore, speech-like sounds, that is to say a phonemic output from printed English text, in lieu of articulated English speech, should be inherently more comprehensible than any other audible code.

Mauch Labs. Thus, while Battelle Labs designed its improved optophone, and Haskins Labs worked toward a synthetic speech machine to produce some form of standard English, Mauch was given the intermediate task of designing a reading machine to produce speech-like sounds. His first prototype used Haskins Labs' pattern playback device to generate sounds that were speech-like in that they were composed of three frequencies meant to correspond to the three formants of vowels, enhanced by the arbitrary addition of a consonant-like hiss at the end of every second letter. The three frequencies and their duration corresponded to the shape of the letter, not its English pronunciation. The result was apparently grotesque, and Mauch took the blame, although from the available information, his design would seem to have embodied Cooper's theory in a proper, if naive way. Mauch changed his design concept so that the output of the second device was prerecorded spoken phonemes. When this device was also rejected, Mauch shifted his efforts to the design of a letter-recognition device, the Cognodictor. There is no evidence that blind readers were involved in any of these decisions which shaped and reshaped the design concept and the output of Mauch's reading machines.

Mauch worked to develop the Cognodictor as a spelled speech reading machine from 1963 through 1976. To achieve character recognition, he devised an ingenious scanner which relied on photocell geometry to provide a unique signal for different letter shapes. An early prototype reportedly achieved recognition accuracies of 90 - 95% at reading speeds of 20 - 30 wpm, but this was no better than reported with direct translation machines. Unfortunately, the geometric scanner imposed impractical demands for precision tracking. A direct translation component was needed to permit a blind reader to align print, and also to distinguish graphics or to interpret numerals and symbols not included in the 32-character Baudot code. The Visotoner demonstrated by Lauer in 1966 had its origins as a direct translation peripheral to the Cognodictor.

The first regular involvement by a blind reader with the Mauch designs began in 1967, more than ten years into the program, when Bonnie Deal, née Reinecke, started working with the second recognition prototype. In 1969, the first field prototype Cognodictor was made in three copies. Mrs. Deal was given one, Mauch retained the second, and the third was given to Harvey Lauer for test by the VA. Lauer found that he could read just as fast and accurately with the Visotoner as with the Cognodictor. Rather than expose the prototype to a broader community of blind readers, Murphy and Mauch decided to focus on the Visotoner as a potential product, while sending the Cognodictor back for a redesign.

The Visotoner was the best optophone device made to date. It was more compact, reliable, and easy to use than the A-2 or the Battelle optophone. Harvey Lauer and a few other blind readers used prototype models of the Visotoner to read at speeds of 30 - 90 wpm. It was Freiberger, the VA program officer, not Mauch, who considered the problem of innovation for the Visotoner. It was the VA which undertook field testing of the Visotoner prototypes, without Mauch's direct involvement. Mauch was at work on designing an improved prototype, the Stereotoner, based on the experience and ideas of Harvey Lauer and Richard Bennett, another blind reader working for the VA.

In the interim, Telesensory Systems, Inc., established in 1970, by Jim Bliss and the Stanford research team, brought to market the Optacon, a competing direct translation concept which converted letter shapes into the tactile equivalent of a Times Square sign. As far as can be determined, the Stereotoner and the Optacon were similar in their utility to blind readers and in their difficulty to learn. In spite of the fact that the Stereotoner cost less than half as much, it failed at innovation, where the Optacon succeeded. As Margaret Butow, a blind instructor at the Hadley School, observed, if the Stereotoner were to succeed at innovation, it needed the advocacy of an organization that knew how to promote sensory aids (p. 133). Neither the VA nor agencies in the service community such as the Hadley school were in a position to promote the Stereotoner by virtue of institutional norms which prohibited them from directly advocating or marketing a particular product. Mauch's commitment was not to what Drucker called, "the systematic process of innovation," but to the practice of engineering design. Although Mauch did fabricate 35 extra Stereotoners, he did not work systematically toward their innovation. Instead, he turned his efforts to improving the Cognodictor design.

After 1973, Mauch's work on the improved Cognodictor brought him ever closer to a synthetic speech machine, as he drew upon the array of new components and concepts being developed for the growing computer industry. Before he could deliver a prototype, however, Kurzweil Computer Products demonstrated a working prototype of a synthetic speech reading machine, and, in 1976, began a program with the National Federation of the Blind (NFB) to improve its design. Mauch abandoned any pretext of intermediacy, and sought VA support to leap beyond Kurzweil with a lower cost, high performance machine, but it was too little, too late. Within two years, Kurzweil had delivered 20 machines and was entering production of the Desk Top KRM. In the face of this success, Murphy shut down the VA reading machine research program.

Haskins Labs again. While Mauch worked to reiteratively design and build a series of prototype reading machines, that were intermediate according to Cooper's taxonomy, Haskins Labs worked reiteratively to advance a set of conceptual designs for synthetic speech machines. Some of these designs were built as prototypes to provide a proof of concept, but like Mauch, Haskins neglected to include blind readers in the reiterative process in any regular or systematic way. Only when designs were nearing completion according to the judgment of the developers and the research community, were blind readers involved in the evaluation of their prototypes or results. In at least one case, this practice had avoidable, unhappy consequences for Haskins Labs.

According to Cooper's taxonomy, a logical precursor to a synthetic speech machine was one which used compiled speech, that is to say a string of prerecorded words. PSAS placed Haskins Labs under contract to build an Intermediate Word Recognition Machine (IWRM) prototype with a vocabulary of 7,200 words, while they pursued research on synthetic speech at the level of phonemes. By 1961, Jane Gaitenby had selected and recorded the vocabulary on data cards, and had spliced together paragraph-length texts, but tests of blind readers were not conducted for ten more years. In part this was an expression of a linear approach to innovation which caused Haskins Labs to postpone user testing of any sort until an advanced prototype could be evaluated by an informed user. In part it was due to the nature of Cooper's practice which relied less on the development of prototypes, and more on the development of concepts. As the IWRM prototype was nearing completion, Cooper decided that the compiled speech concept had been made obsolete by the competing conceptual design of a re-formed speech machine.

Like speech-by-rule, re-formed speech involved the manipulation of phonemes to produce synthetic speech. Like compiled speech, it involved the storage and recovery of a vocabulary of words to be retrieved from storage upon recognition. The concept involved recording and storing a phonemic representation of a vocabulary of words so that the phonemes could be modulated according to syntax to provide more natural sounding speech than a string of prerecorded words. After eight years' development (1961 - 1969), however, Cooper was forced to conclude that reformed speech was not as robust a concept as he originally thought. It required both the storage capacity of a compiled speech machine and the processing power of a speech-by-rule machine, without significant benefit in cost over the former or in performance over the latter. In 1969, therefore, Haskins returned to the compiled speech concept and began work on a computer-based compiled speech generator. When blind readers were asked to judge the utility of compiled speech output in 1971, they so overwhelmingly rejected it that Haskins abandoned the concept.

From 1971, Haskins Labs dedicated its efforts to the development of a reading machine employing speech-by-rule, based upon the progress made in that field in the previous decade – much of it by Haskins Labs and AT&T Bell Laboratories. Since 1957, Murphy and Cooper had taken the informed risk that optical character recognition (OCR) capabilities would be developed which could provide an electronic text file from printed text. This risk-taking seemed to be rewarded in 1972, when Haskins purchased a Cognitronics System / 70, from a firm that had participated in reading machine research conferences from an early date. Perhaps as a result of their experience with compiled speech, Haskins sought to include blind students at the University of Connecticut in tests of the intelligibility of college texts rendered into synthetic speech according to speech-by-rule. In 1973, the laboratory and the university made a joint proposal to the Bureau of Education for the Handicapped to create a center to operate, test, and compare a Haskins synthetic speech reading machine and a text-to-braille device developed at MIT (p. 159). In the absence of BEH funding, this field prototype was never built, and the design of Haskins' laboratory prototype was never stabilized.

It must have been a surprise to the Haskins team when, in 1975, a recent MIT graduate in computer science demonstrated a fully functional speech-by-rule reading machine. At the time, Haskins Labs was rewriting code to transfer their conceptual design to a new computer base. Their prototype still employed a person-in-the-loop to enter phonemic code for words not found in its look-up dictionary. Like Mauch Labs, Haskins worked for three more years with VA support in the hope of achieving a competing design, but to no avail. Haskins was still working to install an improved syllable synthesis program on its new computer, when Kurzweil finished two years of work with hundreds of blind readers from NFB, and began to offer the Desk Top KRM as a commercial product.

BEH. Beginning in the mid-1960s, the federal government expanded its involvement in the development and application of assistive technologies, most notably as part of its growing involvement in education. The Rehabilitation Services Administration (RSA) began sponsoring research and development in technology areas by the beginning of the decade, and in 1967, a major initiative within the new Bureau of Education for the Handicapped (BEH) provided support to the development of the Optacon by Stanford University, as one of its first major projects. Perhaps more important, the constituency of BEH was many times that of the Veterans Administration. Together with the growing number of organized blind persons in the activist NFB and its more conservative offspring, the American Council of the Blind (ACB), these federal programs provided a potential vehicle for creating a marketplace where developers, vendors and customers could meet for the exchange of information and products.

In their different ways, both Jim Bliss, co-developer of the Optacon and President of Telesensory Systems, Inc., and Raymond Kurzweil, developer of the Kurzweil Reading Machine (KRM) and president of Kurzweil Computer Products, took advantage of this potential and helped create that market place as an integral part of their development practices. The quotation from Peter Drucker's article "The discipline of innovation," which introduces this chapter, is meant to draw attention to the evidence that both Bliss and Kurzweil, unlike Mauch or Haskins, approached their technology development practices as if they should be systematically linked to the desired outcome of innovation. Since innovation inevitably involved blind readers, they sought to involve blind readers in the development process, and based their design decisions, in part, on the result. Both Bliss and Kurzweil also found ways to exploit the federal technology system to provide the financial resources necessary for innovation to occur.

The Optacon. The conceptual design of the Optacon was a result of the collaboration of Jim Bliss of Stanford Research Institute and John Linvill of Stanford University's Solid State Electronics Laboratory. Bliss had worked with the reading machine research community and established connections with the service community through John Dupress, while a graduate student at MIT, where his dissertation investigated various modes of tactile communication. Linvill, who was looking for an alternative to the laborious hand-encoding of braille texts for his blind daughter, Candy, saw the potential utility of piezoelectric reeds employed as an analog of a dot-matrix printer head. He patented his idea based on a prototype fabricated by a graduate student, at about the time that Bliss was working for the defense department to create more cumbersome tactile alphabet generators, using computer-driven air jets.

Exploiting resources from Navy and Air Force contracts and grants in general support of the electronics laboratory, with help from Candy and then from a growing number of blind high school and college students, Linvill and Bliss were determined to develop and to innovate a reading machine. Unable to persuade Murphy to further dilute PSAS funds or to abandon his commitment to Mauch Laboratories, the Stanford group secured small grants from RSA and Seeing Eye, Inc., through the auspices of Dupress. Together with their other resources, this was sufficient to the improvement of the tactile display, based on tests with blind readers, and the fabrication of a prototype device. These encouraging results helped Linvill secure a major grant from BEH. The Stanford group continued and expanded their inclusion of blind readers in the reiterative design of four additional prototypes between 1967 and 1971, with the resources provided by that grant. Both at the time and afterwards, Bliss identified the contribution of blind readers as essential to Optacon development. The technology that emerged from this process was especially compatible to the needs of blind students (and professionals), as an alternative to braille for rapid access to printed materials which were not readily available in braille format.

In 1970, Bliss and Linvill formed TSI to manufacture and market the Optacon, relying on an initial order for 50 devices at $250,000, to augment the firms meager start-up capital of $75,000. TSI continued its relationship with blind students and also relied on the services of blind employees and friends of the firm, especially for marketing and sales. The success of the firm and of the Optacon was secured when TSI collaborated with the Mellon Foundation and then the Office of Education to create an Optacon Dissemination Project program which trained teachers of Optacon teachers at the University of Pittsburgh. By 1990 over 14,000 Optacons had been sold.

Linvill saw the development and innovation of the Optacon as a new model for collaboration in innovation among government, academia and industry (pp. 203-4). Susan Spungin of AFB saw in the Optacon Dissemination Project a model for the innovation of assistive technologies. Bliss and Linvill's concept of technology development was one which systematically involved users in the development process as part of a practice that understood innovation to be a contingent outcome which depended on decisions and actions made during the development process.

The Kurzweil Reading Machine. Although Raymond Kurzweil's practices, style and temperament differed from that of Bliss and Linvill in many ways, his approach to technology development shared three important aspects in common. First, from the time he decided to concentrate his efforts on developing a reading machine for the blind, Kurzweil sought the involvement of blind readers, on a scale much larger than the Stanford group. Like Bliss, Kurzweil acknowledged the essential role of blind readers in the development process, and like Bliss, he sought blind employees to help ensure innovation after the initial development phase resulted in a product design.

Second, and by necessity earlier than Bliss and Linvill, Kurzweil structured a firm whose principal goal was not the performance of research and development contracts, but innovation. It might be argued that Kurzweil's principal goal was to profit through sale of the firm and its intellectual property to a buyer like Xerox Corporation, but Kurzweil's long association with the Xerox subsidiary after the sale, and the firm's continued dedication to reading machines for the blind as a small volume product (for Xerox), attest to Kurzweil's honest dedication to providing a reading machine to the blind – a commitment that was first made in 1974 as a means of keeping the firm together and focusing its efforts on a particular product goal.

Third, Kurzweil, like Bliss, found a way to simultaneously recover start-up costs and establish an initial market for his product through sales to federal government agencies with an interest in innovation. Lacking a reliable source of funds for development, Kurzweil did Bliss one better by persuading federal agencies and foundations to buy nineteen beta prototypes as if they were products. In this way, Kurzweil, in a sense, amalgamated the development and innovation processes, disseminating information and experience with his proposed technology to a large group of blind users, while drawing on their experience to revise and refine the design of the KRM.

Fewer details are available on the course of development of the KRM than of the Optacon, in part because of the difference in institutional context for development, and in part because of the swiftness of Kurzweil's success. Kurzweil Computer Products did not operate under a federal R&D contract and made no reports to federal program managers. An outsider to the research community until a short time before its dissolution in 1978, Kurzweil published one article and participated in one major conference in 1977.

Nonetheless, it is clear that the relatively short development period for the KRM reflected Kurzweil's ability to employ off-the-shelf components provided by an expanding technology base. Most notably, these included Data General's NOVA computer and the Votrax speech synthesizer. The general purpose minicomputer permitted Kurzweil to exercise his skills in programming and pattern recognition, and to implement key parts of his design in software. This technique reduced the capital cost of multiple design iterations and speeded up the reiterative process. It stood in marked contrast to the long cycle of circuit design and fabrication which characterized Mauch's development of the Cognodictor. The emphasis on software also enabled a business strategy which allowed Kurzweil to field the KRM at an early stage of its development, with some confidence that he could fix problems as they arose, and upgrade his product by providing users with updated software. It also meant he could improve the product by exporting its software-based design to new computer platforms as they became available. This advantage was not simply something which accrued to Kurzweil by virtue of a changing technology context, it was a systematic strategy for development and innovation, identified as such and articulated by Kurzweil no later than 1977 (p. 249).

In 1978, Kurzweil Computer Products brought the Desk Top KRM to market, and by 1982, had sold more than 300 readers with estimated revenues of $10 million. Few of these early sales were to blind individuals, rather they were purchased by institutional customers – universities, state and local governments, and corporations – for use in public and university libraries. By 1990, after moving the KRM to a microcomputer platform, more than 4,000 Kurzweil Readers had been sold, and competing firms had entered the marketplace. Where Linvill saw the development and innovation of the Optacon as a new model for collaboration among academia, industry and government, Kurzweil and NFB staff members saw their collaboration as a new model for technology developers and organizations of blind people (pp. 239 - 242).

Some patterns of development and innovation

As briefly described in the introduction to this study (p. 8), Stephen J. Kline has observed that an implicit linear model underlies much of our scholarly thinking about innovation. From the case histories considered here, we can observe that such a concept has also served as an implicit model for the practice of some technology developers. Although differing in detail, for example in their willingness to include blind readers in establishing program goals, all of the program managers and most of the technology developers considered here made programmatic and development decisions which reflect a linear understanding of technological change.

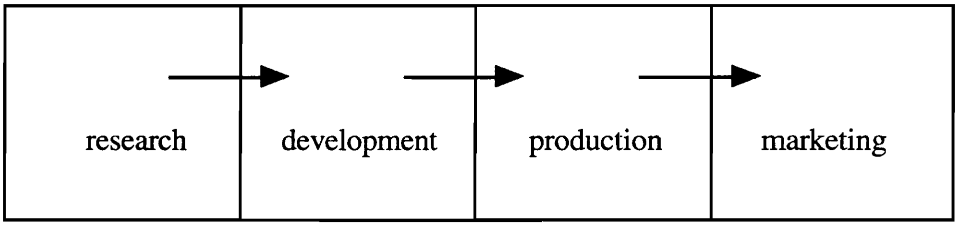
The practices of two of the development teams studied here– Raymond Kurzweil and his colleagues and the team of John Linvill and Jim Bliss – cannot be contained by a linear model of innovation. The history of their development practices and their own contemporary descriptions of their approach to development show that a different conceptual framework was being applied. Once they had formulated an initial concept for a technology in use, these two developers actively sought the participation of blind readers in testing and modifying the concept, at all stages in the development process. They included the knowledge which resulted from this collaboration in their reiterative design decisions. This is an interesting finding, because it provides historical evidence which can be employed to evaluate and advance certain theories of innovation. Successful theories should be consistent with the historical evidence and should include an explanation of why some developers succeeded at innovation and why others failed. The observation that some successful developers' practices do not fit the linear model of innovation provides additional evidence that the model is deficient.

More important is the observation, based on these few cases, that developers' concept of the nature of their practice plays a role in their success or failure at innovation. In the case of reading machines for the blind, it is not simply our finding that some developers acted according to a linear model and some did not. We also find that those who did not follow a linear model were aware that their practice was different from their colleagues and competitors, although they did not describe those differences in theoretical terms. Moreover, those who departed from the linear model succeeded where those who employed it failed. This finding is interesting from a policy perspective. It suggests that technology developers' conceptual understanding of their practice makes a difference to their likely success or failure at innovation. It further suggests that federal program managers who structure and administer technology development programs which seek innovative outcomes should encourage and promote certain kinds of practice and discourage others.

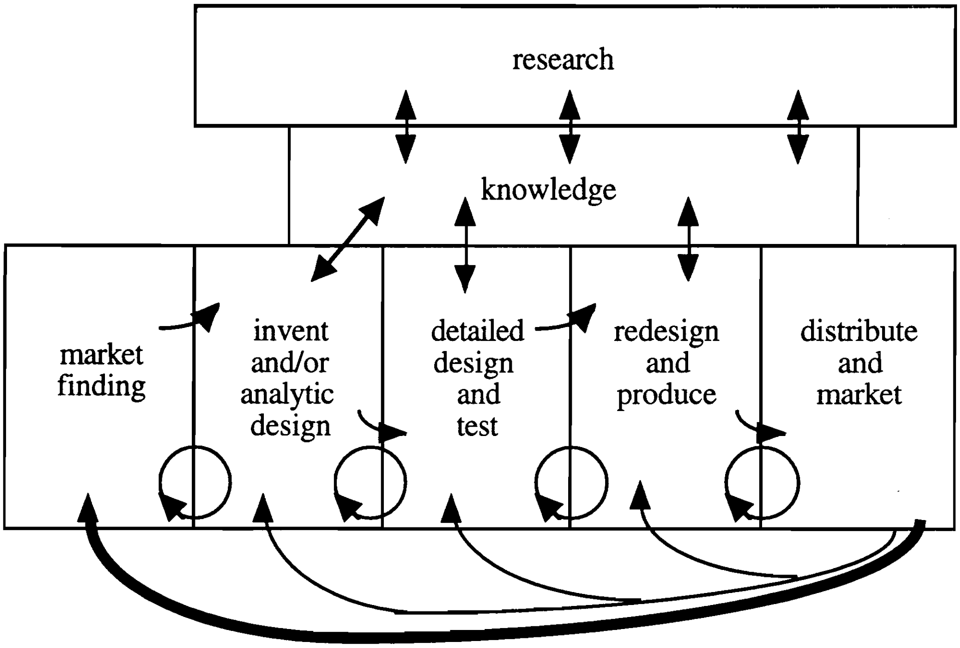
The following section explores some of the implications of these findings for theories of technological change. The last section explores some implications for policy.

Some implications of the history of reading machine development for theories of innovation

Kline proposes, as an improvement on the linear model, a “chain-linked” model of innovation whereby feedback from the market can contribute to the reiterative design of a product at each step in a complex development process (see Figure 29). Not all steps in the chain are essential, though reiterative feedback is. “Organizations that are repeatedly successful in innovation,” Kline observes, “such as General Electric and Bell Labs, have typically given much thought to making these feedback links work effectively.”[2]



a. The conventional “linear model” of innovation



b. Chain-linked model (adapted)

Figure 29. Models of innovation as discussed by Kline (1985)[3]

According to Kline, "Three types of feedback links [are] essential to effective innovation...."[4] The first is represented by the circles in the diagram which represent the exchange of information between the stages of development. The second is represented by the lighter lines under the diagram where the using community indicates needs for improvement in a given design during the several stages of the development process. Kline distinguishes a third kind of feedback from the market, subsequent to innovation, as indicated by the heavy line which represents "the planning and design of later models or new systems," based on market experience.[5] Kurzweil's success with the dissemination and test of beta prototypes as initial products suggests that Kline's third type of feedback can be understood to be a special case of the second. The exchange of information and artifacts between groups that develop technologies and groups that employ them can occur at any stage in the development and innovation process. Based on the cases of the Optacon and the Kurzweil reader, we can add that the exchange of information and artifacts can profitably occur at early stages of the development process.

Kline argues that the connections between engineering development and research, "...lie outside the processes implied by the linear model" and consequently that, except for the work of Walter Vincenti,[6] "...these processes have been relatively little understood and have seldom entered public discussions of current innovation processes." In a discussion that is consistent with recent research by historians of technology, including Vincenti's work and Staudenmaier's review and discussion of the relationship between science and technology in the innovation process, which appeared in the same year,[7] Kline argued that technology development is not simply an elaboration from current research. Rather, it is best understood as a creative process which begins in the human mind, involves the selection of component elements from known ideas and available components, or the creation of new elements if necessary. It is a process which culminates in a synthesis that satisfies a set of known criteria which, to be successful, must meet an unfulfilled market or use. Kline explains, "The first line of reference for innovation processes everywhere along [the] central chain-of-innovation is not research but the *totality of cumulated human knowledge*." Developers draw upon this store of knowledge according to their own interests, backgrounds and practices, turning to new research only when their personal knowledge, that of colleagues, and consultation of experts and the literature do not suffice to the task at hand.[8] Thus, for Kline among others who study historical practices of technology development, the innovation process is not necessarily driven by research, by technology, or by social forces. It is a creative process of knowledge synthesis undertaken by practitioners who can draw upon a combination of scientific, engineering and social knowledge.

In the historical case of reading machine development, differences in developers' practices reflected differences in the practitioners' relationship and approach to the store of human knowledge. With respect to technical knowledge, the differences in practice reflected differences in discipline and training. Mauch approached his practice as an engineering practice. Kurzweil's practice emphasized computer science. In part, the differences in practice reflected changes in the content of the knowledge base, over time. RCA's designs employed vacuum tubes where d'Albe relied on more primitive circuits. Battelle brought transistors to its design, and Kurzweil employed the second commercially available minicomputer. Cooper and Bliss drew upon elements of scientific knowledge that were the result of their own research. Mauch and Kurzweil relied upon scientific knowledge created by others. With respect to social knowledge, differences in practice are not so easily explained.

The issues which are addressed by Kline's model of innovation have been of growing currency in the field of science and technology studies for about ten years. In essence, those issues concern the relationships among researchers, developers, and innovators (users), and the ways in which those relationships can and do affect the course of technological change. In addition to the development-centered approach of Kline, Staudenmaier and Vincenti, such scholars as Thomas Hughes,[9] Hugh Aitken,[10] Trevor Pinch, Wiebe Bijker,[11] Henk Bodewitz,[12] Giovanni Dosi,[13] and Bruno Latour.[14] have sought to draw upon historical cases to craft frameworks for understanding how scientific, engineering, and social knowledge are created and combined in innovation processes that all agree are both complex and reiterative.

As noted by Misa in a recent, topical volume of *Science, Technology and Human Values*, no single, general theory of innovation has yet emerged which relates the elements of technological and social change, although he predicts that "A robust theory of technological change is in the offing," as the result of ongoing work by a community of scholars with an empirical perspective and an integrative approach.[15] In part, the differences among emerging theories of innovation reflect differences in the point of entry into, and the level of focus on, a complex social phenomenon. Aitken, Hughes, and Latour, for example, are often interested in large scale technologies involving large social groups – firms and industrial sectors as system developers, and cities, regions, nations, or civilizations as users. Kline, Bodewitz, and Vincenti have been more concerned with the case of the development team within a firm or laboratory.

In part, as identified by Hughes, differences in emerging theoretical frameworks reflect conceptual and linguistic problems involving "...analytical categories such as technology and science, content and context, foreground and background, and internalist and externalist...." Hughes suggests that an appropriate response to these problems is to "...endeavour to change our way of thinking about technological and scientific change," through a "...resort to neologisms and the abstractions of interaction – such as component and system, entity and network, and actor and actor world." [16] This is the path taken by Latour and Callon, among others, but it suffers the disadvantage of departing from the language and the concepts employed by developers themselves. If we are searching for theories which can inform practice or policy, then we would be well-advised to frame them in terms that are accessible to technology developers and other practitioners.

The history of the development and innovation of reading machines for the blind shows that practitioners such as Bliss and Kurzweil did, in fact, employ ways of thinking about technological change that departed from a linear model. They worked within their organizations to integrate and apply knowledge derived from communities of scientists and engineers, and from communities of users, in a complex and reiterative process of development and innovation. Their understanding of the nature of technology development is implicit in their practices and sometimes explicit in their descriptions of those practices.

The historical practices of reading machine developers are generally interpretable in terms of Kline's chain-link model. Like that model, the practices can be expressed in a familiar terminology, although more precision and a conventional agreement on the meaning of terms is desirable for theory construction or for the elaboration of policy than for more informal uses. For these reasons, and because it is the purpose of this study to inform theory, not to construct it, the following discussion will consider the case histories primarily with respect to Kline's model, although similar explications could be made with reference to the other formulations (such as Vincenti's) or approaches (such as Latour's).

One important finding, previously noted by several scholars, is that a linear model of innovation is not strictly one which is imposed by historians or other observers of innovation. To the contrary, many of the practitioners and administrators of reading machine development programs shared a conception of technology as applied science, and understood their practices in such terms. As with other OSRD projects (p. 63), Bush, Corner, and Cooper approached the problem of reading machine development as one for the application of scientific knowledge to address a social problem made important by the experience of war. Cooper, in particular, sought to approach the technological problem through the conduct of scientific research. Later, under Murphy's direction, Mauch took the results of Cooper's scientific thinking and sought to instantiate them in prototypes through engineering design. RCA and Battelle did not seek to create new scientific knowledge, but, like Mauch, they sought to incorporate recent advances in photoelectric sensors and electronic circuitry into the advanced design of a reading machine. At the end of the engineering process, according to this framework, blind readers were to be trained to use the products of development - a task incorporated into Batelle's development contract.

One requirement for a theory linking development and innovation is that it incorporate and explain these historical practices. Kline's model provides such an explanation: A linear path can be traced through the linked tasks of development, starting from research, invention, analytic design, or detailed design, leading toward the desired result of innovation. Feedback, that is to say information from a following task, is possible at any step in the process, but it does not occur spontaneously. Like other information flows in the development process, it must be managed.

Similarly, information from the market, that is to say social knowledge regarding a technology in use, is potentially available at any step, if the developer chooses to seek and to use it. Some program administrators, notably George Corner and Vannevar Bush, undervalued such knowledge, and actively sought to avoid it. Eugene Murphy sought to include it at the beginning of the development cycle (the heavy line in Figure 29), and at the end, but not in the intermediate tasks. Bliss and Linvill sought information from blind readers at every step. Kurzweil also involved blind readers in all steps, except possibly initial analytic design which he started before deciding to concentrate his efforts on a reading machine for the blind. Even so, his design rationale was initially based on the needs of blind readers as he imagined them to be, and he subsequently and deliberately incorporated information from blind readers in reiterative visits to the analytic design step. This process is most clearly evident in Kurzweil's changing conceptual design of the KRM's control strategy and control panel.

The observation that Kurzweil's initial conceptual design was based on the needs of blind readers as he imagined them to be suggests a general explanation for the ways in which social knowledge is incorporated into a design by technology developers. Cooper imagined that blind readers would have no interest in reading at speeds of less than 100 words per minute. He based that "knowledge" on his experience with reading and speaking in the sighted community, and applied it to make design choices in his own practice of technology development. Technology developers, of course, share in the general knowledge of their communities. Whereas scientific and engineering knowledge are available to developers to the extent they are available within knowledge communities of scientists and engineers, a general knowledge of social behavior is available to developers through their participation in the broader society. Specialized knowledge of technologies in use – whether current, prior, or prospective – resides in groups of users.

Although few technology developers would seek to employ technical knowledge from a group of lay persons without consulting a recognizable body of scientific or engineering knowledge, it is a matter of common experience, confirmed by the historical case of reading machines, that developers do not always seek "expert" social knowledge as part of the development process – especially in the earlier stages. In the case of reading machines for the blind, expert social knowledge was not systematically sought from groups of blind readers until Bliss and Kurzweil did so. Kline has suggested that developers do not seek to create new scientific knowledge through research as long as they find available knowledge to be sufficient to the task. We can observe that developers do not seek to gain access to new social knowledge as long as they find available knowledge to be sufficient. Moreover, developers' understanding of the nature of their practice may cause them to make bad decisions regarding the sufficiency of available social knowledge.

Three factors interact to make the acquisition and evaluation of social knowledge problematic for the developer. The first is identified by Vincenti, who observes that engineers have traditionally been trained to apply criteria for a design that "works" in technical and economic terms. "As what is meant by an engineering problem changes, so also must the kinds of variations engineers have to consider and the areas of [their own] blindness they encounter."[17] In other words, technology developers have not been trained to realize that social knowledge is a manipulable component of design.

The second problem with the acquisition and use of social knowledge is that different developers have different possibilities for access to social knowledge according to the prospective community of users. Sometimes, as in the aerospace and defense industries, development teams work on projects for communities of users which are well known to them. Other industries, such as consumer electronics, have developed sophisticated institutions and methods for providing social knowledge to the developer. But in other cases, where the developer does not have an intimate knowledge of the ways of life of the intended user, access to the best social knowledge may be hard to come by. Such was the case in the history of reading machine development, and such may often be the case where the federal government is supporting development to meet social goals that have been newly recognized, newly articulated or newly legitimized.

In cases where policy makers seek technological innovation in order to achieve social change, it may be difficult to forecast accurately who the potential users may be, either through lack of information, imagination, or foresight. If developers do not address this issue, however, they are in the position of tacitly incorporating social knowledge which is assumed or imagined by the developer, and which is valid only to the extent that a community or group of users shares in that common knowledge. Linvill and Bliss sought access to a group of blind readers by employing blind students into the development process. Kurzweil sought social knowledge from a somewhat different group by enlisting NFB in the development of the Kurzweil reader. These activities could be understood as a matter of network building, but they may also be understood as a process of the exchange of information of various kinds between different social groups.

A third, related problem is that even with good access to a group of potential users, developers must envision a social situation, i.e., a technology in use, that does not yet exist. This conceptual problem is not very different from that which exists with respect to scientific and engineering knowledge in the early stages of a development project, when developers must imagine a device or process that works before it has actually been built. To borrow Vincenti's phrase, it suggests that the stage of conceptual design, which Kline calls invention or analytic design, may include the development of a concept for a device that works in context. It suggests that an informed technology developer is not limited simply to the design of a tool, but either implicitly or explicitly designs a way of life which involves the application of a tool within a particular social context. When that aspect of design is implicit or poorly conceived, the chances of innovation can be reasonably expected to decline.

All of these concerns regarding the application of social knowledge to the development process can be accommodated by models such as Kline's. Further reflection indicates that Kline's model and the related considerations of Vincenti and Staudenmaier, which largely derive from the practices of industrial development in the twentieth century U.S., can be extended to embrace other kinds of social collaboration between developers and users. Pinch and Bijker's study of the development of the bicycle provides an example. They showed how, subsequent to innovation, an extended, reiterative exchange of information between bicycle developers and social groups with interests in the technology contributed to the stabilization of the design of the safety bicycle.[18] This complex process is represented in Kline's model by the heavy bottom line representing feedback to the developer from the marketplace, subsequent to initial innovation.

The history of reading machines indicates that the stabilization of a design can also be a problem for developers prior to innovation, and that participation of groups of users in development can contribute to achieving a stabilized design for innovation. Haskins Labs (Chapter 8) reiteratively visited conceptual designs for compiled speech, re-formed speech, and speech-by-rule, without settling on a stable concept until 1971. At that time, tests with blind readers expeditiously eliminated compiled speech as an alternative, a result which could have been achieved much earlier if users' participation had been sought. Mauch Labs also had difficulty in stabilizing the detailed design for the Cognodictor and the Stereotoner (Chapter 7). It seems possible that the involvement of a group of users could have provided direction to the developer which could facilitate the stabilization of a design. Both the Optacon and the Kurzweil Reading machine did solicit user participation in development, and both converged fairly rapidly on a design that was capable of innovation among a group of readers which resembled the group which participated in development. Two examples do not constitute proof, but this is a proposition which is readily tested by the study of other technology areas.

Pinch and Bijker proposed that the meaning of a technology, as interpreted by different social groups, plays a role, through selection, in its eventual form. In the case of bicycles, the market provided the social location for the selection and generation of design variants, through feedback to competing developers.[19] Such "interpretive flexibility," to use Pinch and Bijker's term, where a technology assumes different meanings to different groups with an interest in its form, is evident in the case of reading machines, from very early in the development cycle, long before innovation occurred. At this early stage, the research community and the development teams which comprised it provided the social location for the selection and generation of designs.

Franklin Cooper was first successful in persuading a reading machine research community of a particular meaning of reading machines for the blind – a meaning which he believed to be based on scientific principles of human communications. His interpretation had a major impact on the shape of the technology, as program funding and management were structured according to his taxonomy. The meanings proposed by Cooper first had to be modified when Eugene Murphy brought blind individuals and technical representatives of the service community into the discussion. As a result of the negotiations conducted in five technical sessions, direct translation machines received a new interpretation based on the new participants' understanding of the value of even slow reading by blind readers of otherwise inaccessible text. Nonetheless, Cooper's taxonomy continued to frame the meanings given to reading machines for the research community for many years. It was not until Linvill and Bliss widened the discussion by including groups of blind readers in the development of the Optacon that new interpretations began to emerge.

Subsequent to innovation, the meaning of reading machines continued to shift in the ways described by Pinch and Bijker. For example, Kenneth Jernigan, writing in 1982, articulated an important new meaning of reading machines for the blind community when he suggested on the one hand that their continued development depended on funds and interests outside the blind community, and on the other that their use by the blind community might lead to an undesirable illiteracy in braille. Specifically identifying the Optacon and the KRM, Jernigan argued that, "unless those of us in the field recognize the importance of Braille and train people to read it and rely on it, it will become a dying skill regardless of its cheapness and availability."[20]

This new meaning was threatening enough to the vendors of reading machines that Raymond Kurzweil sought to counter it with a response to Jernigan's essay in the form of a letter published in *The Braille Monitor.* Although he did not address the proposed meaning of the reading machine as a threat to the use of braille, Kurzweil challenged Jernigan's implication that the KRM's further development was at risk or in the control of forces outside the blind community. The KRM, Kurzweil claimed, had already benefited from "several generations of technology improvement," in which the NFB played a "very important role in helping to guide those developments." Further developments were underway. "As before, we continue to be guided by the input and suggestions of our several thousand users across the country."[21]

Harvey Lauer's continuing contention that an adequate reading machine design must combine certain features of the Optacon, the Stereotoner, and the KRM further illustrates the continuing process of interpretive flexibility. In 1994, he wrote,

> What we have now is two separate reading machines which few people have and which, even for those who have both, are only moderately useful. The talking machines we call OCRs work well with many books and documents but poorly on tasks like reading mail. They are largely coattail uses of commercial systems that require more computer literacy than they

> should. The Optacon is useful for identifying items and reading mail, but it's old technology, slow and difficult to learn. Not the least handicapping is that the two machines are separate instead of integrated as they should be.[22]

Lauer's proposal, Jernigan's concerns, and Kurzweil's response are all examples of a reiterative exchange of information between groups of users and groups of developers. The shape of a technology and the shapes of the individual tools which are part of a technology are the products of negotiation and the exchange of information among the interested groups. That exchange can occur throughout the innovation process, as groups with different interests, which change, merge, and diverge over time, seek to have their particular knowledge selected and used by developers to craft a conceptual design, a detailed design, a prototype or a product in the development process.

A consideration of reading machine development in the light of a developer-centered model of innovation provides insight regarding three issues worth further consideration in future studies. First, we have observed that developers must explicitly or tacitly select elements of social knowledge to incorporate in their technology designs, and that, prior to innovation, it is not always clear which individuals or groups comprise a good source for social information for a prospective technology. Theory should account for how developers make such decisions, and how decisions, once made, influence the course of design and innovation.

Vincenti provides some direction when he suggests that engineers have often understood the goal of their practice to be the development of a device that works to efficiently convert a given input into a given output. This understanding seems to reflect the practices of Flory, Zworykin and Pike at RCA and Mauch and Smith at Mauch Laboratories. It can also be used to describe the practice of Cooper and the team at Haskins Labs, who struggled to define an achievable synthetic speech output and a conceptual design of a reading machine which could produce it without systematic reference to a particular using group. Vincenti suggests that engineers' (i.e., developers') understanding of a technology that works must be extended to mean a device that works in a particular social context. This understanding is close to that expressed in the practice of Bliss and Linvill, who, influenced by their formative experiences in working with blind readers, drew upon the knowledge of blind high school and university students to create a reading machine that could be used by people with the time, the skills, and the motivation to gain access to texts that must otherwise be converted to braille.

The story of the Kurzweil Reading Machine is more problematic. There is no doubt that the contributions of blind readers resulted in numerous modifications to the design of the KRM, and we may grant that those developments resulted in a design that was more capable of innovation than would otherwise have been the case. But ultimately, we know that, for years, the KRM achieved only limited utility to its intended users because of its low tolerance with respect to format and clarity of print. The KRM achieved innovation, but not simply because its design successfully incorporated the social knowledge of a group of potential users. At best, the first generations of the KRM only minimally fulfilled the meaning of a reading machine for blind students and professionals. Given that the KRM met some needs of some blind readers, as testified by readers including Hanan Selvin (pp. 273 - 276), we must look for additional explanations of its success at innovation.

One explanation is that the "feedback" which occurs between developers and the marketplace prior to production and innovation, is two-directional. Thus, when a using community is brought into the development process, that participation can influence the likelihood of innovation. By being included in development, some members of NFB clearly became advocates of the KRM technology. Knowing that they had contributed to the design of the device gave blind readers a stake in its innovation. This social phenomenon might also be used to help explain the success of the Optacon with respect to the Stereotoner. Through the personal experience of a growing number of blind readers and through demonstrations at meetings and conferences of organized blind people and of the service community, Bliss built a constituency for his technology, or at least created an interest group, even before its commercial availability. The Stereotoner, in contrast, remained virtually unknown. At any rate, both Telesensory Systems, Inc. and Kurzweil Computer Products attracted the loyalty of blind readers who became advocates, spokesmen, and marketers for the new technologies.

A second explanation rests in the fact that many Optacons and nearly all Model III KRMs were not purchased directly by blind readers. It was librarians and institutions providing equipment to libraries who made purchase decisions for the KRM. Librarians are concerned with access to books. The KRM was good at reading books, especially hard cover books in single column format. Blind readers could safely and honestly advocate the purchase of a KRM for their occasional personal use in libraries, even if the technology did not meet all of their reading needs. Similarly, the major purchasers of the Optacon were educators of blind readers. Optacon teachers could be expected to advocate a reading machine they felt comfortable to teach. To sighted educators, the display of the Optacon was transparently accessible through analogy with the Times Square sign. They could see the letters cross the Optacon's touch pad. To a blind readers and blind teachers who lost their sight before learning to read, the display of the Optacon was less immediately accessible. It had little in common with braille. According to those blind readers who used both machines, the Optacon and Stereotoner were of similar difficulty to use or to learn. The polyphonic tonal output of the Stereotoner, however, was unfamiliar to sighted teachers. Unlike the Optacon's tactile pattern, it was a code that they could not directly access through a visual analog. It is tempting to speculate that one factor in the Optacon's success was its familiar meaning to sighted teachers of the blind.

At any rate, a full explanation of the innovation of the Optacon and the KRM must include a consideration of the three-way relationship among developers, blind readers, and institutions which actually purchased the machines on their behalf. The case studies have addressed these issues as they historically occurred. A robust theory of innovation must provide for an explanation of innovation which involves multiple parties and social spaces where negotiations are not necessarily arbitrated by simple market forces.

A second issue raised by the history of reading machines is our understanding of the process referred to by the term, *technology transfer*. Technology transfer has been a major concern of federal policy in the area of technology development for more than twenty years. Although the term has been used to label different processes, its major conventional use has been to refer to a final step at the end of development whereby a laboratory or agency undertakes appropriate activities to "transfer" the technology it has developed to some group of users.

Technology transfer is a firmly established concept that underlies major programs at NASA and the Department of Defense. The Federal Laboratory Consortium has been a strong advocate of technology transfer programs. There is a *Journal of Technology Transfer,* and a Congressionally-mandated National Technology Transfer Center. NIDRR sponsors research and development grants for research proposals under the category of technology transfer and has funded a series of Rehabilitation Engineering Research Centers devoted to technology transfer. RESNA, the association of rehabilitation and assistive technology-related professionals, has a technology transfer group.

The history of reading machines, considered in the light of Kline's chain-link model of innovation, suggests that the concept of technology transfer is an artifact of a linear model of innovation. Technology transfer largely corresponds to Freiberger's 1971 description of planning for deployment. (p. 125). The concept encapsulates the ideas that technology users are to be brought into the development process at its end, and that the problem of innovation, or deployment, is one which is to be addressed by developers at the end of a technical, development process.

The history of reading machines for the blind shows how some groups of technology developers can restrict their field for explicit design choices, by excluding certain social knowledge, by virtue of the way they conceive their own practice of technology development. Other developers who had a different conception of their practice escaped that constraint. This seems important because the reading machine developers who integrated user knowledge from an early stage developed technologies that succeeded at innovation. They did not need or employ a separate, technology transfer step, apparently because social knowledge which enabled innovation was incorporated into the design of the technology from an early stage of development. The "transfer" of information, not from developers to users, but between them, was a gradual and reiterative process.

Third and finally, this consideration raises once again the issue of an appropriate terminology for innovation theory. As noted in the introduction (p. 10), the term *innovation* has been used in a variety of ways to refer to processes of technological change. Technology transfer, I have now suggested, is an term conventionally used by many developers and policy makers to designate a process which seems essential to innovation of federally-sponsored research, but which disappears as a distinct activity when considered from a different conceptual framework. It is problems of this kind that Hughes had in mind when he said that conceptual and linguistic problems are central to historians' failure to think clearly about technological change. It appears that conceptual and linguistic problems may also be central to technology developers and policy makers' failure to think clearly about the relationship between development and innovation.

Hughes suggested that theorists avoid the problem of language and concepts by resorting to "neologisms and the abstractions of interaction – such as component and system, entity and network, actor and actor world." Whatever the merits of this suggestion for scholars, a more familiar vocabulary is probably necessary to gain and keep the interest of developers and managers of technology development programs.

One alternative is to anchor terminology in the activities or practices of groups. The history of reading machines suggests that, rather than entities and networks, actors and actor worlds, it is reasonable to understand development and innovation in terms of the exchange of knowledge and information among identifiable social groups. According to this view, the innovation process is one of negotiation among different groups with an interest in the technological outcome. Groups of developers have a certain power in determining outcomes by virtue of the role conferred on them by the larger society, and of their technical knowledge upon which the achievement of a design capable of innovation depends. But groups of users also have a certain power over innovation outcomes because, ultimately, innovation depends on their decisions to adopt or reject a way of life. Moreover, they are in possession of certain social knowledge which developers ignore at the peril of increasing the risk of innovation. Since the negotiation of interests is a well-known area of social science research, a possible route toward elaborating a social theory of innovation would seem to follow from these considerations.

In the case of reading machines, it is possible to identify groups of technology developers whose social role is readily recognized, and whose practices may therefore be taken to be examples of technology development. Technology development, then, is what developers do. It is a set of practices related by family resemblance. It is, in fact, the observation and historical analysis of examples of such technology development practices that underlies Kline, Vincenti and Staudenmaier's discussions of technological change and their consequent rejection of a linear model of technology as applied science. According to this construction, the linear model of technology development may have served a role in defining technology development practices that is similar to the role that the concept of a linear "scientific method" has played in defining scientific practices.

It is also possible to identify groups of users who adopt and employ the product of development. By extension from the terminology of innovation economics, these groups may be said to innovate. Innovation is what groups of people do when they adopt new technologies. By anchoring our terminology in behavior and practice, we can achieve both interpretive flexibility and an empirical referent for conceptual language. Thus, if we use the term *technology* to mean not a device, but a tool in use by a person or a group to achieve an objective within a particular social setting, we can further clarify our thinking about development and better understand how social knowledge is a critical part of a technology. Prospective social knowledge, that is to say an image of a new or modified tool in use, is subject to conceptual design, through a process of variation and selection by a developer. Developers who limit their practice to a consideration of the technical parts of a technology leave to fortune, intuition, or patchwork the answer to the question of whether or not a particular tool will be compatible with the ways of life of a particular group of users.

Taken together, development and innovation may reasonably be referred to as "the innovation process," a term which emphasizes the finding that development and innovation are not necessarily sequential, but may be intertwined, reiterative behaviors. The problem of technology transfer is also clarified by a behavioral approach to the definition of theoretical concepts: If technology is behavior, what exactly do we transfer when we transfer technology? It would appear that we can transfer an artifact from one social setting to another, but the result might be, strictly speaking, a new technology, if the new group of innovators applies the tool in an observably different way. From this perspective, the problem of technology transfer can be seen not as a problem in deployment or marketing, but as a problem of development, where new, different or changing social knowledge must be reflected in the conceptual or detailed design of a technology - not just of a tool, but of a tool in use. The use of such terminology, based on behavior and practice, seems to provide a way to address Vincenti's concern that if engineers are to integrate design characteristics with "the nontechnological dimensions of cultural ambience," "engineers – and society – will have to define engineering problems, and hence what it means by 'works,' differently from how they do today."[23]

Some implications of the history of reading machine development for federal technology policy

Emerging innovation theory captures some, but not all, of the policy lessons which may be drawn from the history of reading machines. In particular, we can identify two important explanations for developers' failure at innovation with implications for federal technology policy. Both concern social issues more clearly than technical ones. Both are related to developers' understanding of the nature of their practice.

First, successful innovators sought to include blind readers from an early stage in the development process. They drew upon the knowledge of groups of blind readers and incorporated that knowledge into their designs and prototypes in a reiterative process that preceded and followed the event of innovation. Theory suggests there are causal relationships between this practice and the successful outcome.

Second, successful developers were focused on innovation as the principal goal of their practice throughout the development process. They organized their activities and their firms toward that end. They sought to stabilize a design and to bring it to market. They learned to use federal government agencies to create a marketplace for their innovation products where none had previously existed. Whether by necessity or choice, they structured their firms so that long-term revenues and survival depended on the sale of the development product, not on the sale of research and development services.

Let us start this discussion of policy by revisiting Cooper's claim that,

> ...the kind of people and the kind of organizations that deal naturally and well with basic research do not usually have the temperament or skills to handle the entrepreneurial job of bringing a device to market. The government, for its part lacks effective mechanisms for bridging the gap between the research it supports and the finished devices that embody that research; that is to say between research and procurement – both of which the government does do – there is much development and testing that is done only by private industry, when it is done at all. Fortunately for the users of reading machines now and in the future, there has been this kind of entrepreneurial effort.[24]

We can now see that this interpretation is partly the product of an implicit linear model of innovation: Research precedes development which precedes procurement. Each is a separate function, requiring a different personality and different skills. According to this perspective, the problem of innovation is one bridging the gaps between each of these "naturally" separate disciplines. Cooper's explanation for success or failure at innovation contains a certain insight – the organization of a development team and the shape of its practices make a difference to innovation outcomes. If the problem of innovation were one of bridging gaps between sequential processes, then technology transfer or other bridging programs would make for good policy. If the problem were one of matching temperament to practice, then we might seek to ensure that researchers stay out of development and developers refrain from marketing or procurement. However, as we have seen, successful developers sometimes conducted basic research and also actively manipulated the procurement process as part of a systematic process of innovation. As Peter Drucker observed,

> What all the successful entrepreneurs I have met have in common is not a certain kind of personality but a commitment to the systematic process of innovation.[25]

The history of reading machines indicates that both commitment and a certain kind of systematic development process are important to innovation. As a result of our consideration of reading machines for the blind, as informed by emerging innovation theory, we are in a position to recommend some directions for innovation policy in the field of assistive technologies. Most of the recommendations have more general application to federal innovation projects.

Let us proceed by examining nine issues which were raised in the introduction and the historical chapters of this study.

1) Federal programs that seek social benefits through technological innovation need to encourage the participation of potential users in the development process from the earliest stages. Although this recommendation is consistent with and supportive of democratic values, it is not a result of ideological considerations. Rather, it reflects a historical finding, supported by innovation theory, that when individuals and groups of people have the ability to choose what technologies to employ, they are most likely to choose those which take account of their social knowledge and ways of life. If technology development is pursued without reference to the social knowledge of potential users, then the resulting product must be "transferred" to them, requiring either a change in the users' behavior and values to conform to the design, or a redesign of the product to incorporate better social knowledge. Furthermore, innovators' participation in development helps to establish a market and to stabilize a design for innovation.

In a free market where start-up costs are low, and where many new and affordable products can be proposed and made available for selection by users, the reiterative process of development can largely proceed subsequent to initial innovation. This was the case for bicycles in the 1890s. As differently noted by Kline and by Drucker, successful developers have evolved systematic methods for generating and incorporating social knowledge into their design. Institutions have evolved for this process, for example, in consumer markets and in specialty markets for durable goods. Developers of such products may not always be explicitly informed by theory, but, like Bliss and Kurzweil, their practices reflect an implicit understanding of the importance of social knowledge to the development process.

Federal programs which seek innovation to the benefit of the public welfare often do so in the absence of a developed marketplace. Where a robust market exists, government in the U.S. will defer to the private sector. In the absence of a market which can provide a return on private investment in product development, the government is, in effect, providing capital resources to developers that the general market will not provide. The marketplace is not just a vehicle for the exchange of goods and capital, however. It also provides a mechanism for the exchange of knowledge among developers, users, and other parties with an interest in the development outcome. Because development has been (wrongly) understood to be the domain of technical experts who straightforwardly apply scientific knowledge to develop a new product, this reiterative exchange of social and technical knowledge has not been systematically encouraged prior to the establishment of a market through innovation. Where such an exchange of knowledge does occur, it often does so at the beginning and the end of a linear development process which is otherwise conducted by scientists and engineers.

As a result of this study, we can strongly recommend that federal programs in assistive technologies require developers to include groups of persons with disabilities – not just as advisors; not only in the articulation of goals; not primarily as evaluators of the product of development; but as active contributors of social knowledge for reiterative incorporation in design at all stages of development.

2) Federal programs that are directed toward technology transfer need to be reconsidered. If the problem of technology transfer is an artifact of a faulty, linear model of innovation then we should not compound the situation by devoting our energies and resources to an artificial problem. Ideally, funds which are directed toward the transfer of a technology at the end of a development process should be redirected to the inclusion of social knowledge throughout development

The field of assistive technologies has one type of technology transfer problem which may be unique to the field. Many ingenious devices are developed by rehabilitation engineers, persons with disabilities, and others, which meet the specific needs of an individual person or client. The unique device is then offered as a prototype for "technology transfer," by which is meant commercialization as a product.

These cases are analogous to that where the developer draws upon his or her own individual social knowledge in the design of a technology. To the extent that the social knowledge incorporated in the design is shared with a group or community of users, it may provide a basis for the design of a technology which is capable of innovation. The problem of technology transfer for such prototypes is not simply one of the redesign of a custom-made device for commercial manufacture. It is also one of design for use within a complex social setting which includes groups of users and other interested parties, such as trainers, service providers, and insurers, in addition to manufacturers. Unless those interests are reflected in the reiterative design of a tool-in-use, innovation is unlikely to occur. If we wish rehabilitation engineers and others who custom-design adaptive devices to design for general innovation, then we may be in the position of fundamentally changing their practice. Alternatively, we could develop programs for evaluating the client-centered designs of rehabilitation engineers at an early stage and then transferring these preliminary concepts or devices to developers who would pursue their reiterative design for innovation in parallel with the design of the individual adaptive device.

In the case of new technology projects directed at innovation to benefit the public welfare, we need to redirect funds for "technology transfer" from the end of projects to the beginning. Developers need to systematically consider the knowledge resident in groups of users and to strive toward innovation as part of a reiterative design process, not as a final step.

3) If innovation is the goal, the best support the federal government can give developers may sometimes be to provide an initial market. This is what occurred in the case of the Optacon and the Kurzweil Reading Machine. Without initial purchases by federal agencies it is unlikely that innovation would have occurred as it did.

Many federal sponsors of innovation understand very well that federal purchases may be necessary to establish a market for a new product. The necessity is typically understood in economic terms as a method of reducing risk to the entrepreneur through the guarantee of a minimum return on investment. Federal policy makers should also understand the creation of a market as a way of providing a mechanism for the exchange of knowledge in an ongoing, reiterative development process.

In the past, some federal activities to establish a market have been partially covert – presented as a step in technology evaluation, or in the training of teachers. Activities to establish a new market for assistive technologies through federal purchases has not achieved the status of full political legitimacy, although the technique is occasionally used. There are those who maintain that the arbitration of goods and services should proceed in the existing marketplace without intervention by government. However, the creation of a new market not only provides the social benefits of innovation, (for example, the ability of blind persons to read a printed text), it also provides a locus for new economic activity. In the case of reading machines, a federal investment of about $1 million in the purchase of

Optacons and a similar investment in the purchase of beta model KRMs were critical to the creation of a new market which has grown to include half a dozen competitors and perhaps $100 million in cumulative sales by 1995. That market, once established, has provided a site for the exchange of knowledge about reading machine technologies, and providing for the reiterative improvement of reading machines as a tool for blind readers.

4) There is a need to maintain a pool of scientific, engineering, and social knowledge upon which technology developers may draw. Just as it is important that users be included in technology development, so is it important that scientists be included. As illustrated by the case of Linvill and Bliss, personal experience and knowledge are uniquely accessible. It would appear that the distinction between basic and applied scientific research is primarily a social one, namely that applied research is conducted to inform a particular development project where basic research is not. The product of either basic or applied research may be available for selection by a developer for synthesis into a technology design. Basic research, according to this understanding, has the potential advantage of providing more unanticipated knowledge.

Not only basic scientific research, but also "basic" engineering research and "basic" social research can be important to developers. In my own experience, one of the major problems confronting developers of assistive technologies is a lack of even basic demographic and physiological information on persons with disabilities. Most information on the ways of life of persons with disabilities is autobiographical or anecdotal. During the period of reading machine development, useful knowledge about blind readers was virtually unavailable. Even basic data, for example, Goldish's estimate of the number of braille readers, is suspect.[26] Bliss and Kurzweil by necessity had to develop information regarding blind readers on their own. Such personal contact is generally commendable, but more widely available information in the form of social science studies could enhance the development process. Rehabilitation professionals could play an important research role here, by virtue of their knowledge and access as observers of groups of persons with disabilities. Ethnographic studies which focus on the use of tools by persons with disabilities should also be valuable to future developers.

5) Federal innovation programs need to distinguish among different kinds of firms and institutions in the structure and award of grants and contracts which have the objective of innovation. A number of organizations, such as NIH, have a clear bias toward academic

research. Within my recent memory, certain grants and contracts from NIDRR were not open to profit-making firms. There exist in both the research and service communities certain norms which inhibit personal commitment to or personal gain from a particular product. As appropriate as this may be to scientific or rehabilitation practices, it is clearly counterproductive to innovation.

The history of reading machines shows that if innovation is the goal it is important that individuals or firms have a vested interest in innovation as an outcome. It is important that developers systematically seek innovation from the beginning of a program. When the business of the firm or institution is research or development, then research or development is a likely product. When the business of a firm is innovation, and its efforts are systematically aimed at innovation, then innovation is a more likely outcome.

The case of reading machines illustrates why small business firms can be especially successful at innovation. It is not necessarily that small businessmen have different personalities, higher creativity, or greater insight. Rather, they have fewer institutional interests that can conflict with a systematic approach to innovation. RCA's developers had all of the skills, resources, and personality traits necessary to bring the A-2 Reader to innovation. Their firm was interested in mass market electronics. Haskins Laboratories, Battelle Memorial Institute and Mauch Laboratories arguably had all of the capabilities necessary to achieve innovation of a reading machine design. These firms were interested in securing research and development contracts. They lacked the corporate interest to systematically pursue innovation.

The case of Linvill and Bliss who organized TSI while employed by Stanford University and Stanford Research Institute shows that development need not originate within a firm which is structured to achieve innovation. In that case, the vested interests in innovation were personal. Linvill was motivated by his interest in his daughter. Bliss was motivated by his graduate student experience with blind readers. Both men developed strong personal relationships with the blind high school and college students who participated in the early stages of Optacon development. Accordingly, at the earliest appropriate time, they created a firm which incorporated personal their interests in innovation, maintaining continuity by a transfer of staff to the new firm.

Today, many research and development grants and contracts call upon proposers to identify a route to commercialization and to forecast a market for the proposed product of research. This part of the proposal is seldom addressed or evaluated rigorously. Developers should be challenged to show how they will have a vested interest in a positive innovation outcome. They should discuss how they will exchange knowledge among developers, users, manufacturers and other interested parties as a reiterative process of design and innovation. They should show how the desired development outcome can be accommodated by an existing marketplace. In the case of more radical innovation, they should address how they will work to create a marketplace as a necessary part of development of a technology.

6) Because of the need to stabilize a design for initial innovation in the face of dynamic technological and social change, federal technology programs should be of a limited duration. For the same reason, development funds should be adequate to the holistic design of a technology in the proposed development period.

In the case of reading machines, both Haskins and Mauch were constrained by inadequate levels of funding and encouraged by long-term projects to focus on the sequential development of parts of a reading machine. As a consequence, by the time they came to the end of a sequence of component designs, the scientific or engineering knowledge available for the last step required a reconsideration of the first. Partly as a result, the design of a complete reading machine for innovation never stabilized.

Technology development, as we have seen, takes place both prior to and subsequent to initial innovation. The goal of federal programs should be early innovation with subsequent development to occur through the action of the marketplace. Toward that end, federal technology managers need to hold developers to rapid progress while ensuring sufficient funds are available to sustain such progress.

7) The finding that technology development is a practice which involves the synthesis of scientific, engineering, and social knowledge has implications for the peer review method of evaluating technology development proposals. If technology development involves the synthesis of engineering, scientific, and social knowledge, then proposals should be judged in some way that reflects all three components. Moreover, if many developers practice according to an implicit, linear model of innovation which is demonstrably deficient, then we must question the criteria by which developers might evaluate the practices and proposals of others.

Communities of scientists have well-established institutions for judging the credentials and methods of their members. It is far less clear how to compare the abilities of a Raymond Kurzweil with those of a Franklin Cooper or to evaluate their likely success at technology development. Standard methods of scientific peer review would surely predict that Cooper would succeed and Kurzweil would fail. And they would be wrong.

An alternative to peer review of technology development proposals, followed by some federal agencies, is that of internal evaluation by the sponsors of research. This is common in the Defense Department and was the method used by Murphy for PSAS programs, subsequent to program start-up. As we have seen, this approach can also lead, over time, to entrenched interests and loyalties. It can help institutionalize particular conceptual frameworks for understanding technologies which may not correspond to the knowledge of potential innovators. It can result in the exclusion from federal government resources of outsiders like Bliss and Kurzweil, who do not fully share in a community or a conceptual framework, but who have a better chance at achieving innovation.

Perhaps the best approach to proposal evaluation and program review is one which reflects the innovation process itself. According to this model, review groups composed of scientists, engineers, users, and others with an interest in the innovation outcome, would exchange information and negotiate outcomes of the award process.

8) Those other groups are what Sørensen and Levold called "meso-level institutions." They are institutions which are smaller than a society or nation as a whole, but larger than the individual or firm which participates in development and innovation. In the case of reading machines for the blind, they included a state library system, the University of Pittsburgh teacher training program, the American Foundation for the Blind, the National Federation of the Blind, the VA Blindness Centers, the Hadley and Perkins Schools, and philanthropic foundations which supported the purchase of reading machines. Such institutions can play an important role in innovation . Knowledge of the behavior and values of such institutions can be important to achieving an innovatable design. All of the observations regarding the importance to developers of social knowledge about users also applies to these kinds of institutions which support or otherwise participate in a user's way of life.

Technology developers should be aware of the important institutions and of their basic interests which might be affected by innovation. Although institutional interests may tend to be conservative and opposed to innovation, the history of reading machines shows that such institutions exist in a complex political environment and that they may sometimes be allied to the cause of innovation. Bush and Corner hoped to use the secrecy of wartime as a pretext for excluding the "political" concerns of the service community. This perspective made sense within a linear model of innovation which saw technology development as applied science. Bliss and Kurzweil, in contrast, sought to engage such institutions, understand their interests, and take advantage of that knowledge in the design of their product and in the creation of a market.

We have seen that technology development is an inherently political process of negotiation and compromise among elements of scientific, engineering, and social knowledge derived from groups with different interests in the innovation outcome. Tacitly or systematically, the developer must manage this process toward innovation. The art of negotiation is such that its practitioners do not always reveal everything they know. Some social knowledge is best left tacit for the sake of peaceful collaboration. It is not always necessary or desirable to make explicit the ways in which an innovation will affect the interests of other parties to the development and innovation process. However, it is necessary that developers consider the role of meso-level institutions, and sometimes seek to shape those roles as part of the development of a new technology. Federal policy makers should help ensure that developers incorporate such concerns in their practices.

9) Finally, if technology developers are conducting their practices according to an implicit, linear model of innovation that inhibits successful innovation, should not federal innovation policy seek to train developers in a new model? The marketplace seems to provide corrective mechanisms for ensuring the reiterative synthesis of social knowledge in technology development subsequent to initial innovation of a new product. In the case of government sponsorship of innovation for the public welfare, however, such institutions may not yet exist. This set of circumstances provides a single explanation for why market-oriented critics perceive federal technology development as inefficient and why liberal critics perceive federal technology development as unresponsive to social needs. Both perceptions can be attributed to the fact that technology developers and federal policy makers make decisions according to an implicit, linear model of technology development. In the absence of the arbitration of the marketplace, by drawing primarily upon the social knowledge of small groups of scientists and engineers, and by failing to incorporate in their designs the social knowledge of communities of users, developers who practice according to this model may unwittingly develop prospective technologies which incorporate their own perspectives instead of those of potential innovators. The result is a technology development system which is unnecessarily inefficient at innovation and less responsive to certain social needs.

Social knowledge, we have seen, may be incorporated in design not only subsequent to innovation, but prior to it. Attention to this fact, it appears, can reduce the risk of innovation and enhance favorable outcomes. If this insight is correct, then federal policy makers should find that it will enhance the success of their programs if developers and administrators are trained in emerging innovation theory and in its implications for the practice of technology development.

Appendix: Attendence at Reading Machine Conferences

2nd Reading Machine Conf., April 1955

Academia

Cttee on Diag. Rdg. Tests	Triggs, Dr. F. O.
Haverford College	Benham, Pr. T.A.
2	2

Service Sector

AFB	Bruel, John
AFB	Ritter, Charles G.
AFB	Witcher, Dr. Clifford
APHB	Zickel, Virgil E.
BVA	Thompson, Dr. W.W.
Ind Home for Blind, NY	Spar, Harry
Perkins Inst	Waterhouse, Edward
5	7

Industrial Research / Contractors

Bell Labs	Dudley, Homer
Canadian Marconi	Jaderholm, H. W.
Franklin Inst.	Duane, Dr. Milliam
Franklin Inst.	Frank, Wallace
Franklin Inst.	Grier, George W.
Franklin Inst.	Karr, Charles A,
Intel. Machines Rsch Corp.	Heasly, Clyde C., Jr.
NY,NY	Kallman, Dr Heinz E.
RCA Labs	Pike, W.S.
Remington Rand	Mauchly, John W.
7	10

Government

Lib Of Congress	Hedges, Thomas B.
NB Stds	Sheretz, Paul C.
VA, PSAS	Friedrich, Sidney
VA, PSAS	Murphy, Eugene
3	4

Individuals

Drexel Hill. Pa	Sharples, A. Roberts
	1

Total Institutions	**Total Individuals**
17	24

Scource: "Summary Second Technical Session on Reading Machines for the Blind - Held at Franklin Institute, Philadelphia, Pennsylvania - April 25, 1955," Box 115, LOC

4th Reading Machine Conf., Aug 1956

Academia

Columbia U.	Proscio, Vito
Haverford College	Benham, Pr. T.A.
MIT	Washington, L. Jr.
MIT	Witcher, Clifford
USC	Metfessel, M.
4	5

Service Sector

AFB	Axelrod, S.
AFB	Ritter, Charles G.
APHB	Zickel, Virgil E.
BVA	Thompson, Dr W. W.
Ind Home for Blind, NY	Richterman, Harold
Ind Home for Blind, NY	Spar, Harry
Perkins Inst	Waterhouse, Edward
SITE	McCollum, M. A.
6	8

Industrial Research / Contractors

American Optical Co.	Glover, C.
American Optical Co.	Shipley, Thorne
Bell Labs	Dudley, Homer
Bell Labs	Gibby, Richard
Canadian Marconi	Jaderholm, H. W.
Control Instruments	Relis, Matthew
Control Instuments Co	Wadsworth, L. H.
Franklin Inst	Frank, Wallace
Haskins Laboratories	Cooper, Franklin S.
IBM	Wheeler, John N.
Intel. Machines Rsch Corp.	Shepard, David
Melpar, Inc.	Bayston, E.
MWRI	Kahler, R. L.
Polarad Electronis	Shaw, Denman
Rabinow Eng.	Rabinow, J.
RCA Labs	Pike, W.S.
RCA Labs	Flory, L. E.
13	17

Source: "Summary Fourth Technical Session on Reading Machines for the Blind, Held at the Veterans Administration, Washington, D.C. - August 23, 24, 1956," date of issue, March 27, 1957. Copy provided from the personal papers of Howard Freiberger

Government

Los Alamos Lab	Cranberg, Lawrence
NB Stds	Wildhack, W. A.
NB Stds	Cook, Herbert
NIH	Gunkel, Ralph
NIH	Ryan, Ralph W.
NRC, Canada	Swail, James C.
USA Diamond Labs	Rotkin, Israel
USAF RADC	Shiner, G. A.
USAF, Op. Apps Lab	Klemmer, Edward
USAF, Op. Apps Lab	Pollack, Irwin
VA, Blind Rehab	Bledsoe, C. W.
VA, Hqs	Middleton, William
VA, PSAS	Friedrich, Sidney
VA, PSAS	Knox, Thomas E.
VA, PSAS	Murphy, Eugene
VA, PSAS	Stewart, Robert E.
8	16

Individuals

Wichita Falls, TX	Surber, C. M.
	1

Total Institutions	**Total Individuals**
31	47

6th Reading Machine Conf., Jan 196

Academia

Cal Tech	Nye, Patrick W.
Dartmouth College	Hall, Leigh S.
Haverford College	Benham, Pr. T.A.
Manhattan College	Welsh, C.A.
MIT	Mann, Robert W.
MIT SAEDC	Dupress, John K.
Peabody College	Richard W. Woodcock
Stanford Univ.	Linvill, John G.
U. Cinncinnati	Sterling, Theodor D.
Univ Münster (Gmy)	Werner, Helmut K. E.
Univ. Michigan	Lawler, Eugene
Unv. Virginia	Inigo, Rafael
Western Mich. U.	Mallinson, George G.
12	13

Service Sector

AAIB	Thompson, R. Paul
AFB	Bruel, John
AFB	Clark, Leslie L.
AFB	Levens, Leo M.
AFB	Robinson, Robert L.
AFB	Rogers, Carl T.
APHB	Zickel, Virgil E.
Catholic Guild for All Blind	Carroll, Rev. Thomas
Catholic Guild for All Blind	Riley, Leo H, M.D.
Hadley School	Hathaway, Donald W.
Howe Press, Perkins School	Friedman, Harry
Jewish Guild for Blind	Krebs, Bernard M.
Md Workshop for the Blind	Quay, Earl
Perkins School for Blind	Morse, John L.
9	14

Industrial Research / Contractors

Bionic Instruments, Inc.	Benjamin, J. Malvern
Century Research Corp.	Sleight, Robert B.
Cognitronics Corp.	Kroeger, Joseph H.
Cognitronics, Corp.	Shepard, David H.
General Dynamics	Houde, Robert A.
Haskins Laboratories	Cooper, Franklin S.
Haskins Laboratories	Gaitenby, Jane
IITRI	Reynolds, W. E.
Lincoln Laboratory	Selfridge, Oliver G.
Lincoln Laboratory	White, Benjamin
W.	
Mauch Laboratories	Mauch, Hans A.
Mauch Laboratories	Smith, Glendon C.
Metfessel Laboratories	Lovell, Constance
Metfessel Laboratories	Metfessel, M.
Philco Corp.	Taylor, Donald
Spitz Laboratories, Inc.	Frank, Wallace E.
The Solocast Company	Beaumont, Alan
12	17

Government

NAS / NRC	Kingham, James R.
NIH	Goldstein, Hyman
NIH	Kurtz, Donald J.
USA Diamond Labs	Rotkin, Israel
USN NAED	Mandelson, E. S.
VA Blind Rehab	Williams, Russell C.
VA, Hines VAH	Apple, Loyal E.
VA, Hines VAH	Lauer, Harvey
VA, PSAS	Freiberger, Howard
VA, PSAS	Knox, Thomas E.
VA, PSAS	Murphy, Eugene
VA, PSAS	Stewart, Robert E.
Voc Rehab Admin.	Bledsoe, C. W.
6	13

Individuals

Lorton, VA	Korb, Alfred
Morgantown, WV	Ryan, Ralph W., MD
Pompton Lakes, NJ	Selwyn, Donald
	3

Total Institutions	Total Individuals
39	60

Source: "Summary Sixth Technical Session on Reading Machines for the Blind, Held at Veterans Administration Central Office, Washington, D.C., January 27-28, 1966," Copy provided from the personal papers of Howard Freiberger

NAS Evaluation Conf., Nov 1971

Academia

Boston College	Bell, Nancy
Boston College	Kieth, William
Boston College	Rowell, Derek
Johns Hopkins	Marks, William B.
MIT	Mann, Robert
MIT	Russell, Lindsey
MIT SAEDC	Proscia, Vito A.
Ontario Crippled Child. Ctr	McLaurin, Colin A,
Stanford Research Inst	Bliss, James C.
Stanford Research Inst.	Linvill, John
Stanford Research Inst.	Schoof, Loren
Stanford Research Inst.	Weihl, Carolyn
UCLA	Lyman, John
Univ. Brit Columbia	Beddoes, Michael P.
Univ. of Nottingham (UK)	Armstrong, John D.
8	15

Service Sector

0	0

Industrial Research / Contractors

ACRIBAR	Riley, Leo H.
Bell Labs	Guttman, Newman
Bionic Instruments, Inc.	Benjamin, J. Malvern
Haskins Laboratory, Inc.	Cooper, Franklin S.
Haskins Laboratory, Inc.	Nye, Patrick W.
L.M. Dearing Assoc., Inc.	Dearing, LeRoy M.
Mauch Laboratories, Inc.	Mauch,Hans
7	7

Government

DHEW	Bledsoe, C. Warren
DHEW	Kaufman, Martin J.
DHEW	McFarland,Douglas C.
DHEW	Moss, James W.
DHEW	Mueller, Max W.
DHEW	Reed, L. Deno
DHEW	Traub, Joseph E.
NAS, NRC	Wilson, A. Bennett,Jr.
NBS	Aellen, John
NBS	Peterson, Roger D.
NIH	Resnik, Robert A.
NRC, Canada	Swail, James C.
USN, NEL	White, Carroll T.
VA, Hines VAH	Lauer, Harvey
VA, Hines VAH	Whitehead, James J.
VA, Hqs	Williams,Russell C.
VA, Palo Alto VAH	McGowan, David
VA, PSAS	Freiberger, Howard
VA, PSAS	Knox, Thomas E.
VA, PSAS	Murphy, Eugene F.
VA, PSAS	Stewart, Robert E.
7	21

Individuals

Kitchener, Ont., Canada	Sande, Innes
Charlottesville, VA	Stamp, Mary
	2

Total Institutions	Total Individuals
22	45

Source: National Academy of Sciences, "Evaluation of Sensory Aids for the Visually Handicapped," (Washington: 1972), Appendix B.

Smith-Kettlewell Sensory Aids Workshop, March 1977 (participants & observers)

Academia	
Case Western Reserve U.	Mortimer, Thomas
CUNY	Levitt, Harry
CUNY	Studebaker, Gerald
Gallaudet College	Jensema, Carl
Gallaudet College	Pickett, James M.
MIT	Rowell, Derek
New York University	Delk, Marcus
Princeton U.	Sherrick, Carl E.
Queens College, CUNY	Kirman, Jacob H.
U.C. Berkeley	Bailey, Ian
University of Louisville	Foulke, Emerson
University of Minnesota	Lassman, Frank M.
Western Mich. Univ.	Suterko, Stanley
11	13

Service Sector	
AFB	Berkowitz, Marvin
Central Inst. for Deaf	Miller, James D.
Clarke School for the Deaf	Boothroyd, Arthur
Fdn for Hearing Aid Rsch	Villchur, Edgar
Helen Keller Center	Betticia, Louis
Helen Keller Center	Kruger, Fred
Orientation Ctr for Blind	Jenkins, Alan
Pacific Med. Ctr	Colenbrander, August
Perkins School	Waterhouse, Edward
Rancho Los Amigos MC	McNeal, Don
San Francisco Lighthouse	Miller, Robert
Teletypewriters for the Deaf	Breunig, H. Latham
U. Cal. Med Ctr	Merzinich, Michael
13	13

Industrial Research / Contractors	
AT&T	Smith, Gale
Bionic Instruments, Inc.	Benjamin, J. M.
Bolt, Beranek & Newman	Nickerson, Raymond
Haskins Labs	Nye, Patrick
Kurzweil Computer Products	Kurzweil, Raymond
Mauch Labs [sic]	Smith, Glen C.
Technical Marketing Assoc.	Goldish, Louis H.
Smith-Kettlewell	Alden, Albert
Smith-Kettlewell	Bach-y-Rita, Paul
Smith-Kettlewell	Collins, Carter C.
Smith-Kettlewell	Easley, Teresa
Smith-Kettlewell	Gerry, William A.
Smith-Kettlewell	Holmlund, Gordon
Smith-Kettlewell	Jampolsky, Arthur
Smith-Kettlewell	Madley, Julius
Smith-Kettlewell	McDonald, Roger
Smith-Kettlewell	Saunders, Frank
Smith-Kettlewell	Scadden, Laurence
Telesensory Systems, Inc.	Bliss, James C.
Telesensory Systems, Inc.	Proscia, Vito
Telesensory Systems, Inc.	Reynolds, Michael
9	21

Government	
DHEW, RSA	Magers, George
DHEW, RSA	Williamson, Dale
KY Dept. Education	Cranmer, T. V.
NASA, Ames R.C.	Holley, Herbert
NIH	Alberts, W. Watson
NIH	Loeb, Gerald
NRC, Canada	Swail, James
National Science Fdn	Harvey, Herman
National Science Fdn	Sternberg, Sydney
U.S. Congress staff	Roodzant, Sherman
VA Hqs	Causey, G. Donald
VA PSAS	Freiberger, Howard
VA PSAS	Murphy, Eugene
VA Hines VAH	Farmer, Leicester
VA Hines VAH	Malamazian, John
VA Palo Alto VAH	Bennett, Richard
VA Palo Alto VAH	Goodrich, Gregory
VA Palo Alto VAH	Paul, Stanton
VA West Haven VAH	De l'Aune, Wm. R.
8	19

Source: The Smith-Kettlewell Institute of Visual Sciences, "Report of the Workshop on Sensory Deficits and Sensory Aids," (San Francisco: 1977), Appendix B.

Notes

Notes on sources

The major resources for the historical case studies were of four types: archival collections, reports of research in scholarly and professional journals and conference proceedings, personal communications from participants in the development and innovation of reading machines, and contemporary articles published in special interest journals. The following paragraphs which discuss these sources are meant to serve as an aid to future researchers in the field of assistive technologies

Archival collections are most helpful for the OSRD period. Record Group 227 of the National Archives includes five boxes of records from the Committee on Sensory Devices, which contain internal and external correspondence files and minutes of meetings. These records cover the period 1943 - 1946. The records of the committee for the period 1947 - 1954 may be found among the archives of the National Research Council's Anthropology and Psychology Division. These records include A. A. Bombe's monthly progress reports and Dr. Kappauf's final report, as well as correspondence files. These rather extensive collections have been augmented by miscellaneous information from the Vannevar Bush Papers maintained by the Library of Congress. Most important among them is Bush's November 8, 1943, memorandum to Caryl Haskins which documents their discussions regarding the establishment of a sensory aids research program within OSRD. These records also document Bush's continuing interest in the program into the 1950s.

I was unable to find archival records relating to the VA's program, although miscellaneous early documents may be found among the papers in the NRC archives and the Vannevar Bush Papers. Nor was I able to find archival records of the program of the Bureau of Education for the Handicapped. The National Archives has not received such records. People I talked with in the agencies had no knowledge of records for the 1950s - 70s. The National Records Service, which holds records for the agencies prior to release to the National Archives, could not locate pertinent files based upon my descriptions, but it is quite possible that some or all of these records are buried in the these holdings. Several reports on Optacon research, including John Linvill's key, 1973 final report to BEH, may be found in the ERIC data base, which is generally available in research libraries on microfiche.

Reports of research in scholarly and professional journals and conference proceedings, are best for the VA - sponsored projects and the research at Stanford which led to the Optacon. The *Bulletin of Prosthetics Research,* which changed its title to the *Journal of Rehabilitation R&D* in 1983, carried semiannual reports on VA-sponsored research from its first issue in 1964 until the program was terminated in 1978, as well as occasional articles on reading machine research. This journal documents all areas of VA research in areas of rehabilitation technology and sensory aids. Since the VA was the leading federal agency for such research from the end of World War II through the early 1970s, the *Bulletin* provides a major resource for technology studies in this area.

Haskins Laboratories published frequent articles in the *Acoustical Society of America Journal* and various IEEE journals and transactions. The latter also published reports from Jim Bliss, John Linvill and the Stanford group. Bliss also published research articles on tactile perception in the journal *Perception and Psychophysics.* The only report on Kurzweil's reading machine development to appear as a research report may be found in the spring 1977 issue of the *Bulletin of Prosthetics Research.*

Important. published conference proceedings include those of the 1962 International Congress on Technology and Blindness, held in New York under the auspices of the American Foundation for the Blind, as edited by Leslie L. Clark's; and proceedings of the 1966 International Conference on Sensory Devices for the Blind, held in London with the sponsorship of St. Dunstan's, edited by Richard Dufton. In 1950, Paul Zahl edited the influential and twice-reprinted book, *Blindness: Modern Approaches to the Unseen Environment,* which combined a report on OSRD's wartime research with a collection of papers on related topics from a broader community. Today we might consider the work a report on a "virtual conference." In 1972, Milton Graham edited papers presented at a conference hosted by the American Foundation for the Blind, under the title, *Science and Blindness: Retrospective and Prospective.*

Personal communications from participants in the development and innovation of reading machines. Several reading machine researchers were kind enough to contribute to this work. Leslie Flory of RCA talked with me about his work and provided documents from his personal archives pertaining to the A-2 Reader and the letter recognition machine. I talked with Eugene Murphy on several occasions. His memories were sharp as his insights. He directed me to Howard Freiberger, who, like Mr. Flory, provided documents from his personal archives. These may be the only surviving documents of VA-sponsored research between 1957 and 1964, when the *Bulletin of Prosthetic Research* was launched. Harvey Lauer at the Hines VA Hospital also provided documents from his personal holdings and prepared a 50 page essay describing his personal experience and insights on the history of reading machines. These papers contain much more information than I was able to incorporate into this history. I hope Mr. Lauer will follow through with his intention to publish a form of his essay.

Jim Bliss was also kind enough to respond in writing to my questions, providing an excellent first-person account of the development of the Optacon. I had interviewed Bernice Broyde and Vito Proscia regarding certain aspects of the Kurzweil Computer Products in 1990. In response to a letter to Raymond Kurzweil, his close colleague, Aaron Kleiner, answered my questions from in a two-hour telephone interview in November 1993, and answered some miscellaneous questions thereafter. Alvin Liberman of Haskins Laboratories kindly answered questions in a brief telephone interview and provided a copy of his manuscript on the development of theories of speech perception. I am most grateful to all of these participants who provided their observations on the events in which they played such important parts.

Articles published in special interest journals were especially important for reconstructing the history of the Kurzweil Reading Machine. Most important was Kurzweil's 1975 speech to the National Federation of the Blind, published in the September issue of *The Braille Monitor*. A number of reports on the Optacon and Kurzweil reader may be found in AFB's *Journal of Visual Impairment and Blindness*. A number of articles on Raymond Kurzweil appeared in the business and computer press in the first half of the 1980s.

Finally, it is important to acknowledge the importance of Frances Koestler's 1976 study, *The Unseen Minority: A Social History of Blindness in America.* This book, written from the archives and perspective of the American Foundation for the Blind, is valuable for establishing the history of the service community and for its consideration of many aspects of the history of blindness in the United States. It is unique in its consideration of the history of reading machines as part of its broader topic. It is especially useful because it also addresses the history of braille and of talking books – much more important to blind people than reading machines which had just begun to be available at the time Koestler wrote.

Notes for Chapter 1

[1] This point was suggested by Lawrence A. Scadden. Personal correpsondence, March 25, 1995.

[2] A brief review of the expanding federal role in the provision of rehabilitation services and the sponsorship of research in the field of technology and disability may be may be found in J. Scott Hauger. 1993. *Ensuring the Accessibility of New Technologies for the Electronic Delivery of Federal Services for Persons with Disabilities.* Final Report to the U.S. Congress, Office of Technology Assessment. Blacksburg, VA: Virginia Technology Associates, Ltd. This report has been available through OTA.

[3] Sandra J. Tanenbaum. 1986. *Engineering Disability: Public Policy and Compensatory Technology.* Philadelphia: Temple University Press.

[4] See, for example, Edward D. Berkowitz. 1987. *Disabled Policy: America's Program for the Handicapped.* New York: Cambridge University Press; F. G. Bowe. 1978. *Handicapping America: Barriers to Disabled People.* New York: Harper & Row, Publishers; Aliki Coudroglou and Dennis L. Poole. 1984. *Disability, Work, and Social Policy.* New York: Springer Publishing Company; Stephen L. Percy. 1989. *Disability, Civil Rights, and Public Policy: The Politics of Implementation.* Tuscaloosa, AL: The University of Alabama Press; and Richard K. Scotch. 1984. *From Good Will to Civil Rights: Transforming Federal Disability Policy.* Philadelphia: Temple University Press.

[5] J. Scott Hauger. 1991. "The Creation and innovation of electronic travel aids and reading machines," in *Technology and Disability 1:1* (Summer), pp. 69-86.

[6] Frances A. Koestler's 1976 work was invaluable to this project. Frances A. Koestler. 1976 *The Unseen Minority: A Social History of Blindness in America.* New York. David McKay Company, Inc. Also useful was Organization for Social and Technical Innovation, Inc. 1971. *Blindness and Services to the Blind in the United States: A Report to the Subcommittee on Rehabilitation, National Institute on Neurological Diseases and Blindness.* Originally presented, June 1968. Cambridge, MA: OSTI Press. Biographical accounts and articles published in *Journal of Visual Impairment and Blindness* and its predecessors, *New Outlook for the Blind* and the AFB's *Research Bulletin* are also useful.

[7] The bibliography identifies the major conference reports and collections, both published and unpublished.

[8] A collection of recent key papers may be found in Christopher Freeman, ed. 1990. *The Economics of Innovation.* London: Edward Elgar Publishing Limited.

[9] Robert E. McGinn. 1991. *Science, Technology and Society.* Englewood Cliffs, NJ: Prentice Hall.

[10] Jon Elster. 1983. *Explaining technical change. New York.* Cambridge University Press.

[11] See, for example: Wiebe E. Bijker. 1992. "The social construction of fluorescent lighting, or how an artifact was invented in its diffusion stage." In Bijker, Wiebe E and Law, John, eds. 1992. *Shaping Technology / Building Society: Studies in Sociotechnical Change.* Cambridge, MA: The MIT Press; Bijker, Wiebe. 1987. "The social construction of Bakelite: Toward a theory of invention," in W.E. Bijker, T. P. Hughes, and T. J. Pinch, eds. 1987. *The Social Construction of Technological Systems.* Cambridge, MA: MIT Press, pp. 159 - 187; John Law and Michael Callon. 1992. The life and death of an aircraft: A network analysis of technical change. In Bijker and Law eds. 1992; John Law. 1987. "Technology and heterogeneous engineering: The case of the Portuguese expansion," in Bijker, Hughes, and Pinch, eds. 1987, pp. 111-134.

[12] John M. Staudenmaier, S. J. 1985. *Technology's Storytellers: Reweaving the Human Fabric.* Cambridge, MA: First MIT Press paperback edition, 1989. Published jointly by The Society for the History of Technology and The MIT Press. See especially pp. 50-61.

[13] T. J. Misa. 1992. "Theories of technological change: Parameters and purposes," in *Science, Technology & Human Values 17* (Winter), pp. 3-12.

[14] K. H. Sørensen, and N. Levold. 1992. Tacit networks, heterogeneous engineers and embodied technology, *Science, Technology & Human Values 17* (Winter), pp. 13-35.

[15] Stephen J. Kline. 1985. "Innovation is not a linear process," in *Research Management 28:4* (July-August), p. 36.

[16] Edward B. Roberts. 1988. "What we've learned: Managing invention and innovation." in *Research-Technology Management* (January-February), p. 13.

[17] Willem Dijkhuis. 1982. "Innovation: Its evolution and present state," in Barrie T. Stern, ed. 1982. *Information and Innovation*, New York: North-Holland Publishing Company, p. 20.

[18] McGinn, pp. 75-76.

[19] Staudenmaier, p. 40 and p. 56.

Notes for Section I preface and Chapter 2

[1] Hauger, 1991, pp. 69-86; Paul A. Zahl, "Research on Guidance Aids for the Blind, in Paul A. Zahl, ed., *Blindness: Modern Approaches to the Unseen Environment* (New York, 1950), pp. 443-461; National Academy of Sciences, *Evaluation of Sensory Aids for the Visually Handicapped* (Washington: 1972), pp. 73-106.

[2] George Corner to Members of the Committee on Sensory Devices, August 17, 1945, NA; "History of the Committee on Sensory Devices, January 1946, p. 15. NA.

[3] Bush to Corner, May 1, 1945 and attached copy of Stimson to Bush, April 27, 1945, NA.

[4] George Corner to Members of the Committee on Sensory Devices, August 17, 1945, NA.

[5] A. A. Bombe to W. S. Tandler, December 17, 1947, NRC.

[6] Franklin S. Cooper. 1950. "Spectrum analysis," *Journal of the Acoustical Society of America 22:6*, p.761; Franklin S. Cooper, Pierre C. DeLattre, Alvin M. Liberman, John M. Borst, and Louis J. Gerstman. 1952. "Some experiments on the perception of synthetic speech sounds, *Journal of the Acoustical Society of America 24:6*, pp. 597-606.

[7] Howard Freiberger. 1971. "Deployment of Reading Machines for the Blind," *Bulletin of Prosthetics Research 10-15* (Spring), pp. 144-156.

[8] Mary Jameson. 1981. "The Optophone: Its beginning and development," *Bulletin of Prosthetics* Research 10-35 (Spring), pp. 25-28.

[9] Patrick W. Nye and James C. Bliss. 1970. "Sensory aids for the blind: A challenging problem with lessons for the future," *Proceedings of the IEEE, 58* (December), p. 1882.

[10] Howard Freiberger. 1981. "Mary Jameson, 1899 - 1980," *Bulletin of Prosthetics Research 10-35* (Spring), p. 329; Barr and Stroud, Ltd. "The Optophone," Pamphlet No 236 (London: Undated commercial pamphlet circa 1940).

[11] Freiberger, 1971, p. 146.

[12] Barr & Stroud Limited to Office of Scientific Research and Development, January 14, 1944, NA.

[13] Albert Abramson. 1981. "Pioneers of television – Vladimir Kosma Zworykin," *SMPTE Journal 90* (July), p. 579.

[14] Minutes of the Third Meeting of the Committee on Sensory Devices, April 21, 1944, p. 5, NA.

[15] Vannevar Bush to Dr. Haskins, November 8, 1943, LC.

[16] Irvin Stewart. 1948. *Organizing Scientific Research for War : The Administrative History of the Office of Scientific Research and Development* (Boston: Little, Brown), pp. 36-79 and p. 171; Jacques Cattell, ed. 1955. *American Men of Science: A Biographical Directory, Ninth Edition* (New York); Vol I, p.268; Jacques Cattell Press, ed. 1979. *American Men and Women of Science, Fourteenth Edition* (New York), Vol I, p. 2057.

[17] Abramson, 1981, pp. 579 - 590; Cattell, ed., 1955, Vol; I, p. 2178.

[18] Minutes of the Third Meeting of the Committee on Sensory Devices, April 21, 1944, p. 4, NA.

[19] Bush to Haskins, November 8, 1943, LC.

[20] Bush to Haskins, November 8, 1943, LC.

[21] V. K. Zworykin to G. W. Corner, April 6, 1944, NA; V. Bush to G. W. Corner, May 3, 1944, NA; Minutes of the Third Meeting of the Committee on Sensory Devices, April 21, 1944, p. 5, NA.

[22] Minutes of the First Meeting of the Committee on Sensory Devices, January 20, 1944, NA.

[23] Bush to Corner, January 7, 1944, LC.

[24] Stewart, 1948, p. 124.

[25] Corner to Bush, December 12, 1943, NA.

[26] Bush to Corner, January 6, 1944, NA.

[27] George W. Corner to Vannevar Bush, February 24, 1944, NA.

[28] James B. Conant. 1970. *My Several Lives: Memoirs of a Social Inventor* (New York: Harper & Row), p. 236.

[29] Paul A. Zahl, "Report on Contract OEMsr-1316," October 15, 1945, NA.

[30] Franklin S. Cooper to George W. Corner, June 9, 1947, NRC.

[31] Cattell, ed., 1955, Vol I, p.99; Vol. II, pp. 170, 225, 341, 445, and 654.

[32] "History of the Committee on Sensory Devices, January 1946, p. 2. NA

[33] Koestler, 1976, p. 281.

[34] Lloyd Greenwood. 1950. "The blinded veteran," in Zahl, ed., 1950, p. 261.

[35] Koestler, 1976, pp. 115 - 175.

[36] Koestler, 1976, pp. 107-109.

[37] Koestler, 1976, pp. 134 - 143 .

[38] Minutes of the First Meeting of the Committee on Sensory Devices, January 20, 1944, NA.

[39] Corner to Bush, April 14, 1944, NA.

[40] The impact of the meeting must have been small. Frances reports that Irwin was unaware of CSD as late as November 1944. (Koestler, 1976, p. 352).

[41] George Corner to American Foundation for the Blind, May 2, 1944, NA.

[42] Corner to Barton, May 12, 1944, NA.

[43] Majeska, Marilyn Lundell, *Talking Books: Pioneering and Beyond,* (Washington: 1988) The Library of Congress: National Library Service for the Blind and Physically Handicapped, p. 22.

[44] Zahl, ed., 1950.

[45] Zahl, ed., 1950, p. v.

[46] George W. Corner, "The Committee on Sensory Devices," in Zahl, ed., 1950, p. 431.

[47] Koestler, 1976, p. 350.

[48] Jerome B. Wiesner. 1972. "Making sensory aids a reality, " in Milton D. Graham, ed. 1972. *Science and Blindness: Retrospective and Prospective* (New York: American Foundation for the Blind), pp. 189-190; Koestler, 1976, p. 351.

[49] Koestler, 1976, pp. 350-351.

[50] Clifford M. Witcher. 1956. "The optical probe – A new tool for the blind," in *Technology Review 59:2,* (December), pp. 98-99 ff.; C. M. Witcher. 1949. "General considerations on guidance devices," A discussion paper dated March 25, 1949 was circulated to 41 primary addressees. A copy forwarded to Vannevar Bush by Eugene Murphy, August 29, 1949, may be found in LOC, Box 115.

[51] Howard Freiberger. 1967. "In memoriam: John Kenneth Dupress, 1922-1967," *Bulletin of Prosthetics Research 10-8* (Fall), pp. 323-324; Koestler, 1976, pp. 365-366.

[52] Leslie E. Flory, January 5, 1994, personal communication.

[53] William E. Kappauf. 1954. Final report of the Committee on Sensory Devices to the Division of Anthropology and Psychology, National Research Council, dated June 30, 1954. NRC. p. 4.

[54] Eugene F. Murphy to Dr. Wilma Donahue, July 11, 1949, NRC.

[55] Murphy to Bush, January 31, 1952, LOC.

Notes for Chapter 3

[1] Jacques Cattell, ed., 1955; Vol II, p.1266.

[2] Stewart, 1948, p. 171.

[3] *Comprehensive Dissertation Index, 1861 - 1972* 1973. Vol 33, p. 26.

[4] "Franklin S. Cooper, Ph.D., receives the silver medal in speech communication." 1975. In *Bulletin of Prosthetics Research 24*(Fall), p 280.

[5] Ibid.; Jacques Cattell Press, ed., 1979, Vol I, p. 953.

[6] Franklin S. Cooper. 1950. "Research on reading machines for the blind," in Zahl, ed., 1950, pp. 512-543.

[7] Minutes of the fourth meeting of the Committee on Sensory Devices, OSRD, June 9, 1944, p. 3, ; Minutes of 6th Meeting, April 28, 1945, p. 3; Minutes of the 7th Meeting, Held at Haskins Laboratories, July 18, 1945. pp. 1-2. NA.

[8] Paul A. Zahl, "Report on Contract OEMsr-1316, October 15, 1945, NA.

[9] Committee on Sensory Devices, Minutes of 6th Meeting, April 28, 1945, NA.

[10] Cooper in Zahl, ed., 1950, p. 513.

[11] Minutes of the fifth meeting of the Committee on Sensory Devices, O. S. R. D., July 27, 1944, NA.

[12] Corner to Members of the Committee on Sensory Devices, June 6, 1945, NA.

[13] Corner to Members of the Committee on Sensory Devices, June 20, 1945, NA.

[14] Minutes of the 7th Meeting, Held at Haskins Laboratories, July 18, 1945. p. 1, NA.

[15] Bush to Corner, July 24, 1945, NA.

[16] Wallace Fenn to George W. Corner, August 1, 1945, NA.

[17] George W. Corner to W. O. Fenn, August 3, 1945, NA.

[18] Haskins to Carlson, August 25, 1945, copy attached to Haskins to Corner, August 25, 1945, NA.

[19] K. S. Lashley to George W. Corner, August 16, 1944, NA.

[20] Bush to Corner, July 24, 1945, NA.

[21] A. C. Ellis to George W. Corner, January 22, 1945, NA.

[22] A. C. Ellis to George W. Corner, April 11. 1945, NA.

[23] Corner to Ellis, April 14, 1945, NA.

[24] Haskins to Corner, August 25, 1945, NA

[25] Leslie E. Flory, January 5, 1994, personal communication.

[26] Harvey Lauer relates that this explanation was told him by V. K. Zworykin, many years after the events. Personal communication, January 7, 1994.

[27] For exceptions, see Corner to Lt. Alan R. Blackburn, Jr., July 7, 1945; Corner to Hector Chevigny, August 14, 1945, NA.

[28] Minutes of the First Meeting of the Committee on Sensory Devices, January 20, 1944, p. 2, NA.

[29] Leslie E. Flory, January 5, 1994, personal communication.

[30] "Committee on Sensory Devices Supplement to Minutes of the 7th Meeting," August 31, 1945, NA.

[31] L. E. Flory. 1946. "Electronic reading aids for the blind." RCA Laboratories Report to CSD under subcontract 13 of W-49-007-MD-347, July 30, 1946. Copy in possession of author, as provided by L. E. Flory.

[32] George W. Corner, "Report of demonstration by Bell Telephone Laboratories ... to members of Committee on Sensory Devices," July 7, 1944, NA.

[33] "Deaf enabled to read sound waves." 1948. In New York Times, November 11, Section IV, p. 9.

[34] Gale M. Smith. 1963. "Telephone service for the totally deaf," *Volta Review: 65* (December), pp. 579-583.

[35] "Deaf teenagers help to introduce the Picturephone." 1964. *Volta Review 66* (October), p. 621.

[36] Cooper in Zahl, ed., 1950, Plate XXI, following p. 512.

[37] Ibid., pp. 523-524.

[38] Ibid., pp. 538-539.

[39] Ibid., Figure 2, p. 525.

[40] Ibid., p. 539.

[41] Wilkinson W. Meeks, John M. Borst, and Franklin S. Cooper. 1949. "Syllable synthesizer for research on speech." Reviewed, draft MS attached to V. Bush to Franklin S. Cooper, November 18, 1949, Box 28, LOC.

[42] Box 28, LOC.

[43] Franklin S. Cooper to Vannevar Bush, August 3, 1954, LOC.

Notes for Chapter 4

[1] Minutes of the second meeting of the Committee on Sensory Devices, March 17, 1944, p. 3, NA.

[2] Minutes of third meeting of the Committee on Sensory Devices, April 21, 1944, pp. 4-5, NA.

[3] Vannevar Bush to George W. Corner, May 3, 1944, NA.

[4] Minutes of the fourth meeting of the Committee on Sensory Devices, OSRD, June 9, 1944, p. 1.; Haskins to Corner, August 19, 1944, NA.

[5] George W. Corner to Loren Jones, August 7, 1944, NA.

[6] Caryl P. Haskins to George W. Corner, August 19, 1944, NA.

[7] V. K. Zworykin to G. W. Corner, January 5, 1945, NA.

[8] Zworykin to Corner, January 5, 1945, NA.

[9] J. E. McQuate to George W. Corner, January 22, 1946, NA.

[10] A. A. Bombe to Files, April 21, 1945, NRC.

[11] Minutes of the 7th Meeting, Held at Haskins Laboratories, July 18, 1945, NA.

[12] Flory, 1946, p. 30 and p. 42.

[13] Barr and Stroud, Ltd., Pamphlet circa 1940.

[14] Cooper in Zahl, ed., 1950, Plate XX, following p. 512.

[15] V. K. Zworykin and L. E. Flory. 1947. "An electronic reading aid for the blind," *Proceedings of the American Philosophical Society 91:2* (April), pp. 139 - 142.

[16] Flory, 1946, pp. 9-20.

[17] Leslie E. Flory, January 5, 1994, personal communication.

[18] A. A. Bombe to G. W. Corner, February 4, 1947, NRC.

[19] Kappauf, 1954, p. 10, NRC.

[20] Cooper in Zahl, ed., 1950, p. 520.

[21] Ibid., p. 522.

[22] Flory, 1946, p. 5.

[23] Ibid., pp. 42-43.

[24] Wilma Donahue to Eugene F. Murphy, August 24, 1949. Copy found in Vannevar Bush papers, Box 115, LOC.

[25] Eugene F. Murphy. 1972. "Evaluation of certain reading aids for the blind," in National Academy of Sciences *Evaluation of Sensory Aids for the Visually Handicapped* (Washington), p. 38.

[26] A. A. Bombe to G. W. Corner, Members of C.S.D., and Mr. Louis Jordan, January 2, 1948, NRC.

[27] A. A. Bombe to G. W. Corner, January 17, 1948, NRC.

[28] George W. Corner to Mrs. Irene Mansure, December 10, 1948, NRC; GWC to Dr. Kappauf, December 11, 1948, handwritten cover to previous correspondence, NRC. Corner stated that RCA was left with three A-2s, one of which was at the Philadelphia Lighthouse, one at Valley Forge Hospital, and one retained at Princeton. One of these devices, in good but nonoperating condition, was in the possession of Mr. Flory as of January 1993, and may be the only remaining A-2.

[29] Irene Mansure to George W. Corner, December 14, 1948, NRC.

[30] A. A. Bombe to G. W. Corner, June 4, 1946, NRC.

[31] Leslie E. Flory, January 5, 1994, personal communication.

[32] A. A. Bombe to G. W. Corner, June 4, 1946, NRC.

[33] A. A. Bombe to G. W. Corner, July 2, 1946, NRC.

[34] A. A. Bombe to G. W. Corner, May 12, 1947, NRC.

[35] Franklin S. Cooper to George W. Corner, June 9, 1947, NRC.

[36] V. K. Zworykin, L. E. Flory and W. S. Pike. 1949. "Letter reading machine," *Electronics*, (June), pp. 80-86.

[37] Ibid., p. 80.

[38] Ibid., p. 81.

[39] Ibid., pp. 80-86.

[40] A. A. Bombe to G. W. Corner, Members of C.S.D., Mr. Louis Jordan, January 2, 1948, NRC.

[41] Zworykin, Flory and Pike, 1949, p. 86.

[42] Cooper in Zahled., 1950, p. 533.

[43] Kappauf, 1954, p. 10, NRC.

[44] Leslie E. Flory, personal communication, January 18, 1994.

[45] James Phinney Baxter 3rd. 1946. *Scientists against Time* (Cambridge, MA: First M.I.T. Paperback edition, 1968).

Notes for Section II preface and Chapter 5

[1] Koestler, 1976, pp. 276-277.

[2] Jacques Cattell Press. ed., 1979, p. 3585; Eugene F. Murphy, personal communication, December 22, 1993.

[3] Eugene F. Murphy, personal communication, October 22, 1993.

[4] Eugene F. Murphy to Wilma Donahue, July 11, 1949, NRC.

[5] Murphy, 1972, p. 40; Eugene F. Murphy, personal correspondence, October 22, 1993.

[6] Cooper in Zahl, ed., 1950, p. 527.

[7] Hauger, 1991, pp. 69-86.

[8] American Association of Workers for the Blind, Inc. 1971. "U. S. government sponsored research to study blindness – 1971 supplement." Washington: American Association of Workers for the Blind, Inc., Reprinted from Blindness 1971 * AAWB Annual. p. 224.

[9] Howard Freiberger. 1966. "The Sixth Technical Conference on Reading Machines for the Blind," in *Bulletin of Prosthetics Research 10-5* (Spring), pp. 8-9.

[10] Leslie L. Clark, ed. 1963. *Proceedings of the International Congress on Technology and Blindness, Volume I* (New York: The American Foundation for the Blind).

[11] Richard Dufton, ed. 1966. *Proceedings of the International Conference on Sensory Devices for the Blind* (London: St. Dunstan's).

[12] Murphy, 1972, p. 39.

[13] Eugene F. Murphy. 1966. "...and sensory aids," in *Bulletin of Prosthetics Research, 10-5* (Spring), pp. 1-2.

[14] "Tentative Agenda, Third Meeting on Reading Machines for the Blind," enclosure to a letter from Eugene F. Murphy to Vannevar Bush, July 19, 1955, Box 115, LOC.

[15] Ibid.

[16] Koestler, pp. 269 - 270.

[17] Ibid.

[18] Freiberger, 1966, "Sixth Technical Conference," p. 9.

[19] H. Freiberger, C. E. Sherrick and Lawrence Scadden,1977. *Report of the Workshop on Sensory Deficits and Sensory Aids held March 22-24 at the Smith-Kettlewell Institute of Visual Sciences, San Francisco.*

[20] Harvey Lauer. 1994. "Answering historical questions about reading machine development," unpublished manuscript (50 pp.), dated February 24, p. 34.

[21] Newman Guttman. 1972. "Preface," in National Academy of Sciences, 1972), p. iii.

[22] Freiberger, 1971, "Deployment of Reading Machines for the Blind," pp. 144-156.

[23] Ibid., p. 144.

[24] Ibid., pp. 147-149.

[25] Ibid., pp. 144-145.

[26] Ibid., p 149.

[27] Franklin S. Cooper and Patrick W. Nye. 1972. "Plans for the evaluation of a high-performance reading machine for the blind," in National Academy of Sciences, 1972, pp. 61-62.

[28] James C. Bliss. 1972. "Optacon evaluation considerations," in National Academy of Sciences, 1972, p. 51.

[29] Murphy, 1972, "Evaluation of Certain Reading Aids for the Blind," in National Academy of Sciences, 1972, pp. 39-40.

[30] Summary, Fourth Technical Session on Reading Machines for the Blind, Held at the Veterans Administration, Washington, D.C" – August 23, 24, 1956, p. 6 and 31. Copy provided by Mr. Howard Freiberger.

[31] Ibid., p. 2.

[32] Ibid., pp. 5- 7.

[33] Ibid., p. 22.

[34] Ibid., p. 31.

[35] Ibid., p. 7.

[36] Dupress, John K. 1963. "The requirements for successful travel by the blind," in Clark, Leslie L., ed., 1963, p. 2.

[37] Koestler, 1976, p. 279.

[38] Summary, Fourth Technical Session on Reading Machines for the Blind, Held at the Veterans Administration, Washington, D.C" – August 23, 24, 1956, p. 31.

Notes for Chapter 6

[1] Summary, Fourth Technical Session on Reading Machines for the Blind, Held at the Veterans Administration, Washington, D.C. – August 23, 24, 1956, p. 2.

[2] Eugene Murphy, personal communication, January 14, 1994.

[3] Howard Freiberger. 1963. "Summary report of developments in the Veterans Administration Research Program on Aids for the Blind," Report number M / R 630901, September 1, 1963. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY, p. 4.

[4] Ibid., pp. 3-7.

[5] Howard Freiberger, "Summary: Reading Machines for the Blind, A Working Level Conference for Veterans Administration Contractors...," June 10, 1958. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY.

[6] Ibid. Fig. 3, attached.

[7] Freiberger, 1963, "Summary report." pp. 7-8; Freiberger, 1958, "Summary report," p. 2.

[8] Eugene F. Murphy, personal communication, October 22, 1993.

[9] Freiberger, 1958, Working level conference, p. 10.

[10] Murphy, 1972, "Evaluation of Certain Reading Aids for the Blind," pp. 41-42.

[11] John L. Coffey, Ray R. McFarland, and William D. Hitt. 1964. "The development and evaluation of optophone devices for the blind." in *Bulletin of Prosthetics Research 10-1* (Spring), p. 138.

[12] Howard Freiberger. 1963. "Notes on a one-week instructor seminar in use of the Battelle aural reading device for the blind," Report number R-630513. May 31, 1963, pp. 4-5. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY. Copy provided the author by Mr. Freiberger.

[13] Freiberger, 1963, "Summary Report, Fig. 1, attached..

[14] Ibid., p. 9.

[15] Howard Freiberger, ed. 1966. "Summary Sixth Technical Session on Reading Machines for the Blind, held at Veterans Administration Central Office, Washington, DC, January 27-28, 1966," p. 10. Report number R-660127. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY. Copy provided the author by Mr. Freiberger.

[16] Howard Freiberger. 1965. "Some laboratory notes on instructing a blind person in the use of the VA-Battelle Optophone," March 18, 1965. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY. Copy provided the author by Mr. Freiberger; Freiberger, ed., 1966, "Summary Sixth Technical Session on Reading Machines for the Blind, p. 9.

[17] Harvey Lauer, 1994, "The history and future of reading machines for the blind: Where they have been and what they can become." Unpublished manuscript (14 pp.), dated February 23, 1994, p. 1.

[18] Howard Freiberger. "VA Contractor Notes," in *Bulletin of Prosthetics Research* (Fall, 1964), p. 163; (Spring 1965), p. 174; Harvey Lauer, 1994, "Answering historical questions" p. 7.

[19] Freiberger, ed., 1966, "Summary Sixth Technical ", p. 16.

[20] Harvey Lauer, 1994, "Answering historical," p. 10.

Notes for Chapter 7

[1] Eugene F. Murphy, personal communication, January 14, 1994.

[2] Eugene F. Murphy to [distribution list], August 29, 1949, LOC, box 115.

[3] "Summary Second Technical Session on Reading Machines for the Blind - Held at the Franklin Institute, Philadelphia, Pennsylvania - April 25, 1955, p. 7." Copy found in Vannevar Bush Papers, Box 115, LOC.

[4] Ibid., p. 13.

[5] Ibid., p. 7.

[6] 'Summary, Fourth Technical Session on Reading Machines for the Blind,' 1956, p. 16.

[7] Ibid., p. 17.

[8] Ibid., p. 20.

[9] Ibid., p. 22 and insert between pages 19 and 20.

[10] Ibid., p. 24.

[11] Jaques Cattell Press, ed., 1979, p. 3250.

[12] Eugene F. Murphy, personal communication, January 14, 1994.

[13] Freiberger, 1958, "Summary, Working Level Conference," p. 10.

[14] U. S. Patent 2,907,833. *Patent Gazette, Vol 747*, p. 227.

[15] Howard Freiberger. 1958, "Summary Report of Developments in the Veterans Administration Research Program on Aids for the Blind, September 15, 1958, Fig. 4, attached.

[16] H. Freiberger and E. F. Murphy. 1961. "Reading machines for the blind," in *IRE Transactions on Human Factors in Electronics, HFL-2:1*, (March), p. 15.

[17] Freiberger, 1958, "Summary: Reading machines for the blind, A working level conference for Veterans Administration Contractors...," June 10, 1958, pp. 10 - 12.

[18] Freiberger, 1958, "Summary Report of Developments," p. 3.

[19] Glendon C. Smith and Hans A. Mauch. 1966. "Summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-6*(Fall), p. 100.

[20] Hans A. Mauch, "Review of the major functional concepts of reading machines," in Clark, ed., 1963, p. 226.

[21] Franklin S. Cooper, "Review and summary," in Clark, ed., 1963, p. 384 and 389.

[22] Milton Metfessel and Constance Lovell. 1972. "Guidelines for developing an alphabet to synthesize spelled speech," in *Bulletin of Prosthetics Research 10-17* (Spring), p. 155.

[23] Milton F. Metfessel. 1963. "Experimental studies of human factors in perception and learning of spelled speech," in Clark, ed, 1963, p. 306.

[24] Ibid., pp. 306-307.

[25] Glendon C. Smith and Hans A. Mauch. 1968. "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-10* (Fall), pp. 129-130.

[26] Freiberger and Murphy, 1961, "Reading Machines for the blind," p. 15.

[27] Cooper, 1963, in Leslie L. Clark, ed., p. 384.

[28] Howard Freiberger. 1963. "Summary report of developments in the Veterans Administration Research Program on Aids for the Blind," p. 5.

[29] Lauer, 1994, "Answering historical questions," pp. 11, 24, 30-31, 33.

[30] Glendon C. Smith and Hans A. Mauch, "Summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-12* (Fall 1969), p. 244; Glendon C. Smith and Hans A. Mauch, "Summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-14* (Fall 1970), p. 180.

[31] Except where otherwise noted, the following summary of the course of Cognodictor development is compiled from reports published by Glendon Smith and Hans Mauch and summary reports prepared by Howard Freiberger in the *Bulletin of Prosthetics Research*, between 1964 and 1970. See Howard Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-1* (Spring 1964), pp. 140-141; *10-2* (Fall 1964), pp. 163-164; *10-3* (Spring 1965), pp. 175-177; *10-4* (Fall 1965), pp. 205-207; *10-8* (Fall 1967), pp. 308-309; *10-9* (Spring 1968), pp. 195-196; Glendon C. Smith and Hans A. Mauch, "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-6* (Fall 1966), pp. 98-124; *10-10* (Fall 1968), pp. 128-158; *10-12* (Fall 1969), pp. 243-271.

[32] Freiberger, 1966, "Summary Sixth Technical Session on Reading Machines for the Blind, p. 41.

[33] Smith and Mauch, "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-6* (Fall 1966), pp. 104-108.

[34] Glendon C. Smith. 1966. "The development of recognition and direct translation reading machines for the blind," in Dufton, ed., p. 369.

[35] Freiberger, 1966, "Summary Sixth Technical Session on Reading Machines for the Blind, p. 41.

[36] Ibid., p. 43.

[37] Ibid., p. 44.

[38] Smith and Mauch, "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-10* (Fall 1968), p. 145.

[39] National Academy of Sciences, 1972, "Evaluation of Sensory Aids."

[40] Howard Freiberger. "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-15* (Spring 1971), p. 247.

[41] Harvey L. Lauer. 1974. Reading aids for the blind, in *Bulletin of Prosthetics Research 10-22* (Fall), p. 71.

[42] Lauer, 1994, "The history and future of reading machines for the blind," pp. 7-8.

[43] American Association of Workers for the Blind, Inc., 1971, p. 224.

[44] Howard Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-15* (Spring 1971), pp. 246-247; *10-21* (Fall 1974), pp. 158-160; *10-24* (Fall 1975), pp. 261-264; Glendon C. Smith and Hans A. Mauch, "Abstract of summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-14* (Fall 1970), pp. 180-181; 10-16 (Fall 1971), pp. 177-178; 10-18 (Fall 1972), pp. 195-196; *10-20* (Fall 1973), pp. 231-232; Glendon C. Smith and Hans A. Mauch, "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-22* (Fall 1974), pp. 427-435.

[45] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-24* (Fall 1975), p. 264.

[46] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-25* (Spring 1976), pp. 218-219.

[47] Glendon C. Smith and Hans A. Mauch, "Research and development in the field of reading machines for the blind," in *Bulletin of Prosthetics Research 10-27* (Spring 1977), pp. 60-71.

[48] Lauer, 1994, "Answering historical questions," p. 31.

[49] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-28* (Fall 1977), pp. 228-229.

[50] Lauer, 1994, "Answering historical question," p. 31.

[51] Ibid.

[52] Ibid., p. 11.

[53] U.S. Patent Nos. 2,807,741; 2,940,213; 3,014,348; 3,044,183; 3,370,807; and 3,531,770.

[54] Walter G. Vincenti. 1990 *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History.* (Baltimore: The Johns Hopkins University Press), pp. 254-255.

[55] Mauch, 1963, in Clark, ed, p. 224.

[56] Metfessel and Lovell,1972, p. 154.

[57] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-1* (Spring 1964), pp. 140-141.

[58] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-2* (Fall 1964), p. 163.

[59] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-3* (Spring 1965), p. 176.

[60] Smith and Mauch, "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-6* (Fall 1966), pp. 111-112.

[61] Ibid., p. 99.

[62] Ibid., pp. 108-110.

[63] Harvey Lauer. 1968. "The Visotoner: A personal reading machine for the blind," in *Bulletin of Prosthetics Research 10-9* (Spring), pp. 99-100.

[64] Smith, 1966, in Dufton, ed., 1966, p. 373.

[65] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-9* (Spring 1968), p. 196; Smith and Mauch, "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-10* (Fall 1968), pp. 145-156.

[66] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-11* (Spring 1970), p. 264.

[67] Smith and Mauch, "Summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-12* (Fall 1969), pp. 257-265.

[68] Freiberger, 1971, "Deployment of Reading Machines," p. 149.

[69] Ibid., p. 150.

[70] Ibid., pp. 151-156.

[71] Mauch and Smith, "The development of personal reading machines for the blind," in *Bulletin of Prosthetics Research 10-22* (Fall 1974), p. 428.

[72] Harvey Lauer. Personal communication to the author, May 4, 1994.

[73] Lauer, 1994, "Answering historical questions," pp. 32-33.

[74] Smith and Mauch, "Abstract of a summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-20* (Fall 1973), pp. 231-232. Mauch and Smith, "The development of personal reading machines for the blind," in *Bulletin of Prosthetics Research 10-22* (Fall 1974), pp. 428-429.

[75] John G. Linvill. 1973. *Research and Development of Tactile Facsimile Reading Aid for the Blind (The Optacon): Final Report.* Washington: U.S. Department of Health, Education, and Welfare, Office of Education, Bureau of Education for the Handicapped, March 1973. Report No. ED 121040 (ERIC). pp. 2-3.

[76] Nye and Bliss, 1970, pp. 1884-1886.

[77] Freiberger, 1971, "Deployment of reading machines for the blind," pp. 148-149.

[78] Mauch and Smith, "The development of personal reading machines for the blind," in *Bulletin of Prosthetics Research 10-22* (Fall 1974), pp. 427-428.

[79] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-24* (Fall 1975), p. 262.

[80] Michael Carberry and Margaret Butow,. 1976. "Research and evaluation of audible output print reading aids for the blind: A final report," in *Bulletin of Prosthetics Research 10-26* (Fall 1976), pp. 148-149; Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-19* (Spring 1973), p. 236.

[81] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-24* (Spring 1976), p. 235.

[82] Ibid. p. 236.

[83] Carberry and Butow, 1976, p. 158.

[84] Ibid., p. 150.

[85] Ibid., p. 153.

[86] Ibid., pp. 158-159.

[87] Ibid., p. 161.

[88] Ibid.

[89] Lauer, 1994, "Answering historical questions," pp. 20 and 24.

[90] Harvey Lauer. Personal communication to the author, May 4, 1994.

[91] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-13* (Spring 1970), p. 266; *10-15* (Spring 1971), p. 248; *10-17* (Spring 1972), p. 260; *10-19* (Spring 1973), pp. 233-234; *10-22* (Spring 1975), p. 264.

[92] Harvey Lauer, personal communication to the author, May 4, 1994.

Notes for Chapter 8

[1] Alvin M. Liberman and Ignatius G. Mattingly, "Citation to Franklin S. Cooper," in Journal of the Acoustical Society of America, 58, Supplement No. 1 (Fall 1975), Insert.

[2] Jacques Cattell Press. ed.1979, p. 953.

[3] Jacques Cattell Press. ed. 1968. *American Men of Science: Social and Behavioral Sciences, 11th Edition,*. New York: Jacques Cattell Press. p. 949.

[4] *IEEE Transactions on Audio and Electroacoustics, Vol. AU-17:4*, p. 270.

[5] Ibid.

[6] Jacques Cattell Press. ed, 1979, p. 3717; *IEEE Transactions on Audio and Electroacoustics, Vol. AU-21:3,* p. 312.

[7] "Summary Second Technical Session on Reading Machines for the Blind - Held at the Franklin Institute, Philadelphia, Pennsylvania - April 25, 1955", p. 7. Box 115, LOC.

[8] "Tentative Agenda: Third Meeting on Reading Machines for the Blind," attached to Eugene F. Murphy to Vannevar Bush, July 19, 1995, Box 115, LOC.

[9] "Summary, Fourth Technical Session on Reading Machines for the Blind", pp. 17-22.

[10] Liberman and Mattingly, 1975, "Citation to Franklin S. Cooper.

[11] Franklin S, Cooper, John M. Borst, and Alvin M. Liberman. 1949. "Analysis and synthesis of speech-like sounds," in *Acoustical Society of America Journal 21*, p. 461 (abstract).

[12] Cooper, 1950, "Spectrum analysis," pp. 761-762.

[13] Franklin S, Cooper, Alvin M. Liberman, and John M. Borst. 1950. "Preliminary studies of speech produced by a pattern playback," in *Acoustical Society of America Journal 22*, p. 678 (abstract).

[14] Franklin S, Cooper, Alvin M. Liberman, and John M. Borst. 1950. "Synthetic speech: a study of the auditory perception of complex sounds," in *Science 112*, (October), p. 426 (abstract).

[15] Cooper, DeLattre, Liberman, Borst, and Gerstman, 1952, "Some experiments," p. 597.

[16] Ibid., pp. 604-605.

[17] Franklin S, Cooper, Alvin M. Liberman, and Louis Gerstman. 1954. "acoustic loci and transitional cues for consonants" in *Acoustical Society of America Journal 26*, p. 137 (abstract); L. J. Gerstman, A. M. Liberman, P. C. DeLattre, and F. S. Cooper. 1954.

"Rate and duration of change in formant frequencies as cues for the identification of speech sounds," in *Acoustical Society of America Journal 26* , p. 952 (abstract); Katherine Safford Harris. 1950. "Cues for the identification of the fricatives of American English," in *Acoustical Society of America Journal* 22, p. 678 (abstract).

[18].K. S. Harris, A. M. Liberman, H. Hoffman, and B. C. Griffith. 1956. "Differential sensitivity in synthetic speech sounds within and between phoneme categories," in *Acoustical Society of America Journal 28*, p. 760 (abstract); L. J. Gerstman, L. Lisker, J. D. O'Conner, A. M. Liberman, P.C. DeLattre, and F. S. Cooper. 1957. "Initial and intervocalic cues for the perception of liquids and semivowels " in *Acoustical Society of America Journal 29*, p. 778 (abstract); A. M. Liberman, P. C. DeLattre, and F. S. Cooper. 1957. "some cues for the distinction between voiced and voiceless stops in initial position " in *Acoustical Society of America Journal 29*, p. 1254 (abstract).

[19] Pierre C. DeLattre, Alvin M. Liberman, and Franklin S. Cooper. 1955. "Acoustic loci and transitional cues for consonants," in *Acoustical Society of America Journal 27:4*, (July), pp. 769-773; Alvin M. Liberman. 1957. "Some results of research on speech perception," in *Acoustical Society of America Journal 29:4*1 (January), pp. 117-123; Katherine Safford Harris, Howard S. Hoffman, Alvin M. Liberman, Pierre C. DeLattre, and Franklin S. Cooper. 1958. "Effect of third-formant transitions on the perception of the voiced stopped consonants," in *Acoustical Society of America Journal 30:2* (February), pp. 122-126.

[20] Liberman, 1957, "Some results of research on speech perception, pp. 121-122.

[21] Eugene F. Murphy, Personal communication to the author, October 22, 1993.

[22] Freiberger, 1958, "Summary report of developments," p. 2.

[23] Jane H. Gaitenby. 1961. "Word reading device: Experiments on the transposability of spoken words" in *Acoustical Society of America Journal 33*, p. 1664 (abstract).

[24] Franklin S. Cooper, Jane H. Gaitenby, and Patrick W. Nye. 1984. "Evolution of reading machines for the blind: Haskins' Laboratories' research as a case history," in *Journal of Rehabilitation Research and Development 21:1* (Spring), p. 73.

[25] Freiberger, "VA Contractor Notes." in *Bulletin of Prosthetics Research 10-1* (Spring, 1964), p. 138, *10-3* (Spring 1965), pp. 173-174, *10-4* (Fall 1965), p. 205.

[26] Cooper, Gaitenby, and Nye, 1984, p. 73.

[27] Ibid.

[28] Ibid., p. 74.

[29] Ibid.

[30] Franklin S. Cooper. 1961. "Word reading device: Design considerations" in *Acoustical Society of America Journal 33*, p. 1664 (abstract).

[31] Cooper, 1963, in Clark, *Proceedings,* p. 386.

[32] Freiberger, VA Contractor Notes," in *Bulletin of Prosthetics Research 10-1* (Spring 1964), p. 137.

[33] Freiberger, VA Contractor Notes," in *Bulletin of Prosthetics Research 10-3* (Spring 1965), p. 172.

[34] Ibid., pp. 173-174.

[35] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-7* (Spring 1967), p. 308.

[36] Michael Studdert-Kennedy and Franklin S. Cooper. 1966. "High-performance reading machines for the blind: Psychological problems, technological problems and status," in, Dufton, ed., 1966, p. 335.

[37] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-12* (Fall 1969), p. 376; *10-13* (Spring 1970), p. 264; *10-15* (Spring 1971), pp. 241-246.

[38] Cooper, Gaitenby, and Nye, 1984, p. 77.

[39] Ibid., p. 73; Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-12* (Fall 1969), p. 374; *10-13* (Spring 1970), p. 263.

[40] Studdert-Kennedy and Cooper, 1966, p. 12-13; Freiberger, 1958, "Summary, report of developments," pp. 1-2; Cooper, Gaitenby and Nye,1984, p. 74.

[41] Eugene F. Murphy, Personal communication to the author, October 22, 1993.

[42] A. M. Liberman, Frances Ingemann, Leigh Lister, Pierre DeLattre, and F. S. Cooper. 1959. "Minimal rules for synthesizing speech," in *Acoustical Society of America Journal 31:11* (November), p. 1491.

[43] Ibid., p. 1493.

[44] A. M Lieberman, [sic.], F. S. Cooper, Katherine S. Harris, and P. F. MacHeilage. 1963. "Motor theory of speech perception," in *Acoustical Society of America Journal 35* p. 1114 (abstract).

[45] Franklin S. Cooper. 1966. "Describing the speech process in motor command terms," in *Acoustical Society of America Journal 39* , p. 1221 (abstract).

[46] Pierre C. DeLattre, Alvin M. Liberman, and Franklin S. Cooper. 1960. "Second and third formant transitions in English fricatives," in *Acoustical Society of America Journal 32*, p. 1501 (abstract); Pierre C. DeLattre, Alvin M. Liberman, and Franklin S. Cooper. 1961. "Second and third formant loci in English fricative consonants," in *Acoustical Society of America Journal 33*, p. 1677 (abstract); Jarvis Bastian, Peter D. Eimas, and Alvin M. Liberman. 1961. "Identification and discrimination of a phonemic contrast induced by a silent interval," in *Acoustical Society of America Journal 33*, p. 842

(abstract); Arthur S. Abramson. 1961. "Identification and discrimination of phonemic tones," in *Acoustical Society of America Journal 33*, p. 842 (abstract); Leigh Lisker and Arthur S. Abramson. 1963. "Crosslanguage study of voicing in initial stops," in *Acoustical Society of America Journal 35*, p. 1889 (abstract); M. Studdert-Kennedy, A. M. Liberman and Kenneth N. Stevens. 1964. "Reaction time during the discrimination of synthetic stop consonants," in *Acoustical Society of America Journal 36*, p. 1989 (abstract); Ignatius G. Mattingly. 1967. "Speech synthesis by rule as a research technique," in *Acoustical Society of America Journal 41*, p. 1588 (abstract); Jane H. Gaitenby. 1967. "Rules for word stress analysis for conversion of print to synthetic speech, in *Acoustical Society of America Journal 42*, p. 1182 (abstract); Ignatius G. Mattingly and Alvin M. Liberman. 1969. "Discrimination of F2 transitions in speech context and in isolation," in *Acoustical Society of America Journal 45*, pp. 314-315 (abstract).

[47] Gloria Lysaught, Robert J. Rosov, and Katherine Safford Harris. 1961. "Electromyography as a speech research technique with an application to labial stops, in *Acoustical Society of America Journal 33*, p. 842 (abstract); Katherine Safford Harris, Jarvis Bastian and Alvin M. Liberman. 1961. "Mimicry and the perception of a phonemic contrast induced by silent interval: Electromyographic and acoustic measures," in *Acoustical Society of America Journal 33*, p. 842 (abstract); Arthur S. Abramson and Franklin S, Cooper. 1963. "Slow-motion x-ray pictures with stretched speech as a research tool," in *Acoustical Society of America Journal 35*, p. 1888 (abstract); Peter F, MacNeilage and George N. Sholes. 1963. "Electromyographic study of timing in vowels," in *Acoustical Society of America Journal 35*, p. 1889 (abstract); Peter F, MacNeilage. 1964. "Electromyographic study of the coarticulation of vowels and consonants," in *Acoustical Society of America Journal 36*, p. 1989 (abstract); Arthur S. Abramson. 1967. "On matching the speech signal to mechanisms of production," in *Acoustical Society of America Journal 41*, p. 1588 (abstract); Leigh Lisker, Arthur S. Abramson, Franklin S. Cooper, and Malcolm H. Schvet. 1969. "Transillumination of the larynx in running speech," in *Acoustical Society of America Journal 45*, p. 1544, ff.; Masayuki Sawashima, Arthur S. Abramson, Franklin S. Cooper, and Leigh Lisker. 1970. "Motion pictures of vocal folds in speech," in *Acoustical Society of America Journal 47*, p. 105 (abstract); Leigh Lisker, Masayuki Sawashima, Arthur S. Abramson, and Franklin S. Cooper. 1971. "Cinegraphic observations of the larynx during voiced and voiceless stops," in *Acoustical Society of America Journal 48*, p. 119 (abstract).

[48] Franklin S. Cooper. 1967. "Haskins Laboratories: Research on human communication, marine ecology, and the biochemistry of protozoa," in *Science 158* (1 December), p. 1213.

[49] Ibid.

[50] For a history of this theory see Alvin M. Liberman. 1993. "Some assumptions about speech and how they changed." Haskins Laboratories status report on speech research, SR-113, 1-32. The essay is to appear as the introduction to a forthcoming collection of papers to be published by MIT Press.

[51] F. S. Cooper, A. M. Liberman, L. Lisker, and Jane H. Gaitenby. 1963. "Speech synthesis by rules," in *Acoustical Society of America Journal 35* , p. 1115 (abstract).

[52] Ignatius G. Mattingly. 1968. "Experimental methods for speech synthesis by rule," in *IEEE Transactions on Audio and Electroacoustics, AU-16* (June), p. 198 and note 1, p. 202; Cooper, Gaitenby, and Nye, 1984, p. 76.

[53] Gaitenby, 1961, "Word reading device", p. 1664 (abstract); Gaitenby, 1967, "Rules for word stress analysis," p. 1182 (abstract).

[54] J. N. Holmes, Ignatius G. Mattingly and J. N. Shearme. 1964. "Speech synthesis by rule," in *Language and Speech 7:3,* (July - September) pp. 127 - 143.

[55] Ignatius G. Mattingly. 1966. "Synthesis by rule of prosodic features," in *Language and Speech 9:1,* (January - March) pp. 1-13.

[56] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-9* (Spring 1968), p.195.

[57] Studdert-Kennedy and Cooper, 1966,in Dufton, ed., pp. 328-331.

[58] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-12* (Fall 1969), p.376.

[59] Ibid.

[60] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-13* (Spring 1970), p.263.

[61] Ibid., p. 268.

[62] Ibid., pp. 263-264; *10-15* (Spring 1971), pp. 242-243.

[63] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-15* (Spring 1971), 242.

[64] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-3* (Spring 1965), p.174.

[65] Freiberger, ed., 1966, "Summary Sixth Technical" pp. 35-36.

[66] Jane H. Gaitenby. 1966. "Problems in machine conversion of print to 'speech,'" in *Bulletin of Prosthetics Research 10-5* (Spring), pp. 38, 39, and 43.

[67] Studdert-Kennedy and Cooper, 1966, in Dufton, ed., pp. 326-327.

[68] American Association of Workers for the Blind, Inc., 1971, p. 224.

[69] Cooper and Nye, 1972, "Plans for the Evaluation," pp. 58-61.

[70] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-16* (Fall 1971), pp. 251-252.

[71] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-17* (Spring 1972), p. 253.

[72] Cooper, Gaitenby, and Nye, 1984, pp. 79-80.

[73] Ibid.; Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-18* (Fall 1972), pp. 273-275.

[74] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-19* (Spring 1973), p. 226.

[75] Ibid., pp. 227-228.

[76] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-20* (Fall 1973), p. 352.

[77] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-21* (Spring 1974), pp. 158-159.

[78] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-24* (Fall 1975), p. 257.

[79] Cooper, Gaitenby, and Nye, 1984, p. 82.

[80] Ibid., pp. 81-82; Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-20*(Fall 1973), pp. 349-351; *10-21* (Spring 1974), pp. 154-156.

[81] Cooper, Gaitenby, and Nye, 1984, p. 83; Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-21*(Spring 1974), pp. 156-157.

[82] Cooper, Gaitenby, and Nye, 1984, p. 83.

[83] Ibid., pp. 83-84.

[84] Ibid., p. 66.

[85] "Summary, Fourth Technical Session," 1956, p. 22.

[86] Freiberger, "VA Contractor Notes," in *Bulletin of Prosthetics Research 10-20* (Fall 1973), p. 348.

[87] Cooper, Gaitenby, and Nye, 1984, p. 85.

[88] Ibid.

[89] Ibid., pp. 85-86.

[90] Lee Edson. 1970. "Substitutes for eyes tested by blind," in *New York Times*, July 24, p. 33; Nye and Bliss, 1970, pp. 1883 - 1884.

[91] Francis F. Lee. 1969. "Reading machine: From text to speech," in *IEEE Transactions on Audio and Electroacoustics, 17:4,* (December), pp. 275 - 282; Nye and Bliss, 1970, p. 1888.

[92] Nye and Bliss, 1970, p. 1888-9.

[93] Lauer, 1994, "Answering historical questions," p. 5.

[94] Clark, ed., 1963,*Proceedings*, pp. 205-469.

Notes for Section III preface and Chapter 9

[1] Coudroglou and Poole, 1984, pp. 19-24; Scotch, 1984, pp. 19-22; Percy, 1989, pp. 44-45.

[2] Organization for Social and Technical Innovation, Inc., pp. 108-110.

[3] Robert E. Stewart. 1965. "Twenty years of progress: An editorial," in *Bulletin of Prosthetics Research 10-3* (Spring) p. 2.

[4] Ibid.

[5] William G. Emener, Richard S. Luck, and Stanley J. Smits, eds. 1981. *Rehabilitation Administration and Supervision.* Baltimore, University Park Press., pp. 8-9.

[6] Percy, 1989, pp. 46-47.

[7] U.S. House of Representatives, Committee on Science and Technology. 1981. *Oversight Hearings on the National Institute of Handicapped Research.* Washington: USGPO, p. 55.

[8] Ibid.

[9] A detailed account may be found in Percy. Other sources include Scotch, Berkowitz, and Bowe (1978), a participant in the disability rights movement.

[10] Percy, 1989, p. 106.

[11] Ibid., p. 52.

[12] Section 504 of the Rehabilitation Act of 1973 (PL93-112).

[13] Scotch, 1984, p. 65.

[14] Ibid., p. 66.

[15] James C. Bliss, "Q. and A. for J. Scott Hauger." Personal communication to the author (13 pp.), dated November 2, 1993, p. 2.

[16] Ibid., p. 9; James C. Bliss. 1969. "A relatively high-resolution reading aid for the blind," in *IEEE Transactions on Man-Machine Systems, MMS-10:1*, (March), p. 7; Koestler, 1976, p. 357.

[17] Koestler, 1976, p. 357; Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 11.

[18] Jaques Cattell Press, ed. *American Men and Women of Science, 15th Edition, IV*, p. 775; *Proceedings of the IEEE, 54:1* (January 1966), p. 52.

[19] Koestler, 1976, p. 356; "Replacing Braille?" in *Time* (September 19, 1969), pp. 52 and 57.

[20] G. J. Alonzo. 1964. "Development of a piezoelectric dynamic embosser for use as a reading machine." Tech Rept. 4813-4. (March). Stanford University.

[21] *Who's Who in America, 1994.* Vol 2.(New Providence, NJ), p. 2106.

[22] Koestler, 1976, p. 357.

[23] *Proceedings of the IEEE, 54:1* (January 1966), p. 51.

[24] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 1.

[25] James C. Bliss. 1962. "Kinesthetic-tactile communications," in *IRE Transactions on Information Theory, IT-8:2* (February), pp. 92- 99.

[26] Kenneth W. Gardiner and J. C. Bliss. 1966. "An optical to tactile image converter," in Dufton, ed., p. 301.

[27] K. Kotovsky and J. C. Bliss,. 1963. "Tactile presentation of visual information," in *IEEE Transactions on Military Electronics, MIL-7:2&3,* (April-July), pp. 108-113.

[28] James C. Bliss. 1963. "Tactual-kinesthetic perception of information," in Clark, ed., pp. 309-323.

[29] Gardiner and Bliss, 1966, in Dufton, ed., p. 300.

[30] Bliss, 1963, "Tactual-kinesthetic perception of information," in Clark, ed., p. 320.

[31] J. C. Bliss and J. G. Linvill. 1966. "A direct translation reading aid: reading alphabetic shapes tactually," in Dufton, ed., p. 389.

[32] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 3.

[33] Koestler, 1976, p. 356.

[34] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 2.

[35] Ibid.

[36] Linvill, 1973., *Final Report*, Appendix III.

[37] Ibid., Appendix V.

[38] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 9.

[39] Ibid., p. 3; Koestler, 1976, p. 366.

[40] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 8.

[41] Ibid., pp. 3-4.

[42] James J. Cremins. 1983. *Legal and Political Issues in Special Education* (Springfield, IL: Charles C. Thomas, Publishers), pp. 12-13.

[43] Linvill, 1973, *Final Report*, p. 4.

[44] J. G. Linvill and J. C. Bliss. 1966. "A direct translation reading aid for the blind," in *Proceedings of the IEEE 54:1,* (January), p. 40.

[45] Bliss, 1969, "A relatively high-resolution reading aid for the blind," pp. 1-9.

[46] Nye and Bliss. 1970, pp. 1878 - 1898.

[47] James Bliss. 1967. "Optical-to-tactile image conversion aids for the blind," in *Archives of Physical Medicine and Rehabilitation 48:7* (July), pp. 352-353.

[48] H. Freiberger, C. E. Sherrick and Lawrence Scadden. 1977. *Report of the Workshop on Sensory Deficits and Sensory Aids held March 22-24 at the Smith-Kettlewell Institute of Visual Sciences, San Francisco.*

[49] *Ibid.*, p. 12.

[50] Ibid.

[51] Bliss and Linvill, 1966, in Dufton, ed., Fig 2, p. 391, and Fig. 5, p. 394.

[52] Ibid.; plus figure 3, p. 392, and figure 11, p. 400.

[53] James C. Bliss, Hewitt D. Crane, Stephen W. Link and James T. Townsend. 1966. "Tactile perception of sequentially presented spatial patterns," in *Perception and Psychophysics*, pp. 125-130; James C. Bliss, Hewitt D. Crane and Stephen W. Link, "Effect of display movement on tactile pattern perception," in *Perception and Psychophysics 1* (1966), pp. 195-202; James C. Bliss, Hewitt D. Crane, Phyllis K. Mansfield and James T. Townsend, "Information available in brief tactile presentations," in *Perception and Psychophysics 1* (1966), pp. 273-283.

[54] Linvill and Bliss, 1966, "A direct translation reading aid for the blind," p. 51.

[55] Gardiner and Bliss, 1966, in Dufton, ed., pp. 300-1.

[56] Linvill and Bliss, 1966, "A direct translation reading aid for the blind," pp. 43-45; Freiberger, ed., 1966, "Summary, Sixth Technical Session," p. 23.

[57] Linvill and Bliss, 1966, "A direct translation reading aid for the blind," pp. 47-50.

[58] Ibid., p. 40.

[59] Ibid., p. 50.

[60] Freiberger, ed., 1966, "Summary, Sixth Technical," pp. 23-24.

[61] Linvill, 1973, *Final Report,* p. 6.

[62] Ibid., p. 2 and p. 6.

[63] Ibid., p. 6.

[64] American Association of Workers for the Blind, *1971,* p. 224.

[65] "Replacing braille?" in *Time 94* (September 19, 1969), p. 52.

[66] Reader for blind recognizes any printing," in *Machine Design 91:* (March 10, 1969), p. 18; J. G. Linvill. 1969. "Development progress on a microelectronic tactile facsimile reading aid for the blind, in *IEEE Transactions on Audio and Electroacoustics AU-17:4,* (December), p. 271.

[67] Nye and Bliss, 1970, p. 1884.

[68] Linvill, 1973, *Final Report,* p. 1.

[69] Ibid., pp. 6-8.

[70] Ibid., pp. 8-10.

[71] Bliss, 1969, "A relatively high-resolution reading aid for the blind," pp. 1-3.

[72] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 8.

[73] Bliss, 1969, "A relatively high-resolution reading aid for the blind," p. 7.

[74] Ibid., p. 6; Bliss, 1993, "Q. and A. for J. Scott Hauger," pp. 9-10.

[75] Bliss, 1969, "A relatively high-resolution reading aid for the blind," p. 7.

[76] Ibid.

[77] Linvill, 1973, *Final Report*, pp. 8-21.

[78] Ibid., p. 15.

[79] Ibid., p. 16; American Association of Workers for the Blind, *1971*, p. 209.

[80] Linvill, 1973, *Final Report*, pp. 16-17; James Bliss. 1972. "Sensory supplementation: Reading," in Milton D. Graham, ed. 1972. *Science and Blindness: Retrospective and Prospective* (New York: American Foundation for the Blind.), pp. 136-147.

[81] Linvill, 1973, *Final Report*, p. 14.

[82] Bliss. 1972. "Optacon evaluation considerations,"pp. 52-53; Linvill, 1973, *Final Report*, p. 20 and pp. 40-42; Bliss, 1993, "Q. and A. for J. Scott Hauger," pp. 9-10.

[83] Bliss, 1972, "Optacon evaluation considerations," p. 52.

[84] Linvill, 1973, *Final Report*, pp. 59-60.

[85] Ibid., p. 22.

[86] Linvill, 1969. "Development Progress," p. 272; Nye, and Bliss, 1970, "Sensory aids for the blind," p. 1885.

[87] Bliss, 1972, "Optacon evaluation considerations," p. 53.

[88] Vito Proscia, interview with the author, November 12, 1990; Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 10.

[89] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 10.

[90] Linvill, 1973, *Final Report*, pp. 40-43.

[91] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 7.

[92] Linvill, 1973, *Final Report*, p. 65.

[93] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 7.

[94] Linvill, 1973, *Final Report*, p. 65; Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 7.

[95] Linvill, 1973, *Final Report*, p. 21.

[96] Ibid.

[97] Ibid., p. 63.

[98] Ibid., p. 40.

[99] Jaques Cattell Press, ed., 1979, *Vol. I,* p. 437.

[100] Linvill, 1973,*Final Report,* pp. 31-33.

[101] Ibid., p ii, and pp. 66-68.

[102] Koestler,1976, p. 357.

[103] Carbery and Butow, 1976, p. 161.

[104] Freiberger, Sherrick and Scadden, 1977, p. 12.

[105] Telesensory Systems, Inc. 1978. "Progress report," (advertisement) in *Journal of Visual Impairment and Blindness 72:7,* (September), inside back cover.

[106] "The Optacon in its second decade: Continuing to expand opportunities," 1981. (advertisement) in *Journal of Visual Impairment and Blindness 75:6* (June), inside back cover.

[107] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 10.

[108] Ibid., p. 7.

[109] Ibid., p. 10.

[110] Mary W. Moore. 1973. "Professional preparation of teachers of reading with the Optacon. Report to the Richard King Mellon Foundation (Summer), (70 pp.). Located in the ERIC data base, Number ED 083 769.

[111] Susan Jay Spungin. 1985. "Corridors of insensitivity: Technology and blind persons," in *Journal of Visual Impairment and Blindness 79,* (March), p. 116.

[112] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 13.

[113] Ibid., p. 8.

[114] "The Mowat Sensor," (advertisement) in *Journal of Visual Impairment and Blindness 71:8,* (October, 1977), inside back cover.

[115] Freiberger, ed. VA Contractor Reports, in *Bulletin of Prosthetics research 10-34* (Fall 1980), pp. 111-112.

[116] Lauer, 1994, "The history and future of reading machines for the blind," p. 8; Lauer, 1994, "Answering historical questions," p. 27.

[117] Freiberger, ed. VA Contractor Reports, in *Bulletin of Prosthetics research 10-18,* (Fall 1971), pp. 278-280.

[118] Freiberger, ed. VA Contractor Reports, in *Bulletin of Prosthetics research 10-21* (Spring 1973), p. 233.

[119] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 8.

[120] Ibid., p. 9.

[121] Lauer, 1994, "Answering historical questions," p. 19.

[122] Bliss, 1993, "Q. and A. for J. Scott Hauger," pp. 12-13.

[123] Patricia D. Gadbaw, Mary T. Dolan, and William R. De L'Aune. 1977. "Optacon skill acquisition by blinded veterans," in *Visual Impairment and Blindness 71(1)* (January), pp. 23-28.

[124] Ivan Terzieff, Vaughan Stagg, and S. C. Ashcroft. 1982. "Increasing reading rates with the Optacon: A pilot study," in *Visual Impairment and Blindness 76(1)* (January), pp. 17-22.

[125] Lauer, 1994, "Answering historical questions," pp. 14-15.

[126] Lauer, 1994, "The history and future of reading machines," p. 5.

[127] Lauer, 1994, "Answering historical questions," p. 16.

[128] Freiberger, Sherrick and Scadden, 1977, p. 12.

[129] Ibid., p. 2.

[130] Ibid., charts between p.3 and p. 4.

[131] Bliss, 1993, "Q. and A. for J. Scott Hauger," p. 12.

[132] American Foundation for the Blind. 1968. *851 Blinded Veterans: A Success Story.* (New York: American Foundation for the Blind). Appendix 2.

[133] Linvill, 1973, *Final Report,* p. 32.

Notes for Chapter 10

[1] Cooper, Gaitenby, and Nye, 1984, pp. 85-86.

[2] Alvin Liberman, personal communication, May 14, 1994; Eugene Murphy, personal communication, October 22, 1993.

[3] Alvin P. Sanoff and Gordon M. Bock. 1983. "Inventive genius is alive and well in the U.S.: Words, music from computers," in *U.S. News & World Report* (June 13), p. 63; Task Force on Women, Minorities, and the Handicapped in Science and Technology. 1988. "Task Force on Women, Minorities, and the Handicapped in Science and

Technology: Public Hearing. Report of the Proceedings." (Cambridge, Massachusetts, April 7)." Washington. EDRS Document ED 317 391, pp. 116-134.

[4] T. A. Heppenheimer. 1985. "Chipmaster," in *Omni, 7* (February), pp. 87-88 ff.

[5] "ACM News." 1979. In *Communications of the ACM 22:1* (January), p. 63.

[6] Ibid.

[7] Louise Melton. 1984. "Mister Impossible: Ray Kurzweil," in *Computers & Electronics, 22* (July 1984), p. 42.

[8] Leslie Helm. 1988, "This whiz kid isn't such a whiz at business," in *Business Week, n. 3034* (January 18), p. 66.

[9] Ellen Cantarow. 1981. "Raymond Kurzweil: Giving 'sight' to the blind," in *Sciquest 54(2),* (February), pp. 21-23; "The computerized creations of Raymond Kurzweil can talk, listen and sing." 1984. In *Science Digest 92,* (February), p. 73; Heppenheimer, 1985, p. 88.

[10] Paul Attanasio. 1984. "What the inventor saw: Raymond Kurzweil and his incredible machines. *Esquire* (December), p. 120.

[11] Cantarow, 1981, p. 22; Jay Fraser. 1989. "Raymond Kurzweil and the second Industrial Revolution," in *EDN 34:23,* (Nov. 9), p. 356.

[12] Aaron Kleiner. Personal communication. January 24, 1995.

[13] Aaron Kleiner. 1993. Telephone interview with the author, November 19. Telephone conversation with the author, January 24, 1995; Heppenheimer, p. 88.

[14] Kleiner, 1993, interview.

[15] Michael Hingson. 1976. "Reading machine testing project begins," in *The Braille Monitor* (Print Edition) (December), pp. 608 - 609; Aaron Kleiner and Raymond C. Kurzweil. 1977. "A description of the Kurzweil Reading Machine and a status report on its testing and dissemination," in *Bulletin of Prosthetics Research 10-27,* (Spring) p. 80.

[16] Raymond Kurzweil. 1975. "The Kurzweil Reading Machine," in *The Braille Monitor* (Print Edition) (September), p. 426.

[17] Hingson, 1976, p. 609.

[18] Kleiner, 1993, interview.

[19] "Kurzweil Reading Machine Testing Project nears a successful conclusion." 1978. In *The Braille Monitor* (Print Edition) (April), pp. 114-115.

[20] Kleiner, 1993, interview; Kleiner and Kurzweil, 1977, pp. 79 - 80.

[21] Kleiner, 1993, interview.

[22] Kleiner and Kurzweil, 1977, pp. 79 - 80.

[23] The service community has been studied as a part of "The blindness system," a term coined by sociologist, Donald A. Schon. For more information, see Donald A. Schon. 1970. "The blindness system," in *The Public Interest 18* (Winter), pp. 25 - 38; and Organization for Social and Technical Innovation, Inc. 1971.

[24] Aaron Kleiner, telephone conversation, January 24, 1995.

[25] Koestler, 1976, p. 281.

[26] For example, Jacobus tenBroek and Floyd W. Matson. 1959. *Hope Deferred: Public Welfare and the Blind.* Los Angeles: University of California Press, pp. 1-9.

[27] Mary Ellen Anderson. 1982. "Status report: Employment opportunities for the blind in the United States in the 1980's," in Mary Ellen Anderson, ed. 1982. *Competing on Terms of Equality: The Goal and the Reality.* Baltimore: National Federation of the Blind, p. 1.

[28] Koestler, 1976, p. 507.

[29] Floyd W. Matson. 1990. *Walking Alone and Marching Together: A History of the Organized Blind Movement in the United States, 1940 -1990.* Baltimore: National Federation of the Blind, pp. 74 - 75; quoted in C. Edwin Vaughan. 1993. *The Struggle of Blind People for Self-determination. The Dependency – Rehabilitation Conflict: Empowerment in the Blindness Community.* Springfield, IL: Charles C. Thomas, Publisher.

[30] Ibid., p. 749.

[31] Koestler, 1976, pp. 506-507.

[32] Ibid., p. 508.

[33] Stephen M. Johnson. 1972. "Judge backs Jernigan's activities as head of blind," in *Des Moines Register* (November 10), quoted in *The Braille Monitor* (Print Edition) (March, 1973), pp. 150-151.

[34] Kurzweil, 1975, pp. 426-427.

[35] "Technology and communications." 1978. In *The Braille Monitor* (Print Edition) (October), p. 293.

[36] "Dismiss blind Iowans' suit." 1973. *Des Moines Tribune* (January 17), quoted in *The Braille Monitor* (Print Edition) (March, 1973), p. 153.

[37] Kenneth Jernigan. 1972. "Dual membership again." in *The Braille Monitor* (Print Edition) (December), p. 643.

[38] Ibid., pp. 643-645.

[39] Johnson, 1972, quoted in *Braille Monitor,* p. 151.

[40] "The new Braille Forum." 1977. In *The Braille Monitor* (Print Edition) (October), p. 349.

[41] Florence Grannis. 1974. "Aids and appliances," in *The Braille Monitor* (Print Edition) (August), p. 409.

[42] Koestler, 1976, p. 347; Loyal Eugene Apple. 1975. "The American Foundation for the Blind: A look ahead," in *The Braille Monitor* (Print Edition) (September), p. 361.

[43] "NFB aids and appliances: Policy statement. 1975. In *The Braille Monitor* (Print Edition) (April), p. 173.

[44] Another possible motive is suggested by Koestler's report that the AFB aids and appliances program operated at a deficit (p. 331). It may be that NFB hoped that the sale of aids and appliances would be a source of operating funds, but found the project to be less than profitable.

[45] Victor K. McElheny. 1976. "Print-to-speech devices are expected to aid the blind," in *New York Times* (January 14), p. 10.

[46] "Kurzweil Reading Machine testing project...," 1978, p. 115.

[47] Kurzweil, 1975.

[48] Kleiner and Kurzweil, 1977.

[49] Documents which supported Kurzweil's proposal to sell eleven machines to RSA and BEH may also survive, but if so, they have not yet passed into the hands of the National Archives, and remain unindexed at the National Records Center.

[50] Kleiner, Personal communication, January 25, 1995.

[51] Kurzweil, 1975, p. 424.

[52] Ibid., p. 422.

[53] "Progress report on the Kurzweil reading machine." 1977. In *The Braille Monitor* (Print Edition) (June), p. 173.

[54] Kleiner and Kurzweil, 1977, p. 78.

[55] Freiberger, Sherrick, and Scadden, 1977, p. 12.

[56] Kleiner, 1993, interview.

[57]Gregory L. Goodrich, Richard R. Bennett, William R De L'Aune, Harvey Lauer, and Leonard Mowinski. 1979. "Kurzweil Reading Machine: A partial evaluation of its optical character recognition error rate," in *Journal of Visual Impairment and Blindness 73(10* (December), p. 390; Kleiner, 1993, interview.

[58] "Kurzweil Reading Machine testing project...," 1978, p. 115.

[59] Lauer, 1994, "Answering historical questions."

[60] Kleiner and Kurzweil, 1977, p. 74.

[61] Kurzweil, 1975, pp. 421-422.

[62] Kleiner, 1993, interview.

[63] Richard Gagnon, Kathryn Fons and Tim Gargagliano. 1984. "Phonetic synthesis," in Geoff Bristow. 1984. *Electronic Speech Synthesis: Techniques, Technology and Applications.* New York: McGraw-Hill Book Company, p 179.

[64] Kleiner, 1993, interview.

[65] Kleiner and Kurzweil, 1977, pp. 77-78.

[66] Ibid., pp. 73-77.

[67] Alfred Rosenblatt. 1973. "Optical page reader prices tumble," in *Electronics 46* (August 16), pp. 73-75; "OCR drops dramatically in price as applications stimulate the market." 1973. In *Electronics 46* (June 21), p. 42.

[68] Kurzweil, 1975, p. 423.

[69] Kleiner and Kurzweil, 1977, p. 75.

[70] Cantarow, 1981, p. 23.

[71] University Microfilms International. 1984. *Comprehensive Dissertation Index: Ten Year Cumulation, 1973-1982.* Ann Arbor, MI. I have been unable to find any additional information on Steve Pelletier.

[72] Helm, 1988, p. 66.

[73] Kleiner, interview, 1993.

[74] Ibid., The precise figures for 1979 came from a written prospectus of that year, from which Kleiner was reading.

[75] Richard H. Brown has left Mitre Corporation, which cannot provide a forwarding address. He apparently has not published in the scholarly or professional press, nor are any Mitre Corporation reports to the federal government indexed under his name. I have also been unable to track down Steve Pelletier.

[76] Kurzweil, 1975, p. 424.23.

[77] Kleiner and Kurzweil, 1977, p. 76.

[78] Kleiner, interview, 1993: "The only thing we didn't do was the actual synthesizer. It was a Votrax. The rules we did."

[79] Gagnon, Fons and Gargagliano, 1984, pp. 178 and-183; Lauer, 1994, "Answering historical questions," p. 46.

[80] Richard T. Gagnon. 1978. "Votrax real time hardware for phoneme synthesis of speech." in *1978 IEEE International Conference on Acoustics, Speech and Signal Processing: Record*, p 178.

[81] It may be noted that the sixty-four Votrax allophone codes were neither pure phonemes nor pure phonetic syllables, but an empirically-derived mix of the two. Except when striving for precision, however, the literature refers to the input to the Votrax as a "phoneme string," a convention that is followed here.

[82] Gagnon, Fons and Gargagliano, 1984, pp. 179 - 182.

[83] Ibid., p. 182.

[84] Ibid., p. 190.

[85] James L. Flanagan. 1972. *Speech Analysis and Perception.* Second, Expanded Edition. New York: Springer-Verlag; Flanagan, James L. 1984. "Voices of men and machines," in Bristow, ed. 1984, pp. 48-69.

[86] F. S. Cooper, A.M. Liberman and J. M. Borst. 1951. "The interconversion of audible and visible patterns as a basis for research in the perception of speech, in *Proceedings of the National Academy of Science 37,* pp. 318-325; and Cooper, DeLattre, Liberman, Borst, and Gerstman. 1952, as reprinted in James L. Flanagan and Lawrence R. Rabiner, eds. 1973. *Speech Synthesis.* A volume in the series: Benchmark Papers in Acoustics. Stroudsberg, Pa. Dowden, Hutchingon & Ross, Inc.

[87] Liberman, Ingemann, Lisker, DeLattre and Cooper, 1959; and Holmes, Mattingly and Shearme, 1964, as reprinted in Flanagan and Rabiner, eds., 1973.

[88] Kleiner and Kurzweil, 1977, pp. 73-74.

[89] Kleiner, 1993, interview.

[90] Kurzweil, 1975, p. 426.

[91] Ibid., p. 422.

[92] Ibid., p. 423.

[93] Kleiner and Kurzweil, 1977, p. 77.

[94] "Kurzweil Reading Machine, Model III." 1981. In *Library Technology Reports 17:6* (Nov-Dec), p. 578.

[95] Lauer, 1994, Answering historical questions, p. 41.

[96] "Progress report on the Kurzweil Reading Machine, 1977, p. 174.

[97] Ibid., pp. 173-174.

[98] Graham, ed. 1968, Table 5.7, p. 163 and Table 5.21, p. 168.

[99] Ibid., p. 90.

[100] Ibid., Table 5.22, p. 168.

[101] "Kurzweil Reading Machine Testing Project ...," 1978, pp. 114-115.

[102] "Technology and communications," 1978, p. 293.

[103] Lawrence A. Scadden. 1978. "Kurzweil reading machine: Evaluation of Model One," in *Journal of Visual Impairment and Blindness 72(10)* (December), p. 418.

[104] [Harvey Lauer]. 1978. "Interim report of KRM project." Unpublished report by VA Central Blind Rehabilitation Center (March 15), p. 2.

[105] "Technology and "Communications," 1978, pp. 294-5.

[106] Scadden, 1978, p. 416.

[107] Ibid., Table 1, p. 416.

[108] Ibid., p. 417.

[109] Ibid.

[110] Ibid., p. 418.

[111] Goodrich, et al., 1979, pp. 390-398.

[112] Harvey Lauer. 1979. "Findings and recommendations on the synthesized-speech program of the KRM" Unpublished report by VA Central Blind Rehabilitation Center (May 24), p. 2.

[113] Goodrich, et al., 1979, p. 399.

[114] [Harvey Lauer]. 1977. "First quarter report" Unpublished report by VA Central Blind Rehabilitation Center (September 2), p. 2.

[115] "Blind readers can use machine to recognize all fonts." 1979. In *Computer 12* (February), p 98.

[116][Lauer], 1977, "First quarter report," p. 6.

[117] Scadden. 1978, p. 418 (Item 2); Lauer, 1994, "History and future," p. 9.

[118] "Blind readers can use machine to recognize all fonts,", p 97.

[119] "Kurzweil Reading Machine, Model III," 1981, p. 578; Harvey L. Lauer and Leonard Mowinski. 1981. "The Kurzweil Reading Machine: A report based on three years evaluation of Models 1 and 3," in *Bulletin of Prosthetics Research 10-35* (Spring), p 80.

[120] Belle Weinberg. 1980. "The Kurzweil machine: Half a miracle," in *American Libraries 11:10* (November), p. 604.

[121] Ibid.

[122] Bernice Broyde. Telephone interview with the author, November 29, 1990; Gerald Jahoda and Elizabeth A. Johnson. 1987. "The use of the Kurzweil Reading Machine in academic libraries," in *The Journal of Academic Librarianship 13:2* (May), p. 99; Kurzweil Computer Products, Inc. [circa 1982] "Kurzweil Reading Machine: Series 400." Cambridge, MA: Kurzweil Computer Products. Undated commercial brochure.

[123] Kurzweil Computer Products, Inc. 1986. "Kurzweil Reading Machine Update." Number Nine. (Fall), p. 1.

[124] Broyde, 1990, interview; Lauer, 1994, "Answering historical questions," pp. 46 - 49; Larry Scadden, personal correspondence, March 28, 1995.

[125] Weinberg, 1980, pp. 603-4.

[126] "Reading machine speaks in style." 1979. *New Scientist 83* (30 August), p. 659.

[127] Kleiner, 1993, interview.

[128] "Kurzweil Reading Machine, Model III," p. 581.

[129] Raymond Kurzweil. 1982. "Comments from Ray Kurzweil," letter to Kenneth Jernigan, dated May 6, reproduced in *The Braille Monitor* (Print Edition) (January, 1983), p. 18.

[130] Eithne Cotter, and Emily McCarty. 1983. "Technology for the handicapped: Kurzweil and Viewscan," in *Library Hi Tech 1:3* (Winter), p. 63.

[131] Kurzweil Computer Products, Inc. 1986. "Kurzweil Reading Machine Update." Number Nine. (Fall), p.3.

[132] Ibid., p. 8.

[133] Freiberger, Sherrick and Scadden, 1977, p. 12.

[134] Kurzweil. 1982, "Comments from Ray Kurzweil," p. 19.

[135] Lauer, 1994, "Answering historical questions," pp. 47 - 48; Larry Scadden, personal correpsondence, March 25, 1995.

[136] Lauer and Mowinski, 1981, pp. 80-1.

[137] Ibid., p. 81.

[138] Harvey Lauer. 1982. "The Kurzweil Reading Machine: A brief report." (May 4). Unpublished internal report (1 p).

[139] Kurzweil Computer Products, Inc. 1986. "Kurzweil Reading Machine Update," p. 5.

[140] Hanan C. Selvin. 1981. "The Kurzweil Reading Machine: False hopes and realistic expectations," in *Journal of Visual Impairment and Blindness 75 (2)* (February), pp. 76 and 77.

[141] Lauer, 1993, "Answering historical questions, p. 48.

[142] Weinberg, 1980, pp. 603, 604 and 627.

[143] Jahoda and Johnson, 1987, pp. 101-103.

[144] Heppenheimer, p. 88.

[145] Kleiner, 1993, interview.

[146] Lauer. 1994. "Answering historical questions," p. 46.

[147] Ibid., p. 49.

[148] J. M. Dixon and J. B. Mandelbaum. 1990. "Reading through technology: Evolving methods and opportunities for print handicapped individuals," in *Journal of Visual Impairment & Blindness 84:10* (December), p. 495.

Notes for Chapter 11

[1] Peter F. Drucker. 1985. "The discipline of innovation," in Jane Henry and David Walker, eds. 1991 *Managing Innovation.* London: Sage Publications, p. 9.

[2] Kline, 1985, p. 38.

[3] Ibid., Figures 1 and 2, p. 37, and adaptations from figures 3 - 7, p. 40.

[4] Ibid., p. 38.

[5] Ibid.

[6] Kline refers to W. G. Vincenti. 1984. "Technological knowledge without science: The innovation of flush riveting in American airplanes, c. 1930 - c. 1950" in *Technology and Culture 25:3* (July). Since then, Vincenti, 1990, has expanded on this work (See pp. 120-21, supra and note 7, below).

[7] Staudenmaier, 1985, pp. 50 -61; Vincenti, 1992, Chapter 7 "The anatomy of design knowledge."

[8] Kline, 1985, pp. 36 - 41. The quotation is from p. 41.

[9] Thomas P. Hughes. 1986. "The seamless web: Technology, science, etcetera, etcetera," in Social Studies of Science 16, pp. 281 - 291.

[10] Hugh G. J. Aitken. 1985. The Continuous Wave: Technology and American Radio, 1900 - 1932. Princeton, NJ: Princeton University Press, esp. "Prologue," pp. 3 - 27, and "Epilogue," pp. 514 - 562.

[11] W. E. Bijker, T. P. Hughes, and T. J. Pinch, T. J., eds. 1987. The Social Construction of Technological Systems. Cambridge, MA: MIT Press.

[12] Henk Bodewitz, Gerard De Vries and Pieter Weeder. 1988. "Towards a cognitive model for technology-oriented R&D processes," in *Research Policy 17*, pp. 213 - 224.

[13] Giovanni Dosi. 1982. "Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change," in *Research Policy 11I, pp. 147 - 162.*

[14] Bruno Latour. 1987. Science in Action: How to Follow Scientists and Engineers through Society. Cambridge, MA: Harvard University Press.

[15] Thomas J. Misa. 1992. Theories of technological change: Parameters and purposes, in *Science, Technology & Human Values 17*, pp. 3 - 12.

[16] Hughes, 1986, p. 291.

[17] Vincenti, 1992, pp. 255-256.

[18] Trevor J. Pinch and Wiebe E. Bijker. 1987. "The social construction of facts and artifacts: Or how the sociology of science and the sociology of technology might benefit each other," in Bijker, W. E., Hughes, T. P., and Pinch, T. J., eds. 1987, pp. 59 - 187

[19] Ibid. pp. 28 - 40.

[20] Kenneth Jernigan. 1982. "Braille: Changing attitudes, changing technology," in *The Braille Monitor* (Print Edition) (May), pp. 163 - 170. The quote is from p. 168.

[21] Kurzweil, 1982, p. 18.

[22] Lauer, 1994, "The history and future of reading machines for the blind," p. 13.

[23] Vincenti, 1990, p. 255.

[24] Cooper, Gaitenby, and Nye, 1984, pp. 85-86.

[25] Drucker, 1985, p. 9.

[26] Scadden, personal March 25, 1995, personal correspondence.

Bibliography

Archival Resources

National Archives. Record Group 227. Office of Scientific Research and Development. Records of the Office of the Chairman, National Defense Research Committee and of the Director, OSRD. Records of Various Committees, c. 1943 - 1946. Committee on Sensory Devices. Boxes Number 18 -22. Referred to in notes as NA.

National Research Council. Program Files, 1940 - 1962. DIV NRC: Anthropology and Psychology. Correspondence. Committee on Sensory Devices. Referred to in notes as NRC.

Library of Congress. Vannevar Bush Papers. Referred to in notes as LC.

Books and Published Reports

Aitken, Hugh G. J. 1985. *The Continuous Wave: Technology and American Radio, 1900 - 1932.* Princeton, NJ: Princeton University Press.

Allen, Jonathan, Hunnicutt, M. Sharon, and Klatt, Dennis. 1987. *From Text to Speech: The MITalk System.* New York: Cambridge University Press.

Anderson, Mary Ellen, ed. 1982. *Competing on Terms of Equality: The Goal and the Reality.* Baltimore: National Federation of the Blind.

Baxter, James Phinney, 3rd. 1946. *Scientists against Time.* Cambridge, MA: First M.I.T. Paperback edition, 1968.

Berkowitz, Edward D. 1987. *Disabled Policy: America's Program for the Handicapped.* New York: Cambridge University Press.

Bijker, Wiebe E. and Law, John, eds. 1992. *Shaping Technology / Building Society: Studies in Sociotechnical Change.* Cambridge, MA: The MIT Press.

Bijker, W. E., Hughes, T. P., and Pinch, T. J., eds. 1987. *The Social Construction of Technological Systems.* Cambridge, MA: MIT Press.

Bowe, F. G. 1978. *Handicapping America: Barriers to Disabled People.* New York: Harper & Row, Publishers.

Bristow, Geoff. 1984. *Electronic Speech Synthesis: Techniques, Technology, and Applications.* New York: McGraw-Hill Book Company.

Bush, Vannevar. 1945. *Science – The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research.* Reprinted May 1980 by the National Science Foundation. Washington: USGPO.

Clark, Leslie L, ed. 1963. *Proceedings of the International Congress on Technology and Blindness.* New York: The American Foundation for the Blind.

Conant, James B. 1970. *My Several Lives: Memoirs of a Social Inventor* . New York: Harper & Row.

Coudroglou, Aliki and Poole, Dennis L. 1984. *Disability, Work, and Social Policy.* New York: Springer Publishing Company.

Cremins, James J. 1983. *Legal and Political Issues in Special Education.* Springfield, IL: Charles C. Thomas, Publishers.

Dufton, Richard, ed. 1966. *Proceedings of the International Conference on Sensory Devices for the Blind.* London: St. Dunstan's. Printed by J. W. Arrowsmith, Ltd., Bristol.

Elster, Jon. 1983. *Explaining Technical Change.* New York: Cambridge University Press.

Emener, William G., Luck, Richard S. and Smits, Stanley J., eds. 1981. *Rehabilitation Administration and Supervision.* Baltimore: University Park Press.

Flanagan, James L. 1972. *Speech Analysis and Perception.* Second, Expanded Edition. New York: Springer-Verlag.

Flanagan, James L. and Rabiner, Lawrence R., eds. 1973. *Speech Synthesis.* A volume in the series: Benchmark Papers in Acoustics. Stroudsberg, PA: Dowden, Hutchingon & Ross, Inc.

Freeman, Christopher, ed. 1990. *The Economics of Innovation.* London: Edward Elgar Publishing Limited.

Goldish, Louis Harvey. 1967. *Braille in the United States: Its Production, Distribution, and Use.* New York: American Foundation for the Blind.

Graham, Milton D., ed. 1972. *Science and Blindness: Retrospective and Prospective.* New York: American Foundation for the Blind.

Graham, Milton D., ed. 1968. *851 Blinded Veterans: A Success Story.* New York: American Foundation for the Blind.

Kim, Yoon Hough. 1970. Th*e Community of the Blind: Applying the Theory of Community Formation.* New York: American Foundation for the Blind, Inc.

Koestler, Frances A. 1976. *The Unseen Minority: A Social History of Blindness in America.* New York. David McKay Company, Inc.

Latour, Bruno. 1987. *Science in Action: How to Follow Scientists and Engineers through Society.* Cambridge, MA: Harvard University Press.

Matson, Floyd W. 1990. *Walking Alone and Marching Together: A History of the Organized Blind Movement in the United States, 1940 -1990.* Baltimore: National Federation of the Blind.

McGinn, Robert E. 1991. *Science, Technology and Society.* Englewood Cliffs, NJ: Prentice Hall.

National Academy of Sciences. 1972. *Evaluation of Sensory Aids for the Visually Handicapped:* A report on a conference sponsored by the Subcommittee on Sensory Aids, Committee on Prosthetics Research and Development of the Division of Engineering, National Research Council held at the National Academy of Sciences, Washington, D.C., November 11-12, 1971. Washington: National Academy of Sciences.

Organization for Social and Technical Innovation, Inc. 1971. *Blindness and Services to the Blind in the United States: A Report to the Subcommittee on Rehabilitation, National Institute on Neurological Diseases and Blindness.* Originally presented, June 1968. Cambridge, MA: OSTI Press.

Percy, Stephen L. 1989. *Disability, Civil Rights, and Public Policy: The Politics of Implementation.* Tuscaloosa, AL: The University of Alabama Press.

Scotch, Richard K. 1984. *From Good Will to Civil Rights: Transforming Federal Disability Policy.* Philadelphia: Temple University Press.

Scott, Robert A. 1969. *The Making of Blind Men: A Study of Adult Socialization.* New York: Russell Sage Foundation.

Staudenmaier, John M., S. J. 1985. *Technology's Storytellers: Reweaving the Human Fabric.* First MIT Press paperback edition, 1989. Cambridge: Published jointly by The Society for the History of Technology and The MIT Press.

Stewart, Irvin. 1948. *Organizing Scientific Research for War : The Administrative History of the Office of Scientific Research and Development .* Boston: Little, Brown.

Stern, Barrie T., ed. 1982. *Information and Innovation.* New York: North-Holland Publishing Company.

tenBroek, Jacobus and Matson, Floyd W. 1959. *Hope Deferred: Public Welfare and the Blind.* Los Angeles: University of California Press.

Tanenbaum, Sandra J. 1986. Engineering Disability: Public Policy and Compensatory Technology. Philadelphia: Temple University Press.

U.S. House of Representatives, Committee on Science and Technology. 1981. *Oversight Hearings on the National Institute of Handicapped Research.* Washington: USGPO.

Vaughan, Edwin C. 1993. *The Struggle of Blind People for Self-determination. The Dependency-Rehabilitation Conflict: Empowerment in the Blindness Community.* Springfield, IL: Charles C. Thomas, Publisher.

Vincenti, Walter G. 1990. *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History.* Baltimore: The Johns Hopkins University Press.

Zahl, Paul A., ed. 1950. *Blindness: Modern Approaches to the Unseen Environment.* Third Printing, 1973. New York: Hafner Press, A Division of Macmillan Publishing Co., Inc.

Articles in Scholarly and Professional Periodicals

Abramson, Albert. 1981. "Pioneers of television – Vladimir Kosma Zworykin," in *SMPTE Journal 90* (July), pp. 579-590.

Bliss, James C. 1969. "A relatively high-resolution reading aid for the blind," in *IEEE Transactions on Man-Machine Systems, MMS-10:1*, (March), pp. 1-9.

Bliss, James. 1967. "Optical-to-tactile image conversion aids for the blind," in *Archives of Physical Medicine and Rehabilitation 48:7* (July), pp. 352-353.

Bliss, James C. 1962. "Kinesthetic-tactile communications," in *IRE Transactions on Information Theory, IT-8:2* (February), pp. 92- 99.

Bliss, James C., Crane, Hewitt D., Link, Stephen W., and Townsend, James T. 1966. "Tactile perception of sequentially presented spatial patterns," in *Perception and Psychophysics !* , pp. 125-130.

Bliss, James C., Crane, Hewitt D., and Link, Stephen W. 1966 "Effect of display movement on tactile pattern perception," in *Perception and Psychophysics 1*, pp. 195-202.

Bliss, James C., Crane, Hewitt D., Mansfield Phyllis K., and Townsend, James T. 1966. "Information available in brief tactile presentations," in *Perception and Psychophysics 1*, pp. 273-283.

Bodewitz, Henk, De Vries, Gerard, and Weeder, Pieter. 1988. "Towards a cognitive model for technology-oriented R&D processes," in *Research Policy 17*, pp. 213 - 224.

Carberry, Michael and Butow, Margaret. 1976. "Research and evaluation of audible output print reading aids for the blind: A final report," in *Bulletin of Prosthetics Research 10-26* (Fall), pp. 139 - 169.

Coffey, John L., McFarland, Ray R. and Hitt, William D. 1964. "The development and evaluation of optophone devices for the blind." in *Bulletin of Prosthetics Research 10-1* (Spring), pp. 138 - 140.

Cooper, Franklin S. 1967. "Haskins Laboratories: Research on human communication, marine ecology, and the biochemistry of protozoa," in *Science 158* (1 December), pp. 1213 - 1215.

Cooper, Franklin S. 1950. "Spectrum analysis," in *Journal of the Acoustical Society of America 22:6*, p.761-2.

Cooper, Franklin S., DeLattre, Pierre C., Liberman, Alvin M., Borst, John M., and Gerstman, Louis J. 1952. "Some experiments on the perception of synthetic speech sounds, in *Journal of the Acoustical Society of America 24:6*, (November), pp. 597-606.

Cooper, Franklin S., Gaitenby, Jane H., and Nye, Patrick W. 1984. "Evolution of reading machines for the blind: Haskins' Laboratories' research as a case history," in *Journal of Rehabilitation Research and Development 21:1* , pp. 51-86.

Cooper, F. S., Liberman, A.M., and Borst, J. M. 1951. "The interconversion of audible and visible patterns as a basis for research in the perception of speech, in *Proceedings of the National Academy of Science 37,* pp. 318-325.

Cotter, Eithne and McCarty, Emily. 1983. "Technology for the handicapped: Kurzweil and Viewscan," in *Library Hi Tech 1:3* (Winter), pp. 63-66.

DeLattre, Pierre C., Liberman, Alvin M. and Cooper, Franklin S. 1955. "Acoustic loci and transitional cues for consonants," in *Acoustical Society of America Journal 27:4*, (July), pp. 769-773.

Dixon. J. M. and Mandelbaum, J. B. 1990. "Reading through technology: Evolving methods and opportunities for print handicapped individuals," in *Journal of Visual Impairment & Blindness 84:10* (December), pp. 493-496.

Dosi, Giovanni. 1982. "Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change," in *Research Policy 11I, pp. 147 - 162.*

Freiberger, Howard. 1981. "Mary Jameson, 1899 - 1980," *Bulletin of Prosthetics Research* 10-35 (Spring), p. 329.

Freiberger, Howard. 1971. "Deployment of reading machines for the blind," in *Bulletin of Prosthetics Research 10-15* (Spring), pp. 144-156.

Freiberger, Howard. 1967. "In memoriam: John Kenneth Dupress, 1922-1967," in *Bulletin of Prosthetics Research 10-8* (Fall), pp. 323-324.

Freiberger, Howard. 1966. "The Sixth Technical Conference on Reading Machines for the Blind, in *Bulletin of Prosthetics Research 10-5* (Spring), pp. 8-9.

Freiberger, Howard. 1964 ff. “VA Contractor Notes,” in *Bulletin of Prosthetics Research 10-1* (Spring 1964), pp. 137-141; *10-2* (Fall 1964), pp. 163-164; *10-3* (Spring 1965), pp. 172-177; *10-4* (Fall 1965), pp. 205-207; *10-7* (Spring 1967), p. 308; *10-8* (Fall 1967), pp. 308-309; *10-9* (Spring 1968), pp. 195-196; *10-12* (Fall 1969), pp. 374-6; *10-11* (Spring 1970), pp. 263-8; *10-15* (Spring 1971), pp. 241-248; *10-16* (Fall 1971), pp. 251-252; *10-17* (Spring 1972), pp. 253-260; *10-18* (Fall 1972), pp. 273-275; *10-19* (Spring 1973), pp. 226-234; *10-20* (Fall 1973), pp. 348-352; *10-21* (Spring 1974), pp. 154-159; *10-21* (Fall 1974), pp. 158-160; *10-22* (Spring 1975), p. 264; *10-24* (Fall 1975), pp. 257-264; *10-25* (Spring 1976), pp. 218-219; *10-28* (Fall 1977), pp. 228-229.

Freiberger, H. and Murphy, E. F. 1961. “Reading Machines for the Blind,” in *IRE Transactions on Human Factors in Electronics, HFL-2:1,* (March), pp. 8 - 19.

Gadbaw, Patricia D., Dolan, Mary T., and De L’Aune, William R. 1977. “Optacon skill acquisition by blinded veterans,” in *Visual Impairment and Blindness 71(1)* (January), pp. 23-28.

Gagnon, Richard T. “Votrax real time hardware for phoneme synthesis of speech,” in *1978 IEEE International Conference on Acoustics, Speech and Signal Processing: Record*, pp. 175-178.

Gaitenby, Jane H. 1966. “Problems in machine conversion of print to ‘speech,’” in *Bulletin of Prosthetics Research 10-5* (Spring), pp. 37-44.

Goodrich, Gregory L., Bennett, Richard R, De L’Aune, William R, Lauer, Harvey, and Mowinski, Leonard. 1979. “Kurzweil Reading Machine: A partial evaluation of its optical character recognition error rate,” in *Journal of Visual Impairment and Blindness 73(10* (December), pp. 389-399.

Harris, Katherine Safford, Hoffman, Howard S., Liberman, Alvin M., DeLattre, Pierre C. and Cooper, Franklin S. 1958. “Effect of third-formant transitions on the perception of the voiced stopped consonants,” in *Acoustical Society of America Journal 30:2* (February), pp. 122-126.

Hauger, J. Scott. 1991. “The creation and innovation of electronic travel aids and reading machines,” in *Technology and Disability, 1:1* , (Summer) pp. 69-86.

Holmes, J. N., Mattingly, Ignatius G., and Shearme, J. N. 1964. “Speech synthesis by rule,” in *Language and Speech 7:3*, (July - September) pp. 127 - 143.

Hughes, Thomas P. 1986. “The seamless web: Technology, science, etcetera, etcetera,” in *Social Studies of Science 16,* pp. 281 - 291.

Jahoda, Gerald and Johnson, Elizabeth A. 1987. “The use of the Kurzweil Reading Machine in academic libraries,” in *The Journal of Academic Librarianship 13:2* (May), pp. 99-101.

Jameson, Mary. 1981. “The Optophone: Its beginning and development,” in *Bulletin of Prosthetics Research* 10-35 (Spring), pp. 25-28.

Kleiner, Aaron and Kurzweil, Raymond C. 1977. "A description of the Kurzweil Reading Machine and a status report on its testing and dissemination," in *Bulletin of Prosthetics Research 10-27,* (Spring), pp. 72-81.

Kline, Stephen J. 1985. "Innovation is not a linear process," in *Research Management 28:4* (July-August), pp. 36-45.

Kotovsky, K. and Bliss, J. C. 1963. "Tactile presentation of visual information," in *IEEE Transactions on Military Electronics, MIL-7:2&3,* (April-July), pp. 108-113.

Lauer, Harvey L. 1974. "Reading aids for the blind," in *Bulletin of Prosthetics Research 10-22* (Fall), pp. 64 - 72.

Lauer, Harvey 1968. "The Visotoner: A personal reading machine for the blind," in *Bulletin of Prosthetics Research 10-9* (Spring), pp. 99-103.

Lauer, Harvey L. and Mowinski, Leonard. 1981. "The Kurzweil Reading Machine: A report based on three years evaluation of Models 1 and 3," in *Bulletin of Prosthetics Research 10-35* (Spring), pp. 79-81.

Lee, Francis F. 1969. "Reading machine: From text to speech," in *IEEE Transactions on Audio and Electroacoustics, 17:4,* (December), pp. 275 - 282.

Liberman, Alvin M. 1957. "Some results of research on speech perception," in *Acoustical Society of America Journal 29:41* (January), pp. 117-123.

Liberman, Alvin M. and Mattingly, Ignatius G. 1975. "Citation to Franklin S. Cooper," in *Journal of the Acoustical Society of America, 58, Supplement No. 1* (Fall), Insert.

Liberman, A. M., Ingemann, Frances, Lister, Leigh, DeLattre, Pierre and Cooper, F. S. 1959. "Minimal rules for synthesizing speech," in *Acoustical Society of America Journal 31:11* (November), pp. 1490-1499.

Linvill, J. G. 1969. "Development progress on a microelectronic tactile facsimile reading aid for the blind, in *IEEE Transactions on Audio and Electroacoustics AU-17:4,* (December), pp. 271-274.

Linvill, J. G. and Bliss, J. C. 1966. "A direct translation reading aid for the blind," in *Proceedings of the IEEE 54:1,* (January), pp. 40-50.

Lisker, Leigh, Abramson, Arthur S., Cooper, Franklin S. and Schvet, Malcolm H. 1969. "Transillumination of the larynx in running speech," in *Acoustical Society of America Journal 45* , p. 1544, ff.

Mattingly, Ignatius G. 1968. "Experimental methods for speech synthesis by rule," in *IEEE Transactions on Audio and Electroacoustics, AU-16,* (June), pp. 198-202.

Mattingly, Ignatius G. 1966. "Synthesis by Rule of Prosodic Features," in *Language and Speech 9:1,* (January - March) pp. 1-13.

Metfessel, Milton and Lovell, Constance. 1972. "Guidelines for developing an alphabet to synthesize spelled speech, in *Bulletin of Prosthetics Research 10-17* (Spring), pp. 154 - 175.

Misa, T. J. 1992. Theories of technological change: Parameters and purposes," in *Science, Technology & Human Values. 17* (Winter), pp. 3-12.

Murphy, Eugene F. 1966. "...and Sensory Aids," in *Bulletin of Prosthetics Research, 10-5* (Spring), pp. 1 - 7.

Nye, Patrick W. and Bliss, James C. 1970. "Sensory aids for the blind: A challenging problem with lessons for the future," *Proceedings of the IEEE* 58 (December), pp. 1878 - 1898.

Roberts, Edward B. 1988. "What we've learned: Managing invention and innovation." in *Research-Technology Management* (January-February), pp. 11-29.

Scadden, Lawrence A. 1978. "Kurzweil Reading Machine: Evaluation of Model One, in *Journal of Visual Impairment and Blindness 72(10*) (December), pp. 415-418.

Selvin, Hanan C. 1981. "The Kurzweil Reading Machine: False hopes and realistic expectations," in *Journal of Visual Impairment and Blindness 75 (2*) (February), pp. 76-77.

Smith, Glendon C. and Mauch, Hans A. 1977 "Research and development in the field of reading machines for the blind," in *Bulletin of Prosthetics Research 10-27* (Spring), pp. 60-71.

Smith, Glendon C. and Mauch, Hans A. 1974. "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-22* (Fall), pp. 427-435.

Smith, Glendon C. and Mauch, Hans A. 1970. "Summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-14* (Fall), pp. 180 - 181.

Smith, Glendon C. and Mauch, Hans A. 1969. "Summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-12* (Fall), pp. 243-271.

Smith, Glendon C. and Mauch, Hans A. 1968. "The development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-10* (Fall), pp. 128-158.

Smith, Glendon C. and Mauch, Hans A. 1966. "Summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-6*(Fall), pp. 98-124.

Smith, Glendon C. and Mauch, Hans A. 1970 ff. "Abstract of summary report on the development of a reading machine for the blind," in *Bulletin of Prosthetics Research 10-14* (Fall 1970), pp. 180-181; *10-16* (Fall 1971), pp. 177-178; *10-18* (Fall 1972), pp. 195-196; *10-20* (Fall 1973), pp. 231-232.

Sørensen, K. H. and Levold N. 1992. "Tacit networks, heterogeneous engineers and embodied technology," in *Science, Technology & Human Values. 17* (Winter). pp. 13-35.

Spungin, Susan Jay. 1985. "Corridors of insensitivity: technology and blind persons," in *Journal of Visual Impairment and Blindness 79,* (March), p. 116, ff.

Stewart, Robert E. 1965. "Twenty years of progress: An editorial," in *Bulletin of Prosthetics Research 1:3,* pp. 1-3.

Terzieff, Ivan, Stagg, Vaughan, and Ashcroft, S. C. 1982. "Increasing reading rates with the Optacon: A pilot study," in *Visual Impairment and Blindness 76(1)* (January), pp. 17-22.

Weinberg, Belle. 1980. "The Kurzweil machine: Half a miracle," in *American Libraries 11:10* (November), pp. 603-4 ff.

Witcher, Clifford M. 1956. "The optical probe – A new tool for the blind," in *Technology Review 59:2,* (December), pp. 98-99 ff.

Zworykin, V. K. and Flory, L. E. 1947. "An electronic reading aid for the blind," in *Proceedings of the American Philosophical Society 91:2* (April), pp. 139 - 142.

Zworykin, V. K., Flory, L. E., and Pike, W. S. 1949. "Letter reading machine," in *Electronics*, (June), pp. 80-86.

Abstracts of Conference Presentations in Scholarly and Professional Periodicals

Abramson, Arthur S. 1967. "On matching the speech signal to mechanisms of production," in *Acoustical Society of America Journal 41*, p. 1588.

Abramson, Arthur S. 1961. "Identification and discrimination of phonemic tones," in *Acoustical Society of America Journal 33* , p. 842.

Abramson, Arthur S. and Cooper, Franklin S, 1963. "Slow-motion X-Ray pictures with stretched speech as a research tool, in *Acoustical Society of America Journal 35* , p. 1888.

Bastian, Jarvis, Eimas, Peter D. and Liberman, Alvin M. 1961. "Identification and discrimination of a phonemic contrast induced by a silent interval," in *Acoustical Society of America Journal 33* , p. 842.

Cooper, Franklin S. 1966. "Describing the speech process in motor command terms, in *Acoustical Society of America Journal 35*, p. 1221.

Cooper, Franklin S. 1961. "Word reading device: Design considerations" in *Acoustical Society of America Journal 33*, p. 1664.

Cooper, F. S., Liberman, A. M., Lisker, L. and Gaitenby, Jane H. 1963. "Speech synthesis by rules," in *Acoustical Society of America Journal 35*, p. 1115.

Cooper, Franklin S, Liberman, Alvin M. and Gerstman, Louis. 1954. "Acoustic loci and transitional cues for consonants" in *Acoustical Society of America Journal 26*, (1954), p. 137.

Cooper, Franklin S, Liberman, Alvin M. and Borst, John M. 1950. "Preliminary studies of speech produced by a Pattern Playback," in *Acoustical Society of America Journal 22*, p. 678.

Cooper, Franklin S, Liberman, Alvin M. and Borst, John M. 1950. "Synthetic speech: A study of the auditory perception of complex sounds," in *Science 112*, (October), p. 426.

Cooper, Franklin S, Borst, John M., and Liberman, Alvin M. 1949. "Analysis and synthesis of speech-like sounds," in *Acoustical Society of America Journal 21*, p. 461.

DeLattre, Pierre C., Liberman, Alvin M., and Cooper, Franklin S. 1961. "Second and third formant loci in English fricative consonants," in *Acoustical Society of America Journal 33* , p. 1677.

DeLattre, Pierre C., Liberman, Alvin M. and Cooper, Franklin S. 1960. "Second and third formant transitions in English fricatives," in *Acoustical Society of America Journal 32*, p. 1501.

Gaitenby, Jane H. 1967. "Rules for word stress analysis for conversion of print to synthetic speech, in *Acoustical Society of America Journal 42* , p. 1182.

Gaitenby, Jane H. 1961. "Word reading device: Experiments on the transposability of spoken words" in *Acoustical Society of America Journal 33*, p. 1664.

Gerstman, L. J., Lisker, L., O'Conner, J. D., Liberman, A. M., DeLattre, P.C. and Cooper, F. S. 1957. "Initial and intervocalic cues for the perception of liquids and semivowels " in *Acoustical Society of America Journal 29*, p. 778.

Gerstman, L. J., Liberman, A. M., DeLattre, P. C. and Cooper, F. S. 1954. "Rate and duration of change in formant frequencies as cues for the identification of speech sounds," in *Acoustical Society of America Journal 26* , p. 952.

Harris, Katherine Safford. 1950. "Cues for the identification of the fricatives of American English," in *Acoustical Society of America Journal 22*, p. 678.

Harris, Katherine Safford, Bastian, Jarvis and Liberman, Alvin M. 1961. "Mimicry and the perception of a phonemic contrast induced by silent interval: Electromyographic and acoustic measures," in *Acoustical Society of America Journal 33* , p. 842.

Harris, K. S., Liberman, A. M., Hoffman, H. and Griffith, B. C. 1956. "Differential sensitivity in synthetic speech sounds within and between phoneme categories," in *Acoustical Society of America Journal 28*, p. 760.

Huebner, Mary Kathleen. 1980. *An Optacon Dissemination Project Follow-through: A National evaluation Study.* Dissertation, University of Pittsburgh. Abstracted in *Dissertation Abstracts International 41(6):*, p. 2552.

Lieberman [sic.], A. M, Cooper, F. S., Harris, Katherine S., and MacHeilage, P. F. 1963. "Motor theory of speech perception," in *Acoustical Society of America Journal 35* , p. 1114.

Liberman, A. M., DeLattre, P. C. and Cooper, F. S. 1957. "Some cues for the distinction between voiced and voiceless stops in initial position " in *Acoustical Society of America Journal 29*, p. 1254.

Lisker, Leigh, Sawashima, Masayuki, Abramson, Arthur S. and Cooper, Franklin S. 1971. "Cinegraphic observations of the larynx during voiced and voiceless stops," in *Acoustical Society of America Journal 48* , p. 119.

Lisker, Leigh and Abramson, Arthur S. 1963. "Crosslanguage study of voicing in initial stops," in *Acoustical Society of America Journal 35* , p. 1889

Lysaught, Gloria, Rosov, Robert J., and Harris, Katherine Safford. 1961. "Electromyography as a speech research technique with an application to labial stops," in *Acoustical Society of America Journal 33* , p. 842.

MacNeilage, Peter F, 1964. "Electromyographic study of the coarticulation of vowels and consonants," in *Acoustical Society of America Journal 36* , p. 1989.

MacNeilage, Peter F, and Sholes, George N. 1963. "Electromyographic study of timing in vowels," in *Acoustical Society of America Journal 35* , p. 1889.

Mattingly, Ignatius G. 1967. "Speech synthesis by rule as a research technique," in *Acoustical Society of America Journal 41*, p. 1588.

Mattingly, Ignatius G. and Liberman, Alvin M. 1969. "Discrimination of F2 transitions in speech context and in isolation," in *Acoustical Society of America Journal 45* , pp. 314-315.

Sawashima, Masayuki, Abramson, Arthur S., Cooper, Franklin S., and Lisker, Leigh. 1970. "Motion pictures of vocal folds in speech," in *Acoustical Society of America Journal 47*, p. 105.

Studdert-Kennedy, M., Liberman, A. M., and Stevens, Kenneth N. 1964. "Reaction time during the discrimination of synthetic stop consonants," in *Acoustical Society of America Journal 36*, p. 1989.

Articles in Books and Published Reports

Anderson, Mary Ellen. 1982. "Status report: Employment opportunities for the blind in the United States in the 1980's," in Mary Ellen Anderson, ed. 1982. *Competing on Terms of Equality: The Goal and the Reality.* Baltimore: National Federation of the Blind pp. 1-5.

Bijker, Wiebe E.. 1992. "The social construction of fluorescent lighting, or how an artifact was invented in its diffusion stage. In Bijker, Wiebe E. and Law, John, eds. 1992. *Shaping Technology / Building Society: Studies in Sociotechnical Change.* Cambridge, MA: The MIT Press.

Bijker, Wiebe. 1987. "The social construction of Bakelite: Toward a theory of invention," in Bijker, W. E., Hughes, T. P., and Pinch, T. J., eds. 1987. *The Social Construction of Technological Systems.* Cambridge, MA: MIT Press, pp. 59 - 187.

Bliss, James C. 1972. "Optacon evaluation considerations," in National Academy of Sciences. 1972. *Evaluation of Sensory Aids for the Visually Handicapped.* pp. 51 - 54.

Bliss, James. 1972. "Sensory supplementation: Reading," in Milton D. Graham, ed. 1972. *Science and Blindness: Retrospective and Prospective* (New York: American Foundation for the Blind.), pp. 136-147.

Bliss, James C. 1963. "Tactual-kinesthetic perception of information," in Leslie L. Clark, ed. *Proceedings of the International Congress on Technology and Blindness* (New York: The American Foundation for the Blind), pp. 309-323.

Bliss, J. C. and Linvill, J. G. 1966. "A direct translation reading aid: Reading alphabetic shapes tactually," in Dufton, ed., *Proceedings of the International Conference on Sensory Devices for the Blind.* London: St. Dunstan's. Printed by J. W. Arrowsmith, Ltd., Bristol, pp. 389-407

Cooper, Franklin S. 1963. "Review and summary," in Clark, Leslie L., ed. 1963. *Proceedings of the International Congress on Technology and Blindness, Vol I.* New York: American Foundation for the Blind, pp. 381-392.

Cooper, Franklin S. 1950. "Research on reading machines for the blind," in Zahl, Paul A., ed. 1950. *Blindness: Modern Approaches to the Unseen Environment.* Third Printing, 1973. New York: Hafner Press, A Division of Macmillan Publishing Co., Inc. pp. 512-543.

Cooper, Franklin S. and Nye, Patrick W. 1972. "Plans for the evaluation of a high-performance reading machine for the blind," in National Academy of Sciences. 1972. *Evaluation of Sensory Aids for the Visually Handicapped.* pp. 55 - 64.

Corner, George W. 1950. "The Committee on Sensory Devices," in Zahl, Paul A., ed. 1950. *Blindness: Modern Approaches to the Unseen Environment.* Third Printing, 1973. New York: Hafner Press, A Division of Macmillan Publishing Co., Inc. pp.. 431-442.

Dijkhuis, Willem. 1982. "Innovation: Its evolution and present state," in Stern, Barrie T., ed. 1982. *Information and Innovation,* New York: North-Holland Publishing Company, pp. 3-25.

Dupress, John K. 1963. "The requirements for successful travel by the blind," in Clark, Leslie L., ed. *Proceedings of the International Congress on Technology and Blindness, Vol I.* New York: The American Foundation for the Blind, pp. 6-11.

Flanagan, James L. 1984. "Voices of men and machines," in Bristow, Geoff. 1984. *Electronic Speech Synthesis: Techniques, Technology, and Applications.* New York: McGraw-Hill Book Company, pp. 48-69.

Gagnon, Richard, Fons, Kathryn, and Gargagliano, Tim. 1984. "Phonetic synthesis, " in Bristow, Geoff. 1984. *Electronic Speech Synthesis: Techniques, Technology, and Applications.* New York: McGraw-Hill Book Company, pp. 177-191.

Gardiner, Kenneth W. and Bliss, J. C. 1966. "An optical to tactile image converter," in Dufton, ed. 1966. *Proceedings of the International Conference on Sensory Devices for the Blind* . London: St. Dunstan's. Printed by J. W. Arrowsmith, Ltd., Bristol, pp. 299-308.

Greenwood, Lloyd. 1950. "The blinded veteran," in Zahl, Paul A., ed. 1950. *Blindness: Modern Approaches to the Unseen Environment.* Third Printing, 1973. New York: Hafner Press, A Division of Macmillan Publishing Co., Inc. pp. 261-271.

Guttman, Newman. 1972. "Preface," in National Academy of Sciences. 1972. *Evaluation of Sensory Aids for the Visually Handicapped.* p. iii.

Law, John. 1987. "Technology and heterogeneous engineering: The case of the Portuguese expansion," in Bijker, W. E., Hughes, T. P., and Pinch, T. J., eds. 1987. *The Social Construction of Technological Systems.* Cambridge, MA: MIT Press, pp. 111-134.

Mauch, Hans A. 1963. "Review of the major functional concepts of reading machines," in Clark, Leslie L., ed. 1963. *Proceedings of the International Congress on Technology and Blindness, Vol I.* New York: American Foundation for the Blind, pp. 215-226.

Metfessel, Milton F. 1963. "Experimental studies of human factors in perception and learning of spelled speech," in Clark, Leslie L., ed. 1963. *Proceedings of the International Congress on Technology and Blindness, Vol I.* New York: American Foundation for the Blind, pp. 305-308.

Murphy, Eugene F. 1974. "Evaluation of certain reading aids for the blind," in National Academy of Sciences. 1972. *Evaluation of Sensory Aids for the Visually Handicapped,* pp. 37-46.

Studdert-Kennedy, Michael and Cooper, Franklin S. 1966. "High-performance reading machines for the blind: Psychological problems, technological problems and status," in, Richard Dufton, ed., *Proceedings of the International Conference on Sensory Devices for the Blind* . London: 1966, pp. 317-342.

Smith, Glendon C. 1966. "The development of recognition and direct translation reading machines for the blind," in Dufton, ed. 1966. *Proceedings of the International Conference on Sensory Devices for the Blind.* London: St. Dunstan's. Printed by J. W. Arrowsmith, Ltd., Bristol, pp. 367-387.

Wiesner, Jerome B. 1972. "Making sensory aids a reality," in Milton D. Graham, ed. 1972. *Science and Blindness: Retrospective and Prospective* . New York: American Foundation for the Blind, pp. 189-190.

Zahl, Paul A. 1950. "Research on guidance aids for the blind," in Zahl, Paul A., ed. 1950. *Blindness: Modern Approaches to the Unseen Environment.* Third Printing, 1973. New York: Hafner Press, A Division of Macmillan Publishing Co., Inc. pp. 443-461.

Articles in General Periodicals

Apple, Loyal Eugene. 1975. "The American Foundation for the Blind: A look ahead," in *The Braille Monitor* (Print Edition) (September), pp. 360-365.

Attanasio, Paul. 1984. "What the inventor saw: Raymond Kurzweil and his incredible machines." *Esquire* (December), pp. 118- 122.

Cantarow, Ellen . 1981. "Raymond Kurzweil: Giving 'sight' to the blind," in *Sciquest 54(2),* (February 1981), pp. 21-23.

Drucker, Peter F. 1985. "The discipline of innovation," in Jane Henry and David Walker, eds. 1991 *Managing Innovation.* London: Sage Publications, pp. 9-17. Reprinted from *Harvard Business Review* (May- June 1985), pp. 67-72.

Edson, Lee. 1970. "Substitutes for eyes tested by blind," in *New York Times*, July 24, p. 33.

Fraser, Jay. 1989. "Raymond Kurzweil and the second Industrial Revolution," in *EDN 34:23*, (Nov 9, 1989), pp. 356-359.

Grannis, Florence. 1974. "Aids and appliances," in *The Braille Monitor* (Print Edition) (August), p. 409.

Helm, Leslie . 1988, "This whiz kid isn't such a whiz at business," in *Business Week, n. 3034* (January 18), p. 66.

Heppenheimer, T. A. 1985. "Chipmaster," in *Omni* (February), pp. 87-88 ff.

Hingson, Michael. 1976. "Reading machine testing project begins," in *The Braille*

Monitor (Print Edition) (December), pp. 608 - 609.

Jernigan, Kenneth. 1982. "Braille: Changing attitudes, changing technology," in*The Braille Monitor* (Print Edition) (May), pp. 163 - 170.

Jernigan, Kenneth . 1972. "Dual membership again," in *The Braille Monitor* (Print Edition) (December), p. 643.

Johnson, Stephen M. . 1972. "Judge backs Jernigan's activities as head of blind," in *Des Moines Register* (November 10), quoted in *The Braille Monitor* (Print Edition) (March, 1973), pp. 150-151.

Kurzweil, Raymond. 1982. "Comments from Ray Kurzweil," letter to Kenneth Jernigan, dated May 6, reproduced in *The Braille Monitor* (Print Edition) (January, 1983), pp. 17 - 19.

Kurzweil, Raymond. 1975. "The Kurzweil Reading Machine,"" in *The Braille Monitor* (Print Edition) (September), pp. 421 - 427.

McElheny, Victor K. 1976. "Print-to-speech devices are expected to aid the blind," in *New York Times* (January 14), p. 10.

Melton, Louise . 1984. "Mister Impossible: Ray Kurzweil," in *Computers & Electronics, 22* (July 1984), pp. 40-45 ff.

Rosenblatt, Alfred . 1973. "Optical page reader prices tumble," in *Electronics 46* (August 16), pp. 73-75.

Sanoff, Alvin P. and Bock, Gordon M. . 1983. "Inventive genius is alive and well in the U.S.: Words, music from computers," in *U.S. News & World Report* (June 13), p. 63.

Schon, Donald A. 1970. "The blindness system," in *The Public Interest 18* (Winter), pp. 25 - 38.

Smith, Gale M. 1963. "Telephone service for the totally deaf," *Volta Review: 65* (December), pp. 579-583.

Nonattributed Articles

"ACM News." 1979. In *Communications of the ACM 22:1* (January), p. 63.

"Blind readers can use machine to recognize all fonts." 1979. In *Computer 12* (February), pp. 97-98.

"The computerized creations of Raymond Kurzweil can talk, listen and sing." 1984. In *Science Digest 92,* (February), p. 73.

"Deaf enabled to read sound waves," 1948. In *New York Times*, (November 11) Section IV, p. 9.

"Deaf teenagers help to introduce the Picturephone," 1964. In *Volta Review 66* (October), p. 621.

"Dismiss blind Iowans' suit." 1973. *Des Moines Tribune* (January 17), quoted in *The Braille Monitor* (Print Edition) (March, 1973), p. 153.

"Franklin S. Cooper, Ph.D., receives the silver medal in speech communication," in *Bulletin of Prosthetics Research 10-24*(Fall: 1975), p 280.

"Kurzweil Reading Machine, Model III." 1981. In *Library Technology Reports 17:6* (Nov-Dec), pp. 578-583.

"Kurzweil Reading Machine Testing Project nears a successful conclusion." 1978. In *The Braille Monitor* (April), pp. 114-115.

"The Mowat Sensor." 1977. [advertisement] in *Journal of Visual Impairment and Blindness 71:8*, (October), inside back cover.

"NFB aids and appliances: Policy statement. 1975. In *The Braille Monitor* (Print Edition) (April), p. 173.

"The new Braille Forum." 1977. In *The Braille Monitor* (Print Edition) (October), pp. 347-350.

"The Optacon In Its Second Decade: continuing to expand opportunities," 1981. [advertisement] in *Journal of Visual Impairment and Blindness 75:6* (June), inside back cover.

"OCR drops dramatically in price as applications stimulate the market." 1973. In *Electronics 46* (June 21), p. 42.

"Progress report on the Kurzweil reading machine." 1977. In *The Braille Monitor* (Print Edition) (June), pp. 173-174.
[Biographic information]. 1966. *Proceedings of the IEEE, 54:1* (January), pp. 51- 52.

"Reader for blind recognizes any printing." 1969. In *Machine Design 91:* (March 10), p. 18.

"Reading machine speaks in style." 1979. *New Scientist 83* (30 August), p. 659.

"Replacing braille?" 1969. In *Time* (September 19), pp. 52 ff.

"Technology and communications." 1978. In *The Braille Monitor* (Print Edition) (October, 1978), pp. 292-295.

"Telesensory Systems, Inc. Progress Report. 1978. [advertisement] in *Journal of Visual Impairment and Blindness 72:7*, (September), inside back cover.

Unpublished reports and manuscripts

Alonzo, G. J. 1964. "Development of a piezoelectric dynamic embosser for use as a reading machine." Tech Rept. 4813-4. (March). Stanford University.

Flory, L. E. 1946. "Electronic reading aids for the blind." RCA Laboratories Report to CSD under subcontract 13 of W-49-007-MD-347, July 30, 1946. Copy in possession of author, as provided by L. E. Flory.

Freiberger, Howard ed. 1966. "Summary Sixth Technical Session on Reading Machines for the Blind, Held at Veterans Administration Central Office, Washington, DC, January 27-28, 1966," p. 10. Report number R-660127. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY. Copy provided the author by Mr. Freiberger.

Freiberger, Howard. 1963. "Summary report of developments in the Veterans Administration research program on aids for the blind," Report number M / R 630901, September 1, 1963. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, New York. Copy provided the author by Mr. Freiberger.

Freiberger, Howard. 1963. "Notes on a one-week instructor seminar in use of the Battelle aural reading device for the blind," Report number R-630513. May 31, 1963. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY. Copy provided the author by Mr. Freiberger.

Freiberger, Howard, 1958. "Summary report of developments in the Veterans Administration research program on aids for the blind, September 15, 1958. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY. Copy provided the author by Mr. Freiberger.

Freiberger, Howard. 1958. "Summary: Reading machines for the blind, A working level conference for Veterans Administration contractors...," June 10, 1958. Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, New York, NY. Copy provided the author by Mr. Freiberger.

Freiberger, H., Sherrick, C. E., and Scadden, Lawrence. 1977 Report of the Workshop on Sensory Deficits and Sensory Aids held March 22-24 at the Smith-Kettlewell Institute of Visual Sciences, San Francisco. RSA report under Grant No. 23-P-57590/9-02. Copy provided the author by Mr. Freiberger.

Hauger, J. Scott. 1993. Ensuring the Accessibility of New Technologies for the Electronic Delivery of Federal Services for Persons with Disabilities. Final Report to the U.S. Congress, Office of Technology Assessment. Blacksburg, VA: Virginia Technology Associates, Ltd., (58 pp.).

Kappauf, William E. 1954. Final report of the Committee on Sensory Devices to the Division of Anthropology and Psychology, National Research Council, dated June 30, 1954. Located in NRC archives.

Lauer, Harvey. 1994. "The history and future of reading machines for the blind: Where they have been and what they can become." Unpublished manuscript (14 pp.), dated February 23.

Lauer, Harvey. 1982. "The Kurzweil Reading Machine: A brief report." Unpublished internal report (May 4), 1 p. Copy provided the author by Mr. Lauer.

Lauer, Harvey. 1979. "Findings and recommendations on the synthesized-speech program of the KRM" Unpublished report by VA Central Blind Rehabilitation Center (May 24), 7 pp. Copy provided the author by Mr. Lauer.

[Lauer, Harvey]. 1978. "Interim report of KRM project." Unpublished report by VA Central Blind Rehabilitation Center (March 15), 6 pp. plus attachments. Copy provided the author by Mr. Lauer.

[Lauer, Harvey]. 1977. "First quarter report" Unpublished report by VA Central Blind Rehabilitation Center (September 2), 17 pp. Copy provided the author by Mr. Lauer.

Liberman, Alvin M. 1993. "Some assumptions about speech and how they changed." Haskins Laboratories Status Report on Speech Research, SR-113, 1-32. This essay is to appear as the introduction to a forthcoming collection of papers to be published by MIT Press.

Linvill, John G. 1973. *Research and Development of Tactile Facsimile Reading Aid for the Blind (The Optacon): Final report.* Washington: U.S. Department of Health, Education, and Welfare, Office of Education, Bureau of Education for the Handicapped, March 1973. Report No. ED 121040 (ERIC).

Moore, Mary W. 1973. "Professional Preparation of Teachers of Reading with the Optacon. Report to the Richard King Mellon Foundation" (Summer 1973), (70 pp.). Located in the ERIC data base, Number ED 083 769.

"Summary, Fourth Technical Session on Reading Machines for the Blind, Held at the Veterans Administration, Washington, D.C. – August 23, 24, 1956." Copy provided by Mr. Howard Freiberger.

"Summary Second Technical Session on Reading Machines for the Blind - Held at the Franklin Institute, Philadelphia, Pennsylvania - April 25, 1955." Copy found in Vannevar Bush Papers, Box 115, LOC.

Task Force on Women, Minorities, and the Handicapped in Science and Technology. 1988. "Public Hearing. Report of the Proceedings." (Cambridge, Massachusetts, April 7, 1988)." Washington. EDRS Document ED 317 391.

"Tentative Agenda: Third Meeting on Reading Machines for the Blind," attached to Eugene F. Murphy to Vannevar Bush, July 19, 1995, Copy found in Vannevar Bush Papers, Box 115, LOC.

Pamphlets, brochures, etc.

American Association of Workers for the Blind, Inc. 1971. "U. S. government sponsored research to study blindness – 1971 supplement." Washington: American Association of Workers for the Blind, Inc., Reprinted from Blindness 1971, AAWB Annual. p. 224.

Barr and Stroud, Ltd. [circa 1940] "The Optophone," Pamphlet No 236. London: Undated commercial pamphlet.

Kurzweil Computer Products, Inc. 1986. "Kurzweil Reading Machine update." Number Nine. (Fall).

Kurzweil Computer Products, Inc. [circa 1982] "Kurzweil Reading Machine: Series 400." Cambridge, MA: Kurzweil Computer Products. Undated commercial hand out.

Majeska, Marilyn Lundell. 1988. *Talking Books: Pioneering and Beyond.* Washington: The Library of Congress: National Library Service for the Blind and Physically Handicapped.

Interviews and correspondence

Bliss, James C. "Q. and A. for J. Scott Hauger." Personal communication to the author (13 pp.), dated November 2, 1993.

Broyde, Bernice. Telephone interview wit the author, November 29, 1990.

Freiberger, Howard. Telephone conversation with the author, January 31, 1994.

Kleiner, Aaron. Telephone interview with the author, November 19, 1993. Telephone conversation with the author, January 24, 1995.

Lauer, Harvey. "Answering historical questions about reading machine development." Personal communication to the author (50 pp.), dated February 24, 1994. Telephone conversation with the author, November 30, 1993.

Murphy, Eugene F. Telephone conversations with the author, October 22, 1993, January 14, 1994, and January 21, 1994.

Proscia, Vito. Interview with the author, November 12, 1990.

Scadden, Lawrence A., E-mail correspondence with author, March 25, 1995.

Reference Books

Cattell, Jacques, ed. 1955. *American Men of Science: A Biographical Directory, Ninth Edition* . New York.

Comprehensive Dissertation Index, 1861 - 1972 . 1973. Ann Arbor, MI.

Jacques Cattell Press, ed. 1982. *American Men and Women of Science, 15th Edition,.* New York: Jacques Cattell Press.

Jacques Cattell Press, ed. 1979. *American Men and Women of Science, Fourteenth Edition* . New York: Jacques Cattell Press.

Jacques Cattell Press. ed. 1968. *American Men of Science, Social and Behavioral Sciences, 11th Edition.* New York: Jacques Cattell Press.

U. S. Patent 2,907,833. *Patent Gazette, Vol 747.*

University Microfilms International. 1984. *Comprehensive Dissertation Index: Ten Year Cumulation, 1973-1982.* Ann Arbor, MI.

Who's Who in America, 1994. Vol 2.New Providence, NJ.

Vita for J. Scott Hauger

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Education

1995. Ph.D. in Science and Technology Studies, Virginia Tech, Blacksburg, Va.
1976. M.A. in history, University of Chicago, Chicago, Il.
1973. M.A. in American studies, Stetson University, DeLand Fl.
1969. M.A. in chemistry, the Johns Hopkins University, Baltimore, Md.
1967. B.S. in chemistry, *cum laude*, Stetson University, DeLand, Fl

Work Experience

1991-present. Research Associate, Senior Research Associate, Associate Professor of Science and Technology Studies, Virginia Tech. While working toward the Ph.D. in Science and Technology Studies, Virginia Tech made it possible for me to accept a temporary faculty position in research administration. Served as Assistant Director for Program Development, of the Biobased Materials Technology Development Center, where I managed sponsored research and technology transfer activities in areas related to natural biopolymers and recyclable materials. Helped establish a Biomass Conversion Technology Demonstration Center, which is now operating to develop and demonstrate technologies for the conversion of waste materials to biopolymers.

Upon completion of this task, I was asked to serve as Coordinator, Accessibility Research and Planning, to ensure accessible programs and facilities for members of this 26,000-person university community with disabilities. Serving as a member of the University Management Committee on ADA, and chair of the Equipment Task Force, I prepared Virginia Tech's ADA Self Evaluation, and an accessibility guide for faculty and staff. Worked with the University Architect's Office to resolve issues related to accessible facilities and served on review panel for architectural proposals. Worked with the Dean of

Students' Office and university colleges, departments, and extension activities to identify accessibility problems and develop solutions.

I also established a research program on technology for aging in the Center for Gerontology. This interdisciplinary program draws on resources in the Colleges of Human Resources, Architecture and Urban Studies, Engineering and Arts and Sciences to address social problems of an aging society. In October, 1993, the center was awarded its first competitive research contract by the U.S. Access Board for study of detectable warnings for persons with vision impairments.

In 1995, as I completed the Ph.D. in Science and Technology Studies, I was asked to serve as Coordinator, STS Graduate Program at the Northern Virginia Graduate Center, to help extend the STS program to students in the Washington metropolitan area.

November, 1989- present. Consulting as Virginia Technology Associates, Ltd., with permission of Virginia Tech. Clients include the U.S. Architectural and Transportation Barriers Compliance Board (ATBCB), the U.S. Congress Office of Technology Assessment (OTA), Apple Computer, Inc., and the Institute for Defense Analysis (Office of the Secretary of Defense). Major projects included Regulatory Impact Assessment for ADA Accessibility Guidelines (ADAAG) for Title II facilities, U.S. Architectural and Transportation Barriers Compliance Board (1993), and co-editing the 1991 *Defense Critical Technologies Plan.*

1979 - 1989. President, Applied Concepts Corporation, Winchester, Virginia. Founded and led this technology development and engineering services firm from a business idea to a firm with eighteen professional employees. Provided engineering, analytical and policy support services in the fields of industrial automation and robotics, alternative energy systems, defense, and technology and disability. I was responsible for corporate direction and management, including full profit and loss responsibility. The firm formed and led unique teams of researchers from industry and academia to solve problems of new technology applications in areas where there were no ready-made or off-the-shelf solutions.

Served as principal investigator for research and development programs in the areas of technology and disability, innovation economics, alternative energy, and defense. Clients included National Institute for Disability and Rehabilitation Research, NASA's Jet Propulsion Laboratory, the National Science Foundation, U.S. Army and Air Force, U.S.

Departments of Energy, Education, Defense and Commerce; and U.S. Architectural and Transportation Barriers Compliance Board. Accomplishments included design, fabrication, and test of nation's first point-focusing solar industrial steam plant (1982); research leading to first national TDD-relay system (1984) and to the specification of standards for fire alarms for the deaf (1988); a determination of the impact of national tax policies on innovation in high technology business (1986), and of the extent of foreign dependency on high technology components in U.S. weapons systems (1986); and development of the first effective artillery-delivered propaganda round (1989).

Sold the firm in 1989, in order to pursue an academic career.

1977-1979. Staff Member, then Associate Manager, BDM Corporation, McLean, Virginia. Participated in and led a variety of technological studies and analyses, including 1977 studies of defense against cruise missile systems, and photovoltaic systems' applications; 1978 projects in the societal impacts of nuclear waste disposal options, artillery interdiction modeling, and photovoltaics' manufacture; and 1979 analyses of solar thermal energy systems, and military logistics modeling.

Teaching Experience

Virginia Tech, 1995 to present. Scheduled to teach graduate courses is the history of technology and science and technology policy beginning August, 1995.

Cochise College, Sierra Vista, Arizona. 1976. Instructor, Department of History. Taught Introduction to American History, while on active duty for training at Ft. Huachuca, Arizona.

Stetson University 1972-73. Instructor, Department of Chemistry. Taught freshman chemistry and team taught the Honors Program Science Seminar with Physics and Biology Depts, while working toward M.A. in American Studies.

Johns Hopkins University, 1967-69. Graduate Assistant and Instructor, Department of Chemistry. Taught conference and laboratory sections of freshman chemistry and organic chemistry laboratory.

Military Experience.

Called to military service in 1969, while a doctoral candidate at Johns Hopkins University. Received a direct commission in the U.S. Army Reserve. Spent three years on active duty, principally as a strategic intelligence officer at a NATO Army Group headquarters in Izmir, Turkey, working with allied forces from Greece, Turkey, Italy and the U.K. Active in Army reserves 1972-1980. Assignments with the Defense Intelligence Agency, the Army Assistant Chief of Staff for Intelligence, the U.S. Army Intelligence Center & School, the Defense Intelligence School, and the 354th Civil Affairs Brigade. Received honorable discharge at the rank of captain, in 1980.

Current Membership in Professional Associations and Offices Held

American Studies Association
Philosophy of Technology Society
RESNA (Rehabilitation Engineering Society of North America) Member R&D Committee, and
  Chair, Special Interest Group (SIG) on Universal Access.
Sigma Xi, The Scientific Research Society.
Society for the History of Technology
Society for the Social Studies of Science

Awards and Honors

Special award recognizing contributions as chair, Technology Transfer SIG, RESNA. 1991.
Award for Effective Research, Interagency Panel on Barrier Free Design, 1988 (for Alarms Documentation Project, 1986).
NDEA Fellow, University of Chicago, 1975-76.
Departmental fellow, University of Chicago, 1973-75.
NSF fellow, Johns Hopkins University, 1967-69.
Stetson Scholar, Phi Society, Scroll and Key, honors program, Stetson University, 1964-67.

Other work-related activities

Served on peer review panels for National Science Foundation (1993, 1994), and National Institute for Disability and Rehabilitation Research (1991). Peer review for the *Journal of Rehabilitation R&D* and *Journal of Applied Gerontology.*

Member, University Committee on ADA, Chair of ADA Equipment Task Force and Task Force on Housing and Dining Programs for Students with Disabilities, Virginia Tech

Have written proposals winning more than $7 million in federal research grants and contracts.

Research Interests

The practice of new technology development
The embodiment of cultural norms and values in technological products
Comparative (i.e., international) technological and social change
U.S. federal government role in technology development since WWII
The nature of technological knowledge
Technology and disability, accessible design and technology and aging

Personal Information

Born in Kenton, Ohio, 7/20/47
Married to Karin Thomassen Hauger, 7/22/67
Three daughters, Kristin, Erin and Anna

Selected Publications and Reports

a. Refereed or reviewed journal articles and conference presentations

Hauger, J. S. 1991. The Creation and Innovation of Electronic Travel Aids and Reading Machines, in *Technology and Disability, 1:1* , (Summer 1991) , pp. 69-86.

Hauger, J. S. and Rigby, J. C.. 1989. Visual Signals Project, in *RESNA '89: Proceedings of the 12th Annual Conference*, pp. 317-318. Washington: RESNA Press.

Cordes, J. J., Watson, H. S., and Hauger, J. S. 1987. Effects of Tax Reform on High Technology Firms, in *National Tax Journal, Vol. XL, No. 3*, pp. 373 - 391.

b. Analytic Reports

Hauger, J.S., Hubbard, Will and Travis, David, Jr. 1995. A Guidebook for Achieving Accessible Programs. Virginia Polytechnic Institute and State University. (49 pp.).

McAuley, William J., Hauger J. S., Safewright, Marcia P. and Rigby, Joyce C. 1995. *The Detectable Warnings Project: Final Report.* Virginia Polytechnic Institute and State University. (166 pp.).

Hauger, J.S. and Hubbard, Will. 1993. A Self-Evaluation of the Accessibility of Programs at Virginia Tech. Blacksburg, VA: Report to Virginia Tech ADA Management Committee. (56 pp.).

Hauger, J.S. 1993. *Ensuring the Accessibility of New Technologies for the Electronic Delivery of Federal Services for Persons with Disabilities.* Final Report to the U.S. Congress, Office of Technology Assessment. Blacksburg, VA: Virginia Technology Associates, Ltd., (58 pp.).

Hauger, J. S. 1992. *Regulatory Impact Analysis for ADA Accessibility Guidelines for Buildings and Facilities.* Report to the U.S. Architectural and Transportation Barriers Compliance Board. Blacksburg, VA.: Virginia Technology Associates, Ltd. (152 pp.).

Office of the Secretary of Defense. 1991. *Defense Critical Technologies Plan, 1991.* Washington: Department of Defense. (Co-editor with R. White and F. Riddell).

U.S. Department of the Army. 1990. *Army Technology Base Master Plan, 1990.* Washington: Department of the Army.. (Co-editor with P. Richenbach and F. Riddell).

Hauger, J. S. and Rigby, J. C. 1989. *Auditory Alarms Project: Technical Paper.* Final report to the U.S. Architectural and Transportation Barriers Compliance Board. Winchester, VA: Applied Concepts Corp. (87 pp.).

Hauger, J. S., ed. 1989. *A Comparison of Domestic and Selected Foreign Standards and Codes for Accessible Facilities.* Report to the U.S. Architectural and Transportation Barriers Compliance Board. Winchester, VA: Applied Concepts Corp. (217 pp.).

Hauger, J. S. and Brain, T. 1989. Identification of Technical and Managerial Barriers to the Successful Development of Projectile 105 mm, RAKE, XM872. Report to the U.S. Army Armaments Research, Development and Engineering Center. Winchester, VA: Applied Concepts Corp. (10 pp.).

Hauger, J. S., Rigby, J. C., et al. 1989. *MGRAD / UFAS Evaluation Project: Final report* . Report to U.S. Architectural and Transportation Barriers Compliance Board. Winchester, VA: Applied Concepts Corp. (114 pp).

Hauger, J. S. and Powers, T. D. 1989. Portable, Programmable Sound Recognition Device. A report of the design and testing of the alpha prototype to the National Institute for Disability and Rehabilitation Research. Winchester, VA: Applied Concepts Corp. (44 pp.).

Hauger, J. S. and Rigby, J. C., 1988. *Visual Signals Project: Modifications to Minimum Guidelines and Requirements for Accessible Design.* Final report to the U.S. Architectural and Transportation Barriers Compliance Board. Winchester, VA: Applied Concepts Corp. (112 pp.).

Hauger, J. S. 1988. An Assessment of the State of the Art of Stirling Engines for DoD Applications. Report for the Institute for Defense Analysis. Winchester, VA: Applied Concepts Corp. (29 pp).

Hauger, J. S. 1986. *Alarms Documentation Project: Final Report.* Report to the U.S. Architectural and Transportation Barriers Compliance Board. Edinburg, VA: Applied Concepts Corp. (115 pp.).

Hauger, J. S. Starns, J., *et al.* 1986. *A Study of the Effects of Foreign Dependency.* Final Report for the Joint Logistics Commanders of the United States. Edinburg, VA: Applied Concepts Corp. (246 pp.).

Hauger, J. S. Cordes, J. J, and Watson, H. S. 1986. *An Analysis of Domestic and Foreign Tax Treatment of Innovation and High Technology Firms.* Final report for the National Science Foundation. Edinburg, VA: Applied Concepts Corp. (479 pp.).

Hauger, J. S. *et al.* 1984. *Telecommunications Access with and within the Federal Government: A Consideration of Issues and Applications for Telecommunication Devices for Deaf Persons (TDDs).* Final report for the U.S. Architectural and Transportation Barriers Compliance Board. Edinburg, VA: Applied Concepts Corp. (113 pp.).

Hauger, J. S., Adams, W. A., and Uphoff, R. L. 1984. *USAF Mobile Electric Power and Facilities Electric Power System Analysis.* Dayton, Ohio: USAF Systems Command. (273 pp.).

Hauger, J. S. and Pond, S. S. 1982. *Capitol Concrete Solar Industrial Process Heat Experiment: Final Report* . Report to U.S. Department of Energy, Albuquerque Operations Office. Herndon, VA: Applied Concepts Corp. (78 pp.).

Hauger, J. S. and Simpson, J. S. 1981 *USAF Solar Thermal Applications Study: Final Report.* Report to NASA Jet Propulsion Laboratory. Herndon, VA: Applied Concepts Corp. (118 pp.).

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