New Engineering Companies and the Evolution of The United States Computer Industry

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The electronic digital computer industry emerged tentatively onto the world stage in 1946, with the founding of two engineering companies and the incorporation by several large firms of the new electronic computing ideas into their planning. Only a handful of large firms participated in this new computer phenomenon--IBM, Raytheon, Bendix, and Burroughs. The small startup firms included Eckert-Mauchly Computer Corporation (1946), Engineering Research Associates, Inc. (1946), and California Research Corporation (1950). These latter three firms were eventually absorbed into larger firms. Eckert-Mauchly Computer Corporation and Engineering Research Associates went into Remington-Rand in 1951 and 1952, respectively, and California Research Corporation became National Cash Register's computer division in 1954. Raytheon later confined its computer efforts to fire control and missile systems, while Bendix, after developing several computer systems, became part of Control Data Corporation in 1962. Burroughs is now one of two main components of Unisys Corporation along with Sperry Rand, the successor of Remington-Rand, and, of course, IBM is still the principal company in the computer industry. A similar story could be told about a number of startups in the first half of the 1950s, but the story would be the same. The small firms with an engineering emphasis in leadership and capability provided an important stimulus to the early computer industry in the United States. These businesses were organized at a time before a stable computer design was available, and they participated in the development of standard schemes for designing, manufacturing, and servicing computers.

In the received history of the early computer industry, writers have assumed that Eckert Mauchly Computer Corporation possessed the capability and an advanced state of knowledge, which should have given them an edge. This edge was blunted by the inability to convince potential funders/purchasers. Authors have also assumed that IBM resisted devices that would affect the tabulator market, and when they realized it might take away their market share, they entered the market late with dedication and overwhelmed the smaller firms. Engineering Research Associates (ERA) is not evaluated in this analysis, because it is seen only as a military contractor rather than a competitor for commercial business. Many in the industry assume that

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IBM waited until EMCC demonstrated the techniques and then entered the market. I believe the evidence demonstrates a contrary position, that is, that all these companies struggled with computer ideas in the early years, because they needed to learn a great deal about how to implement designs and produce a digital computer system. Each contributed differently to the process. What made IBM and ERA different from EMCC was the resources they could draw on. Within the company, IBM could support R&D on computers because of their successful tabulator business. ERA had the support of the U.S. Navy. EMCC had neither of these resources. The areas of the government and businesses EMCC relied on for support were cautious about when success would be achieved and held back somewhat. In addition, EMCC had a range of problems unconnected with machine design. The story goes that left to themselves with the right financing, EMCC would have succeeded. If we examine these companies more closely using some criteria of Nelson and Winter, we see a different and more complex history. Nelson and Winter, in their study *An Evolutionary Theory of Economic Change*, bring out three areas of firm capability that are particularly relevant to the history of computing. These areas are the need for clear and achievable objectives, an adequate state of knowledge, and choices embedded in the talents of the personnel. With respect to objectives, they noted that

> objectives like profit, market share, or growth do not serve to guide action in the absence of specific understanding as to how they are to be achieved. Unless this understanding is obvious, shared by all those who are involved in decision making, even the deepest commitments to a common ultimate objective will not serve to focus attention and coordinate action. To serve this purpose, objectives must be articulated in such a way that they are relevant to the decisions at hand....choice of operational objectives is an important arena for managerial decision [3, p. 56].

None of these companies defined clear and achievable objectives in 1946; they came to them over time. Overarching objectives were apparent to the participants in computing, but operational objectives were not. We need to add to this criterion evaluation of the role of the customer in setting objectives. An adequate state of knowledge about computing was just developing. Indeed, it took a decade to arrive at sufficient knowledge to develop all the aspects of constructing a stable computer system. Along the way, all the firms interested in digital computing machines struggled with pushing back the envelope around the known into the unknown. And the accumulated experience of the personnel in these firms influenced the definition of problems investigated and the solutions proposed. The state of knowledge was arguably adequate in 1946, but became so by 1950, and many groups played a role in the definition. The talents of the personnel in these groups, while impressive, needed honing.

The search for a stable computer design by all involved inside and outside these firms is the key to understanding this history. In the quest for a stable design, emphases were placed on speed, storage, and reliability. Early computer designs were slow, had small storage, and were insufficiently reliable to encourage faith. Speed could be increased in two ways: decreasing interaction time of parts of the computer, such as reducing distances electrical signals must travel, and increasing the amount of data and instructions stored inside the machine. Thus, an array of research programs in companies and universities pursued techniques to increase storage and decrease the time to isolate a single data element, keeping costs in mind in most cases. This search culminated in the development of magnetic core memory, which swept the industry in the mid-1950s. The reliability issue was, of course, twofold also. The need for reliability in components led to new developments. Industry developed a range of new components suitable for use in computers, including mass production techniques for their manufacture. Designers crafted more reliable circuits for the transfer of data and instructions internally.

In this paper, I concentrate on the two 1946 startups in the computer business: Eckert-Mauchly Computer Corporation (EMCC) and Engineering Research Associates, Inc. (ERA). EMCC began with a general design for a computer based on the work of the principals at the University of Pennsylvania. ERA organized to design and develop data processing machinery to advance the state of the art beyond wartime devices. By 1951, each had a computer to market; both machines were important designs and contributed to the stable design that emerged in the middle of the 1950s, both contributed substantially to an understanding of speed, storage, and reliability for computers. In the development of these firms, nothing was routine, in the Nelson and Winter sense.

After 1956, a short decade after the introduction of the ENIAC, however, use of digital computers was spreading and a digital computer industry was beginning to flourish. The computer stimulated technical developments and modes of social behavior that made the computing enterprise into a major phenomenon. Out of this came a new world that, over the next four decades, and maybe beyond, contained new opportunities and new tensions. The seeds of these opportunities and tensions were present in the efforts of the men and women working in this emerging enterprise in the decade beginning in 1946.

The Companies

The story of the founding of the new digital computer industry goes back to early 1945. Even during the ENIAC development period (1943-1945) Eckert and Mauchly were discussing the design of future internally-controlled computers and of the prospects for commercialization. They slipped easily into plans to build a commercial stored-program electronic computer, and in the spring of 1946, established an enterprise to do so. EMCC never deviated from the objective to build commercial machines.

A principal lesson of the war had been the value of rapid deciphering of private messages of other governments. The Navy concluded that more sophisticated machinery would be needed in a more complicated peacetime world. Deciphering had been done by a section that was composed of a hastily assembled group of cryptologists, mathematicians, physicists, engineers, and chess and bridge masters. The Navy's first order of business was to try to keep this group together. Foiled at keeping the prime group together after the war as civilian employees to pursue such work under direct supervision, the Navy assisted in the establishment of a private company, comprised of many of those same men, to perform the same investigations with classified contracts. This company was ERA located in St. Paul, Minnesota. ERA's prime objective, though different than that of EMCC, was just as simply stated as those of EMCC: to build data processing equipment for use by the U.S. Navy.

In these two cases, overall objectives were set through discussions between the companies and their customers; proximate decisions taken within the company focused on engineering issues. What was not clear in the beginning was how much of a role the customer would play in shaping the product. Partly, this resulted from the attempt to bring a new, previously unavailable concept to market by small firms. In fact, customer involvement greatly improved the result.

ERA influenced the field in ways both similar to and different than EMCC. Among the similarities are major inventions for storage techniques, commercialization in the early 1950s of a machine produced originally for a military purpose, and as a fountainhead for new companies. The principal differences are the manner of operation of the company, that is, tight classification in the early years; production of a volume (published in 1950) that contained an assessment of techniques available in 1949 for design of computers that influenced developments worldwide; and a prudent manufacturing and marketing strategy.

Like EMCC, ERA also had a customer to satisfy and developed systems for the customer's use. The company evolved to meet customer needs in new ways. EMCC was on an almost continuous search for customers and investors. While they succeeded eventually, as did ERA, in producing a good system, they had to emphasize the development side over marketing and use.

By contrast, IBM entered the business machines area in 1911 as Computer-Tabulating-Recording Company, a successor company to the Tabulating Machine Company of Herman Hollerith. Between 1911 and 1945, IBM had developed a commanding position in the tabulating machine business. Since the aim of companies like EMCC was to replace tabulating equipment with electronic computers, IBM had a business to protect. From IBM's perspective, all development had to be evolutionary from the business perspective, in essence, the customer's perspective, regardless of how revolutionary the technology. Beginning in the late 1930s, IBM developed electronic calculators. During the war, IBM personnel assisted Harvard's Howard Aiken with the design and building of the Automatic Sequence Control Calculator, a relay computer. After this project, IBM designed and built their own Selective Sequence Control Calculator and, in 1946, organized an electronic laboratory whose mission it was to investigate concepts for electronic devices. Proceeding in fits and starts, this group enlarged over time and in the early 1950s designed two machines for two markets: the IBM 650 and the Defense Calculator, which became the IBM 701. Even though customers were consulted, IBM set its own objectives through discussion inside the company [1].

Developing the Knowledge Base

The presence in all these companies of electrical engineers with experience in advanced circuit design, some with experience on computer projects, of mathematicians who addressed the use of computers and participated in the design of new techniques for problem solution on computers, and physicists with knowledge of magnetic and electric techniques for the development of storage and communication components for computers placed all these companies at the forefront of the field. The EMCC group had an edge in that many of them had participated in design of a previous machine. But the IBM and ERA staffs that had contributed to wartime cryptology and advanced electronic devices were not far behind the people of EMCC. We turn now to descriptions of how they applied their skills to the design of new computer systems.

EMCC

During late 1945 and early 1946, Eckert and Mauchly engaged in discussions with various government groups at the National Bureau of Standards (NBS), the Census Bureau, and the Navy about the possibility of building a computer for one or more of these agencies. NBS conducted a survey of development among various projects and sought advice from George Stibitz, an early computer developer at Bell Laboratories. Stibitz concluded that the circumstances were not ready to proceed directly to construction of a computer. Further research, he thought, was essential. Among other recommendations, Stibitz suggested a phased approach to acquisition--research and design; building and testing of components; and construction of a machine.

In June 1946, NBS submitted a proposed contract along lines suggested by Stibitz. The contract with NBS, accepted by EMCC in September 1946, called for the company to "supply the necessary qualified personnel and facilities for and prepare plans, specifications, and wiring diagrams for automatically sequenced electronic digital computing machine or machines suitable for general mathematical computations and for preparation of census reports, and construct and test such models of components as may, in the opinion of the Contractors or Scientific Officer, be necessary to insure the adequacy of these plans and specifications" [7, Folder 117]. Eventually, this was understood to mean the construction and demonstration of a delay line memory device and a magnetic tape input/output device.

The task had been divided by EMCC into six parts. (1) Memory: besides the mercury delay registers, the group investigated other methods, such as beam deflection tubes. (2) Electronic circuits for arithmetic and control units: here, also, an array of circuits suitable for several memory systems were under investigation. (3) Magnetic tape materials and reading and recording heads. (4) Key-operated input mechanisms and automatic output printers. EMCC decided that already designed equipment would be the best solution to problems here. (5) Servo devices for controlling tape. (6) Logical design: the group noted only that special control features that might allow more compact and efficient problem coding were to be devised.

Eckert and Mauchly estimated the development costs to be between $413,000 and $671,000, representing the minimum and efficient requirements [9, Box 4a; 4, 267]. The two partners assumed they would be able to obtain other contracts for sale of the machine that would provide additional development funds. Among the many contacts made by Mauchly in late 1946 and early 1947, four stand out because of later contracts: Army Air Forces, Northrop Aircraft Company, A. C. Nielson, Co., and the Prudential Life Insurance Company. For example, toward the end of 1946, Mauchly began conversations with the Nielson Company, and on 4 January 1947 he sent a proposal for the construction of a group of "electronic statistical machines" to them. In early April, Mauchly was hired as a consultant to the Northrop Company. Northrop, and North American Aviation as a subcontractor, were working in the Snark missile program of the Army Air Force. Mauchly spent ten days from 5 to 16 May at the Northrop facility in Hawthorne, California. Each day he spent two-hours "instructing a small group on the subject of electronic digital computers." The purpose of the instruction was to inform the group on what had been accomplished in the field so far, and "to explore the possibility of applying similar techniques to control problems encountered in the project work" [7, Folder 330]. By late June, Northrop had entered negotiations with EMCC for a computer "to prove the feasibility of a particular method of navigation." This machine would be called the Binary Automatic Computer (BINAC), and in the minds of Mauchly and Eckert, would serve as a prototype for the larger machine to be designed for the NBS.

At about this time, Mauchly approached the Prudential Insurance Company. The time was propitious, because the company's Edmund Berkeley had only recently completed an evaluation of the computer field. By mid-December, he had talked with people at many organizations involved with calculating machinery, and he had concluded that the problems of the Prudential could only be handled on a general-purpose digital machine. Eckert and Mauchly prepared a two-part proposal for the Prudential on the "Application of High Speed Computing Machines to Certain Problems of the Prudential Life Insurance Company" [7, Folder 18]. The proposal was about equally divided between a discussion of the problems faced by the Prudential that were susceptible to solution by an EDVAC-type machine and a description of the machine system.

A detailed consideration of the Prudential proposal sheds light on at least four areas. (1) The proposal revealed EMCC's progress in design of applications and assessment of the machine's capability, which supplements information in the reports sent to NBS. (2) It provided evidence of the considerations that slowed EMCC's progress on the NBS contract. (3) The proposal contains a view of EMCC's emphasis on applications. And (4) the role of the customer in helping to set objectives is fairly explicit. While Eckert and Mauchly evaluated the Prudential's tasks and designed ways that their machine could handle them more efficiently, and how the machine could be modified to do so, they had that much less time to complete the design on the machine. But if EMCC had not expended this effort on applications, the entire process of machine design might have been slowed anyway due to insufficient development funds.

The first part of the proposal outlined the way the machine would handle three principal activities of the company: premium billing; mortality studies; and group insurance. For each activity, EMCC described the machine's approach, the number of people required to use the machine, the cost to the company of the basic service, including the cost of the machine, and the cost to convert the punched card and other files to magnetic tape. They emphasized that the cost of conversion was a one-time cost. The machinery costs came to $373,500, which could be reduced to about half under a scheme to distribute development costs. The second part of the proposal contained a detailed description of the order code to be used in the machine, called Code C-2 (dated 7 May 1947). Included with the code plan was a general description of the components of the machine. EMCC presented detailed design specifications of the tape system and how data would be recorded on the tape (with no more than 20% loss of space), the typewriter operation and speed, the contents capability of delay-line memory, and methods for checking. They also offered some comments on the manner of operation of the control circuits.

While EMCC prepared their report to NBS in June 1947, Mauchly asked for another extension of the NBS contract, to 1 August 1947. Ten days later, Mauchly proposed a specific work plan for the added time, which involved testing the reliability of various reading and recording methods for magnetic tape, doing such tests on a full scale, model tape transport mechanism, and evaluating the mercury delay line storage devices using the pulse envelope system. Time would also be devoted to design of high-speed flip-flop and gated oscillators for regenerating signals in mercury delay lines [8, Box 1]. NBS agreed, and the contract was extended once again, this time to 15 August 1947 [6, Exh. 6024].

So in August 1947, EMCC was bringing the NBS machine design contract to a close in the hope of obtaining the contract to build the machine for the Census Bureau; accepted a contract with the Prudential to design a similar machine for them (most of the problem here was application codes and demonstration of equipment needed, as we have seen); and accepted a contract from Northrop to design and build a different but somewhat similar computer (this one by 15 May 1948).

While all this work on hardware proceeded, Mauchly and Betty Snyder tried to perfect and extend the capabilities of the code. Several new codes were transmitted to the Prudential--C4 and C5, and of a number of visits by Prudential people to EMCC to discuss various ways to code problems and to convert punched card data to magnetic tape [7, Folder 23].

Other technical designs were under investigation and, in mid January 1948, EMCC filed a disclosure notice for an electrostatic memory system designed by Herman Lukoff. This was part of Eckert's plan to investigate as many methods for memory as possible. The system Lukoff designed contained a CRT, timing and deflection circuits, a regeneration unit for memory operation, and power supplies [6, Exh. 6296].

Work on BINAC began in earnest in the late spring of 1948. Delivery had been specified in the contract as 15 May 1948. Toward the end of May, Al Auerbach reported that the designs of the computer, memory, power supply and control box were each 90 to 100% complete. Only the computer and the memory drafting had been done and most of the material for construction of these units had been acquired. Each was about half constructed. Nothing else had been done on the other units besides design [6, Exh. 6470]. Lukoff reported that most of the engineers were assigned to the BINAC project at this time. Lou Wilson, Al Auerbach, Jim Weiner and Bob Shaw were the major designers of the "CPU." Brad Sheppard and Lukoff were responsible for the tape-loader input device. And Pres Eckert was everywhere helping with design decisions [2, p. 77]. The machine was delivered a year late in mid 1949, and work resumed on the UNIVAC. By this time, negotiation with customers was complete; all design characteristics had been approved by the several customers and components had been tested satisfactorily. But satisfactory components and a completely functioning system proved to be two different things. Many more design changes were made to the UNIVAC system before it was delivered in 1951, but the machine performed well for the Census Bureau and for the other customers who received systems in the 1950s.

ERA

In its first proposal to the Navy, ERA focused on three areas for investigation. First, ERA wanted to make an assessment of the type and nature of problems arising in the Navy for solution on data processing machines. This type of investigation would generate information about the similarities and differences among problems with an eye toward reformulating them to fit the machines "recently developed" and understanding the required accuracy and amount of storage. The problems not solvable by known machines could be used for a second area of investigation: decisions about "the direction of development of the computing machine art." The third area would involve ERA in the design and construction of the various components needed for new solutions [2, p. 2]. The proposal went on to discuss what ERA saw as the first problem needing attention: storage. "The storage problem is one of the most difficult in building computing machines" [2, p. 5].

ERA received its first contract for such work in February 1946. The contract did not coincide with the areas of the proposal, but involved a series of projects. Since it took almost five months for personnel to be released from the service, it was only in summer that the work under this contract was well underway [9]. With the beginning of work on this and other contracts from private firms, ERA was a broader based company than EMCC. Functionally, ERA developed four product areas, classified as areas A, B, E, and N, two of which evolved from the above contract with the Navy. The A group (8 projects) addressed aviation problems, such as a ground speed recorder and a parachute landing shock reducer, mostly contracts for various sections of the U. S. Air Corps. The B projects (4 in number at this time) included several for Navy and Army agencies. Another set of airline projects (E, 11 in all) were sought by the president John E. Parker to stimulate cash flow. These ranged from broadcast consulting to plans for an airline reservation program, many of which were in the original prospectus for ERA. And there were 13 N projects for the Navy with such colorful names as Celery, Alcatraz, and Orion [9]. In later histories, ERA became noted as a result of developments in two of these project areas: B and N, and we will focus on aspects of them here.

Another contract to ERA from the Office of Naval Research also took effect in August 1946 [10]. This contract contained three objectives: (1) a survey of the computing field similar to the one proposed by ERA, including an analysis of problems to be solved, the components and equipment needed in the solution, and a formulation, as explicit as possible, of the requirements for new components or techniques needed for the solution of naval problems; (2) Research looking toward the development of these new components and techniques, such as the availability of multiplexing techniques for use in storage and transmission of data; and (3) the furnishing of consulting services to the Office of Naval Research on questions concerning the development and application of computing equipment and techniques [9]. This contract called for ERA to examine everything other projects were trying to accomplish and to design a storage device with multiplexed input and output. It was from this clause in the contract that ERA's emphasis on magnetic storage was to emerge.

In a few months, from sometime in mid-1945 to March 1946, the ERA people, Howard Engstrom, Charles Tompkins, Lawrence Steinhardt, and John Howard, in particular, had analyzed this new field and reached the level of the Eckert-Mauchly and the Institute for Advanced Study von Neumann/Goldstine groups in an appreciation of the nature of the problem. Each of these groups went in separate ways, of course. But this proposal shows that the ERA team was just as thorough as the other two in identifying the nature of the problem and carving out a promising direction. Next ERA had to work with their customers on design specifications and needed functional parts, and, through testing of components, learn the art of computer system construction.

By June 1946, ERA had organized several projects related to the search for a better data storage system. One of these was to analyze the use of photographic film as a potential tape source. Another was to examine solid-state delay lines as a storage medium. Yet another focused on the use of magnetic media as a storage source, the primary area of personnel talent. In the beginning, these projects went under the codenames Orion or N-1011. Eventually, ERA emphasized only magnetic media, even though under the Navy's urging they continued to investigate other possible storage media.

The machine to incorporate these ideas was codenamed Goldberg. Goldberg was analogous to Binac in the role it played in ERA's path to the 1101 system. (IBM had its own analogue to Goldberg/Binac: the Tape Processing Machine (1949-1951).) Goldberg was designed to analyze data of a "teletype nature" at a rate of 20,000 pulses per second. There were to be six functional parts to the Goldberg machine. (1) An IBM tape reader would be used for punched tape input and output to the machine. (2) Two magnetic drums were to be constructed, one for internal and one for external memory. The internal memory drum of 31 inches diameter was to have 22 or more tracks and store 5000 magnetized "spots" around its circumference. The Navy specified that the data on this drum should be analyzed at a rate of 20,000 items per second. Three magnets would be employed for reading, erasing, and rewriting.

The calculational part of the machine was composed of translators and counters. (3) Goldberg was to have three types of translators for converting data from one system into binary code. The complexity of these translators went from two-unit translators with two inputs and four outputs, to six-unit with six inputs and 64 outputs, to a 36x36 matrix. (4) There were 36 electronic pulse counters, each with a maximum capacity of 9999, controlled by a gate tube in the input signal circuit. (5) Four control signals for timing, starting, stopping, and canceling, and it was necessary to provide control circuits for these. In addition, the plan specified a set of control circuits for the functioning of the counters, reading schemes, and printing results--a total of nine circuits in all. And (6) a mechanical printer was to be supplied having a capacity of 38 five-digit numbers [5].

During May, the final designs for the reading and re-writing amplifier and the electronic memory units were completed, and production prototypes were under construction by the end of the month. But other circuit design changes were being undertaken, especially in the carry-over chassis. The continuous read, erase and rewrite feature was successfully tested for durations of up to 90 minutes. "No deterioration of the pattern was observed." Other circuits were in various stages of design. A comprehensive study of control circuits and equipment began. Much work still remained to be done over the next seven months--the projected completion date of drum construction [5].

The sorting out and education processes that occurred from mid-1946 to mid-1947, when Goldberg was delivered, allowed ERA to learn the field of computing, accumulate the engineering skills to pursue research and development on an organized and sustained basis, and to carve out for themselves an area of computing machine development that would have an important influence on the field. Thus, the critical years in ERA's growth were 1947 and 1948. In these years they changed from an electronic project shop to a computer design company.

In October 1946, Tompkins wrote a memorandum to William Norris about five probable sources of computing machine business. Besides ONR and NBS, he cited the United States Army, Prudential Life Insurance, and the University of Chicago [10, Box 7]. In spite of the awarding of the ONR contract in August 1946, containing as it did requirements for a survey, services and bread-board models, ERA was still trying to obtain a contract for a larger computing machine project.

During 1947 under the ERA contract with ONR to survey computer projects in the United States, Tompkins, Cohen, and others visited a number of installations to discuss the work of those projects and other subjects of mutual interest. For this work, in 1947 they visited MIT (Whirlwind), Brown University (the solid-state delay line work of Arenberg), the University of Pennsylvania (EDVAC), Harvard (Mark II and III), and knew about developments at the IAS. Through NBS they obtained the instruction code for Univac [9]. From these considerations came ERA's computer design project labeled B-3001.

Conferences for this B-3001 project started toward the end of February 1947, apparently between Tompkins and ONR personnel. By 10 March Tompkins had met with Arnold Cohen and George Hardenbergh to discuss "the preparation of the list of components for computing machines...and to start additional researches concerning magnetic storage of pulses." Three groups would do the pulse work, led by Coombs, Rubens, and Gutterman, respectively.

ERA developed a twelve-point program concerned with head, media, circuit and system problems. Further work was to be done on head shape and size, lamination for improving the efficiency of high-frequency response, the size of gaps between the heads and the magnetic surface, and the materials out of which the head was made. Possible new research on media components would be balanced with research on placement of these components on drums. By the beginning of September 1947, in all its essential features the work on the magnetic storage system was complete and ERA had achieved the objectives set out in the contract [5].

With the completion of this project, John Howard recommended that "ERA hold *immediately* a large-scale symposium for all personnel who might have ideas as to possible applications" of the storage device. Seventeen members of the engineering staff attended the meeting. The ideas for use offered by others at the meeting were not very much advanced over the first description of products circulated at the time of ERA's founding. They had to do with mass communication problems, as a consulter for wage rates in connection with punched card machines, store credit information for quick reference, use in storing data for maps and weather, and rapid recording of experimental data. One of the more intriguing suggestions at the meeting by Howard was the coupling of the drum with an IBM machine [9].

Howard received so many suggestions at the meeting that he was able to assemble them into fourteen categories in a twelve-page memorandum to Ralph Meader prepared on 8 March [9]. The categories seem to be ranked in order of importance. Seven ideas were grouped in a category on "sequence control applications." These ranged from automatic control of looms for pattern weaving and of machine tools to automatic control of guided missiles and airplanes. This latter idea was already part of the analysis by Tompkins of the needs of the various missile development groups of the Navy as part of the components survey. In the "dynamic inventory applications category," we find airline reservations systems, large-scale inventory problems, the census, and automatic accounting systems for banks. Over the next two years many of these ideas were presented by ERA to corporations and the government with limited success.

ERA's aim to build a computing system had been achieved, however. By this time, ERA was heavily involved in completing the components survey for ONR, deeply immersed in a design of a major computing system for the Navy, the system to be known as the ERA Atlas, and in its commercial version, the ERA 1101. They were also negotiating with NBS for design of yet another computer based on the needs of the U.S. Air Controller's office. These tasks precluded shifting personnel to an investment venture of the firm at the expense of assured contracts.

With Atlas, ERA went through the same building and testing steps as EMCC. After considerable interaction with the Navy, ERA delivered the Atlas in December 1950. With some minor modifications and permission from the Navy, ERA offered this machine for sale thereafter as the 1101.

Conclusion

From this brief history, we learn first that the starting points for the three companies was the same: they all emphasized storage systems development first. For ERA, the storage system was an end in itself, but it developed into a project for a complete machine--the Atlas and the 1101. For both EMCC and IBM, storage systems were starting points in a longer program to produce a computer. None of the companies, indeed no project anywhere, had a sufficient knowledge of how to build functioning computer storage elements or any other part of the machine to ensure success. Other authors have called attention to the transfer of information among all the projects. This played a particularly important part in ERA's activities. Information transfer was also significant to IBM, but less so to EMCC, though they did benefit from attendance at the various conferences held in the late 1940s.

Second, the strong interaction between designers and users in the determination of machine specifications and functioning ability has not been examined giving equal weight to both sets of people. Users demands have been treated in the literature as reactionary, whereas designers ideas have been portrayed as revolutionary. In fact, the roles of NBS, the Census Bureau, and the Prudential Insurance Company in EMCC's design and planning were critical to bringing a functional machine to market. EMCC's contracts were designed by them to converge and at the same time meet customer demand. The view in 1946 that such a device could be constructed from standard radio parts did not prepare the designers or the anxious users for the large number of obstacles the designers needed to overcome before an operating machine became available. Many design changes occurred along the way, and a number of components and test instruments needed to be newly designed and built for proper performance in computer systems.

The U.S. Navy played a different role for ERA. Navy contracts provided a systematic learning and R&D period for ERA, during which they could advance from smaller to larger scale system contracts. While IBM's start may be considered slow from some perspectives, the time frame for bringing a machine to market is about the same as for EMCC and ERA. IBM's objectives were quite different than those of EMCC, even though they were somewhat similar in their end--to obtain commercial customers for the new machinery. IBM's approach to the development problem was quite different than EMCC's, and in some respects different than ERA's. In at least one instance, IBM's R&D program converged with ERA's and IBM contracted with ERA to pursue design of magnetic drums for use in IBM machinery. This contract held out the possibility of significant commercial business for ERA, and might have spelled the difference between independence and absorption, except that IBM decided to go it alone and finance their own development. This decision was reached after much discussion within the company about customer needs and market potential.

Third, each company experienced about a five-year time from start of design to delivery of a computer system. EMCC began first in 1946 and delivered the BINAC in 1949. The BINAC, which incorporated many features prominent in the later UNIVAC, was delivered to Northrop Aviation in mid-1949. UNIVAC 1 was delivered to the Census Bureau in early 1951. ERA received a contract to design and build the Atlas in 1947 and delivered the machine to the National Security Agency in December 1950. Its commercial counterpart, the ERA 1101, was first delivered in 1953.

Development at IBM on the 701 and the 650 took just about as long. The IBM 650 project, begun in 1948, assumed sustained activity in 1952 and produced a machine in 1954. The Defense Calculator appeared in 1951, and its commercial version the IBM 701 reached the market in December 1952. The IBM systems designs were more complete in that they considered manufacturing requirements and customer service needs. The routine of the IBM tabulator business was transferred in so far as possible to the making of computer systems. EMCC and ERA developed better processes for manufacturing and servicing later, as evidenced by the succession of modified models of the UNIVAC and the ERA 1101.

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9. Sperry Corporation Records, Hagley Musuem and Library.
10. Yutter Collection, Hagley Musuem and Library.