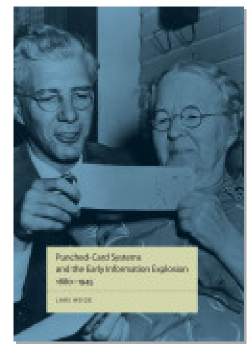
Punched-Card Systems and the Early Information Explosion, 1880–1945



Heide, Lars

Published by Johns Hopkins University Press

THREE

U.S. Challengers to Hollerith

American offices in the turn of the twentieth century, as they do now, processed the information needed to produce, distribute, sell, and purchase products and services in the country's private enterprises and public organizations. They recorded sales and purchases in financial accounting, administered wages and salaries, and compiled information on the internal transactions and production in their company. The massive expansion of private enterprises between the Civil War and the 1930s was reflected in the growth in scale and scope of tasks that were carried out in more and bigger offices. The distinction between the growth of scale and of scope facilitates an analysis of the dynamics of offices and office machine production beyond the initial phase of mechanization in the late nineteenth century.

The research on office dynamics in this period has focused on the rising number of employees in offices, their changing educational background, gender, and the routinization and mechanization of jobs. The traditional American office before the Civil War was staffed by male clerks, who wrote everything by hand in pen and ink. Their work was done in bound volumes, like account ledgers, copy books of outgoing letters, and minutes of the board of directors' meetings, when the company became incorporated and a board was appointed. Bound volumes had the advantage of keeping things together, and they prevented fraud. Incoming letters were loose leaf, which was considered a problem. Some companies bound incoming letters, others kept brief records in bound letter journals, while a third answer was just to keep the loose-leaf letters stitched on strings or as a stack in a drawer or a box. Vertical filing systems were marketed for this purpose around 1900, and accurate filing was ensured by trusted clerks and through records in bound volumes.[1]

The growth in the number of clerical workers in the United States was striking; from 1870 to 1930 numbers rose from 81,619 to 4.2 million, that is, by a factor of 51. Women contributed significantly to this expansion. Only 1,910 women were recorded as clerical workers in 1870, but by 1930 the total had soared to 2,038,494, accounting for 49 percent of the total clerical workforce.[2] This growth came about through changes in the structure of the office and in the office workers' career paths. The small traditional offices had had few organizational levels; the new larger offices had multilevel hierarchies.

The male clerks in the traditional office had received an in-service, general training, and their positions formed part of a career leading to managerial positions. In contrast, a large proportion of the workers in the new-style offices were assigned narrow duties involving routine work, like typing, punching, or shorthand, based on training in these fields. Female office workers were often employed in this kind of routine job, and most of them remained in such positions. Routinization, formal hierarchies, and office machines became crucial components in the organization of big offices. An expert on railroad accounting in the United States found in 1919 that the value of office machines "lies chiefly in greater speed and volume of output, accuracy, and the assignment of women operators thereto, relieving the male clerks of general routine work and allowing them to concentrate their entire time on more difficult mental work. The assignment of women operators was particularly valuable during . . . [the First World War] and the resultant scarcity of clerical and other labor in general."[3] Office machines—and female office workers—were regarded as tools to enhance the scale of office work at a low price.

In addition to the increase in scale, the development of office machines between 1900 and 1940 underwent a growth in scope, which reflected a growth in the scope of significant office tasks. Industrial production of simple keyboard office machines emerged from skilled, almost craftsmanlike, methods in separate industries for typewriters and adding machines. Typewriter print was more legible than most handwriting, and adding machines enhanced the operators' arithmetic skills. These were standalone machines with few organizational requirements beyond training the operator.

Remington of Ilion, New York, started to produce typewriters in 1874. Their success encouraged competitors to enter the market, so that by 1890 thirty typewriter producers existed in the United States, growing to eighty-five producers by 1910.[4] Similarly, the first reliable keyboard adding machines started to be produced in the United States by Dorr E. Felt and William S. Burroughs in the 1880s. In 1887, Felt began to market his nonprinting adding machine, in which the total was displayed on a visible result register. Subsequently, to produce his machine, Felt went into a partnership with manufacturer Robert Tarrant and founded Felt and Tarrant.[5] Burroughs' first adding machine design from 1885 also used a visible register. However, in 1887, he added what became his adding machines' outstanding accomplishment: printing the numbers as they were entered and the totals.[6] A printout enabled the operator to check an addition much more easily; previously operators had had to repeat their calculation until they got the same result twice. Furthermore, some businesses, like banks, needed a written record. Serial production of the printing Burroughs machine started in 1891.

By 1900, separate typewriter and adding machine industries had emerged, each based on a machine stabilized in one or a few versions, and each market segment was highly competitive. After the stabilization, the calculating machines remained more open to development than did typewriters. Calculating machines could add or multiply, be equipped with a printing capability, have a full keyboard or just ten keys—and additional features continued to emerge. In 1902, Felt and Tarrant launched a machine that could cross-tabulate, that is, add two or more columns of figures horizontally—as well as the more typical vertical addition.[7] Three years later, Burroughs launched a machine that could print identification numbers and dates in addition to the figures posted, enabling a bank, for example, to print the account number for each entry. Both machines had a wide carriage that allowed the use of wide sheets or forms. This eased the use of adding machine prints as pages in loose-leaf ledgers. Burroughs developed a machine that could handle both subtotals and grand totals in 1910.[8]

The emergence of a subtraction capability around 1910 greatly improved the adding machines' suitability for bookkeeping. Until then, credit-debit bookkeeping could only be carried out in one of two ways: Keeping debit and credit in separate registers, or entering the debits as complements (i.e., adding the "opposite" number rather than actual subtraction).[9] As complements require nontrivial computations, calculating machines were sold with a special keyboard for entering complements.[10] In 1911, Burroughs produced a machine that could subtract without entering complements.[11]

The integration of typewriters and adding machines emerged in several variants. One type consisted of invoicing machines based on combinations of typewriters and adding machines, for example the Ellis adding-typewriter and the Moon-Hopkins billing machine. They were complex designs and slow to use, as the operator had to type the full name and address for every invoice. The design of the Ellis adding-typewriter was finalized in 1906 and subsequently produced. Production of the Moon-Hopkins billing machine started in 1908.[12] An alternative was to use a set of separate machines to calculate, issue, and address invoices. For example, addressing could be performed by use of an addressograph, but then the alphabetic capability was only used for writing invoice specifications. Further, it was necessary to perform multiplications either by hand or by use of a separate multiplication machine.[13]

But it was not a simple matter for the various machine producers to decide how to improve the capabilities of their machines for bookkeeping operations to enhance their competitive position, except that this application required more than could be accomplished by use of a typewriter, a keyboard adding machine, or Hollerith's standardized punched-card system for statistics processing from 1907. Producers needed to answer several questions: For example, what was important for machine-based invoicing? How important were computation capabilities like subtraction, multiplication, or division, none of which were available on key adding machines or punched-card machines by 1900? How important was the ability of the machines to write specifications on an invoice or a wage statement? How about the capability to print the recipient's name and address on an invoice or a wage statement?

As early as 1901, Hollerith clearly intended to extend the tasks his machines could accomplish bookkeeping through the development of a system for wage administration based on punched cards, but he never attempted to implement this idea. He chose instead to develop a standardized punched-card system for statistics processing, which became a major tool in large-scale business statistics.

In the decade after 1905, three challengers to Hollerith emerged: the Census Bureau machine shop, John Royden Peirce's punched-card systems, and the Powers Accounting Machine Company. In 1907, the year Hollerith finalized his statistics-processing system, John Royden Peirce envisioned a punched-card system of mechanized bookkeeping that replaced the ordinary statement of accounts by printouts of the transactions on loose-leaf ledgers. In 1913, *Scientific American* broadcasted these ideas in an article, "Keeping Books by Machine: The Punched Card as a Saver of Brain Energy." The vision was a machine, that

> performed the remarkable feat of recording approximately eleven entries of a single transaction—eleven entries which would ordinarily have to be made with pen with eleven chances of making a mistake. In recording a sale, the amount is entered upon a sales check, to be entered upon a bill, again upon the segregated sales record, again into the sales ledger, through another operation placed to the credit of the sales person, then to some department, in addition to a record as to whether the package was delivered by mail, carried away or sent by regular delivery express. Instead of this constant juggling with the same figures through a maze of operations there will be an original entry upon a punched card, and this card will, through the medium of motor-driven machines, be automatically sorted into various divisions and subdivisions, and recorded item by item upon counters or wheel sets into adding mechanisms . . . After the [printed] ledger postings are complete, the sales checks will be passed through the machine again and listed according to departments.[14] (Listing was to print selected information from every card.)

This was a production-line form of bookkeeping system facilitated by punched cards, though the card remained a processing tool. No data were to be stored on punched cards beyond the next closing of accounts, and there was no vision of using the system to generate additional extracts of accounts or collection forms. Compared with the key-set bookkeeping machines built during the next couple of decades, the core advantage of the punched card was the need for only one data entry for several jobs. The cost of attaining this was higher standardization requirements and more rigorous organization.

The Census Bureau Machine Shop

The first challenger to the Tabulating Machine Company's prime mover position was the Census Bureau machine shop established in 1905. The machines that came out of this shop were intended to break the Tabulating Machine Company's monopoly and to find an alternative for the excessive prices charged by the company as a result of their monopoly. However, the scope of the new enterprise remained within the Tabulating Machine Company's emerging closure of punched cards for statistics processing. This, in turn, became a major reason for containing the machine shop within the Census Bureau—a situation that led to its slow suffocation.

The Powers Accounting Machine Company was the only full punched-card competitor to emerge during the 1910s. This brought about conflict over the Tabulating Machine Company's patents, a cornerstone of their prime mover position. Powers planned to go for bookkeeping jobs; from the outset he based his punched-card system on a numeric printing capability and called his machines "accounting machines." However, he imagined that a numeric printing capability would be sufficient to make his system applicable to bookkeeping jobs. The actual requirements for extensive bookkeeping applications proved more demanding, and the Powers company only reached a closure on a complete system of punched cards for bookkeeping in 1943.

In contrast to these conservative approaches to machine development, John Royden Peirce was the visionary contender who first proposed bookkeeping and alphanumeric systems using punched cards to gain access to business of much greater volume. He challenged the closure of punched cards for general statistics and did not even accept Hollerith's established punched-card standard. Peirce encountered severe problems in converting his visionary designs into well-functioning constructions and in establishing machine production. The stories of the three challengers illustrate a prime mover position's robustness and the demand in offices in the United States in the 1910s for advanced mechanization.

The Census Bureau machine shop was established by a Congressional appropriation in 1905, and subsequent appropriations ensured its existence for several decades. Establishing and maintaining this machine shop was a part of the federal government's growing influence in society since the 1870s, and it had two immediate contexts: First, the Census Bureau's endeavor to establish for itself a permanent role, which was used to analyze the break with Herman Hollerith. Second, the antimonopoly wave since the 1870s, aimed at the new big companies and all sorts of market manipulations. The general public believed that American industry was being monopolized, but a monopoly was no simple entity and the federal government granted patent monopolies. The legislature tried using the antitrust laws, the Interstate Commerce Act (1887), and the Sherman Act (1890) to protect the free market through bans on restraints of free competition.[15] But in 1905 Hollerith had no competitors and the punched-card market was small. In addition, the antimonopoly endeavor came up against the federal patent system that granted a seventeen-year protection for inventions, conditional on their subsequent transfer to the public domain. The purpose of the patent system was to encourage inventions, and similar systems existed in all European and North American countries.[16] The punched-card history illuminates how further technological development enabled the extension of a patent-based monopoly far beyond the initial seventeen years.

To obtain the best available system to process the returns from the census in 1900, the office of this census had invited tenders. The invitation was based on the processing of population returns, like ten years earlier, and three offers were received: Hollerith's well-tried system from the previous census competed with two systems submitted by Charles F. Pidgin, who also had submitted proposals for census processing ten years earlier. This time he offered a manual card system and a key-entry system. The office of the census in 1900 (which became the permanent Bureau of the Census in 1902) once again chose Hollerith's offer.[17]

The Census Bureau in 1904 adopted a strategy of establishing its own production of punched-card machines. The following year, the bureau obtained a congressional appropriation to establish a machine shop.[18] Hollerith immediately withdrew his tabulators to avoid their being used as models for the bureau's own machine production. The Census Bureau's gamble had put them in a position of no return, which placed heavy strains on their new machine shop. They had less than five years to build the reliable machines needed to process the next census in 1910, but they experienced three interrelated problems: their ambitions to build better machines than Hollerith's were confounded by technical problems, the constraints of the still-valid Hollerith patents, and the difficulty of hiring qualified people to build their machines.

The early Hollerith patents would expire in 1906, which enabled the Census Bureau to copy the machines that he built for the census in 1890. From the outset, the Census Bureau had no intention of infringing any patent or competing commercially with Hollerith.[19] Their machine building was a parallel to Gore's punched-card system built during the 1890s at the Prudential Insurance Company and, as such, was not a cause for litigation. It proved difficult, however, to observe their intention neither to compete nor infringe existing patents. As the Census Bureau's ambitions exceeded the simple sorting of the Gore system, Hollerith's still-valid patents proved difficult to circumvent, and the bureau could not prevent employees from resigning to compete with Hollerith, as James Powers did in 1911.

Further complicating the issue, Hollerith had improved his punched-card machines substantially after 1890. He had built a mechanized feed, brush reading, and an adding unit for his tabulator, a sorter and a keyboard punch, and his patents on these facilities and machines would remain valid well after the census in 1910. In particular, it proved difficult not to violate Hollerith's patents on sorting and punching.[20]

The Census Bureau Director, Simon N. D. North, planned to improve on Hollerith's system from 1890 and, probably, even on his contemporary systems. To attract mechanics capable of making the needed inventions and innovations, these were allowed to take out private patents on their inventions in government service—with the proviso that they should be freely available for government use.[21] This privilege was a reasonable concession to attract mechanics, but it initiated commercial competition with Hollerith, which he considered a threat.

The machine shop staff grew from two people in 1905 to twelve in 1907 and to sixteen in 1909. Four were former Hollerith employees, one of whom had been at Hollerith's company for twelve years, part of the time as a foreman.[22] Hollerith considered this a theft of expertise, but he had no arrangement to prevent his former employees from taking their new positions. However, their importance as agents of technology transfer was probably limited as Hollerith was a drawing board inventor, who had outsourced innovation for machine production and production. His company only maintained machines and printed punched cards.

One of the people who moved from Hollerith to the Census Bureau machine shop, Charles W. Speicer, incorporated the Speicer Tabulating Machine Company in Washington, D.C., in 1912. The company tried to sell punched-card machines in Britain, and Speicer was granted a patent on tabulating equipment. However, he was not successful as a punched-card challenger, and he filed a patent application in 1914 on an invention in a different field—indicating that he had moved away from punched cards.[23]

James Powers was the most promising inventor hired by the Census Bureau machine shop, and he had not been employed by Hollerith. He was born in Odessa, which was then part of Russia, and graduated from a technical school there. Then he was employed for a period in a precision shop making scientific instruments for the physical laboratory at the University of Odessa. James Powers immigrated to the United States in 1889. During the next eighteen years, he worked for several firms in New York and became a partner of a small experimental workshop in Los Angeles.[24] He carried experimental work on in several fields, including cash registers, typewriters, and adding machines.[25] This and his subsequent work showed that he was a fine machinist and craftsman, who preferred purely mechanical constructions. Powers had no need to rely on electric constructions, as Hollerith had originally done. Powers' experimental work and inventions were spread over many fields, and he had still not settled in one field when he was hired by the Census Bureau in 1907. Up until that point he had proven himself an inventor, not an entrepreneur. He had tried to get others to develop his patents into marketable items and then had moved on to new projects.[26]

Powers lived in New York and was working at the mechanics laboratories of Francis H. Richards when he was hired by the Census Bureau. The Census Bureau had an agreement with this laboratory for workshop facilities. The census shop in Washington, D.C., at that time focused on the development of tabulators, while Powers was employed to construct a sorter. This arrangement showed the census workshop's limited capacity. In 1909, Powers finished his basic machine design for a punch and a sorter and moved to work in the Census Bureau machine shop in Washington, D.C.[27]

The Census Bureau shop's punched-card plans were based on the 24-column punched card that had been used to process the population census returns in 1890 and 1900. This allowed for all the punches used for these censuses, but it prevented the use of the twenty sorters bought for the agricultural census in 1900 because they were built for a shorter card of only twenty columns. The original Census Bureau plans consisted of three machines: an improved counting tabulator that could print the results, a sorter and, less urgently, an adding tabulator.[28] The desire for a printed result was probably inspired by printing adding machines. If implemented, this set of three machines would have placed the Census Bureau's technology ahead of Hollerith's. The key to the bureau's success was the ability to design and build a printing numeric tabulator and a sorter.

The machine shop's starting point was the transfer to public domain of Hollerith's early tabulator patents in 1906. This allowed the bureau free copying of the old pantograph punch and Hollerith's tabulator with manual card feed from 1890,[29] as well as Hollerith's electrical reading method. The machine shop started to develop their own counting tabulator, which soon included two improvements: mechanical card feed and numeric printing. For the card feed, they started with plans for a fully mechanical feed but ended up substituting an electric button for the hand lever. With the Census Bureau's new system, the operator placed the card in the reader and pushed a button that released an electric motor turning down the press. This process required less energy from the operator, and the new card reader raised the speed of the tabulator by about half, but it still required manual handling of every card and it only operated at a third of the speed of Hollerith's newest tabulator. From 1909 to 1910, one hundred copies of this tabulator were built by the Sloan and Chance Manufacturing Company of Newark, New Jersey, who specialized in making precision machinery.

First in 1911, the Census Bureau machine shop succeeded in building a mechanical card feed using an electric pin box, which required the card to stop during the reading. Despite the intermittent card movement, this tabulator's speed was 50 percent higher than Hollerith's. Number printing was the most conspicuous tabulator improvement in the Census Bureau machine shop. For the first time, a tabulator could print the result on paper. This removed the time-consuming process of reading and writing manually from forty to sixty counters, an important source of error. The printing unit consisted of six rollers containing ¾-inch- (2.5-cm-) wide paper strips, which were carried under each of the six rows of counters in the tabulator. When the printing unit was released, the numbers were printed on the paper strips by hammers and ink ribbons. As the print of a set of results filled up 27 inches (90 cm) of paper strips, it was still necessary to transcribe the data to consolidation sheets before making any use of them in preparing tables. In 1912, the Census Bureau machine shop succeeded in building a tabulator unit that printed the figures from all the sixty counters on one sheet of paper, and this new tabulator was used to process returns from the census in 1910.[30]

James Powers had been employed to build a sorter, but during this work he conceived the idea of an "automatic" punch as a substitute to Hollerith's pantograph and key punches from the censuses in 1890 and 1900. The Census Bureau adopted this idea as an additional machine building project. The Powers keyboard punch from 1908 was "automatic" in the sense that an electromotor performed the punching operations, which significantly reduced the operator's work.[31] The Powers keyboard differed from its predecessors. Hollerith's original pantograph punch had one "key" that was moved to punch in all positions, and the card was placed on a carrier in his key punch and moved, column by column, under the same punches, as the eleven to thirteen keys were operated. The Powers keyboard punch had 240 keys, one for each of the twelve punching positions in twenty columns on the card.[32] The full keyboard had twelve keys in each digit position, as did the Burroughs and Felt and Tarrant adding machines. The celluloid keys held abbreviations for each punching position.

Powers' punch was unique because the operator keyed in all the information for one card, before he or she, by use of a special key, ordered the machine to perform all the perforations in one operation. An electromotor punched, moved the punched card out of the punch, and entered the next card. Previously any keying error had caused a card to be scrapped; now the errors could be corrected before the card was punched. This enabled the correction of any errors discovered while keying-in, although those detected later still required a new card to be punched. Further, this punch was easier to operate than Hollerith's key punch, as the operator did not have to perform the punch manually. However, all these capabilities meant that the new key punch had an extremely complex design.[33]

Three hundred Powers keyboard punches were produced for the census in 1910, but the new punches were not reliable and were abandoned, making their three hundred copies a big test production.[34] To alleviate this problem, the Census Bureau reintroduced Hollerith's old pantograph punches from 1890 to punch a third of the information on the population census in 1910. The Powers punch was advanced compared with its predecessors and was designed to reduce the workload of the key punch operator. However, its construction was not essential for the Census Bureau, and its development and production diverted attention from building a much-needed sorter.

Building sorters was the second most important machine construction project originally planned for the census in 1910. James Powers was hired for this task in 1907, but the following year he refocused his work to design the keyboard punch. After completing the punch, he returned to his original project and developed a sorter. Whereas Hollerith's machine sorted on one column at a time, Powers' first effort enabled sorting in one operation using several punching positions spread out over the card.[35] However, Powers' sorter was a complex mechanical design that only could operate at a third of the speed of the Hollerith sorters. In addition, it was an infringement of Hollerith's still-valid sorter patent, which made the Powers sorter a dubious project.

The alternative for the Census Bureau was to rebuild the twenty sorters bought from Hollerith for the agricultural census in 1900. Rebuilding was necessary to use the 24-column card for the population census; the sorters had been built for the shorter 20-column card used for processing the agricultural census in 1900.[36] The rebuilding alternative was chosen, but Hollerith's Tabulating Machine Company brought a lawsuit claiming that the alterations to these machines infringed their patents. The case was dismissed by the court, as the alterations were not considered sufficient to constitute an infringement of the Hollerith's sorter patent, and also because Hollerith's basic sorter patent was filed after the sorter had been disclosed to the public by being supplied to the Census Bureau, which nullified the patent.[37]

An adding tabulator was the last of the Census Bureau's original machine building projects. Their machine shop worked on the tabulator from 1908 to 1909, but it never became operative.[38] This combined with the animosity toward Hollerith's company compelled the Census Bureau to abandon punched-card processing of the returned information in the agricultural census, which was accomplished by purchasing key adding machines and reducing the investigations.[39]

The Census Bureau's development strategy was based on a development group, in contrast to Hollerith's lonely inventor approach, which, in fact, relied on a set of subordinate technicians. The Census Bureau's strategy resembled the contemporary introduction of development departments at many big industrial firms. In the Census Bureau, this strategy proved successful for building the counting tabulator that could print, but building a keyboard punch and a sorter was assigned to one individual, James Powers, who worked in a way similar to Hollerith.

The Census Bureau machine shop accomplished designing and producing the first numeric printing tabulator for the census in 1910, but this accomplishment was not sufficient to keep the Census Bureau machine building project afloat. It failed to build two of the three planned machines, the sorter and, particularly, an adding tabulator. It simply was not able to attract a sufficient number of able people. Only two of the sixteen machine shop staff subsequently were granted patents. Charles E. Speicer was granted only one punched-card patent, and James Powers used his attained punched-card expertise to establish his own personal punched-card machine company. However, none of his sophisticated machines designed for the Census Bureau were reliable.

The census in 1920 witnessed a reduced role for the Census Bureau machine shop, as no new machine was built, and equipment was acquired from the Tabulating Machine Company. The problems with the counting tabulators from the census in 1910 were corrected. Further, for processing the census returns in 1910, the bureau only had the twenty sorters, which they originally purchased from Hollerith for the census twenty years earlier and later rebuilt. For the census in 1920, the machine shop built several additional horizontal sorters based on Hollerith's original design, without interference from the Tabulating Machine Company.[40] By then, Hollerith was no longer a problem. His basic sorter patent had expired and his patent on the horizontal sorters for the census in 1900 had been nullified in his lawsuit against the government in 1910.[41]

The Census Bureau never resumed their building of either the Powers sorter or the Powers punch from the census in 1910. Only the work on the adding tabulator continued during the 1910s, where the people in the Census Bureau machine shop encountered the problem that several adder designs were patented by Hollerith and by the adding machine producers. Then only the early simple designs had reached public domain. The Census Bureau machine shop preferred to base their design on expired patents, for example, they tried to use the design of the Burroughs adding machine. These difficulties combined with the problems of hiring capable engineers caused the project of building an adding tabulator to be abandoned, and tabulators were rented from the Tabulating Machine Company for tasks requiring addition.[42] This solution was then feasible, as all the main contenders in the battle from 1903 to 1911 had moved elsewhere, namely Hollerith and the census directors North and Durand.

During the censuses in 1930 and 1940, the Census Bureau gradually introduced the 45-column card for processing population census returns. The population census in 1930 was processed using the old 24-column card, but a column layout was applied and IBM punches were used. (The Tabulating Machine Company had been renamed International Business Machines, or IBM, in 1924.) The new column layout required changes in the various characteristics punched. One change was punching the age in tens and units that required two columns, instead of in five-year periods and their units that required two and a half columns, as in the census in 1920. Another change was that state of birth—both domestic and foreign—was punched by use of a two-digit code, which had to be looked up or memorized by the key punch operator. Finally, the old pantograph punches from 1890 were retired. In 1940, IBM's 45-column card was introduced, and for the new punched-card format the Census Bureau machine shop rebuilt its existing sorters and counting tabulators. IBM had introduced the 80-column card in 1928, but processing using 45-column cards was cheaper. Also, the Census Bureau got 45-column punched-card machines from IBM, such as punches and adding tabulators. Thus it took the bureau and the company twenty-five years to get together again.[43]

The outcome was a reduced Census Bureau machine shop. During the years around 1910, the focus had been inventions and innovations. Later, its main occupations had become producing, modifying, and repairing equipment, with only modifying and repairing remaining after 1930.[44] To the Tabulating Machine Company and IBM, the absence between 1905 and 1930 of big counting statistics orders from United States censuses caused all their tabulator development work to be focused on adding tabulators, which were operated at a lower speed than simple counting-based machines to process counting statistics. In contrast, IBM's British agency, the British Tabulating Machine Company, had built or rebuilt machines for processing population statistics since 1910. Only in the late 1920s, did the American parent company return to design a special punched-card machine for counting-based statistics.[45]

The Census Bureau did not accomplish breaking the Tabulating Machine Company's monopoly, but they provided James Powers with the technological expertise he subsequently used to establish his own company. And once Powers emerged as the first open competitor, the Tabulating Machine Company's patents forced him to cooperate, and it regulated its market, which exposed it to an antitrust prosecution.

Powers Accounting Machines

The story of the Powers Accounting Machine Company started in 1911, when James Powers resigned from the Census Bureau to establish a company to design and build punched-card machines for "statistical and commercial works."[46] His main jobs involved numeric bookkeeping, but he would also collect statistics jobs, which for many years had provided the foundation of Hollerith's Tabulating Machine Company. This strategy proved harder to implement than Powers had anticipated. He ran into several technical and managerial problems, and he only attained well-functioning machines through engineer William Lasker, who brought experience from office machine building.

James Powers had built a punch and a sorter while employed at the Census Bureau from 1907 to 1911, but both were failures, due their high mechanical complexity. Further, Powers had no part in building the successful printing tabulator at the Census Bureau during his employment. However, he gained expertise in punched-card machinery.

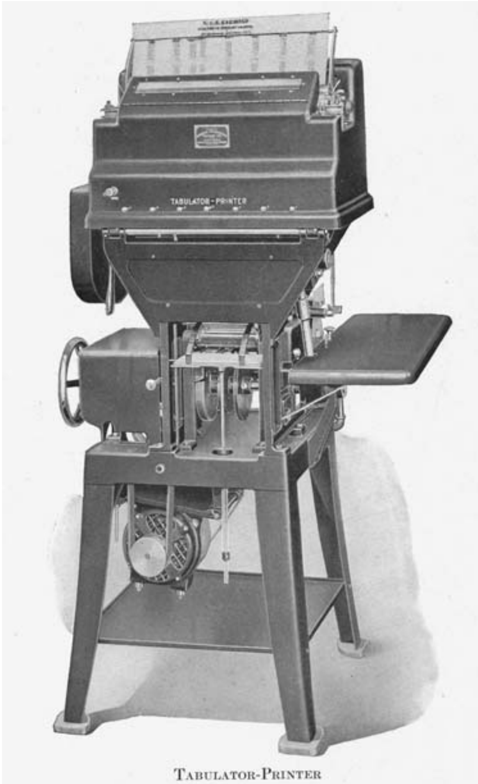
From the outset, James Powers based his commercial machines on the 45-column punched card, introduced by Hollerith in 1907, which made this card an industry standard that remained until 1929. Powers needed to build a punch, a sorter, and a tabulator to establish his business, and he completed prototypes of all three machines in 1912.

Powers first wanted a to make a punch, so he tried but failed to improve his complex design for the Census Bureau from 1908.[47] A major problem was his approach with a full keyboard. The Census Bureau only needed to punch twenty columns, which required 240 keys, but these punches never became reliable. Now, his choice of a 45-column card would require a full keyboard of 540 separate keys, more than double the number. After having realized the shortcoming of his full keyboard design, Powers simplified the design and replaced the keys with slides, one for every column on the card, which reduced the number of entry determinants to forty-five slides. Powers retained the ability to simultaneously punch all the columns from his Census Bureau machines, and his company's punches continued to be able to perform this function.[48]

Powers built a new horizontal sorter with two decks. Probably the motivation for the two-deck design was to save floor space to compete with the vertical sorter from the Tabulating Machine Company. The Powers sorter operated at similar speed as the contemporary sorter from the Tabulating Machine Company.[49]

A programmable and printing tabulator proved hard to build. The ability to print and program was essential to attract bookkeeping jobs, as several tabulator settings were needed in a bookkeeping installation. Powers' first tabulator was a prototype that was based on the technology of the printing Felt and Tarrant adding machines, which greatly eased his work, but he never was able to make these machines reliable. The Powers tabulators read the punched cards in a pin box while the card was at a standstill. The reading was performed as spring-loaded steel pins, one for each punching position, went up toward the underside of the card in the pin-box reading unit. When there was a hole, the pin went through and affected an adding unit through a "connection-box." This was an interchangeable unit consisting of a rigid frame, which held rows of thin steel pins that could move a fixed distance up and down. The pins transferred, by the use of bar pulling, the movements from the pin-box reading to the adding units, where the bars pushed the various keys on the units.

The connection box was a joint unit, which could easily be exchanged for another when the tabulator was switched to another job, or programmed for the other job using today's terms.[50] Generally speaking, a user had one connection box for every task. The advantage of the connection box was to enable a quick and efficient switch from one task to the next, an operation only requiring instruction for a few minutes. At the same time, connection-box programming was inflexible, as even a small



Powers company printing tabulator from 1914. (*The American-Canadian Mortality Investigation, Based on the Experience of Life Insurance Companies of the United States and Canada during the Years 1900 to 1915, Inclusive on Policies Issued from 1843 to 1914, Inclusive,* New York: Actuarial Society of America, 1918, facing page 14)

change required the box top be rebuilt at the company's factory, which took time and cost money.[51]

The Powers tabulator's ability to print was a requisite for most bookkeeping tasks. Also, printing became a useful capability of actuarial statistics, which was the reason the Actuarial Society of the United States chose Powers equipment for their big mortality investigation, which was processed from 1916 to 1918.[52]

Like the machines that Powers built at the Census Bureau, all his subsequent machines were based on exclusively mechanical technology, the only electrical part in a machine being an electromotor to operate it. This minimized their dependency on the various electrical powers systems of the age, which had direct or alternating current and diverse voltage. A machine could be moved from one power system to another just by changing the electric motor. Also, the choice of mechanical technology enabled the use of design and components from the adding and accounting machine industry, such as the use of a Felt and Tarrant adding unit for Powers' first tabulator.

Mechanical technology was not backward compared with electromechanical technology but rather more appropriate. Poor punched cards and unstable power supply had less impact on mechanical than on electromechanical punched-card systems. Punched cards did not always have the best quality. They could hold electric conductive particles, metal, or carbon grains, which became false holes in electric reading. Small cracks or fallen out bits could cause false reading for both kinds of machines, but the conductive particles only caused problems on electromechanical machines.[53] In addition, the direct current applied for card reading in the electromechanical machines required a stable voltage, and any brief power break could cause holes not to be read.

The major advantage of punched-card-based printing was the automatic execution, but in advance of being printed, all cards had to be packed in a deck of cards. Further, the paper applied was advanced by rubber rollers, which had limited precision. These operational problems were the focus of subsequent machine development. Powers' first tabulator showed his realistic vision of extending the scope of punched-card applications to bookkeeping and his technical problems in implementing this vision.

His first punch, sorter, and tabulator of 1912 were improved in the years until 1920, when a verifier was built to expand the scope of punched cards and attract bookkeeping applications. During this process, the mode of machine development was extended from the lone inventor, James Powers, to a group of people, similar to his earlier experience in the Census Bureau. During his Census Bureau years, Powers had gained experience in developing machines in cooperation with engineers at Francis H. Richards's machine shop and with the other people in the Census Bureau machine shop. Soon, he engaged his own team of engineers, first and foremost William Walter Lasker, who brought expertise in typewriter design.[54] Also, his company profited from inventions by the Powers agencies in Europe.[55]

The most urgent development task was a reliable tabulator. Powers and Lasker built an improved tabulator with fewer parts to make production cheaper and to ease maintenance.[56] The Felt and Tarrant adding mechanism was replaced by an adding unit from the Dalton Adding Machine Company. This was the first successful printing tabulator that both listed information from punched cards on a sheet or paper roll and printed totals. The operation of the machine, either listing all cards or printing the totals, was selected by shifting a switch. The tabulators in the Census Bureau could only print totals, and the Tabulating Machine Company only supplied a printing tabulator in 1921. However, in spite of this technical advantage, the Powers company did not do that well, and the Tabulating Machine Company remained by far the biggest company.

From 1914 to 1919, Powers' company amended the bookkeeping capability of their line of machines through the introduction of a verifier and an improved tabulator. The first verifier appeared in 1914 and was a crucial improvement for bookkeeping applications. Formerly, two cards had to be punched independently, and they were then superimposed and compared by looking at the light peeking through the perforations. The second card was subsequently thrown away. Powers' first verifier resembled his slide punch. When the slides were adjusted, a mask was superimposed on the printed card and a light was lit to check that the two perforations were identical.[57]

At the same time, work started on producing a machine that could make successive totals. Often several bunches of vouchers were recorded in bookkeeping or statistics operations, which required a subtotal at the end of each bunch of vouchers and a grand total at the end of the last bunch. On a tabulator up until that time, this was accomplished by running each bunch of punched-card voucher copies as a separate job. When a job ended, the operator stopped the tabulator and copied the result manually on a tabulator from the Tabulating Machine Company or released the printing mechanism on a Powers tabulator.

For the operator of a tabulator from the Tabulating Machine Company, this appeared reasonable, as he or she anyway had to copy the result by hand. This was not the case on a Powers tabulator, which the operator only had to stop the machine and print. The key to bypassing these simple but tedious operations was devising a way to instruct the tabulator when to make a total. For this purpose, Powers introduced separate "total cards" and "stop cards," which William W. Lasker implemented. A total card was a blank card with a special perforation in such a location as to allow a plunger to go through, thereby causing the adding unit to print a total without stopping the machine. A stop card had a perforation in a different location and caused the tabulator to stop. A stop card was inserted in a stack of punched cards at every point at which a total was to be calculated.[58] However, this arrangement only allowed one level of totals, which was a shortcoming for many commercial users.

When processing several bunches of related punched cards, for example a bunch from each department, they needed both subtotals and a grand total at the end of the job. However, they had to choose between the subtotals and the grand total, as it was only possible to transmit information from a card to one calculating unit on the tabulator. Only in 1923 did Powers introduce a tabulator that could do subtotals and grand totals by superimposing a grand total unit on the usual adding unit. Printing numbers from the grand total required the operator's initiation.

The slide punch seems to have been reliable, but entering figures was cumbersome. Powers worked through several designs, but William Lasker developed the successful automatic key punch that was launched in 1916. It had a small keyboard with twelve keys, one for each row on the card, and control keys for skipping a column, and so on. Further it retained the Powers punches' simultaneous electromotor-powered punching when the operator had keyed in all information for a card, and the automatic transport of cards. These capabilities eased the key punch operator's labor compared with the punch from the Tabulating Machine Company.[59] For more than ten years, this new punch from the Powers company remained the best punch available. Lasker also built a one-deck horizontal sorter, marketed in 1919, that remained the basis for all sorters from the Powers companies in the interwar years.[60] It had a simpler design than its two-deck predecessor, but it occupied more floor space.

Thus by 1919 Powers' company completed its first well-functioning set of punch, sorter, and tabulator that was necessary to exploit its original competitive advantage of a punched-card system with number printing. But this process had taken eight years, and the company's business organization was not yet fit to make the best of its technical accomplishments.

The Powers Accounting Machine Company had started machine production in 1914, but it ran into several problems. To establish production, it needed a license for tabulating and sorting patents held by the Tabulating Machine Company. This was granted, but the conditions were harsh. Powers was authorized to produce mechanical punched-card machines, but the company had to pay about 20 percent of its revenues in royalties to the Tabulating Machine Company. This should be compared with the 5 percent royalty for a similar license in Germany, which was imposed through different legislation. The Powers company could reduce its royalty payments through the development and production of machines that were outside the scope of the Tabulating Machine Company's patents. A futile attempt to this end was Lasker's invention of a sorter using a circular movement in contrast to the linear concept in Hollerith's patent, but it was never produced.[61]

In addition, the new company ran into financial problems. Costs to establish production proved to be higher than James Powers originally had anticipated. Powers had raised money to incorporate his company in 1911, but that did not prove sufficient to finance his machine building during the next several years, until the new company started to earn sufficient profits through sale. As a consequence, the company was reconstituted by money from financier John Isaac Waterbury from Morristown, New Jersey, in 1913, and three years later, the company received additional capital through a big loan.[62]

Further, the company's sales were poor, which was revealed by the company only getting a separate sales manager in 1920.[63] However, this was just a visible aspect of the company's managerial problems. James Powers did not care to manage and resigned from the company in 1918. The announced reason was failing health, but Powers lived as an active inventor for another nine years, and he filed five patents that were granted.[64] Further, he assigned three additional punched-card patents to the company from 1924 to 1925, and he even tried, in vain, to get reemployed in his old company.[65] These acts also paint him as a restless character, which is substantiated by his patent record.

In contrast to Hollerith and Peirce, Powers never settled in a technological field. For example, while engaged in the Powers Accounting Machine Company between 1911 and 1918, he filed eight patents in six separate fields other than punched cards, and three of his five patents filed after 1918 were outside the punched-card field.[66] His patent record and his preserved correspondence portray him as a prolific and eccentric inventor, but not an able entrepreneur, who returned to his preferred occupation as an independent inventor in 1918. Only for his punched-card patents did he try the role as entrepreneur.

The Powers company's management improved as able hired managers came to replace James Powers. He was succeeded as chef engineer by William W. Lasker in 1918.[67] However, the company encountered economic problems for several more years. It went into receivership in 1920, became charged to the Chase National Bank of New York and was offered for sale. Two years later, the company merged with a producer of mechanical adding machines and was reorganized twice. The receivership was only terminated, as the company was sold to the new Remington Rand Corporation in 1927.[68]

Remington Rand

The Remington Rand Corporation emerged as a general supplier of office machines and other office equipment through a broad merger in 1927. This merger was guided by James Henry Rand of Rand Cardex Services and had substantial financial backing. Rand Cardex Services was one of the country's most important producers of record control systems, and it merged with the Remington Typewriter Company, the country's leading typewriter producer, and the Dalton Adding Machine Company. Also in 1927, Remington Rand acquired the Powers Accounting Machine Company, which became the Powers Accounting Machine Division.[69] Over the next few years, the scope of the new company expanded through the acquisition of several companies producing loose-leaf ledgers, vertical filing systems, and safe deposit boxes.[70] The Remington electric shaver followed in 1938.[71]

The main advantage of Remington Rand was its ability to improve the use of the production capacity of its many constituent companies. Simultaneously, the wide scope of activities was the company's weakness, which resembled the Computing Tabulating Recording Company's situation in 1911 (see chapter 4). The acquisition of competitors, including three additional typewriter producers, strengthened the company's position by accumulating expertise and patents, but there was little interaction between the producers of typewriters, key adding machines, punched-card machines, loose-leaf ledgers, and vertical filing systems, not to mention electric shavers for the consumer market. However, in spite of the low level of integration, it proved difficult to get all the old companies to feel comfortable, which had an adverse effect on the creativity of inventors and innovators.[72]

Remington Rand proved more vulnerable to the economic crisis in 1929 onward than did IBM, due to its low integration and the high level of debt incurred during the merger. Remington Rand experienced a sharp dive in sales from 1930, causing net losses in fiscal years 1930–1931 and in 1931–1932. An injection of new capital reconstituted the company in 1936, but it proved difficult to reach the revenues and profits that had been attained in the last year before the crisis in 1929.[73]

The new company had inherited the patent license agreement with IBM from the Powers Accounting Machine Company.[74] This agreement expired in 1929, and $350,000 in royalty payments to IBM was due. The patents constituting the basis for the agreement in 1914 had expired, but Remington Rand still needed Hollerith's automatic group control patent. Hollerith had filed a petition for this in 1914, but it was only granted in November 1931.[75] Eight months earlier, a new five-year patent license agreement had been reached with IBM. Remington Rand was to pay the amount due, and in addition $25,000 in each of the five years. Further, the two companies agreed on pricing, which the following year caused an antitrust suit to be filed by the Department of Justice against the two companies.[76] The burden of the royalty payments was lower in the new agreement, but the very fact that Remington Rand entered the new agreement displays the difficult position of a challenger. Remington Rand still had to accept the conditions for the punched-card trade that were laid down by IBM as a prime mover.

Numeric printing had been the Powers company's original competitive advantage, but only in 1919 did it attain a full set of reliable punch, sorter, and tabulator machines to make the best of this advantage—which they then lost two years later when the Tabulating Machine Company introduced their numeric printing tabulator. These problems with their original competitive advantage combined with the restraints of the receivership between 1920 and 1927, restricted the Powers company to a strategy of developing its mechanical machines to compete with the Tabulating Machine Company on the markets for statistics processing and numeric bookkeeping. However, the Powers company twice attempted to develop new and exclusive punched-card application fields. First, the Powers Accounting Machine Company worked to develop bookkeeping applications requiring letter printing in 1924. Second, Remington Rand attempted to build special machines and cards to develop bookkeeping automation for the expanding department stores in 1932 and 1933.

Punched-card-based letter printing was first marketed by the British Powers company in 1921. However, this feature could only manage a reduced alphabet, and letter printing was restricted to separate printing positions, which could not print numbers. The British Powers company developed this feature at the instigation of the Prudential Insurance Company in London that wanted names as well as amounts to be represented in the perforated cards.

As early as 1916, the British Powers company filed a patent application on letter printing, but at the same time the American company refused to adopt this facility. The American company first embraced alphabetic printing in 1924. Lasker implemented the British design by developing a new tabulator that could print letters and numbers in separate printing positions like the British model. Lasker's tabulator was based on a reduced alphabet of twenty-three letters, like the British alphabet printing system. Further, to facilitate letter printing, a new model of the American company's key punch was built, furnished with alphabetic in addition to numeric keys. [77]

The first American alphabetic printing tabulator was installed in the Metropolitan Life Insurance Company in New York in 1925.[78] This installation replaced Metropolitan's cooperation with John Royden Peirce, which had existed since 1918, to develop punched-card machines with alphanumerical capability. However, Peirce had not proven able to build the promised machines and had been hired by the Tabulating Machine Company in 1922, which by then was not interested in this capability. In 1925, the Powers company's system with a reduced alphabet was the only other punched-card system with letters available in the United States. However its success was very limited, and Remington Rand chose not to implement it on the 90-column punched card, when it introduced this card as its standard between 1929 and 1935. This history indicated that the Powers company and Remington Rand perceived a very weak demand for letter printing until the mid-1930s.

The second attempt to develop a new punched-card application field was when nonstandard machines and cards were developed for bookkeeping automation for the expanding department stores in 1932 and 1933. This system was exclusively numeric and showed how far Remington Rand went to build nonstandard punched cards and equipment to gain a new market segment, in which it would be a prime mover.

The American department stores' sales had grown by 39 percent between 1919 and 1929, to $4.4 billion from 4,221 department stores, and constituted 9 percent of total retail sales in the country.[79] Further, credit sale made up a growing share of the department stores' sales. Punched cards were well suited to administer credit sales, as they facilitated distributing information on every sale to the customers' accounts and processing frequent statements of all customer accounts for the purpose of monitoring them. Punched cards offered mechanical sorting and printing of lists, and since this bookkeeping operation only required processing of numbers, punched cards were eminently suitable.

In 1932 and 1933, Remington Rand's punched-card division and a company specializing in electric automation designed a central record system for the Kaufmann's Department Store in Pittsburgh, Pennsylvania. It introduced up to two hundred fifty counter type sales transmitters, which were wired to transmit punched information to a common credit and authorization office with fifteen teleprinters, and to a central accounts receivable office equipped with twenty on-line recording and card punching machines.

Various types of nonstandard equipment were applied to handle the nonstandard punch tokens, which were small cardboard cards holding price and other sales information as perforations. Also, a recording punch was developed for the accounts receivable section to print and accumulate the same information on paper as was punched.[80]

It was planned to use punched cards in issuing customer statements, as opposed to address plates that were usually used for this purpose in the Remington Rand applications at that time. The addresses were to be produced by use of the reduced Remington Rand alphabet with twenty-three letters and three cards for every address, each corresponding to one of the lines: name, street number and name, and city and state. This application was to be based on the old 45-column card, as the new 90-column card could not yet hold letters. This project was never implemented, and Remington Rand did not pursue a comparable integrated system until the end of the Second World War. Mistakes due to technical imperfections were highly probable, but Remington Rand's subsequent nonpursuance of this promising application indicates a lack of demand rather than technical difficulties.

The main efforts to improve the Powers company's and Remington Rand's punched-card systems between 1920 and 1935 were responses to two significant improvements by the Tabulating Machine Company and IBM. One was that the Tabulating Machine Company's initial numeric printing tabulator from 1921 was also the first to offer automatic group control, which was a significant competitive advantage compared with the tabulator from the Powers company. Automatic group control rendered superfluous the cumbersome and time-consuming insertion and removal of total cards. However, the Powers company only managed to design and implement the ability to perform this task on its machines in 1927. The new mechanism allowed the tabulator to sense the change of designation on the cards and, without requiring action by the operator, to record the total at the end of each card group (for example, a customer number) and to begin processing the next group of cards without a pause.

This capability was attained through substantial and protracted labor. Eight years earlier, James Powers had filed a patent describing this mechanism. However, neither Powers nor Lasker was able to implement this mechanism, which was only achieved after they had hired Robert Edward Paris.[81]

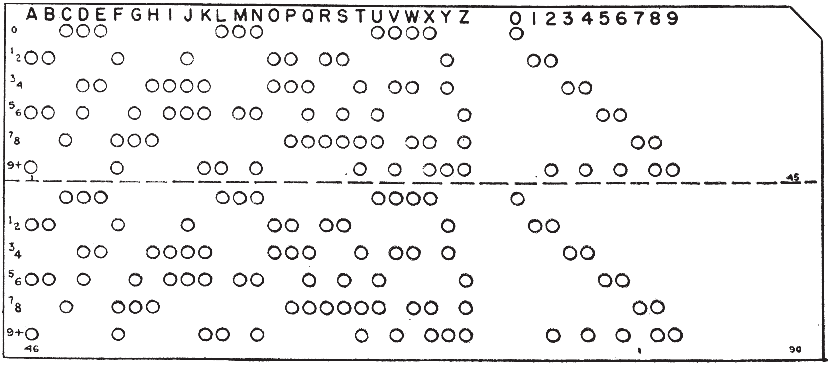
The other significant improvement was that IBM changed the focus of punched-card machine development in 1928 from improvements of the numeric capability to increased card capacity through the introduction of a new card with eighty columns and matching machines. The new card was the same size as the old 45-column card, and IBM accomplished this increase of 78 percent by introducing rectangular perforations to avoid weakening the cards when inserting more columns. IBM patented the new card to prevent others from doing the same, which made it proprietary. This card became known as the IBM card.

Remington Rand accepted the challenge of creating a card with increased capacity. The rectangular perforations were no advantage to the mechanical Remington Rand machines. Therefore, their researchers decided to squeeze more information onto the same card either by applying smaller holes and more columns—or by introducing a more compact proprietary punch code. In contrast to the British Powers company, Remington Rand chose a more compact punch code and introduced their proprietary 90-column card in 1929, a double-deck card also based on the existing standard 45-column card. It kept the old card's layout of perforations, but redefined their meaning, by splitting the card into two decks of every six rows. On each deck, row number 0 was used for control information, like the negative sign in a debit figure, which left five rows to represent the ten digits.[82] This design could be extended into an alphanumeric representation, as six rows can hold up to sixty-three different characters, which could accommodate both a full alphabet and the ten digits with control information. However, this possibility was not pursued for the next nine years.

The numeric double-deck card became the basis for Model 2, Remington Rand's new line of punched-card machines, introduced in 1929.[83] However, this equipment only became available in 1931, as all the machines had to be redesigned to accommodate the new card and production established. Though the new Remington Rand card had capacity to become alphanumeric, the first new machines only served the double-deck card with numeric representation. The American Powers system of reduced alphabet representation from 1924 had not been a sufficient success to be included into Remington Rand's new line of machines. However, it was possible to use a part of a punched card for letters to be printed, by using the old standard 45-column positions, and the rest of the card for the numeric double-deck standard. But such an arrangement reduced the card's capacity and required both machines for 90-column cards and machines for 45-column cards.

The difficulties of visual reading of the numeric double-deck standard, distinguished it from the old numeric 45-column standard. To alleviate this problem, Remington Rand produced an "interpreter" that printed the meaning of the punched holes on the card.

During the period from 1932 to 1935, the Model 2 line of machines was extended by the introduction of a new verification scheme, a summary punch, and a multiplier. The new verification system introduced in 1932 was composed of an attachment for the key punch and the "automatic verifier." The verifier attachment to the key punch elongated or offset the original perforation when the card was punched a second time by a separate operator. The automatic verifier searched these twice-punched cards.



The Remington Rand 90-column numeric punched card introduced in 1929, a double-deck card derived from the existing standard 45-column card. The perforation was in Remington Rand's alphanumeric system from 1939. (H. L. Tholstrup, "Perforated Storage Media," *Electrical Manufacturing* December 1958, 58. Measurement details deleted.)

When a circular perforation was detected on a card, it indicated an error, and a signal card was inserted in the deck of cards on this card.[84]

Remington Rand marketed a punched-card multiplier in 1935 that multiplied two figures punched on a card and punched the outcome. This design was based on a patent of the United Accounting Machine Company, which had been acquired by Remington Rand in 1934.[85] This multiplier completed Remington Rand's development of punched-card machines for numeric bookkeeping before 1945.

Only in 1938 did Remington Rand introduce a new line of alphanumeric punched card machines, which broke its focus after 1924 on the numeric capabilities. The new line of machines was called Model 3 and was based on extending the numeric representation on their double-deck card to become alphanumeric.

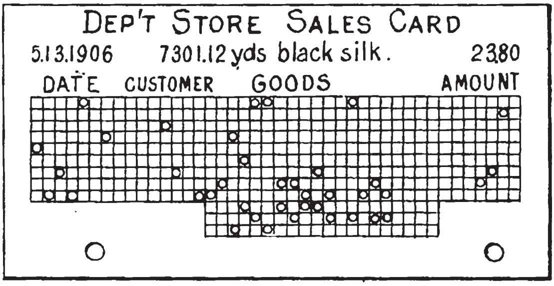
Demand from public utilities and public administrations provided the major impetus for Remington Rand to develop this system. Remington Rand had suffered the painful experience in 1936 of having their punched-card system turned down by the Social Security administration because of its lack of alphanumeric capability. The Social Security administration was looking for a system to handle the compulsory old age savings by many millions of Americans, which would have provided extensive business for the company awarded the contract, which IBM won.

Addressing items was the core functionality of alphanumeric systems. Addressing was made easier in 1943 by a new tabulator that could print the three lines of an address from the same card. Before, only one line could be printed from a single card, meaning three cards for each address, which was extremely cumbersome to handle.[86]

John Royden Pierce's Punched-Card Systems

John Royden Peirce was born in Maine in 1878. His father headed a construction company and directed several large construction projects in New York City. With this background it is not surprising that John Royden Peirce graduated an engineer—though a mechanical engineer—from the Stevens Institute of Technology in Hoboken, New Jersey, in 1900 at the age of twenty-two. [87] The Stevens Institute of Technology had opened in 1870, and within a few years it was widely recognized as a premier academic institution for training mechanical engineers. Like Columbia College (later Columbia University), the teaching at Stevens emphasized mathematics and sciences rather than machine shop experience.[88] However, Peirce chose to base his constructions on mechanical technology, in contrast to Hollerith who was trained at Columbia College.

After graduation, John R. Peirce worked for four years as an estimating and costing clerk in New York with two construction companies. During this period, his inventive skills found outlet within construction work and office jobs. First, he invented several machines to improve basic construction techniques, the first in 1904, which resulted in his being awarded several patents.[89] Second, Peirce became involved in office mechanization. He conceptualized a mechanized punched-card system for bookkeeping in 1906, based on mechanical technology. Each of his punched cards held the items of information required in a bookkeeping entry, and he used the cards to print the entries on loose-leaf ledgers. To enhance the quality of these printed lists, he introduced letters into his punched-card system. His punched card had forty-three columns and was tailored to the application.[90] Peirce's tailoring of the card to an application indicated that he planned to design different punched cards for various applications, which would have required different machine models. He planned to build a new punch and an adding tabulator, since his cards were different from



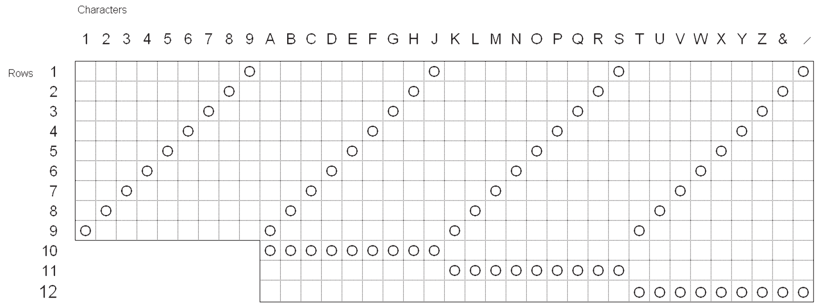
A John Royden Peirce punched card for department store bookkeeping, 1907. (J. R. Peirce, Perforating machine, [U.S.] Patent 998,631, filed and issued 1911. Reference numbers deleted.)

Hollerith's card, which prevented his using machines from the Tabulating Machine Company.

During the following year, Peirce designed a tabulator and a key punch, which simultaneously typed a keyed-in character on the card and punched it.[91] The new punch applied a modified standard typewriter key board with thirty-seven keys. He now had a punch code using twelve punching positions that represented each character by punching one or more holes in one column. This system was most ingenious as it introduced letters on punched cards, but Peirce applied separate representations for numbers and letters that required printing digits in some positions and letters in others. He had nine rows or punching positions for digits (zero was not represented) and twelve rows for letters.

Peirce developed his early designs for several applications over the next six years. He designed applications to produce restaurant invoices, to record consumption in electricity and gas utilities, for bank accounting, for stock bookkeeping, and for processing sales in a department store.[92] Wherever possible, punching the card was carried out within an existing procedure to save labor and reduce errors, in contrast to a subsequent isolated punch operation. For example, the card used for reading an electric or gas meter was entered into the meter that mechanically punched the reading.

For all the applications considered by Peirce, the card was the original form that recorded the transaction. This shows that Peirce saw punched cards in a different role than his competitors did. He was the first to realize that a punched card could contain the original entry. In contrast, Hollerith, the Census Bureau, and Powers had the card as a copy of the original form



Peirce's punch code, 1907. Zero was not represented, and the letter *I* was represented as a numeral 1. Except for zero, the numeric code followed Hollerith's contemporary code. (Drawing based on J. R. Peirce, [U.S.] Patent 1,236,475, filed and issued 1917)

or invoice. Anyway, there is no evidence that any application was developed in cooperation with a real company or institution. The applications just served as a basis to implement Peirce's original concept.[93]

Peirce shaped his punched-card systems as he worked to implement his ideas. The letter representation disappeared and the punched card became smaller, as reading letters using two holes in each column was difficult to implement. Furthermore letters did not prove crucial for the chosen applications and offered no scope beyond the contemporary numeric key bookkeeping machines. The outcome was several small punched cards and a compact character representation, only comprising the digits.[94] Further, Peirce's small cards enabled him to design compact machines. The choice of basing his design on several applications resulted in various punched-card sizes and plans for specially designed machines, like a cash register perforating the amounts entered and an electric meter equipped with a small perforating attachment to facilitate punched-card-based reading of the meter.

The next problem for Peirce was implementing his designs, which he only seems to have attempted after several years of designing. A prototype tabulator was completed in 1912 that displayed his technical approach. Like Powers, Peirce used exclusively mechanical technology for card reading, data transmission, and adding and printing, and he also applied an electric motor to operate the machine. The adding units printed only totals and were based on Burroughs adding machine wheels. Their patents had expired and a former Burroughs engineer supervised the machine building, which can explain why Peirce succeeded in using this approach in contrast to the people in the Census Bureau machine shop.

The electromotor operated the machine feed of punched cards, and the prototype tabulator had a processing speed of about half that of the contemporary tabulators from the Tabulating Machine Company, but Peirce envisioned a higher speed for the planned serial produced machines. Peirce's tabulator used a manual feed of paper for printing, as did several key accounting machines, which circumvented machine feed problems and simplified exact printing on forms. Mechanized location of the print on the paper required precise horizontal and vertical control of paper movement, which was crucial when using preprinted forms. Peirce planned to sell the tabulator at a price from $1,000 to $1,500, depending on the number of adding positions.[95] This was cheaper than renting a tabulator from the Tabulating Machine Company for two years. The lower price and modest ambitions of his individual application indicates a business strategy of selling to medium-size firms.

John Royden Peirce moved to incorporate a production company in 1912 based on the prototype tabulator and his ideas for applications. Until then, he had worked with his inventions and development as an individual; now, he needed to raise $400,000 to establish a company to produce and sell his machines. He only found $100,000, and, consequently, had to find additional funding for development and to establish production. In the prospectus used for raising money for the incorporation in 1912, his machines were recommended by nineteen statisticians and accountants, of which fifteen were from big companies or important federal organizations.[96] This could indicate a change in Peirce's business strategy toward big business and major federal organizations, who could be partners in his development and production of punched-card machines, in contrast to the small and medium-size firms apparently targeted in his development strategy thus far.

One of the recommendations in his prospectus in 1912 came from the comptroller of the Mutual Benefit Life Insurance Company in New York City, a moderately large company.[97] Peirce supplied this company with punches and sorters to process their insurance statistics in 1914. This, together with the several tabulator versions on the drawing board at that time, indicated that Peirce's tabulator design was not yet finalized.[98]

The contract with the Mutual Benefit Insurance Company supports the impression of a change in business strategy to pursue big customers. This is further substantiated by a contract he had been awarded, in 1913, to develop punched-card machines for the Metropolitan Life Insurance Company, in New York City, which was the largest insurance firm in both number of policies and value of insurances in the United States. This contract tied Peirce to a large company that could finance his machine development. However, he had little choice, as his original business strategy of selling to small and medium-size companies required that he was able to finance his development work and the establishment of production—which he had proven unable to do. By then, his development work had lasted for six years, and he had not sold a single machine.

The Metropolitan Life Insurance Company contract in 1913 entailed a system for compiling and printing five standard numeric reports used to control the transactions in the big company, like lists of policy numbers, possible disabilities, premiums to be paid and whether the policies were paid annually, semiannually, or quarterly. The tabulator was to be a substantial improvement on his prototype tabulator from 1912, as it would both list information from cards and print subtotals and grand totals, without intervention from the operator.[99] Formerly such lists had been compiled by fifty-four clerks.[100] Now Peirce had an order, but he experienced problems in providing the machines promised within the contractual time limit in 1914. The machines were only completed in 1916, with the tabulator costing double the originally agreed price; but in addition to the original stipulations, the Metropolitan Life Insurance Company received automatic group control, which eased processing of punched cards. The delay and additional machine development created financial problems for Peirce, and Metropolitan had to pay every invoice he received from the builder of his machines, the DeCamp and Sloan Manufacturing Company in Newark, New Jersey. When the machines were completed in 1916, Peirce claimed they had cost his company $21,000 in excess of Metropolitan's payments.[101]

However, the Metropolitan Life Insurance Company did not consider Peirce's problems more serious as it, in 1916, contracted for additional Peirce machines that were not yet developed. Already during the negotiations in 1913, Peirce had proposed a system based on a "master card" on every policy that held punched information of the policyholder's name and address along with the relevant numerical information indicating amount insured, amount to be paid, date of payment, and other relevant information. The punched information was also to be printed on the card, which would be used to generate invoices, receipts, and other transaction documents.[102]

This was an ingenious concept, but its implementation would be protracted. The master card revived Peirce's original vision of punched-card systems with letters, but no one had any experience using letter codes in punched cards in 1913. A suitable code was needed, together with a punched card holding sufficient information. After much consideration, Peirce settled for a code using four punching positions, or rows, for numbers and six rows for letters. His new master card held an ambitious total of one hundred fifty characters, which should be compared with the forty-five digits on the cards from the Tabulating Machine Company.[103] In addition, Peirce's new machines remained to be built. Considering the technical ambitions among the other punched-card producers in the 1930s this was extremely ambitious, and, once more, Peirce encountered problems implementing his concepts in the machine shop. Regardless, by 1916 he submitted a detailed proposal to Metropolitan to build customized punched-card machinery to prepare and address premium notices, receipts, and notices that would be mailed to the policyholders. Further, Peirce proposed preparing various internal records, including a register of policies issued and an agent's list of notices. The planned alphanumeric punch was a modernized version of his punch design from 1907 and resembled a typewriter.

The proposed system also included a listing machine and a machine duplicating information from one card to a new card, which relieved the wear and tear on the master cards. Peirce made additional elaborations of this plan, and he concluded a contract with Metropolitan Life in 1918 to build customized punched-card machines for administering their policies. By 1922, this system included a prototype tabulator that implemented the first alphanumeric representation in punched cards, needed for addressing letters to policyholders.[104]

To improve his revenues, Peirce got additional orders in 1918 to supply punched-card machines to the Prudential Insurance Company in Newark, New Jersey, and the Bureau of War Risk Insurance. The Prudential Insurance Company's contract had a limited scope of application, compared with the Metropolitan Life's contract, and it only comprised two tabulators and two sorters.[105] In contrast, the Bureau of War Risk

Insurance entered a contract for the development of systems for both actuary and policy administration. This contract resembled the contract with Metropolitan Life.[106] The Bureau of War Risk Insurance in the Department of the Treasury insured members of the armed forces after 1917.[107] In addition to these contracts, Peirce tried to capitalize his foreign patents to raise money.[108]

However, in 1922 he had not yet fulfilled any of his three insurance contracts from 1918, and he sold his patent rights to the Tabulating Machine Company and became a development engineer in that company.[109] The three insurance companies had received some of the contracted machines, but the three contracts ceased to exist one by one over the next few years, without any known regress from the insurance companies. The Metropolitan Life contract was the last to be terminated—in 1926.[110]

Since 1918 Metropolitan Life had paid $1.1 million to Peirce for developing and building punched-card machines. However, by the termination of the contract from 1918, the total cost of the machines in the contract was estimated to be about $3 million, thus there remained about 63 percent of the machine development and production.[111] Still Peirce had problems completing his machines. The $1.1 million paid also disclosed the importance ascribed by Metropolitan Life to a system to mechanize their policy administration. Eight years had elapsed since their first contract with Peirce and a usable Peirce system was still estimated to be several years away, substantiated by the fact that Peirce had not yet settled on a standard for a letter representation in punched cards by 1922.[112] But Metropolitan Life still had no other option for punched-card based policy invoicing and payment control. The reduced alphabet system developed by the British Powers company and marketed by the American Powers company in 1924, was not a viable alternative. Further, IBM did not yet offer letter representation in punched cards.

A Challenger's Possibility

Alfred D. Chandler analyzed the position of a company challenging another company's first mover position in terms of certain internal features of the challenger including its organizational capabilities, which he defined as the company's total physical facilities and human skills.[113] The three challengers to the Tabulating Machine Company's first mover position in the United States were the machine building in the Bureau of the Census, the Powers Accounting Machine Company, and John Royden Pierce's work before he was hired by the first mover. However, to understand the possibilities of these challengers, the analysis needs to be extended to encompass the patent system used by the first mover to enforce his position and the technology. The technology provided possibilities to challenge the prime mover, but patents were a powerful tool to restrict their options.

The prime mover, the Tabulating Machine Company (later IBM), originated in the inventions and innovations of Herman Hollerith in the 1880s. In 1889, Hollerith was granted patent protection on his original equipment, lasting for seventeen years.[114] Hollerith's improvements in the 1890s were the basis for additional patents granted in 1901.[115] This renewed his patent protection, which enhanced his prime mover position. The second renewal was his patent on "automatic group control," which he filed in 1914, while James Powers' less comprehensive patent application was filed the following year and granted in 1917. These two applications ran into a lengthy patent conflict in the United States both with each other and several other patent applications. Therefore Hollerith's important patent was only granted in November 1931, making it valid from 1914 to 1948.[116] Consequently, the prime mover succeeded in achieving substantial patent protection for about sixty years based on five patents. The stories of the challengers in the United States document the importance of these patents in shaping the punched-card industry.

The people in the Census Bureau machine shop envisioned their development of punched-card equipment within Herman Hollerith's closure of punched cards for general statistics, from 1907. They worked to establish what today would be called a clone production of equipment simply to reduce the bureau's costs. In addition, the existence of the machine shop enhanced the bureau's position in the federal government. Their objective was a punched-card system with a number-printing tabulator, which represented a significant improvement on the machines then available for general statistics. This objective was accomplished, but they failed to build other needed machines. The project at the Census Bureau was foiled by a combination of internal and external factors: the inability of the engineers in the Census Bureau machine shop to design the needed machines, the containment of the project within the Census Bureau with its yearly struggle for appropriations, and the restrictions on the machine-building possibilities imposed by the patents granted to the prime mover.

The longest lasting importance of the punched-card endeavor in the Census Bureau was through its offspring, the rival company founded by James Powers. His company was the only full punched-card competitor to emerge in the United States, which brought about conflict with the Tabulating Machine Company's patents. The outcome was a costly license that had a lasting negative impact on the business potential of the Powers company. From a technological perspective, the provisions of the license excluded it from applying electromechanical technology for two decades.

James Powers' punched-card equipment originated in Hollerith's closure of punched cards for general statistics. However, he believed that it was possible to extend the technology within this closure to encompass bookkeeping tasks through building numeric printing tabulators. The requirements for extensive bookkeeping applications proved more demanding and the Powers company only achieved a closure on punched cards for bookkeeping in 1943. This raises the question of the delineation of technological capabilities within a closure, which will be addressed at the end of the next chapter. A most amazing part of the Powers company's punched-card history was the robustness of the Tabulating Machine Company's first mover position, demonstrated by its ability to its position in spite of its abstention from the bookkeeping market until 1921.

In contrast to the two other challengers, John Royden Peirce was a visionary and from the outset worked for punched-card-based bookkeeping and alphanumeric systems to gain access to business of much greater volume. By doing this, he opened a renegotiation of the very nature and purpose of punched cards and which abilities punched-card technology should have. However, Peirce ran into problems caused by his inability to implement his ideas and designs and to produce reliable machines, the well-known problem of an inventor who becomes an entrepreneur, a transition accomplished only by Herman Hollerith in the United States punched-card industry. Peirce's brilliant conceptualization led him to devise a clever version of the "automatic group control" patent, which IBM acquired in 1922 and thus continued to control the industry through patents. The acquisition of the patent also involved hiring John Royden Peirce for the Tabulating Machine Company's machine development.