

Towards the Automated Map Factory: Early Automation at the U.S. Geological Survey

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ABSTRACT: This paper is concerned with changes in map work at the U.S. Geological Survey during the period from 1950 to 1974. At the start of this period, mapmaking at USGS was dominated by manual techniques organized to conform to twentieth-century advances in photogrammetry, drafting techniques, materials, and industrial organization. During the 1950s and 1960s, technologies that had been developed in other sectors of American science and industry were inserted into mapping processes with hopes of huge productivity gains and added efficiencies. The development paths of two in-house devices, Autoplot and Autoline, illustrate the ways in which cartographic automation became an agency policy as well as a powerful ideology.

KEYWORDS: Cartography, labor process, automation, United States Geological Survey, oral history

Introduction

This study of cartographic change focuses on the labor process in cartography, specifically the ways in which the automation of cartographic work became a goal and policy at the United States Geological Survey (USGS) after World War II. In the context of this paper, "labor process" refers to the ways that work is organized and tasks are carried out in specific sectors of wage labor economies. Insofar as cartography in the twentieth century was primarily organized as a wage labor activity with a complexly articulated wage system, studies of the labor process are a necessary and critical component of a complete understanding of change in cartography. Specialization of tasks and workers within the mapping workforce became commonplace with the incorporation of new technologies, such as aerial photography and photogrammetry, which allowed a more detailed and rationalized division of workers according to education, training, pay scales, and professional status. A hallmark of industrial organization during the twentieth century, this differentiation is commonly associated with the management theories of F.W. Taylor, known broadly as "scientific management" (Taylor 1911, pp. 25-26).

Cartography offers few examples of large-scale mass production with high levels of labor specialization. During the late nineteenth and early twentieth centuries, the USGS evolved into America's principal civilian mapping agency, responsible for the systematic large-scale mapping of the nation's land, water, and mineral resources (Edney 1986). During the twentieth century, mapmakers in the USGS (not unlike their counterparts in Europe) experienced numerous technological changes that drastically altered the ways in which work was performed and organized. As will be seen, some of these changes came from within the mapping community while others came from outside. In addition, the scientific-technical nature of the work required highly trained professional workforce composed of engineers, technicians, surveyors, and cartographers, who, in the postwar period, found themselves in highly centralized and industrial workplaces with a rigid, hierarchical system of government employment categories and the associated wage schedules. At the USGS, this system gave a distinct advantage to individuals who either entered the agency with engineering credentials or were trained within the agency as engineers.

Maps and cartographic information produced by the USGS are peculiar commodities in the United States economy, insofar as they reflect activity in both the public and private sectors (McHaffie 1993). This mixture raises fundamental questions about the nature of the product itself, as well as the driving mechanisms behind technological change and the ways in which managers, supervisors, and

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directors achieve cooperation and acquiescence within the workforce. In the United States, the cartographic profession is characterized by a strong sense of corporatism or state capitalism, a shared ethic that accepts the existence of a strong public sector in mapping and the worth and benefits of large, publicly financed projects, such as the topographic mapping program.

The public-domain nature of the product has produced a phenomenon unusual in American public life: a long-term commitment to social goods and general acceptance of broader social and economic benefits than were immediately evident in the actual production process. Whether this ethic, which permeated professional life in American cartography in the twentieth century, fostered a measure of cooperation and acquiescence in the mapping workforce will remain an open question. Clearly the drive toward rationalization and standardization of production processes that occurred in the USGS throughout the century must be explained as a drive toward increased economy and efficiency in a federal agency faced with successive waves of fiscal restraint and expansion. And, in the USGS, efficiency was measured as square miles mapped per worker-year, at least for new mapping (Northcutt 1967). This productivity metric is fundamentally different from private-sector measures, which are based on profitability and market considerations.

The different worlds of public- and private-sector cartography are clearly evident in standardized pricing systems for public-domain cartographic products that seemingly ignore simple cost-accounting and supply-demand rules that govern private-sector planning and production. If universal large-scale mapping series were left to the private sector, maps of most rural areas would either not exist or be priced disproportionately high to recover costs.

Studies of the historical development of labor processes (see Barley and Orr 1997; Braverman 1974; Peck 1996; MacKenzie 1996; Shaiken 1984) must distinguish between substitution automation, in which existing tasks and workers are replaced by technology, and infrastructural automation, in which existing lines of work and existing tasks become more technical. An example of substitution automation in cartography would be the development of modern, numerically controlled plotting devices capable of producing high-quality output on a variety of media. In some instances these machines have replaced workers who were involved in drafting finished-quality map separates and other components of finished maps.

Examples of infrastructural automation can be found throughout the mapping process, particularly in the gradual mechanization of lettering and annotation, or in the shift from tracing to hand digitizing. These processes are seldom explained solely by economic efficiency; close examination reveals that shifts from manual to automated techniques can be highly complex and involve multiple causes (Kuhn 1970; Monmonier 1985; Grint 1991).

In this paper, the USGS will serve as a case study to shed light on how automation transformed the work of cartography in a particular place and institutional setting during the last half of the twentieth century. This transformation is important to understand for a number of reasons. With over 2500 workers at its peak in the 1960s, the USGS Topographic Division (later renamed the National Mapping Division), illustrates a well articulated labor process. Of central importance to the mapping community at large during this period, the USGS served as a major employer and place of technological innovation as well as the principal source for public-domain maps and data. With important ties to other federal and state agencies and private-sector firms, the agency also served as a catalyst and model for scientific standardization, technological progress, and professionalization of the mapping community.

In this essay I will supplement primary sources with personal interviews of individuals intimately involved with the USGS during the 1940s, 1950s, and 1960s. These oral histories in themselves serve as overwhelming testimony to the scope and scale of change (technological, organizational, scientific) that took place at the principal American mapping agency in the last half of the twentieth century.

Setting the Stage: 1900 to 1950

Two sets of factors provided much of the impetus for change in the organization of work at the USGS during the twentieth century: salient trends in American industry and the enormous challenge of producing ever more detailed series of base maps. The 30-minute series at 1:125,000, initiated in the early years of the USGS but never completed, was replaced early in the twentieth century by the 15-minute series (also not completed) at 1:63,360 and 1:62,500. These series were replaced after 1945 by the 7.5-minute series at 1:24,000, which was completed in the late 1980s.

Each of these map series was compiled using different technologies and work organizations.

The 30- and 15-minute map series were mainly compiled using field-based techniques pioneered in the nineteenth century. This period, roughly between 1880 and 1930, was characterized by the jack-of-all-trades topographer (rarely female), who typically spent part of the year in the field as a plane table mapper, crew chief, and surveyor-engineer, and the rest of the year in the office as a draftsman and map editor. Topographers recruited crews of temporary workers in the field as assistants; indeed, many twentieth-century mappers got their starts as assistant topographers. Many of these assistant topographers were eventually promoted to the status of full topographer through an apprentice system.

Photogrammetric techniques, introduced into the mapping process during the 1920s and 1930s, led to a gradual but marked change in the organization of the work. Pioneered during the 1930s in Chattanooga, Tennessee, as a cooperative project between the USGS and the Tennessee Valley Authority (TVA), photogrammetric mapping became the preferred method of map compilation at USGS. Morris Thompson, one of the early photogrammetrists recruited from the New Deal era Resettlement Administration, described the inception of the project:

This was the USGS-TVA Multiplex Mapping office (in Chattanooga). The purpose of this was to map the entire Tennessee River Basin, something like 250,000 square miles, and it was the biggest photogrammetric mapping project ever undertaken anywhere in the world up to that time. . . . We were trained to be photogrammetrists. [For] two courses [taught to the new workers] they brought professors in from the University of Tennessee to teach us some optical principles and photogrammetric principles and meanwhile we mostly learned by doing it. [After] a short period of practice then we were put to work on maps and got right into mapping right off the bat (Thompson 2001).

Thompson was well prepared for work in the technically evolving field of photogrammetry, having completed his BS and CE in engineering at Princeton during the mid 1930s. His colleagues differed in ability and skill:

The existing personnel at USGS were field people who had done all the mapping in the field. They didn't know much about what you could do with photographs, and as a matter of fact, they insisted that you could not make a good map—an accurate map—from photographs because of the tilt of the camera and

the relief of the ground. But we were all college graduates . . . and this is something that the old hands didn't believe, but it turned out that we did it very successfully (Thompson 2001).

Innovation and modification of existing technology was a hallmark of the USGS-TVA cooperative project. Thompson recalled a particularly innovative colleague:

Our group got in with then TVA employee, Russell K. Bean. He was the director of our office, the joint office, TVA-USGS. . . . All of our equipment then was Zeiss multiplex equipment, and it had its shortcomings. So under his direction, we redesigned the multiplex system including projectors and even the printers. It was all patented by the government under Russell Bean's name, but the patent was assigned to the government, and Bausch & Lomb, at that time, was the [successful] bidder on manufacturing the equipment. So when World War II came around and we actually got into the war, we had equipment that was manufactured in the United States by Bausch & Lomb... That was really due to the energy of Russell Bean. He was a genius in photogrammetry [but] did not have the mathematical background that some of us young engineers had and he depended on us to work out the mathematical problems (Thompson 2001).

Incorporation of aerial photography and photogrammetry into the mapping process in the 1930s and 1940s necessitated a reorganization of the work force. The topographic mapping operation was organized into three large groups: Field Surveys, Photogrammetry, and Cartography. Field workers, who had previously been largely responsible for the compilation of map manuscripts in the field, now served a secondary role that included the establishment of control for photogrammetric operations and field checking of manuscripts that had been compiled photogrammetrically. Field surveyors included professional engineers and land surveyors, as well as various non-professional technicians and engineering aides. Photogrammetry became the central operation because the needs of the photogrammetrists determined the assignments of field workers, and the photogrammetric operation produced manuscript products that were sent to cartography for finishing. Photogrammetry was dominated by professional engineers; in fact, many workers who entered the USGS as technicians achieved engineer status through either in-house training programs or night school. Professional engineers

were more likely to advance within the agency and could command higher salaries if they left. By contrast, cartography involved several specializations including negative engraving and drafting (initially in ink but replaced by scribing in the early 1950s), offset photographers, lettering and annotation, compilation, and editing. Over the next several decades, workers in each of these functional components of the mapping process were affected by both substitution and infrastructural automation.

The 1950s: The Modern Map Factory

In the two decades following World War II, American society underwent fundamental and startling changes, in part as a consequence of wartime investment in industrial technology and the triumph of American technology and industry over their Axis counterparts. The close relationship among industry, science, and the military, which was essential to winning the war, was cemented in the late 1940s and aligned into a semi-permanent structure through the creation of such quasi-civilian institutions as the National Science Foundation and the Office for Naval Research, a pioneer among the services in funding civilian research. The impetus for this alliance of public and private sectors was the postwar deterioration of relations with the Soviet Union, and later China, and the decision to remain on a permanent wartime footing as a response to perceived communist designs abroad.

At the same time, industrial managers were faced with a domestic labor force that was more organized and in many ways more militant than at any time in history, with more work stoppages due to strikes between 1940 and 1945 than during any similar period in the nation's history (Noble 1990). Many governmental and industrial leaders viewed this unrest as a reflection of the influence on the labor movement of communist sympathizers and other leftists. In the years immediately following the war the nation's power elite sensed two principal threats with a common source: communist aggression abroad and communist-inspired labor unrest at home.

Defense-sponsored applied research during the war years had allowed major advances to be made all across industry but particularly in the areas of electronics, and precision electrical controls. As economic historian David Noble writes:

By the end of the war there had emerged a theory of servomechanisms that was uni-

versally applicable and easy to manipulate. Moreover, there was now a mature technology of automatic control, which included precision servomotors, for the careful control of motion; pulse generators, to convey precisely electrical information; transducers, for converting information about distance, heat, speed, and the like into electrical signals; and a whole range of actuating, control, and sensing devices. Finally, the wartime research projects had created a cadre of scientists and engineers knowledgeable in the new theory of servomechanisms, experienced in the practical application of such systems, and eager to spread the word and put their new expertise to use (Noble 1990, pp. 48-49).

As a direct result of defense sponsorship in the war years, early digital computers were created, mainly for ballistic calculations. These include the Mark I, the Bell Relay Computer, and Altanasoff's early computer as well as the ENIAC. At about the same time, similar machines were developed in Britain and Germany. Among the scientists and engineers responsible for creating these new devices, new ways of thinking also became orthodox during this period. Much has been written about the birth of operations research (OR) and its later incarnation, systems analysis. By the late 1950s the technical developments of the late 1940s had combined with OR and systems analysis to create a powerful ideological justification for industrial automation.

Although the staff of the USGS Topographic Division in the 1950s and 1960s were peripheral to key technological and scientific currents in American industry, they were nonetheless influenced by these developments. As mentioned above, mapmaking at the USGS had been reorganized after 1930 to meet the needs of photogrammetric compilation. Changes during the 1950s, such as the large-scale introduction of scribing, made map finishing a more standardized operation that was highly dependent on materials developed during the war by the chemical industry. Scribing generally involved hand etching of emulsion-coated plastic sheets, using either manuscript copy on a light table as a tracing guide or water-coated images photo-fixed on the emulsion. This process produced negatives that could be used to directly expose offset litho plates. The work was generally considered to be tedious and capable of being mastered quickly with little training. In 1953 the *Topographic Division Bulletin* noted that "new employees can produce acceptable work much earlier, and . . . their line work is generally sharper

and more consistent than by drafting process . . . A substantial increase in production per man-year is also indicated, and we expect that this will be in the neighborhood of 25 or 30%" (Fuechsel 1953, p. 50). These changes, which tied the mapping program to external industrial concerns, demonstrate the long-standing concern for increased productivity and standardization of procedures, products, and symbols.

Photogrammetry was the first segment of the USGS mapping operation to be substantially impacted by numerical control and computing devices. Beginning in the mid 1950s, photogrammetrists at USGS began using computers to solve many of the problems that had previously been performed manually. In 1956, Irving Shulman wrote an important article for the *Topographic Division Bulletin* titled "Maps and the Electronic Brain." In the foreword, Morris Thompson made no mistake in pointing out the significance of Shulman's work:

In these days of Automation, the magic word is "ELECTRONIC". There is perhaps a tendency for some people to become unduly hypnotized whenever the word is mentioned. On the other hand, no responsible scientific body can afford to ignore the tremendous advances that have been made in the development of electronic devices capable of performing tasks of great complexity at breath-taking speed (Thompson, foreword to Shulman 1956, p. 1).

For photogrammetrists, the computationally complex tasks were space resection (an analytical solution that determines the position and orientation of the aerial camera based on measurements taken from known ground locations on an aerial photograph) and control extension (the establishment of new control points using photogrammetric methods). Analytical procedures had previously been worked out for both problems but, without high-speed computers, the calculations were considered too laborious—given a relatively dense control network established through field survey methods, mapmakers could obtain acceptable solutions using analog stereoplotters. Shulman demonstrated that computers provided an economical analytical solution:

In considering an analytical procedure for the extension of control, a number of questions come to mind: A. Can the method easily be converted into a high speed digital computer-process? B. What will be the resulting economy in time? C. What will be the resulting economy in dollars and cents? D. What degree of accuracy can be obtained with the procedure under

varying conditions? . . . We have some indication of the possible economy in time from the fact that the solution to a space resection and orientation problem which normally takes a few hours of desk calculator time has been accomplished in 4 minutes on a[n] IBM electronic Card Programmed Calculator. It has been estimated that the ratio of speed, (C.P.C. to Univac) is 1:200. On a comparable basis, the solution to the space resection-orientation problem requires 4/200 minutes or *1.2 seconds!* It is quite evident that every effort must be made to take advantage of this breath-taking, fantastic speed, to establish an electronic-computer triangulation procedure (Shulman 1956, p. 7).

The USGS Office of Research and Design conducted work on computer-based solutions to photogrammetric problems in the late 1950s, first with a Burroughs 605 Datatron and then a Burroughs 220 computer. The Burroughs machine had 25,000 tubes and was very large. As Morris McKenzie, a programmer in the Topographic Division office of Research and Technical Standards (RTS), told me, "Maintenance involved coming in once a week and stepping up the voltage and trying to blow as many of those 25,000 fuses as they could" (McKenzie, personal communication 2001). Primitive by today's standards—core memory consisted of approximately 12,000 bytes—the system was used to solve problems in photogrammetry as well as problems from the field surveys office in the Office of Research and Technical Standards. By the early 1960s, the Burroughs machine would be used throughout the Geological Survey.

Another technological substitution at this time was the AUSCOR (Automatic Scanning Correlator), which was developed in Canada and implemented as the Stereomat at USGS. The Stereomat used a combination of photomultiplier tubes as a primitive scanner to automate the process of stereoscopic correlation. The system could correlate stereopairs by correlating voltage readings between two stereoscopic photographs. "Error voltage" between the two scanning heads was then used to drive servomotors that oriented the projectors in the stereomodel. The system could also generate contour lines automatically. Even so, USGS researchers were cautious. As Chief Topographic Engineer George Whitmore reported:

The Stereomat is a long way from being perfected, and the specialist who operates photogrammetric mapping equipment is in no current danger of being supplanted by a

machine. Nevertheless, the indications are plain that automation will be a vital factor in the future of mapping operations (Whitmore et al. 1959, p. 1062).

Stereomat technology was also being considered for adaptation to the Orthophotoscope, a USGS innovation patented under Russell Bean's name in 1959, in order to automate the production of orthophotographs. Whitmore believed the orthophotoscope would remove the "tedious part of the production [because it] is reasonable to expect that this height adjustment operation can be made automatic by means of hardware similar to that used in the Stereomat" (Whitmore et al. 1959, p. 5).

By the end of the 1950s, key personnel at USGS were committed to new ways of making and using maps. This commitment is apparent in the MAP III program, completed in late 1959 by the Branch of Special Maps under contract to the National Damage Assessment Center, a Cold War civil defense agency. USGS personnel working with the Office of Civil and Defense Mobilization used the Army Map Service 1:500,000 map series as a base to prepare more than 2000 six-inch-square templates to code information for keypunching. Included were political boundaries, natural features, and major cities for the continental United States. The project eventually covered Alaska as well. These templates were punched onto standard computer cards, which, when processed by a Univac Scientific 1103 computer and printed on a Sperry-Rand high-speed printer, provided an outline map for use with vulnerability studies. Although the intent was to use the outline to orient the printout on a conventional base map (Figure 1), USGS was sufficiently impressed by the output to devote an entire page of the *Topographic Division Bulletin* to its reproduction (Collins 1959).

1960 to 1964: "... but it takes all the fun out of the game"

By 1960 American industrial engineers had made great strides toward creating systems that addressed postwar challenges. What is more, they had created an ideology of automation that had become a key feature of the American self-image. Evidence of this fundamental shift can be seen in a number of monographs published about this time that dealt with the topic of automation (e.g., Buckingham 1961; Brady 1961). In the two decades after World War II, American science and engineering responded to the challenge of

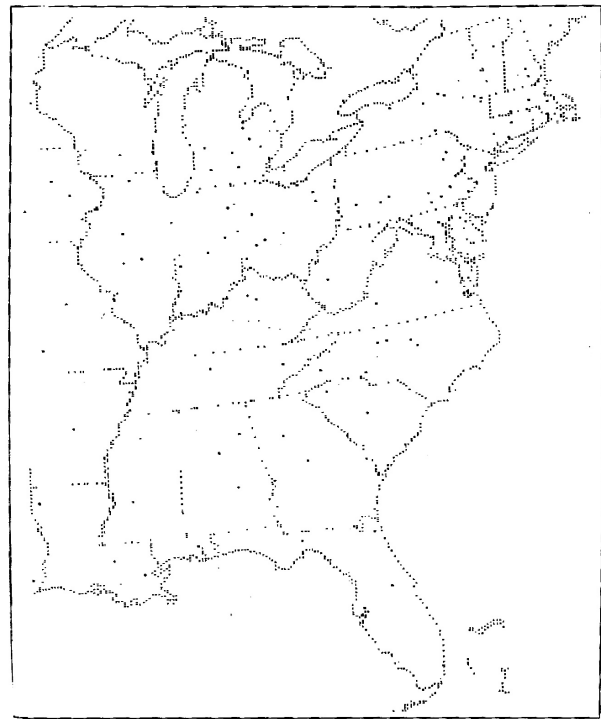


Figure 2. Simplified printout for use with Standard Civil Defense Map.

Figure 1. This early computer-produced map was made in cooperation with the National Center for Damage Assessment in 1959.

the Cold War by creating what Paul Edwards calls a "closed world." The creation of command and control technologies and techniques at the behest of the Department of Defense suggested an ominous future with thinking and working machines, space-based surveillance systems, and scientific-rational approaches to understanding and representing the world. The field of operations research, spawned during the war as a way of systematizing strategic and logistical problem solving, moved into the mainstream in the postwar world. As Edwards notes:

This extension of mathematical formalization into the realm of business and social problems brought with it a newfound sense of power, the hope of a technical control of social processes to equal that achieved in mechanical and electronic systems. In the systems discourses of the 1950s and 1960s, the formal techniques and tools of the "system sciences" went hand in hand with a language and ideology of technical control (Edwards 1996, p. 114).

In the USGS, this ideology found fertile ground as a consequence of the technical nature of the work and the dominance of professional engineers in management positions. The newly established Research and Design Branch (later renamed the Office of Research and Technical Standards or

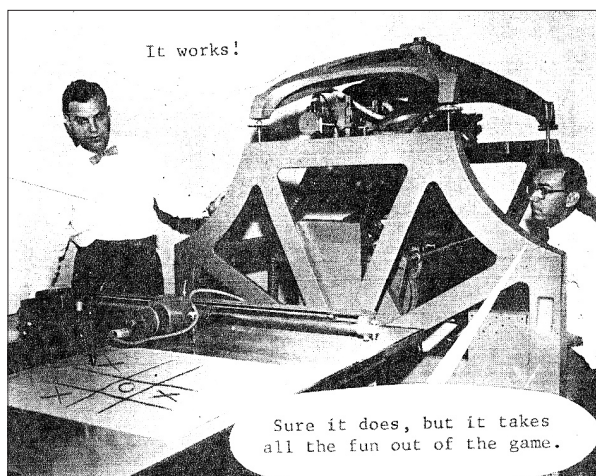


Figure 2. This doctored photograph appeared in the *Topographic Division Bulletin* in 1963.

RTS) was associated with the Atlantic Region office in Arlington, Virginia. Headed by Russell Bean, this office was organized to develop new instruments and techniques for map production in the Topographic Division. In addition to a staff of several engineers and career cartographers, the office included full-time machinists and a fully equipped instrument laboratory. The pace of innovation at USGS had increased during the 1950s with the development of the ER-55 and Twinplex plotters, the Orthophotoscope, stereotemplates, and other new and improved mapping instruments (Patterson 1960).

Ever longer revision cycles in the cartography section became a cause of concern in the early 1960s. Map revision followed the same four-step process (office completion, drafting, checking, and final edit) as new mapping and consumed 425 calendar days on average. Concern over production bottlenecks associated with revision led to the creation of an experimental group in the Atlantic Region to investigate the possibility of simultaneously sequencing mapping operations, in effect allowing production phases in cartography that were normally sequential to be performed at the same time. The main finding of this experiment suggested that a reorganization of the entire cartography section around small 15-20 person units, each organized as a team responsible for all of the four phases of map revision, would increase productivity and substantially shorten the revision cycle. Although decentralized units became more common during the 1960s in the various branch offices, this proposal was never adopted in this form (Roney and Palmer 1961).

In early 1962, Chief Topographic Engineer Whitmore began an exhaustive effort to complete

the 7.5-minute topographic mapping program over the next thirty years. At that time around 65 percent of the program had been completed. Whitmore's plan, produced with the help of the Office of Program Development and published in the *Topographic Division Bulletin* in summer 1963, included a projected increase in the workforce from roughly 2200 to around 3500 by the late 1960s (Overstreet 1963). Standard quadrangle mapping was to be completed by the early 1980s, when a gradual reduction in the workforce would ensue. Officials anticipated that by the 1980s, the cartographic work would largely consist of revision and maintenance of completed series, and the projection extended to 1994. No provision was made to maintain the 15-minute series, no major new programs were anticipated, and no mention was made of new technologies that might affect productivity assumptions. The article concluded with a significant caveat:

During the time frame covered by this program, it would not be unusual for additional programs to be added. Such increases in the mapping activity of the Division would only add to man-year requirements to complete the Long-Range Program, or delay the date of the existing programs... For the Division to succeed in implementing this program, the challenge to increase productivity beyond the current rates must be met (Overstreet 1963, p. 48).

In a somewhat ironic twist, a photo captioned as a cartoon was added at the bottom of the page as a filler. It depicts two workers busy at a large machine as if they were playing a game (Figure 2). "It works!" one exclaims, and the other answers, "Sure it does, but it takes all the fun out of the game." The photo appeared originally in *Topographic Division Bulletin* for December 1960 (without the balloon captions and the tic-tac-toe game) to illustrate an article on the Office of Research and Technical Standards. The two men shown are A.R. Shope and M.B. Scher, and the instrument is a slave-operated coordinatograph.

In April 1963, Richard Wong, a systems analyst in the Office of Plans and Programs, attended a Civil Service Commission sponsored program titled "Management Sciences Orientation." The one-week program focused on Automated Data Processing (ADP), Operations Research (OR), and the behavioral sciences. Wong was taken by the material presented and decided to share his experience with the entire division in a short article for the *Bulletin*. In a memo attached to the manuscript copy of his short paper Wong emphasizes the sig-

nificance of Operations Research and Automated Data Processing:

I have also taken the opportunity to use this report as a means to express my ideas about ADP & OR applications within the Topographic Division. The ideas advanced, of course, are untested and unproven and should, necessarily, be considered merely as possibilities. There are many avenues to explore and the proposals which I have made do not represent the limits which I can see for ADP and OR applications. (Wong 1963b, n.p.)

In his article Wong makes wide-ranging and sometimes vague claims about expected social consequences from cybernation, “an invented term used as a substitute for the combination of automation and computers” (Wong 1963a, p. 3).

Cybernation, the use of both computers and automation, poses immense problems for the future. Someday measures must be found to counteract its grave consequences. In the meantime, strong competitive forces will compel the acceptance of cybernation because computers and operations research will bring tremendous competitive advantages to those who are able to apply them. . . . In combination, computers and operations research will have enormous impact in the future. Together, they will increase unemployment. As a consequence there will be changes in economic, social, political, and moral attitudes. Those who are not alert to the consequences of cybernation will find it difficult to survive against increasingly intense competition. For competitors, both domestic and foreign, will face reality and accept cybernation completely (Wong 1963a, p. 21).

Wong's domestic competitors were the private-sector mapping firms clamoring for a share of the work performed in-house by USGS. Friction also existed between private mapping firms and the U.S. Coast and Geodetic Survey and the Army Map Service (Langer 1963). For Wong there was little doubt what course the Topographic Division should follow:

The handwriting is on the wall. Regardless of the evils of cybernation, it must be adopted. Perhaps some counteracting force will soften its impact. But much will be lost in the meantime if a wait and see attitude is adopted; the competition will not wait. Competition in the mapping field has been mentioned. The evidence strongly suggests that the Geological Survey faces a challenge. A new environment will prevail, in which the Survey will

be confronted with perplexing problems. . . . Computers, operations research, and automation will cause vast changes in existing ways of doing things. . . . I recommend that the Division increase its efforts in exploring these fields (Wong 1963a, p. 23).

Wong's summary impressed both Whitmore and the Associate Chief Topographic Engineer, William Radlinski. For his part, Radlinski felt that Wong was “not only enthusiastic about the subject, but also quite capable. . . . This is only an increment of what we propose to accomplish in automation in OPD” (Radlinski 1963, n.p.). Whitmore was even more expansive:

To say the least, it is very interesting, enlightening reading. . . . I assume we firmly intend not to fall behind in proper utilization of these tools, ergo, I assume we mean to follow the recommendation: But how? Who? Where? When? etc. (Whitmore 1963)

In addition to suggesting what today would be the fairly routine automation of office procedures in the Office of Program Development, Wong's article signified a sea change in the Topographic Division. Shortly after its publication the Office of Research and Technical Standards launched new initiatives that would dramatically move the division towards automating key elements of the cartographic operation, particularly in the Branch of Cartography. The justification for these initiatives was the need for increased productivity, efficiency, and economy and the reduction of “time-hogging” work practices. Through the mid to late 1960s these efforts would not only become a showpiece of technological innovation at the USGS but also set the stage for dramatic changes during the 1970s in organization, procedures, and production.

1965 to 1974: Autoplot and Autoline

By early 1965 the Office of Research and Technical Standards was ready to automate integral parts of the map production process. Increased pressure to produce savings in the division targeted areas considered to be “time-hogging,” particularly the several tasks comprising cartography. An assessment of the long-range prospects for the mapping program conducted during 1962-1963 had considered briefly the possibility of new programs, but new initiatives that were to occur over the next two decades could not be foreseen in the long-range plan prepared in 1963 (Overstreet 1963). As mentioned earlier, the Topographic Division's mission

within the Geological Survey focused attention on productivity gains measured in square miles mapped per man-year.

Drawing on the successful automation of complex manual tasks such as metal machining, RTS personnel began exploring ways of increasing map production through automation. Roy Mullen, an engineer and division chief in the Office of Research and Technical Standards, was a key figure in these developments. According to Mullen, the turn toward automated procedures was a logical step for RTS engineers and technicians, who had first-hand experience with map production. Although no systematic study of the production process was conducted to isolate inefficiencies and bottlenecks there was a general feeling among former RTS staffers that the Branch of Cartography could benefit substantially from automation. Particular tasks that could be automated included the compilation of map graticules and the scribing of planimetric and contour manuscripts. When asked recently about the impetus for this initiative, Mullen responded:

Well, there were numerical tool machines like lathes and things like that. And I thought 'well now why don't we apply that technology to moving this needle point around and plotting and get that person who... spent his entire day for 25 years standing over that coordinatograph.' (Mullen, personal communication 2001)

The Department of Defense had contracted for automated plotters but these were considered too expensive for the civilian agency and its Topographic Division. Led by Dean Edson, several RTS staffers began working on a prototype plotter that would use a standard rack-and-pinion Haag-Streit coordinatograph as the main building block for an automated, numerically controlled system for creating base map graticules on emulsion-coated Mylar sheets.

Working with Edson were Hugh Loving, Morris McKenzie, Mullen, and other staff technicians and engineers in RTS. Edson was a long-time employee of the topographic division from San Diego. Like many of his generation, he had started during World War II as a field mapper for the Santa Fe Railroad in the Western United States. Following service in the Pacific during the war with the 29th Engineers Battalion, a mapping unit, he returned to finish his high school degree, and after finishing a year of college took a job with the USGS Topographic Division in 1947. After a number of years as a photogrammetrist, he was assigned to the Topographic Division's Washington office in

the early 1960s. Edson was one of many USGS staff who achieved professional certification as an engineer without completing a college degree, but in the performance-based culture of the USGS, this deficiency did not thwart promotion to a supervisory position. He recalled the challenge of controlling costs with limited funds for capital equipment:

So we were looking for something that would fit our mapping budget. My task was not just to try to develop a first step in automation but in a dollar saving way and that was a tough assignment. That's why I went to the machine tool industry to look at their drive logic and their drive motors and adapted that to a manual plotter. That was the first Autoplot and our first demonstration to our director, George Whitmore—I'll never forget it—brought him out and turned the machine on and it wrote his name on a piece of Mylar. That really impressed him (Edson, personal communication 2001).

Need for a new way to produce precision map graticules was heightened by the Branch of Photogrammetry's switch to analytical techniques during the previous decade. These techniques produced pass-points used for positioning stereo-models during the map compilation phase in an x- and y-coordinate format. All of these points, as well as map projections, grids, and control points (up to 200 per sheet) had to be plotted manually (Mullen 1967).

Early in the development phase, a magnetic tape drive replaced the paper-tape drive used for input to the prototype Autoplot (Figure 3). RTS staff modified the coordinatograph to accommodate "stepper motors" and a new precision gearbox that would drive and position the plotting head at the speed of 0.7 inch per second with a precision of 0.0005 inch. The newly designed plotting head included scribing and inking tools able to perform multiple tasks. The new (1967) IBM System/360 computer generated input for the device, and the basic data included control point coordinates, scale, projection, and quadrangle name. As Mullen observed:

The master program, written in FORTRAN IV, generates on the magnetic-tape all instructions needed for (1) scribing the map projections, grids, and symbols, (2) plotting the pass points and geodetic control points, and (3) printing the alphanumeric (sic) characters required for identifying the quadrangle and the various plotted points (Mullen 1967, p. 4).

There were also subroutines for converting between geographic and plane coordinates. Morris McKenzie, another engineer in RTS who had gotten his certification through the internal Engineer Training Program, had studied computer programming since 1960 and helped Edson design the control programs. As McKenzie recalls:

The original use of these stepping motors was to control some kind of a machine tool... some kind of a lathe or something. It was a repetitive job. So they could put this paper tape in there and it would drive this tool over and over and over for this repetitive operation. It was a milling tool and so I wrote a program to have it step over to draw these base sheets and put it on magnetic tape. So Dean Edson and Red [Loving] rigged it up so that the machine would read magnetic tape instead of paper tape and what I would do is I'd draw the conversion that the parallels, they curve up when you lay them out on a flat sheet. So I would figure out how much curvature it needed to ... how many steps I had to go up, let's say, North. I would have to divide... it wouldn't move on a bias, you had to go so many -x and so many steps in -y so I would have to split and move so many steps in -x and one in -y and that's the way it would move. (McKenzie, personal communication 2001)

In early 1968, Autoplot machines installed in each of the four regional offices were quickly put to various plotting tasks, creating over 600 base map sheets by October 1968. In general, the machines were operated by the existing coordinatograph operators, although according to Edson, "it would almost be a demotion to be the operator . . . because it was such an easy operation, you had to mount the coated Mylar sheet on a flatbed and index it and essentially mount a tape and turn it on" (Edson, personal communication 2001). Development of special routines and tasks continued in the regions, and the system had completely replaced the manual plotting of base sheets by late 1968.

The USGS was excited to share this development with the mapping community. At the annual joint meeting of the American Society of Photogrammetry and the American Congress of Surveying and Mapping, held in Washington in March 1967, Mullen presented a paper on the Autoplot and demonstrated the machine. As Mullen pointed out, the benefits to be derived from this were obvious:

First and most important, we get a significant saving in time. Manual plotting and scribing

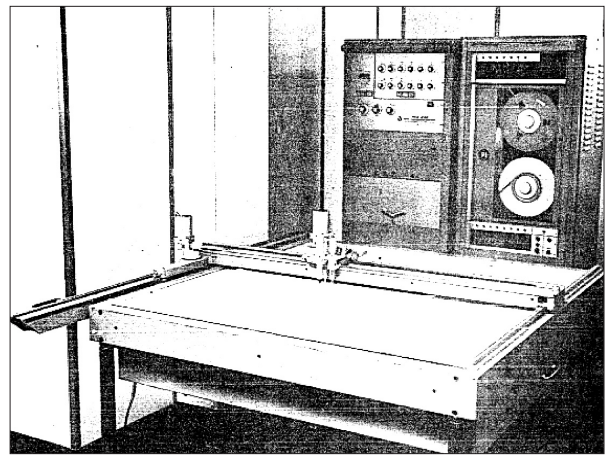


Figure 3. The Autoplot was developed in the Office of Research and Technical Standards in the mid 1960s.

of a standard USGS base map with horizontal pass-point positions requires from 8 to 12 hours of tedious work by the coordinatograph operator. This same operator can now thread the magnetic tape, set the appropriate switches, and then attend to other duties while the Autoplot system produces a map base in approximately 30 minutes. Another benefit is increased accuracy which results from the elimination of the human error in observing the plotter dials (Mullen 1967, p. 5).

It is not completely clear whether these changes reflect replacement or infrastructural automation. Although an existing line of work (coordinate and base-sheet plotting) had been substantially automated, the original personnel operated the new machinery, which suggests infrastructural automation. Even so, automated plotting was hardly their only task insofar as the time saved with the Autoplot had to be used somewhere else. If the original operators of the coordinatograph were reassigned to other duties, and thus replaced by automated machinery, this would be substitution automation. Either way, the Autoplot marked a significant change in the map production process.

The Autoline or "line-following device" (Figure 4) was a concurrent attempt by RTS to automate a tedious task in the map production process. Unlike the Autoplot, the Autoline met with only marginal success and was never put into regular production—a victim perhaps of accelerating developments in scanning and manual digitizing tablet technologies. Moreover, the purpose of the device would change during the course of its life. Originally conceived as a way to automate the redrafting of map manuscripts compiled through photogrammetry, it was later pitched as a way to

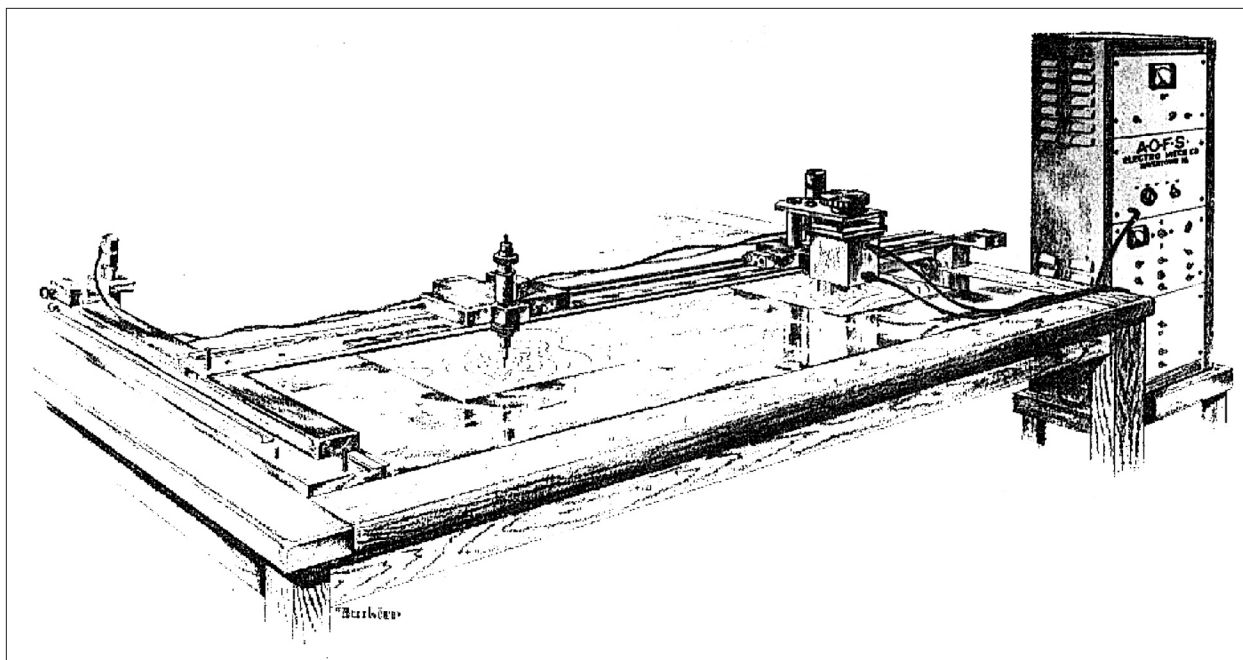


Figure 4. The “line-following device,” or Autoline, was an important project in the Office of Research and Technical Standards during the late 1960s.

digitize and thus more easily update or reproduce the Geological Survey’s huge collection of published map separates (normally Mylar negatives), which numbered in the tens of thousands. This effort was similar to an ongoing and well documented project in the Experimental Cartographic Unit (ECU) at the Royal College of Art in London (Foresman 1998). Dean Edson visited the ECU in late 1968 for several weeks and collaborated with David Bickmore in organizing an international meeting on map digitizing in 1969 (USGS 1970; Foresman 1998).

As the Topographic Division was configured in the mid-1960s, the 7.5-minute topographic map series involved numerous job categories (USGS 1966a). Table 1 lists the numbers of employees in each during 1963-1965. The peak year was 1964, when the Topographic Division employed 2,576 people. Because many of the workers classed as “Engineering Technicians” had previously been designated “Status Quo Cartographers,” much of the work carried out at this time by ETs would be considered production cartography. This job category was a catchall that included field and office workers. The “Other” category mainly included temporary employees hired across the range of categories.

There was a general feeling among the engineers in the Office of Research and Technical Standards that the job of negative engraving could be automated through the application of line-fol-

lowing and servo-technology to the redrafting and engraving of manuscripts produced by photogrammetrists. As early as 1965 RTS began investigating the application of a machine manufactured by Electro Mech, Inc. and marketed for use with milling machines. As the Geological Survey’s semi-annual report noted:

Line copy placed on the bed of the milling machine is observed by an optical sensing head which causes the bed to be driven horizontally so that its motion duplicates the copy...In addition the device has the capability of following the copy at a predetermined perpendicular offset distance. ... The purpose of this investigation will be to determine if the device has applicability in mapping operations (USGS 1965, p. 5).

Although the original intent was simply to copy line work using an automated scribe, the line-follower’s assignment quickly expanded to include the capture of digital data. As the first semiannual report for 1966 noted:

This system will probably be developed in several stages. For the first stage a semiautomatic system of the line-following type appears most feasible and is proposed for use in scribing the contour plate only. In subsequent stages systems will employ magnetic tape or other media that will store digitized map data. A fully automatic digitized system could eventually be expanded to allow a continual updating

of the tapes with new map data. This could be a partial solution to the revision problem (USGS 1966b, p. 2).

The second semiannual report for that year clarified the line-follower's expanded role:

The ultimate objective of this research is to develop a system that will automatically execute most of the color-separation scribing operations (USGS 1966c, p. 2).

In early 1967, RTS entered into a lease-purchase agreement with Electro Mech for an automatic line-follower adapted to a coordinatograph. The initial test results of the machine were so favorable that the purchase option was exercised almost immediately. The original intent of the machine was clear:

The line-follower is now being adapted to a Coradi coordinatograph, and in this configuration the system is expected to produce clean scribed copy from pencil drawings. Contour manuscript will be used as input in the first experiments (USGS 1967a, p. 2).

But problems with the system would prove difficult to resolve. Later that year, RTS reported that:

The line-follower has been able to follow contours, roads ... and drainage from copy equal in quality to a compilation manuscript. The instrument cannot, however, in its present form follow with predictability lines that intersect. ... For this reason line-following experiments so far have been limited mostly to contours (USGS 1967b, p. 8).

During 1968 and 1969 the Office of Research and Technical Standards continued to experiment with and improve the prototype instrument. Improvements included updating the electronic circuitry for greater reliability, design, and fabrication of a new optical head, and the addition of digital encoders and readout equipment (USGS 1969). Thompson reported in 1969 that the experiments held out the "potential for eliminating two costly and time-consuming operations in the map-production sequence: initial scribing by the stereocompiler, and final color separation scribing" (Thompson 1969, p. 12). He noted, though, the unsolved problem of intersecting lines.

The annual report for 1970 mentioned for the first time the device's new name, "Autoline" (USGS 1970, p. 24). By 1971 there was little mention of the line-following device, perhaps because of the purchase that year of the first Bendix Datagrid digitizer and the in-house development of a raster digitizing scanner. The scanner quickly showed promise for generating three-dimensional topographic data from scribed contour plates, albeit

Job title	1963	1964	1965
Engineers	362	364	356
Professional Cartographers	87	93	96
Engineering Technicians and Aides	845	901	900
Cartographic Technicians and Aides	290	276	275
Negative Engravers and Draftsmen	290	282	254
Offset Photographers	87	85	84
Administrative and Clerical	153	154	157
Miscellaneous, including Geographers	22	25	23
Other	359	396	336
Total	2495	2576	2481

Table 1. Number of workers, by job title: 1963, 1964, and 1965.

at low resolution (USGS 1971). The Autoline's demise can be attributed to increased emphasis on cost accountability for automated procedures after Robert Lyddan became Chief Topographic Engineer in 1968. As Lyddan complained:

One of the prime dangers of our age is that of being caught doing something because it can be done rather than because it should be done. This danger is particularly evident with computer applications in which no savings or benefits have resulted. The computer can produce volumes of data very quickly, but the means for effective and beneficial use of all the data may not be available. We must be equally alert to the pitfalls of producing excess mapping data or collecting data in a sophisticated but inefficient manner (Lyddan 1971, p. 8).

Several RTS alumni now believe that the line-follower simply did not serve its intended function: replacing the draftsman or scribe. Because the scanning head had problems staying on line, a technician had to monitor it constantly. According to Joseph Pilonero, a staff engineer in RTS who worked on the line-follower in the late 1960s:

So you couldn't rely on it, you had to have a man there checking it constantly and that defeated the purpose. ... We all knew that by eliminating the draftsman or cartographer, it would save a lot of money. You could just put it on a line-follower and let it go. But it didn't work (Pilonero, personal communication 2001).

Morris McKenzie added, "You know I think that thing died a slow death, but I don't remember. It never got out of the research stage. ... I guess it just slowly disappeared without having a quick funeral or anything" (McKenzie, personal communication 2001). In a description of the USGS Advanced Mapping System, Hugh Loving (1972) noted that the Autoline was used on photogrammetrically derived analog profiles to control the vertical motions of the Orthophotoscope, but he

said nothing about its use for digitizing or copying line work. Over the next two or three years, RTS's semi-annual research and development reports fail to mention the line-follower but discuss, at considerable length, the use of manual tablet digitizers to capture digital data from existing map separates. In 1974, the agency began evaluating commercial line-following devices.

In December 1974, USGS and the American Congress on Surveying and Mapping sponsored the first of several conferences titled "Auto-Carto: International Conference on Automation in Cartography." Held in Reston, Virginia, home of USGS headquarters, the meeting was intended as a gathering for the nascent fields of automated cartography, computer processing of spatial data, GIS, and remote sensing. Auto-Carto was also an assembly at which many of the early theoretical positions that shaped the development of geospatial technologies over the past twenty-five years were staked out. The USGS personnel were conspicuous as presenters and participants, Dean Edson served as conference chairman, and William Radlinski, Associate Director of USGS, was the keynote speaker. The program itself was straightforward: a series of hardware and software sessions organized as panels (Output Devices, Editing Methods, Input Methods, Cartographic Data Bases, Cartographic Data Structures, GIS Panel, etc.), three general sessions (Governmental Implications of Automation, Professional Implications of Automation, Operating Systems), and a closing session and summation. For his part, Radlinski offered five reasons for automating cartography: speed, economy, new products, revision, and reduced error (ACSM 1976). His list reflected the evolution of thought at USGS over the previous decade, when the initial goal of replacing slow workers with lightning-fast machines was superseded by the development of new products for more demanding users, which was followed in turn by a focus on revision, increased standardization, and the removal of mapmaking "from the frailties of human judgment" (ACSM 1976, p. 8).

Concluding Remarks

The most interesting aspect of events described here is their occurrence within the federal government, and thus outside the capitalist logic assumed to drive rationalization and substitution automation in the private sector. The managers, engineers, technicians, and cartographers associated with automation efforts at the Topographic Division acted in ways indistinguishable from what

one would expect from private-sector actors in similar circumstances. That said, the development and ultimate triumph of corporate capitalism during the twentieth century cannot be separated from the growth of science-based industries, defense-sponsored research and development, and the movement into the management class of technically trained engineers and scientists (Noble 1977).

At one point during my research for this essay, a former USGS staffer remarked that the Topographic Division had "missed the boat" for GIS. He was thinking, no doubt, about the Geological Survey's early focus on hardware, perhaps to the detriment of analysis or applications, followed by a preoccupation with data during the 1970s, which left USGS with a somewhat stodgy and backward reputation in the mapping community.

I offer another interpretation, namely, that the USGS actually *built the boat* by manufacturing analog and digital products that—as baseline planimetric data—drove the rapid growth of GIS in the United States since the 1980s. The story told here sheds light on the period during which USGS moved from a vast, manual cartographic operation to an organization permeated, if not overwhelmed, by an ideology of automation. In this respect, USGS was not unique among mapping organizations. What was unique were the ways in which automation entered the work process, the fiscal constraints that emphasized creative low-budget research and development, and the gradual shift of federal automation policy during the 1960s and 1970s from a focus on devices (widgets) to a preoccupation with data (digits).

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