Planning for Optical Disk Technology with Digital Cartography*

Donald L. Light
U. S. Geological Survey, Reston, VA 22092

ABSTRACT: Since the late 1960's, cartographers have recognized the potential of modern computer technology for making revolutionary changes in conventional mapping processes. During the decade of the 1970's, computer systems diminished in physical size and cost, but dramatically increased in processing speed and capacity. Such progress in the computer field continues to suggest that the transition from traditional analog mapping systems to digital systems has become a practical possibility. A major shortfall that still exists in digital systems is the need for very large mass storage capacity. The decade of the 1980's has introduced laser optical disk storage technology, which may be the breakthrough needed for mass storage. This paper addresses system concepts for digital cartography during the transition period. Emphasis will be placed on determining U.S. Geological Survey mass storage requirements and introducing laser optical disk technology for handling storage problems for digital data in this decade.

INTRODUCTION

SINCE THE LATE 1960's, cartographers have recognized the tremendous potential of modern computer technology for making revolutionary changes in conventional mapping processes. The time-proven methods, utilizing analog and (or) analytical instrumentation and aerial and lithographic films, have enjoyed several years of cost-effective economic success that have contributed to their longevity as the best approach to the mapping process.

In the 1960's, the emerging influence of digital computers associated with interactive manipulation, display, and analysis of cartographic data seemed destined to replace the conventional approaches. But it was not until the 1970's that advances in computer technology began to suggest a challenge to conventional approaches in terms of cost effectiveness and more efficient responsiveness. The digital influence has accelerated considerably since the late 1970's, with rapid advances in micro-, mini-, mainframe, and super-computer technology. In fact, the five components of a computer system, i.e., processor, random access memory (RAM), input devices, output devices, and auxiliary storage, have each been remarkably improved over the past decade and there is more to come. These advances have been associated with a downward trend in hardware prices that may be placing digital cartography within the reach of most organizations engaged in Earth science, resource management, and mapping. Main memory processor cycle times have gone from microseconds (10^{-6}) to nanoseconds (10^{-9}) since the 1960's. Also, the phenomenal growth from the 4K-bit RAMto 1 million-bit RAM in ten years is shown in Figure 1. Figure 2, performance of super computers (Davis, 1984), shows a remarkable upsurge in processor capacity measured in million floating point operations per second for mainframe computers. The Cray* and Cyber 205 super computer systems lead the super pack in the United States. The next decade promises even more speed and capacity from these fifth-generation giants.

Figure 3, network architecture, illustrates four of

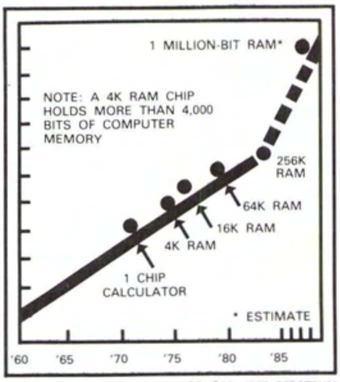


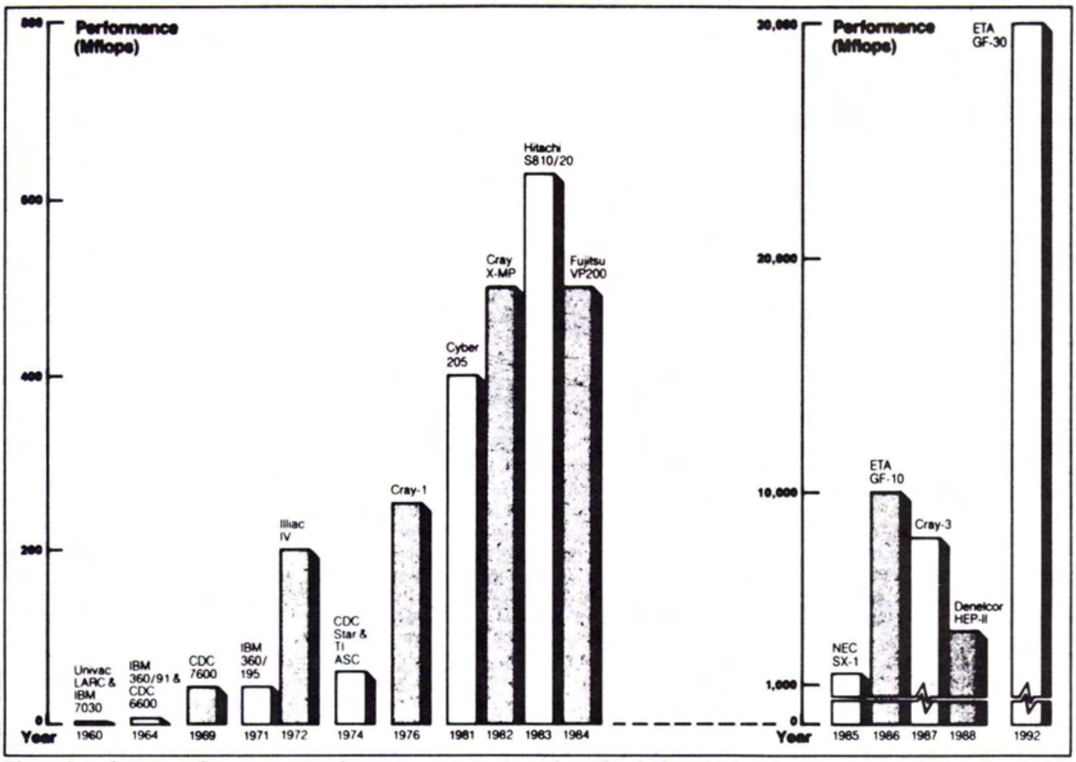
FIG. 1. Growth in Memory Capacity of Computer Chips.

*This is a follow-on to the article, "Mass Storage Estimates for the Digital Mapping Era," which appeared in the March 1986 issue of this Journal.

*Any use of trade names and trademarks is for identification only and does not constitute endorsement by the U. S. Geological Survey.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 52, No. 4, April 1986, pp. 551–557.

0099-1112/86/5204-551$02.25/0



The peak performance of supercomputers has progressed steadily during the past two decades. Performance capabilities will jump dramatically over the next several years, however, if the various projects planned meet their goals. This chart approximates each machine's theoretical peak megaflop (million floating-point operations per second) rating, which is rarely attained in actual operations. For example, the 64-processor Illiac IV never came close to its theoretical peak performance.

FIG. 2. Performance of Super Computers.

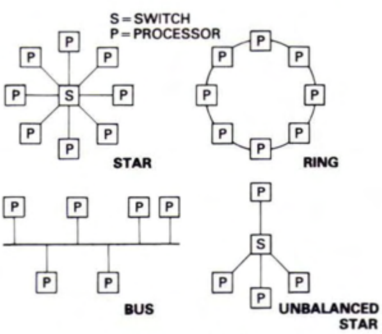


FIG. 3. Network Architeture.

the most common architectures for interconnecting computer systems in a distributive network.

Computer architectural developments on standard serial computers and the special-purpose array, parallel, and concurrent processors also continue to make the trend to digital computer modes for cartographic application more inviting.

Simultaneous with these processor hardware advances, the decade of the 1970's brought on input device development (Pingry, 1984) as shown in Figure 4. Note that the keyboard has given way to high-technology scanners and vector digitizers for input. Scanners, digitizers, and voice data entry systems are already in operation in the U.S. Geological Survey's (USGS) Mapping Centers.

A wide variety of output devices are available also. Line printers are capable of 900 lines per minute. Perhaps the most significant output plotter at the USGS is the Scitex Laser Plotter. This large format, map size plotter is being upgraded to permit plot-

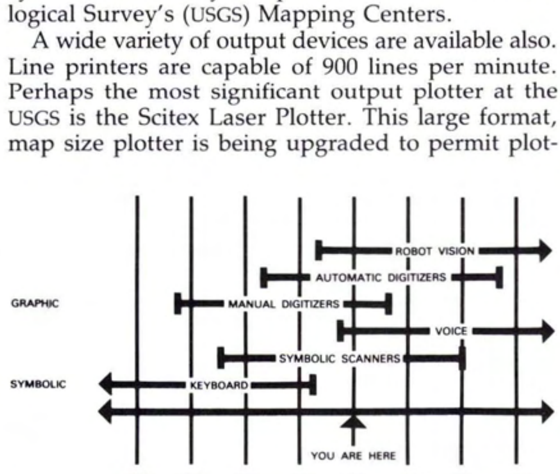


FIG. 4. Lifespans of Various Types of Input Devices. The Ranges Begin With the First Marketable Product and End With Industry Maturity.

ting of continuous-tone image map output. This new capability allows the USGS to output both black-and-white linework and color separates for color image mapping.

All of this hardware development speeds up input and processing of digital cartographic data, but such large volumes of data create the need for comparative amounts of auxiliary storage. Further, it is recognized that mass storage on magnetic media, such as tape and disks, is expensive due to the short shelf life (less than three years) of magnetic media. For these reasons, a breakthrough in high-density storage technology seems essential for coping with the masses of data that are prevalent in digital cartography.

Figure 5, magnetic versus optical recording, shows the prediction that optical recording technology may be the answer to the auxiliary storage dilemma. Note in Figure 5 that optical disks greatly exceed the areal data density of both magnetic disks and film. During the transition period, it may be difficult to break even economically; but cartographers can't quit because of the tremendous long-term benefits visualized.

Recognizing that there is a real movement to digital technologies, it seems obvious that cartographers will exploit these technologies and continue to move cartography into a digital mode. In the conventional mode, map data reside on film separates for each color to be printed. In the digital mode, the map data must be stored in a machine-readable storage media. Again referring to Figure 5, optical

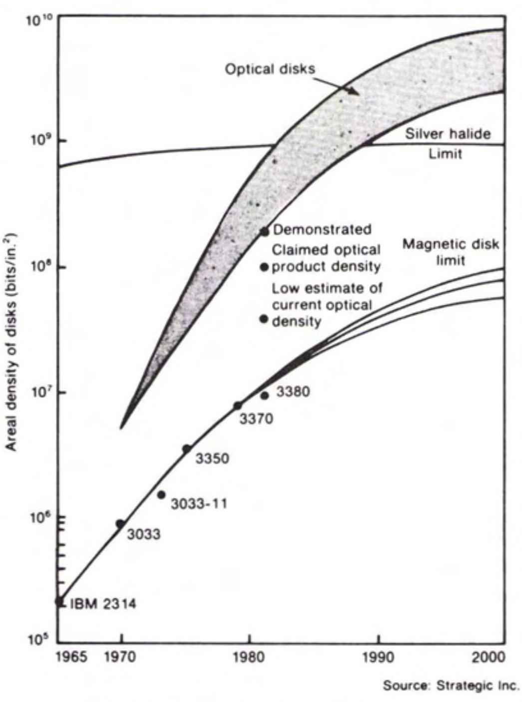


FIG. 5. Magnetic vs. Optical Recording.

disk technology has the potential for being the breakthrough needed for the success of digital cartography in the next decade. In view of this, it is interesting to address the vital issue of mass auxiliary storage requirements for digital mapping in our own area of responsibility—the United States.

Storage Requirements For Mapping The Lower 49 States At Scale 1:24,000

A previous paper (Light, 1986), studied the digital storage requirements for cartographic data for the lower 49 States. For this project the assumptions were:

- Approximately 54,000 7.5-minute standard topographic quadrangle maps at 1:24,000 scale cover the lower 49 States.
- Technological advances in the 1980's may permit these 54,000 quads to be stored in digital form as an archive for digital mapping data. Considering these 54,000 quads, two different approaches were derived to estimate the terrain cell size (*Cs*) required to adequately represent these data in digital form. Method 1 in this paper assumes a slightly different criterion than that previously used (Light, 1986); Method 2 is the same. Both methods are summarized as follows.

Method 1. An Image Mapping Criteria - 300 lines/inch

- Accept that standard quality halftone printing is usually done with a 175 lines per inch (7 lines per millimetre) screen. Assume that the current concept of screenless printing allows at least a 1.7× improvement over the halftone process. Some researchers claim as much as 2.5× improvement. This improvement means that screenless printing may produce a product equivalent to using a 300 line/inch (12 l/mm) screen. Screenless printing represents the state-of-the-art in high-resolution printing, so it is used here to represent the best case when using an image mapping criterion.
- Using 300 lines/inch as the smallest terrain element that can be represented by printing on an image map, the cell size of the ground corresponding to 300 lines (l) is computed as follows:

$$Cs = \frac{1 \text{ in}}{300l} \times \frac{1 \text{ m}}{39.37 \text{ in}} \times \text{map scale}$$

$$Cs = 8.47 \times 10^{-5} \text{ m} \times \text{map scale} \qquad (1)$$

For example, at a scale of 1:24,000

$$Cs\ (\text{m}) = 8.5 \times 10^{-5} \times 24{,}000$$
$$Cs = 2.04 \text{ m}$$

Thus, 2.04 m is the terrain cell size that the digital data must represent in order to meet the high-resolution 300 line/inch capability assumed for screenless printing. This makes the digital word unit stored in the mass storage media capable of representing the high resolution screenless printing.

Method 2. Cell Size from Digital Stereophotogrammetry and Contouring Criteria

This method utilizes national map accuracy criteria for contouring by stereophotogrammetric methods. The method computes the proper *Cs* to permit stereocontouring from the data, and that Cs will be represented digitally in the mass storage media.

The equation derived (Light, 1986) is

$$Cs = \frac{1}{K} \cdot \frac{B}{H} \sigma h \qquad (2)$$

Where

K = a nondimensional number which expresses the degree to which stereocorrelation can be achieved,

H = the flying height of the sensor above the ground,

B = the base distance between exposure stations, and

σh = the error in determination of height in a stereointersection.

To meet the criteria for 90 percent of elevations to be correct within one-half the contour interval (CI), National Map Accuracy Standards imply that

$$\text{CI} = 3.3\ \sigma h$$

Then, as an example, for the 10-foot (3-m) contour interval which is common on 1:24,000-scale maps,

$$\sigma h = \frac{\text{CI}}{3.3} = \frac{3.0\text{m}}{3.3} = 0.91\text{ m}$$

As an example, let $K = 0.40$, $B/H = 0.6$, and $\sigma h = 0.91$ m.

Then, using Equation 2,

$$Cs = \frac{1}{0.4} \times 0.6 \times 0.91\text{ m}$$

$$= 1.36\text{ m}$$

Now that cell size has been established by two different methods, what remains is to structure and count the binary bits required per cell and to calculate the total bits of storage capacity needed for the 54,000 quads. Figure 6, cell data storage concept, illustrates a vertical layering concept for a variety of products such as thematic, image, and topographic maps. Notice in Figure 6 that the layers are allocated bits as follows:

Data Item	Bits	Comments
Lines	2	One bit would suffice
Imagery	8	256 shades of gray
Elevations	16	Spans from lowest to highest elevation on Earth in metres

A total of 64 bits is required to describe all layers of one ground cell in Figure 6. Considering topographic mapping, including both line and image maps, 34 bits per cell adequately represent the five overlays, the image map, and the elevation value for each pixel cell. No allocation has been made for attribute codes or topological linkage; only the map content is represented by 34 bits. Table 1, cell size and storage estimates, shows that the lower 49 States have an area of 7.84×10^{12} m^2 and gives a tabulation for cell sizes of 2.04 m (Method 1) and 1.36, 1.82, and 2.28 m (Method 2). It is established that cell sizes ranging from 1.4 to 2.3 m emerge as the requirement, with 2 m being a reasonable rule-of-thumbe size. From observing the right-hand column of Table 1, it is clear from both methods that the estimated mass storage requirements for the lower 49 States is on the order of 10^{13} to 10^{14} bits.

The 10^{14} -bit estimate is based on complete arrays of terrain cells similar to arrays of picture elements (pixels) in raster technology. The digital cartographic systems evolving today are a combination of raster and vector technology. It is generally accepted that vector data require less storage capacity than raster data, but the 10^{14} estimate does not include attribute codes and topological structuring which is required to have a queryable smart data base system. In view of this, the 10^{14} -bit estimate should be used for sizing the mass storage system for the future.

LASER OPTICAL DISK TECHNOLOGY

Optical recording is a new technology using lasers to record and play back information, which promises many of the desirable characteristics needed in a mass storage media. There are three kinds of disks used in laser optical recording. Table 2, optical recording technology, tabulates the basic characteristics of each. The subject of this paper pertains to the Laser Optical Disk only as given in the right column. The operational concept of this disk is

- Focus laser beam to a micrometre size spot,
- Selectively burn holes (pits) in the disk surface to record information—a binary 0 or 1, and
- Play back (read) recorded pits using a lower powered laser.

This technology is called the "direct read-after-write" (DRAW)concept. The disk is not erasable as are magnetic media. Erasable disks are expected in a few years.

One means of visualizing the high capacity of optical recording technology is to compare it to other commonly known media. Table 3 compares the Storage Technology Corporation's (STC) optical disk capacity (32×10^9 bits) with other magnetic media. Note that one optical disk is equivalent to about 100 standard 1600 bpi minicomputer tapes.

Table 4, number of storage units required for 10^{14} bits, tabulates the number of storage units (disks or tape reels) needed for each of storage media listed. Note that 3,100 optical disk platters are needed for 10^{14} bits. Because this tabulation does not consider any inefficiency in recording, it seems more correct to increase the platter estimate from 3,100 to 4,000. It is reasonable to assume for planning purposes that 4,000 platters can hold the data for 54,000 quads.

Figure 7, STC 7600 Optical Storage System, shows the disk drive which was scheduled to undergo evaluation and tests at the Geological Survey. The cartridge which holds and protects the disk and its

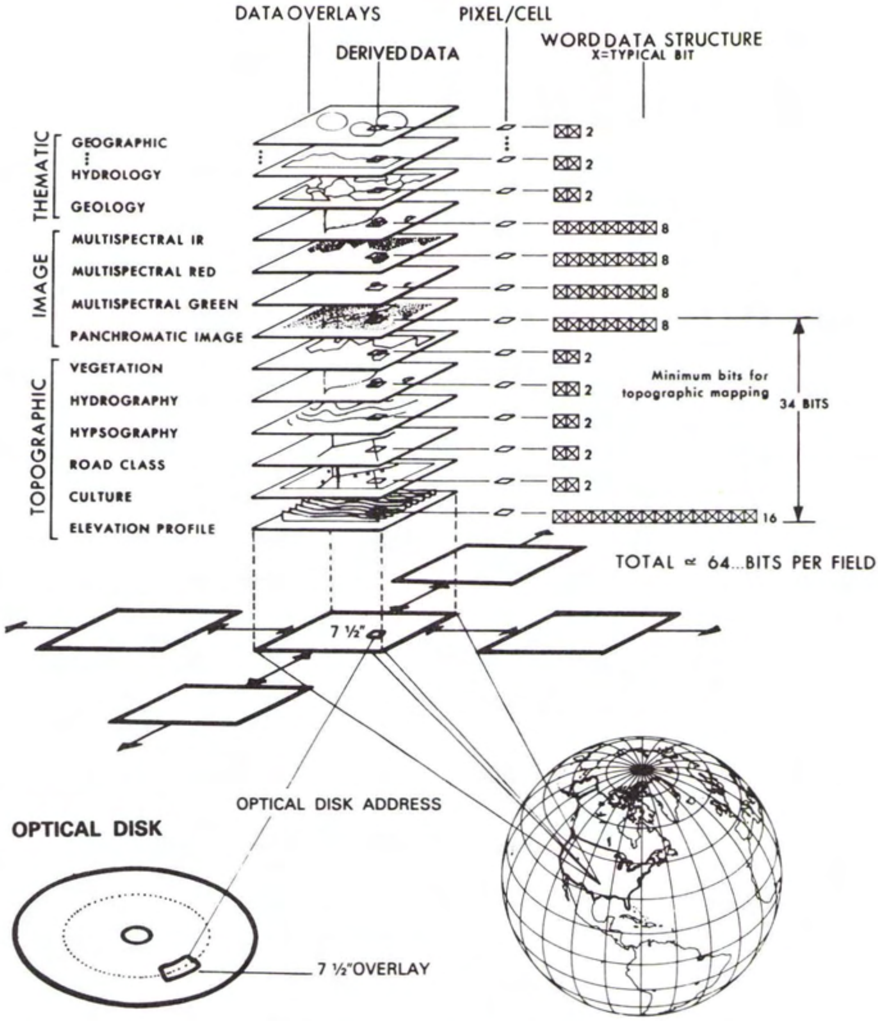


FIG. 6. Cell Data Storage Concept.

TABLE 1. CELL SIZE AND STORAGE ESTIMATES.
APPROXIMATE AREA FOR CONTINENTAL U.S. AND HAWAII, 7.84 × 10^{12} M^2 (3,028,710 SQ MI)

	Cell Size (metres) On Ground	Cell Area (metres²)	Total Cells Required	Total Bits • Graphic Overlay - 10 Bits • Image Data - 8 Bits • Elevation - 16 Bits 34 Bits/Cell
METHOD 1, An Image Mapping Criteria - 300 lines/inch				
	2.04	4.16	1.88 × 10^{12}	6.4 × 10^{13}
METHOD 2, Contouring Criteria: CI = 10 ft (3 m)				
B/H				
0.6	1.36	1.85	4.24 × 10^{12}	1.44 × 10^{14}
0.8	1.82	3.31	2.37 × 10^{12}	8.06 × 10^{13}
1.0	2.28	5.20	1.51 × 10^{12}	5.13 × 10^{13}

K = 0.4, correlation accurate to 0.4 of a pixel.

32 × 10^9 bits fits into the mouth of the disk drive near the top left of the cabinet. STC has dropped its line of optical disk products as of December 1985. The USGS is continuing to evaluate the technology for application to its Digital Cartographic Data Base. Fig 7 as shown is no longer in production by STC,

TABLE 2. OPTICAL RECORDING TECHNOLOGY.
[LASER PITTING TECHNOLOGY IS BASICALLY THE SAME FOR VIDEO AND DIGITAL DATA STORAGE DISKS. THE MAJOR DIFFERENCE IS IN HOW THE LASER BEAM IS MODULATED DURING RECORDING.]

Video Capacitance-Electronic Disk (CED)	Video Disk	Laser Optical Disk
Resembles a phonograph record, except it stores video images.	For video recording, the length of the laser pulse is determined by the amplitude of the analog video signal.	Digital data is encoded by turning the laser on and off–a binary system.
Images are encoded as tiny grooves in a continuous spiral track on a vinyl platter.	Low amplitude signals produce short pulses, and thus smaller holes.	The presence of a spot (pit) signifies a data 1, the absence of a pit signifies a 0.
During playback, a diamond stylus rides along the track, sensing variations in its surface as fluctuations in capacitance.	High amplitude signals produce long pulses, and corresponding larger holes.	Data stream may be organized in 8, 16, 32, or *N*-bit words.
Very high capacity, but subject to wear.	During playback, the varying spot size can be used to re-create the original analog signal.	Bit error rates are much lower than video recording.
Most suitable for feature length films.		

TABLE 3. COMPARISON OF MAGNETIC STORAGE MEDIA WITH OPTICAL DISK.

Storage Media	Capacity (Bits)	Comparison- Optical Disk Capacity / Other Media Capacity
Optical Disk	32×10^9	$\frac{OD}{OD} = 1$
300 MB Mag Disk	2.4×10^9/PACK	$\frac{OD}{MD} = 13$
CCT 1,600 BPI	0.3×10^9	$\frac{OD}{CCT} = 107$
CCT 6,250 BPI	1.3×10^9	$\frac{OD}{CCT} = 25$

TABLE 4. NUMBER OF STORAGE UNITS REQUIRED FOR 10^{14} BITS.

Storage Media	10^{14} Bits/Unit Capacity	Units Required for 10^{14} Bits
Optical Disk	32×10^9	$3.1 \times 10^3 = 3,100$
300 MB Mag Disk	2.4×10^9	$4.2 \times 10^4 = 42,000$
CCT 1,600 BPI	0.3×10^9	$3.3 \times 10^5 = 330,000$
CCT 6,250 BPI	1.3×10^9	$7.7 \times 10^4 = 77,000$

but it protrays the approximate size that can be expected for optical disk drives.

Given that computer technology and storage capacity is increasing and becoming more available every year, it is time to plan for future online digital mapping systems. Figure 8, USGS/NMD cartographic mapping processes for new mapping (future system), shows a concept for mapping systems in which the data collection devices all collect digital data properly formatted for editing and attribute coding.

The data could then be stored in the 4,000-platter online mass storage system. To minimize setup time, it is most important to capture and store all topographic data in the mass storage system at the time of compilation. This conceptual system could produce both the traditional line of graphic map products and the newer line of digital products from one source on call by means of the data management system.

The concept depicted in Figure 8 describes a planning concept. It represents the flow of data that we may expect when more digital systems and proce-

FIG. 7. Storage Technology Corporation 7600 Optical Storage System. STC has discontinued this line.

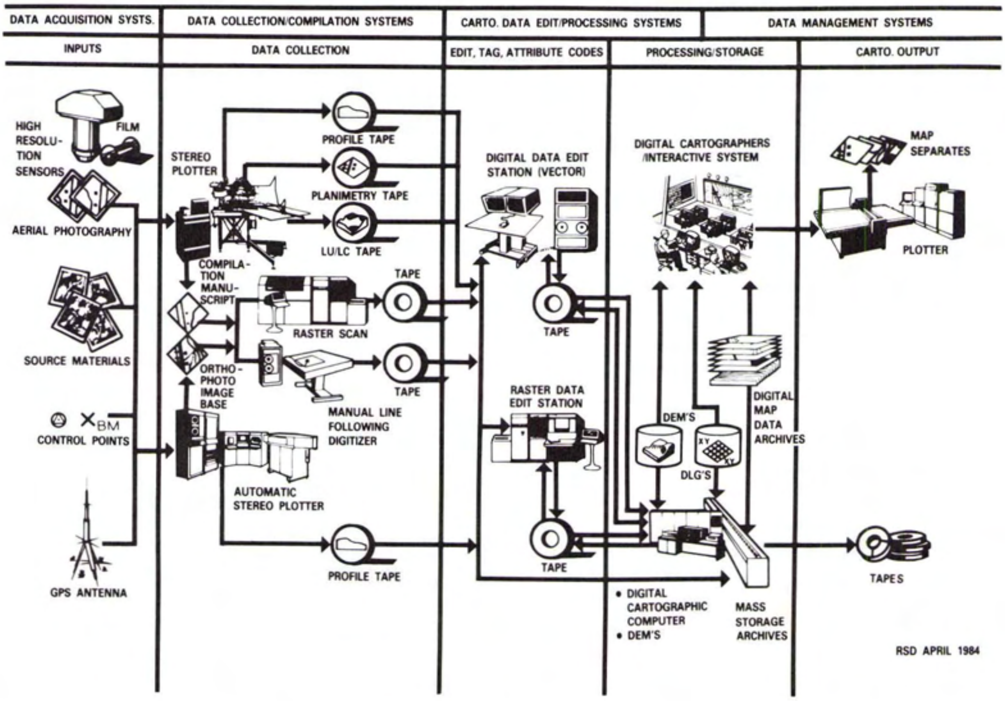


FIG. 8. U.S. Geological Survey/National Mapping Division Cartographic Mapping Process For New Mapping (Future System).

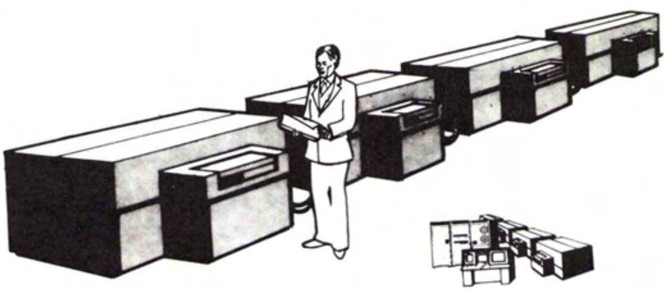


FIG. 9. Optical Disk Library System (Artist's Concept).

dures are implemented throughout the decade. Figure 9 is an artist's concept of a mass storage data library or jukebox system for the future. The library would contain the 4,000 platters as estimated in this paper.

SUMMARY

In summary, with computers getting smaller in size and greater in speed and capacity, and with optical disk technology recognized as a breakthrough in mass storage media, it is feasible to plan a cartographic system as shown in Figure 8. Such configurations may be commonplace in the 1990's.

REFERENCES

Davis, Dwight B., 1984. Super Computers: A Strategic Imperative: *High Technology*, May 1984, pp. 44–52.

Light, Donald L., 1986. Mass Storage Estimates for the Digital Mapping Era: *Photogrammetric Engineering and Remote Sensing*, Vol. 52, No. 3, pp. 419–425.

Pingry, Julie, 1984. Inputting Graphics by Digitizer: *Digital Design*, April 1984, pp. 102–108.

(Received 4 March 1985; accepted 29 October 1985)