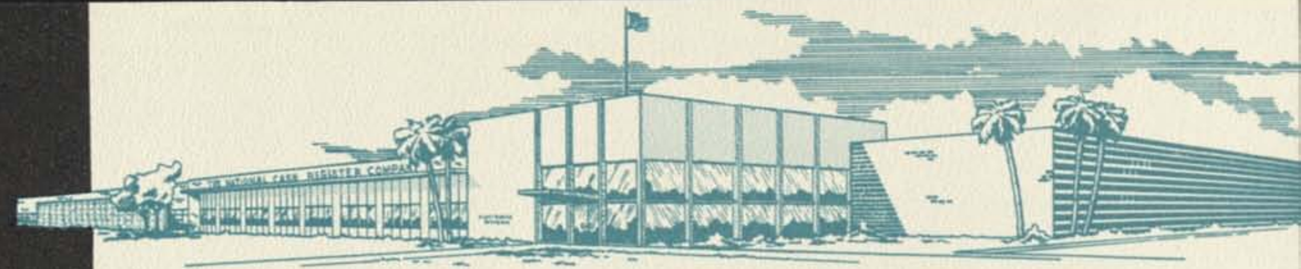
NCR



ELECTRONICS DIVISION

THE PHOTOCHROMIC MICRO-IMAGE MEMORY

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THE NATIONAL CASH REGISTER COMPANY

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THE PHOTOCHROMIC MICRO-IMAGE MEMORY

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INTRODUCTION

Recent research and development within The National Cash Register Company has resulted in a new technique for the storage and retrieval of document images. This technique has made very high density document storage practical at reductions of 200:1 and greater. Miniaturization of document image size to this degree makes feasible a relatively simple, high-speed, random access capability. Writing and storage rates of 7200 image fields per hour serially and 4300 per hour randomly are envisioned. In the retrieval mode of operation, when recording the output on film, rates of 36,000 per hour serially and 10,000 per hour randomly, are expected. In addition to the ability to create static photomemories, this technology provides a new capability in document manipulation by its ability to alter the stored document image by erasure and rewriting.

The equipment described in this paper provides one form of photochromic mechanization and, with respect to hardware, a number of alternate approaches are possible. However, a specific configuration leads to a clearer discussion of details than would be possible with the more general approach. The system to be discussed has not been built, beyond a breadboarding of some of the functions. The laboratory studies have indicated that this system is not only feasible, but that it is well within the state-of-the-art. Examples of output copy from this type of memory system are shown in the Appendix.

PHOTOCHROMIC COATINGS

NCR photochromic coatings are similar to photographic emulsions in appearance and in other properties. They can be made to retain two-dimensional patterns which are optically transferred to their surface; they can be, in general, coated on the same types of substrates as photographic emulsions; and they can exhibit excellent resolution capabilities. In addition, both positive-to-negative and direct-positive transfers are possible.

Photochromic coatings differ from silver-halide emulsions in a number of respects. Since the photochromic coatings consist of a molecular dispersion of reversible light-sensitive dyes in a suitable coating material, they are completely grain-free and are inherently high resolution coatings. Further, no development process is required. The image appears as the individual molecules are switched from the visible-light transmitting state to the visible-light absorbing, or colored, state (or the reverse situation, switching from the colored to colorless state) by radiation of the proper spectral distribution. All the materials presently in use switch to the colored state when subjected to near ultraviolet radiation. Switching to the colorless state can be accomplished either by heat and/or visible illumination of the proper spectral distribution.

Photochromic coatings which are relatively insensitive to erasure by visible light are called heat-erasable. The coatings erasable by visible radiation are called light-erasable, although they too are erasable by heat. Since the spectral region used for reading written images is also that used for erasing the light-erasable coatings, readout tends to erase the recorded image. To a lesser degree, this is also true of the heat-erasable coatings. By taking into account the energies involved, system design can permit thousands of readouts before severe loss of contrast in the image occurs.

The colored state of the photochromic coating is a higher energy state and, therefore, is unstable. A natural decay occurs to the colorless state which is temperature dependent. At room temperature and in the dark, the half-life can be measured in terms of hours for some coatings. In the dark and under refrigerated conditions achievable by standard refrigeration equipment, the half-life of the colored-state decay can be extended to years.

The quantum nature of the molecular switching mechanism coupled with the absence of a development process, which acts as an image amplifier, leads to low photosensitivities for photochromic coatings. Thus, reasonably fast exposures require light sources of high intensity. To date, achievement of adequate exposure of a micro-image field in terms of hundreds of milliseconds has been practical. The speed is a function of the particular optical configuration used, as well as the properties of the light source. Such speed considerations dictate that the input to the micro-image system should be in the form of transparencies.

Another restraint, though not serious for many micro-image applications, is the fatigue, or wear of the photochromic coatings with use. This wear factor is primarily a function of the number of exposures to near ultraviolet for a given field (or frame). A life expectation which appears reasonable with some presently available materials is 1000 ultraviolet exposures. End-of-life is associated with the inability to read what is considered a necessary initial contrast for overall system operation, and will differ with the application. This factor cannot be compensated for by increasing the exposure.

Working with suitable optics, photochromic coatings have retained patterns with resolutions greater than 1000 lines/per millimeter. Acceptable images of ordinary documents reduced 200 to 400 times have been obtained. This corresponds to area reductions from 40,000 to 160,000 times.

In summary, the spectral absorption curves of Figure 1 illustrate some of the important characteristics of a typical coating. The first is that the coating absorbs selectively in the visible spectrum when written, i.e., it is colored rather than gray or black. This implies that maximum readout contrast will be obtained through the use of filters matched to the absorption of the coating. The second characteristic is that the absorption is a function of the previous ultraviolet exposure and can take on all values between Curves 1 and 3. Thus, though the individual molecules switch in a binary fashion, the coating exhibits excellent gray-scale capabilities. The third characteristic is that there is always a tendency for the coating to return to the ground state, Curve 1. As the coating undergoes fatigue, the height of Curve 3 will gradually decrease.

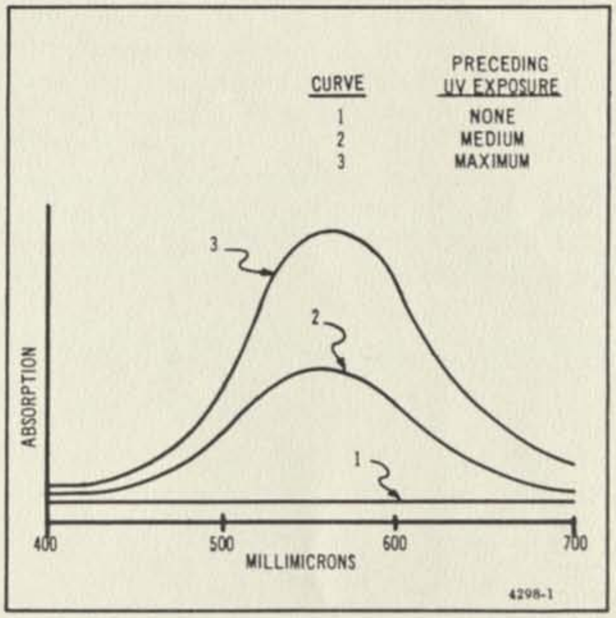

Figure 1. Typical Spectral Absorption Curves of a Photochromic Coating

PHOTOCHROMIC MICRO-IMAGERY

With the availability of a material possessing the characteristics described above, there arises a new capability for the storage and retrieval of document images at very high packing densities. This capability is primarily based on the following properties of the coatings:

1. High resolution with no grain
2. Image visible upon exposure
3. Erasure and rewrite capabilities

High resolution without grain leads to very high-density document storage. For example, at 200:1 reduction, a single cabinet can store all the documents in 40,000 cabinets. Thus, 6-1/4 square feet of filing floor space can replace one-quarter million square feet of filing floor space. Of course, such a comparison is an oversimplification, but it relates the magnitudes involved when storing at such a reduction.

Image visibility upon exposure offers immediate inspection, when desired. This inspection is possible prior to, during, and after exposure. Immediate visibility also leads to immediate readout, if desired, without a wait for a development process. Immediate inspection capability implies that the user can have a guarantee that a useful image has been recorded. If a faulty image occurs, it can be rewritten while the original is still in position for recording. With such a guarantee, there is likely to be much less reluctance to store thousands of micro-images on a single storage plane.

With silver halide systems, one or more faulty images (not sensed until after development) could make the whole memory plane useless. At one image a second, a 100,000 image plate would take approximately 28 working hours to fill. Under such conditions a practical system would require an almost 100% yield of such memory planes. The practical solution with silver halide systems is to limit the capacity of the storage plane so that reasonable yields are obtained and a rejected plane does not represent a considerable loss, economically speaking.

The ability to erase and rewrite supplements the ability to engage in continuous inspection. A storage position need not be lost by the appearance of an imperfect image. It might be erased and replaced by one that is satisfactory. In addition, erase and rewrite capability brings to document image manipulation some of the same power and economy that digital computers have brought to digital data processing. Optical techniques allow manipulations within a document while at the micro-image dimensions. It is possible to erase a part of as well as the whole micro-image field and to write into the erased portion or a portion previously unwritten. An example of this operation is given under the section describing the operational procedure.

The basic micro-image concept has been known for over one hundred years. The photochromic version is illustrated in Figure 2. It has added the additional features of immediate visibility on exposure, erase and rewrite. In essence, any micro-image system reduces a document to minute dimensions from which information may be extracted by subsequent enlargement.

The erasing tendency of the readout process makes it necessary to minimize the exposure (product of the radiant power density and time) of the photochromic coating during readout. There are readout techniques available which are compatible with this requirement. Such techniques permit thousands of readouts from a given photochromic micro-image. They are based on the use of high-sensitivity, photosensitive surfaces for readout as compared to the sensitivity of photochromic coatings.

It has been shown feasible to bulk transfer at the micro-image dimension an entire plane of photochromic micro-images to a high-resolution, silver-halide emulsion. Thus, a technique is available for

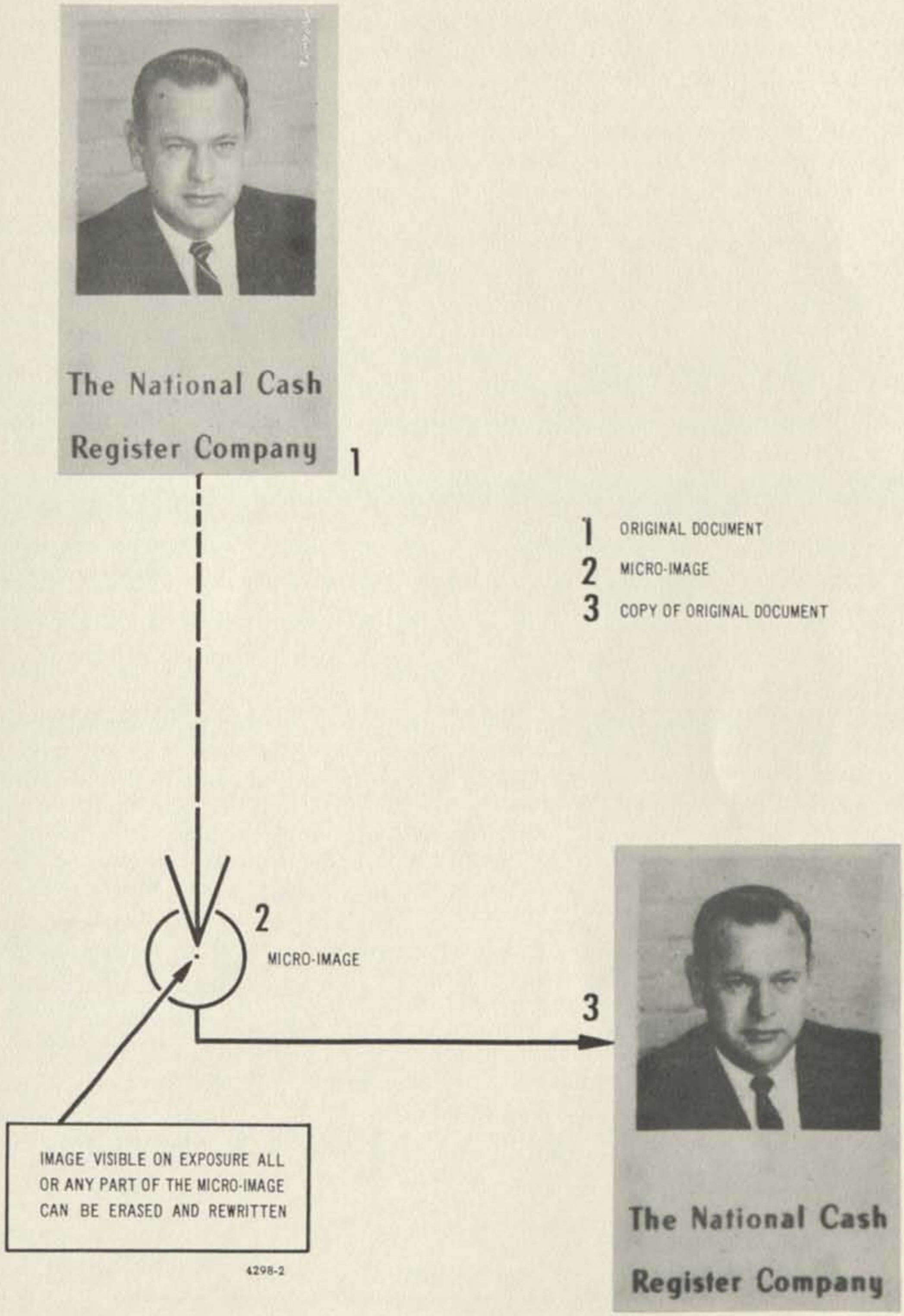

Figure 2. The Basic Photochromic Micro-Image Concept.

making the entire memory permanent. This technique promises to overcome many of the objectional features associated with the direct writing of great numbers of micro-images onto a silver-halide emulsion. The bulk transfer process is relatively nondestructive to the photochromic micro-images so that up to a hundred or more transfers can be made before the micro-images suffer appreciable erasure.

Reverse bulk transfer, photographic micro-image to photochromic micro-image, is also feasible. The number of allowable transfers back and forth is a function of the reduction used, the detail in the document, and the acceptable quality of the eventual output. The most straightforward scheme for document input and output calls for the use of regular microfilm transparencies. With such an input-output organization, photochromic micro-image stores can be made compatible with many present-day operating systems.

GENERAL APPLICATION

The information cycle, typical of many storage and retrieval applications, is shown in Figure 3. Printed data is received and analyzed to determine which index terms are to be associated with the document. An index code is created and the document is placed in a file. A user interacts with the index and the file, obtaining ideas and facts, and eventually starts the cycle over again by generating a new document.

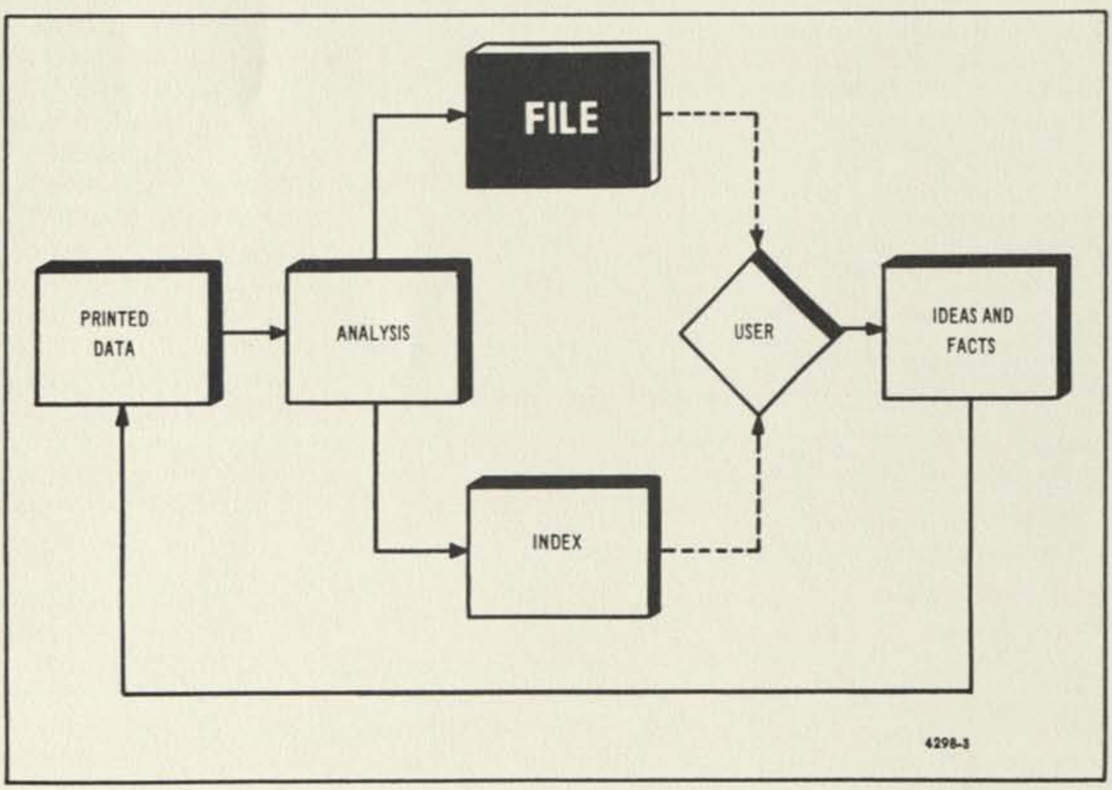

Figure 3. Typical Storage and Retrieval Information Cycle

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For this type of system, the file is a natural application for the micro-image store. The index can be maintained separately from the file. The index code has associated with it the document memory location. When the index is interrogated, the location of data is supplied to the off-line memory mechanism which finds the image and copies it. With this organization, the micro-image memory is compatible with any type of analyzing and indexing system maintained at any level of mechanization.

The photochromic micro-image memory can also handle a wide range of other applications. Among these are those of business record-keeping, record updating applications, files requiring periodic purging, and micro-image publishing.

GENERAL MECHANIZATION OF A PHOTOCHROMIC MEMORY SYSTEM

The general mechanization philosophy presented in this section is a result of the research studies to be described later. No complete micro-image memory has been built as such, and any hardware effort would undoubtedly result in departures from the system described to best meet specific requirements. However, the mechanization described is both feasible and practical.

The purpose of this description is to provide some indication of system feasibility, potential, and simplicity. The description is functional in that only the major units in the device described are blocked out, and detailed discussions of these units are omitted. This approach is necessitated by a number of factors: some of this information is still proprietary; optimum design has not been established in some of the areas; and the major recent effort has been concentrated on generating basic data in the laboratory. However, the simplicity of the system should suggest a number of alternate approaches for achieving the required hardware to those skilled in the art.

The system to be described is shown in Figure 4. The capability of this particular configuration by no means takes full advantage of the unique properties of a photochromic memory. The capability shown was chosen, rather, as a representative and relatively simple example of how one might go about calling out such a memory which takes advantage of some of the characteristics of photochromic coatings.

The mechanization is quite simple in principle. Properly filtered near-ultraviolet radiation is directed through the microfilm transparency and into the micro-image forming optics. These optics form a miniature image on the photochromic coating, where it is recorded. To read out, the microfilm aperture is cleared and properly filtered read-light passes through the system to the photochromic micro-image. The read light passing through the micro-image is intercepted by the read optics and an enlarged image is formed on the sensitive surface of the output microfilm.

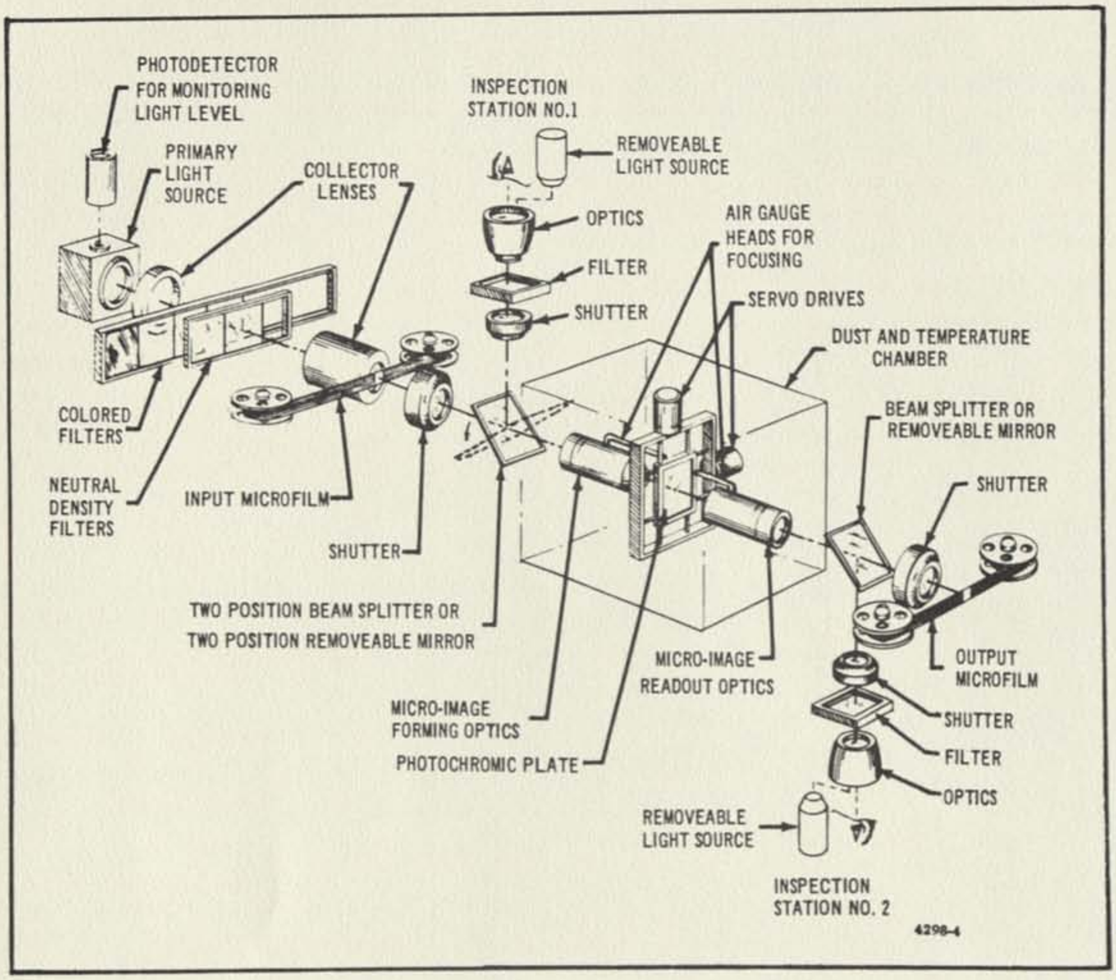

Figure 4. Photochromic Micro-Image Mechanization

The proper control of the system of Figure 4 can be partially satisfied by having the functional input instructions automatically control the filters, shutters, cycle times and microfilm mechanisms. For example, the read, write and erase operations require special spectral bands and relative intensity adjustment. An instruction calling for one of these operations can automatically actuate the filter control mechanism to place the correct spectral and neutral density filters into position. In addition, the instruction could set the shutter speed for that particular operation. For read, this implies the proper sequencing of shutters as well. To insure proper exposure a monitoring photodetector is called for in a feedback stabilization circuit.

Other operations, such as memory field location on the photochromic plate, can be introduced as specific instructions. A manual operation capability is desirable for special types of operation, setup, test and maintenance. Most of the control functions are straightforward and, for the anticipated speeds of operation, are well within the state-of-the-art.

The inspection stations provide a means for viewing micro-images (or unwritten fields) before, during or after any of the operations. This inspection can be carried out at any time for the micro-image on the optical axis.

DISCUSSION OF INDIVIDUAL UNITS AND FUNCTIONS

Primary Light Source. The primary light source is required to emit actinic radiation in the near-ultraviolet for write and in the middle of the visible spectrum for erase and read. In addition, it must be of high intensity and the luminous area should be no larger than that which is acceptable by the entrance pupil of the micro-image forming optics when used with the selected condensing system. The mercury-arc concentrated light source has been found satisfactory for this application. The unwanted radiation is suppressed by the filters mentioned previously.

Collector Lens System. The collector lens system is selected to properly illuminate the micro-image forming optics as well as to make efficient use of the light emitted by the light source. For best results, the microfilm frame is located just to the right of the final collector lens.

Micro-Image Optics. The micro-image forming and readout optics are selected for field dimensions and the maximum number of lines per field. The latter is the important optical consideration rather than lines per millimeter. As all parts of a document require equal legibility, in general, the micro-image forming optics should produce equal resolution over the whole field. Some image distortion is permissible at the micro-image dimension as it can be corrected by a compensating distortion in the readout optics.

Shutter and Film Handling Mechanisms. Shutter and film handling mechanisms appear to offer no severe problems and are obtainable either by purchase and modification or by special design and construction. The shutters can be placed at other positions along the optical path if special considerations warrant, as can the filters. The film handling mechanism on the input side may include a rack-over, or equivalent, capability for clearing the field during erase.

Storage Plane. The storage plane consists of a photochromic coating on a glass plate between 10 and 20 inches on a side. The micro-images are typical documents reduced from 100 to 300 times. At 200 times reduction and 8 by 10 inch originals, a 16 by 16 inch plate can store well over 100,000 images (500 per square inch) with adequate surface left for mounting borders.

Digital Servomechanisms. Digital servomechanisms for accessing the storage plane are available which can step up to 500 steps per second. A 1-mil tolerance for positioning appears reasonable and the overall servo-design is relatively straightforward.

Dust and Temperature Chamber. The dust and temperature chamber contains the photochromic storage plane, the micro-image optics, an air gauge focusing mechanism and equipment for providing the bulk transfer of the photochromic memory plane micro-images to a high-resolution photographic storage surface. An interlock chamber is used to minimize dirt and temperature variations when moving components into and out from the main chamber. The simple home freezer-type refrigeration equipment requires no special care and can be expected to maintain a temperature of -40°C or F in the main chamber. The air for the air gauge mechanism must be dry and clean. This air is expected to maintain the chambers under a slight positive pressure. The bulk transfer mechanism is still under development and is of a proprietary nature which precludes further discussions concerning the technique or equipment.

Inspection Stations. The inspection stations in their simplest mode are used for direct viewing. For more elaborate systems, an output could be provided to a television monitor by use of vidicon or flying-spot scanner sensing. With a raster signal available, high-speed automatic particle (dirt) sensing before exposure is quite feasible. With additional hardware, a television difference signal could also be generated in a number of different ways from the microfilm transparency and the written image; this technique would permit automatic checking before the subject microfilm frame is moved out of the writing aperture, to determine if the recorded image is a satisfactory reproduction. Note that the television scan can be produced to operate through the input microfilm, with the illumination passing on through the system, as well as produced to operate primarily through the inspection optics. With such techniques, possibilities exist which rival video tape processing techniques and yet the recorded image can retain the image quality capability of a pure optical approach. These techniques are not treated further in this paper. The following discussion assumes inspection is the simple, direct viewing mode of operation.

Inspection station No. 1 provides a means for inspection of the optical signal leaving the microfilm station. With the eye replaced by a light source and the beam properly directed, an effective clear aperture (no need to rack-over microfilm carriage) is provided for illuminating the micro-image. If the mirror is a beam splitter, such a channel provides illumination to partially "wash-out" the image of the transparency created by light from the main light source. When this station is provided with illumination from inspection station No. 2, inspection of the photochromic micro-field can be made without interference from the main light source beam, even during the image recording operation.

Inspection station No. 2 provides a means for inspecting the micro-image of the transparency before writing, and the coating at any time, with partial or complete illumination of the entire field. It provides a means for registering partial image erasure masks and new data for insertion into previously recorded or partially erased images. When a light source replaces the eye, it acts as an illumination system for inspection station No. 1.

The functions of the inspection stations are given in Table I.

TABLE I. Functions of Inspection Stations

INSPECTION STATION NO. 1	INSPECTION STATION NO. 2
Inspection of optical signal leaving microfilm. Inspection of photochromic coating and micro-image when illuminated by inspection station No. 2 Illuminates micro-image for inspection station No. 2 Illuminates micro-image for readout, if desired.	Inspection of optical signal impinging on photochromic coating. Inspection of optical signal leaving read optics. Viewing for registering partial fields for partial image write and erase. Illumination system for inspection station No. 1

Permanent Memory. The permanent memory (or slave memory) uses the planes created by the bulk transfer process from the photochromic micro-image plane in the working memory. This memory has reduced requirements and has no inherent temperature control requirement. The optical filtering and source intensity requirements are relaxed and the read is non-destructive. Such a permanent, non-volatile memory can provide increased output capability as compared to the working memory. This capability includes direct projection, microfilm, Kalvar film, television (of various types), electrostatic printers, microfilm type viewer-printer, Polaroid and others.

In general, the permanent memory would be less expensive and adaptable to many levels of mechanization. These could run from automatic rapid access to completely manual devices. Such memories can be considered as off-line interrogation stations with one photochromic working memory servicing any number of stations.

AN OPERATIONAL PROCEDURE FOR OPTIMUM IMAGE YIELD

This portion of the paper illustrates the unique capabilities of a photochromic working memory which insures the recording of data in the form of micro-images. It is assumed that the application is one requiring maximum reliability and image quality and that speed of operation is a secondary consideration. Most applications could omit one or more of the steps described. The manual process described should not be taken as an implication that such a procedure could not be automated, as indeed it might if the user were willing to pay the price. Actual error rates should be very low. The first design objective will call for an error rate of one in 10^5 or better.

Total Image Manipulation. In the following procedure, it is assumed that the microfilm is advancing through the system serially and a "worst-case" situation occurs. For clarity of explanation, the necessary control manipulations are not mentioned in the procedure.

1. The photochromic micro-image field is examined before the write operation and a large imperfection is noticed. Since an imperfect image would result, the entire field position is written with an "imperfect-field" mark, e.g., a large X.

2. The photochromic plate is advanced to the next field position, where a particle of dirt appears. The transparency is imaged with non-writing illumination on the field, and it is observed that the dirt particle obliterates part of a word. The transparency is repositioned slightly to place the dirt between lines, or words, and the micro-image is written.

3. After (or during) the image write operation, the image is inspected for quality. The image is found to be out of focus. The malfunction is corrected and the micro-image is erased and rewritten. Final inspection indicates an acceptable micro-image, and thus, the cycle begins again for the next image.

Note that if a defective microfilm frame occurs, a field can be left unwritten for that frame until that single frame is remicrofilmed and placed back into the working memory. This can be done at a later time, when convenient, and it will not interfere with the recording of the remainder of the original microfilm roll. An expedient alternative is to print the defective frame as is, with a defective frame symbol added; the frame can be corrected by erasure and rewrite when a corrected microfilm frame is available.

Partial Image Manipulation. The outputs which would be obtained after partial micro-image manipulation are shown in Figure 5. It is evident that the registration problems are more severe in partial image manipulations than in the manipulation of an entire field. The registration can be handled manually or it can be mechanized. For simplicity, it can be assumed, as in the preceding example, that a manually-controlled memory is being described.

Figure 5-A illustrates the typical entry of a micro-image document into the memory. Figure 5-B illustrates an ordinary read instruction which leads to the production of a hard-copy output.

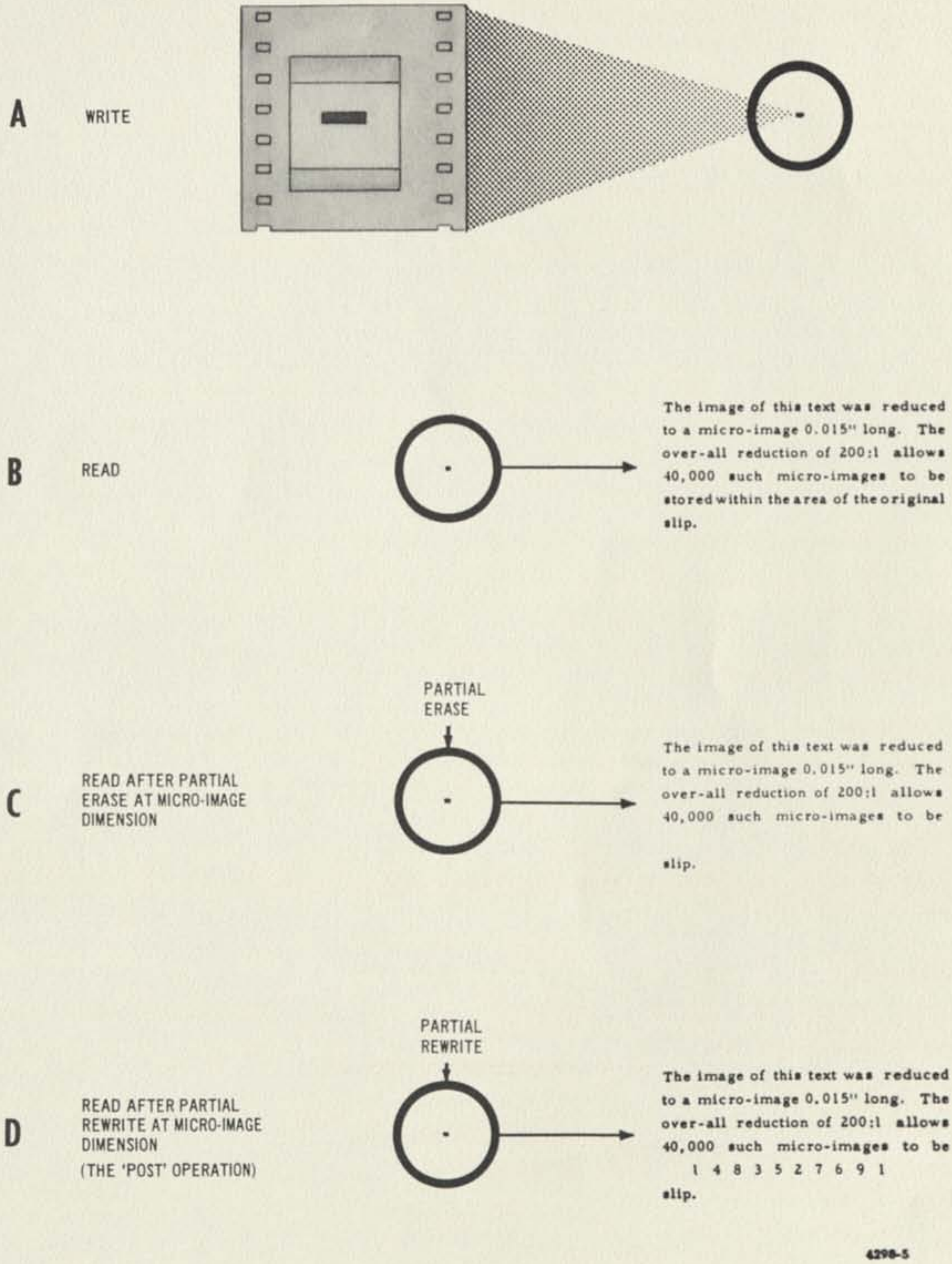

Figure 5. Example of a Partial Image Manipulation

A partial erasure at the micro-image level followed by a read instruction is illustrated in Figure 5-C. The manual registration of the erase mask is realized by viewing (through the inspection optics) the image of the erase mask on the photochromic micro-image and manipulating the mask, by the proper mechanical controls, at the microfilm dimensions. Thus, the mask registration position mechanism need only be designed to microfilm tolerances rather than micro-image tolerances. After proper registration is accomplished, the erase procedure is initiated.

A partial rewrite of a partially erased micro-image (or a micro-image containing an area previously unwritten) is shown in Figure 5-D . This type of operation is commonly referred to as a "posting" operation. For the present discussion, it is assumed that the data to be entered exists on a micro-film transparency. This transparency is registered with respect to the micro-image in a manner similar to that described for erasure and the "write" operation is initiated.

SYSTEM CHARACTERISTICS

From the preceding it is evident that the photochromic micro-image memory promises to be a useful and versatile tool. In line with this versatility is the fact that this tool is compatible with a wide range of input-output devices. Figure 6 is a block diagram which presents the general system characteristics in a simple form. The control instruction describing the mode of operation and the memory

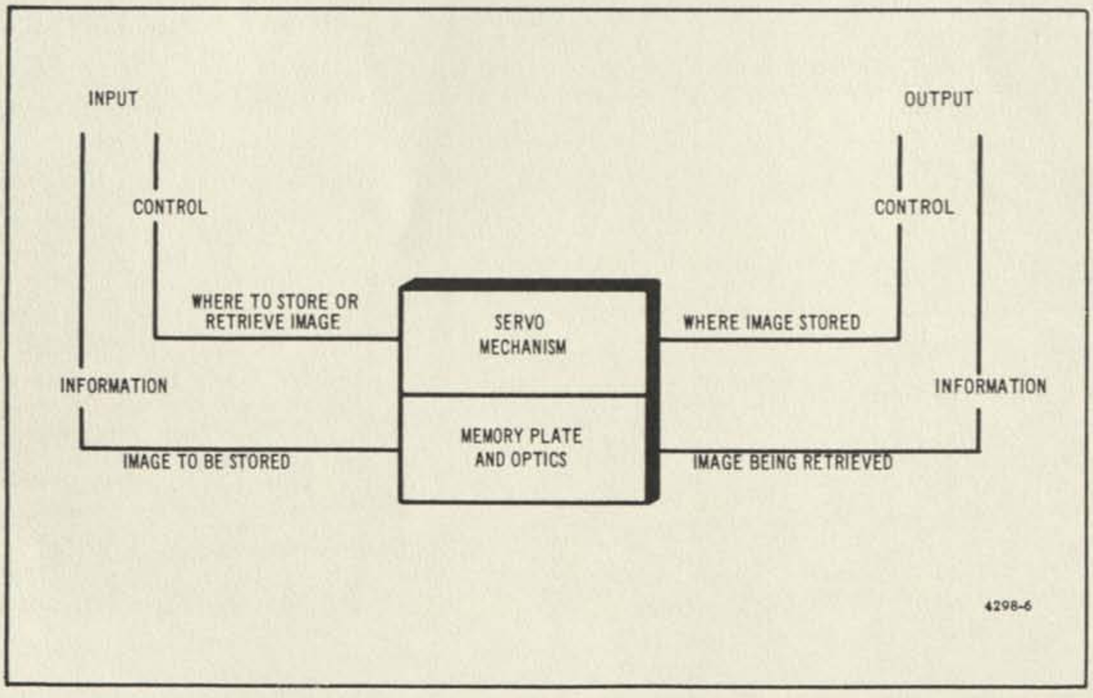

Figure 6. Overall System Characteristics

location can come from any digital source. Typical digital input devices are keyboards, readers for punched tape or punched cards, and remote integrogation units. Similarly, the memory can report the result of its actions in a variety of commercial digital devices. Hence, the memory is capable of communicating with the index system that controls its use.

The combination of the working and permanent memories are equally flexible in the handling of information. Systems can be built to communicate with standard microfilm (8 mm to 105 mm) both in input and output, and systems could be designed to handle other inputs if the data is available on a transparent backing. A wide range of outputs are possible, including microfilm, aperture cards, remote TV, projection and copy-type printers, as mentioned previously.

SUMMARY OF MICRO-IMAGE INVESTIGATIONS

In this section of the paper the micro-image studies are summarized in a qualitative manner. Quantitative data is presented in the following section. The basic equipment used for research studies of micro-imagery is shown in Figure 7. A number of different optical configurations were used as various modifications naturally occurred during the course of the investigations. These investigations have amply demonstrated that photochromic micro-imagery is both reliable and easily controlled and mechanized.

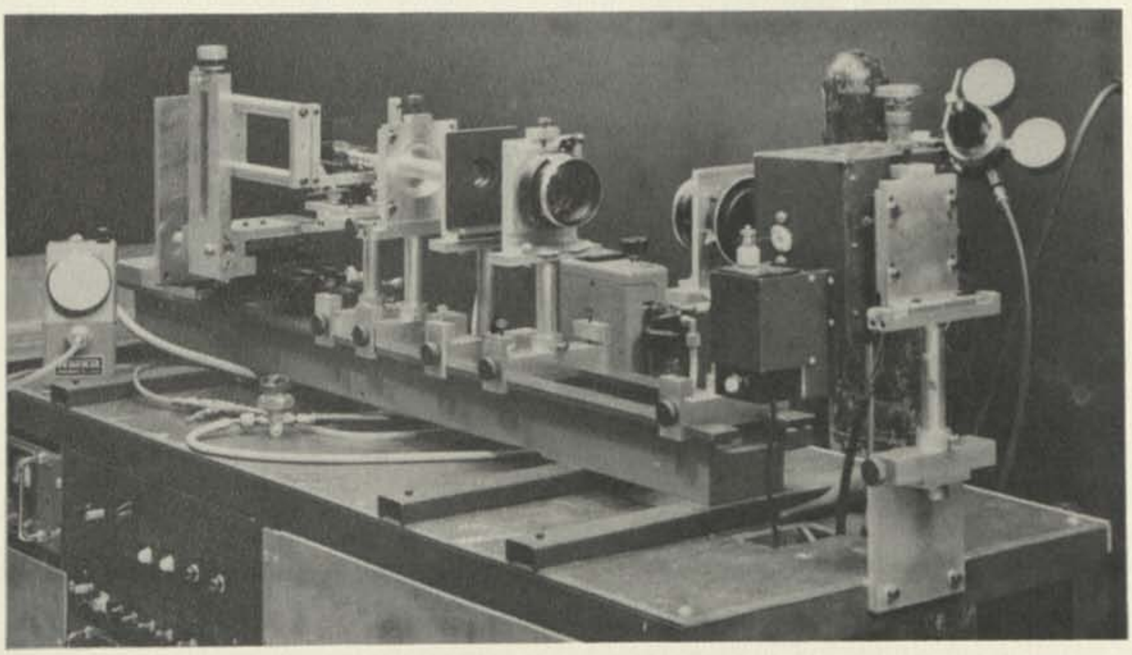

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Figure 7. Equipment Used for Research Studies

Photochromic Coatings. Both heat-erasable and light-erasable photochromic coatings were used. Imagery appears to be a surface phenomenon to a great extent, and thus, high resolution was achievable on coatings many mils thick. However, as coatings are reduced to fractions of a mil in thickness, it is possible to improve resolution by a significant amount. This tends to be accompanied by increased writing time and lower ultimate contrast. Contrast has been found quite acceptable, in general, and gray-scale rendition was excellent. Available coatings gave uniform background with no apparent grain. Subjectively speaking, the photochromic micro-images were always preferable to those on high resolution photographic (silver halide) materials, even when these were considered to be excellent.

Both reversal and direct positive micro-images were studied on photochromic coatings. The latter are made by first switching the coating to the colored state and then erasing it with visible illumination. Excellent micro-images were obtained by both techniques.

The reduction used, in general, was between 200 and 250 times from the original. Originals ranged from copy 4 by 6 inches to copy 8 by 10 inches, or slightly larger. Larger micro-images were also studied. Useful legibility at the system output was achieved for a business letter reduced 400 times at the micro-image level. Acceptability on a lines per millimeter basis was found to be misleading as the copy frequently appeared much better than one might expect from such reasoning.

No refrigeration or dust chambers were used on the optical bench. The half-lives of the coatings at room temperature were sufficient to allow a number of micro-images to be printed before appreciable decay of the first micro-image occurred. If this had not been the case, the research effort would have proceeded at a much slower pace, indeed. A refrigeration storage unit, consisting of four separate chambers, was obtained for storing written coatings at different temperatures. The results, so far, indicate a conservative estimate of one year as the half-life for the colored-state contrast, for the selected-light reversible coating (at -20°F or less).

Both partial and complete image erasure and rewrite were easily accomplished. The registration was accomplished at the microfilm holder while visually observing the relative placement of the mask. Thus, the accuracy required in positioning the mask, or information to be recorded, is relaxed by the reduction taken at the micro-image step.

Light Sources. Because of the need for high intensity actinic sources for the writing of micro-images, small mercury arc sources of high brightness were used in the laboratory studies. The size of the arc for optimum results is a function of the condenser system used, the reduction taken and the micro-image forming optics. Contrary to statements heard recently and read in the sales literature, point-source illumination is not the best, in general. The best source for optimum results, and not the most specular, was that which properly illuminated the entrance pupil of the micro-image forming optics. With a smaller source, the image quality suffered and the micro-image began to record patterns created by slight imperfections within the lenses and filters through which this highly specular illumination passed.

Condenser Lenses. Although it is recognized that an optimum condenser system will have to be constructed for this application, the laboratory studies made use of available optics in minimal type of set-ups for the various studies undertaken. One of the most difficult problems with such an arrangement has been the obtaining of adequate field illumination at the micro-image level. Regular condenser lenses have imperfections, in many cases, that are troublesome when used with semi-specular or specular illumination. The use of high-quality aerial camera lenses for performing the condenser function was found to be beneficial and these were used to produce some of the best results. A Köhler-type condensing system appears to be the most ideal for an operating memory and future studies of this type of system for photochromic micro-imagery are planned.

Micro-Image Read and Write Optics. A number of different lenses were tested to serve these functions. In general, they were microscopic-type objectives, used with eyepieces in some cases and without eyepieces in other cases. Since it was necessary to work with off-the-shelf optics, we were not able to obtain optimum illumination with all lenses tested. It was found that the best results for simultaneous flat field (uniform resolution over the field) and high resolution are obtained with the objectives known as planopachromats.

The real Figure-of-Merit for the intended application is the lines per field. Thus, if a lower resolution lens with a larger field can provide a greater number of lines within its field than a higher resolution lens can in its respective field, the first lens is capable of producing better images. The actual field size is a separate consideration.

It was found more pleasing to view document images with uniform resolution over the whole field than to view documents with the same edge-of-field resolution, but with higher center-of-field resolution. Thus, the ordinary lens specifications, which is center-of-field resolution, is not adequate unless it is also a flat field lens. In calculating lines per field, the calculation is best made by multiplying the poorest resolution point in the field times the field diameter.

Microfilm and Microfilm Systems. The testing of the input and output microfilm and the camera- microfilm combination for production of the input microfilm was undertaken by a number of different methods. These included a visual estimate of line patterns just resolved, evaluation by a microdensitometer scan of square wave patterns from test charts, and subjective evaluation of actual document recordings at different reduction ratios.

In general, it appears that resolution claims are exaggerated in the microfilm field. The experiments, and the evaluation of the work of others, indicates that actual results are only about 70 percent to 80 percent of the claimed resolution. A tendency to be somewhat sensitive in this area was related to the fact that, in many cases, the laboratory system was microfilm-limited as far as resolution was concerned.

Because of the limitations inherent in data recorded on microfilm, some emphasis has been placed on the use of a minimum reduction at the original microfilm, e.g., between 8 and 12 times, with a maximum reduction taken at the micro-imaging step. This is to insure optimum output quality. Of course, with higher reductions taken on the microfilm original, the microfilm original definitely tends to become the limiting factor in the system and any image degrading effects of the micro-imaging process are much less pronounced. It is analogous, in essence, to passing a low-fidelity signal through a high fidelity system.

The use of high contrast microfilm was found to be an obstacle except for very special types of documents. This does not mean to imply the micro-image memory cannot handle such microfilm, as it can. Rather, it implies that the output quality of the majority of microfilm systems would be substantially improved if lower contrast film were used. There is no point in having "blacker" blacks and "whiter" whites if a reduced information content results in the hard-copy output. Out studies indicated greater comfort in reading lower contrast copy of higher quality than reading high contrast copy with its attendant loss of detail. In addition, low contrast systems are able to easily handle pictorial data containing gray scales, whereas high contrast systems are not.

High-Resolution Silver-Halide Emulsions. The first thing one notes on working with commercial, high-resolution, silver-halide emulsions is their extreme resolution, better than 1000 lines per millimeter. The second thing noted is their slow speed, or relatively high exposure requirement. It is the price paid for high resolution and makes such emulsions somewhat impractical for use as regular microfilm.

The standard processing of these emulsions leads to high contrast, somewhat of a drawback as noted under the microfilm discussion. Special processing can lead to lower contrast to the extent that even pictorial data can be handled adequately. At least one special emulsion is available with even more desirable properties in this respect.

Studies with high-resolution, silver-halide materials have indicated that excellent micro-images can be supported by them. However, there was no comparison in simplicity and reliability when such emulsions were compared with photochromic coatings for the production of large numbers of micro-images.

The bulk transfer of the photochromic micro-images to the silver-halide emulsions gave excellent silver-halide micro-images as compared to those recorded directly on these emulsions. This transfer process was found reliable and easily accomplished, with the right equipment and techniques. A reverse transfer, photographic-to-photochromic, was also found feasible. The contrast of the photochromic micro-images appears to be well matched to what is required for affecting an optimum transfer.

Silver grain, which is hard to specify quantitatively, was apparent at the reductions taken in these emulsions. The grain was not objectionable and does not seriously affect the hard copy output from the silver-halide micro-images. However, the comparison of a photochromic and silver-halide micro-image through a microscope leads to the choice of the grainless photochromic version. It is best described as just a much more pleasing image without the harshness of the silver-halide version.

PHOTOCHROMIC MICRO-IMAGE MEMORY SPECIFICATIONS

The best estimates of numerical parameters for photochromic micro-imagery obtained from the laboratory studies to date are given in Table II. The "Realizable" columns give estimates as to what can be achieved in the laboratory under controlled conditions, while the "Practical" columns take into account the need for tolerances in practical hardware used by relatively unskilled personnel. The data in Table II is based on the use of a 1.5 millimeter diameter micro-image field.

A somewhat conservative application of the data of Table II to a photochromic micro-image system, produced the specifications as given in Table III. This data is provided only as a general indication of system capability. For special applications, one or more of the parameters might be significantly improved (usually at the expense of some other parameter).

CONCLUSIONS

This paper has described a reversible, light-sensitive material capable of extreme resolution, and techniques whereby this material is capable of storing micro-images at very high packing densities. In addition, the reversibility has been shown to bring into the realm of feasibility a concept of document manipulation which is somewhat analogous to the manipulations of digital data in electronic computers.

The problem of securing permanency of micro-images recorded on a volatile material has been circumvented by a bulk-transfer process to a high-resolution, silver-halide emulsion. Many bulk transfers are possible from the photochromic medium and a great many bulk transfers are possible from the second generation micro-image plane on the silver-halide emulsion.

TABLE II

NUMERICAL PARAMETERS OF PHOTOCHROMIC MICRO-IMAGERY BASED UPON LABORATORY STUDIES

CHARACTERISTIC	PHOTOCHROMIC WORKING MEMORY		
	Achieved	Realizable	Practical
Writing Speed Secs/Field	0.25	0.05	0.1-0.3
Resolution Lines/mm	1000	1400	650-750
Lines/Field	1500	2100	900-1000
Bulk Transfer Secs/ Memory Plane	30	millisecs*	5-10
Processing-minutes	30	20	20
Resolution Lines/mm	800	unknown	500-600
Lines/Field	Transfer 0.8-0.9 of working memory in work to date		

*With high intensity flash sources.

TABLE III

PRELIMINARY SPECIFICATIONS FOR A PHOTOCHROMIC MICRO-IMAGE SYSTEM

CHARACTERISTIC	WORKING MEMORY	PERMANENT MEMORY
Capacity-images	100,000	100,000
Exposure Times-Seconds		
Write	0.3-0.5	15-30/plane
Read	0.005-0.010	0.005-0.010
Erase	0.3-0.5	---
Max. Access Time-Seconds	0.6-0.8	0.6-0.8
Serial Access Time-Seconds	0.002-0.004	0.002-0.004
Memory Plane Size in Inches (With Borders)	16 by 16	16 by 16
Reduction Ratio	200:1	200:1
Maximum Cycle Rates-Images/Hr		
Writing Serially	7200	---
Writing Randomly	4300	---
Reading Serially	36,000	36,000
Reading Randomly	10,000	10,000
Input	Microfilm	Bulk Transfer
Output	Microfilm Bulk Transfer	Microfilm Aperture Cards Television Projection (optical) Hard Copy Printers Polaroid

An Appendix is included to demonstrate the quality of output obtainable from the micro-image store. This Appendix includes output copy from the original microfilm, from the photochromic coating, and from micro-images on a silver-halide, bulk-transfer copy of the entire photochromic memory plane. A direct comparison is then possible between outputs which have been through the micro-imagery process and those directly out of the input microfilm.

ACKNOWLEDGEMENT

The authors wish to thank other members of the National Cash Register Company for their interest and assistance in this program. Special thanks are due to the NCR Fundamental Research Department, Dayton, Ohio for providing the photochromic coatings and data on these coatings. The technicians duties were carried out by Peter Monzo.

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2. G. W. W. Stevens "Microphotography", John Wiley and Sons, New York, N. Y., 1957.

APPENDIX

The reproductions used in this appendix are illustrations of actual results from the micro-image research studies. Figure 8 indicates the points within the overall operation from which the outputs were produced. The enlarged outputs were all made from the microfilm images on a darkroom photographic enlarger. Some loss in quality is expected in the reproduction process used for this publication.

Some detailed data on the reductions and magnifications used can be found in Table IV.

Figures 9, 10, and 11 are quite informative for comparison of the losses experienced at the various steps as the document image moves through the system.

Figures 12 and 13 illustrate a picture containing gray scales and the ability of the micro-image system to handle such images.

Figure 14, a 400:1 reduction at the micro-image level, illustrates that, for ordinary documents, 200:1 reductions are not pressing the resolution limit of the system.

TABLE IV

DATA ON APPENDIX FIGURES

Figure	Reduction		Micro-Image	Magnification	
	To Input Microfilm	Microfilm to Micro-Image	Field Size	Micro-Image to Output Microfilm	Microfilm to Hard Copy
9	12X	-	-	-	11.3X
10	12X	16.7X	0.05"	20X	9.5X
11	12X	16.7X	0.05"	20X	9.5X
12	1/2 frame	-	-	-	-
13	1/2 frame	-	0.06"	14X	5X
14	12X	33.4X	0.025"	40X	8X

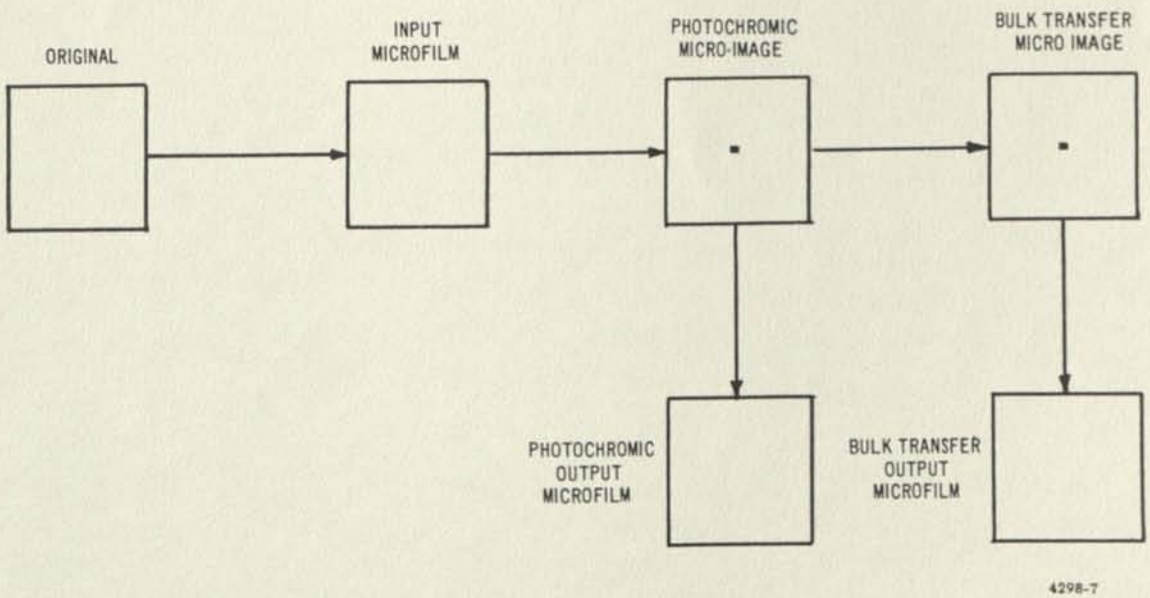
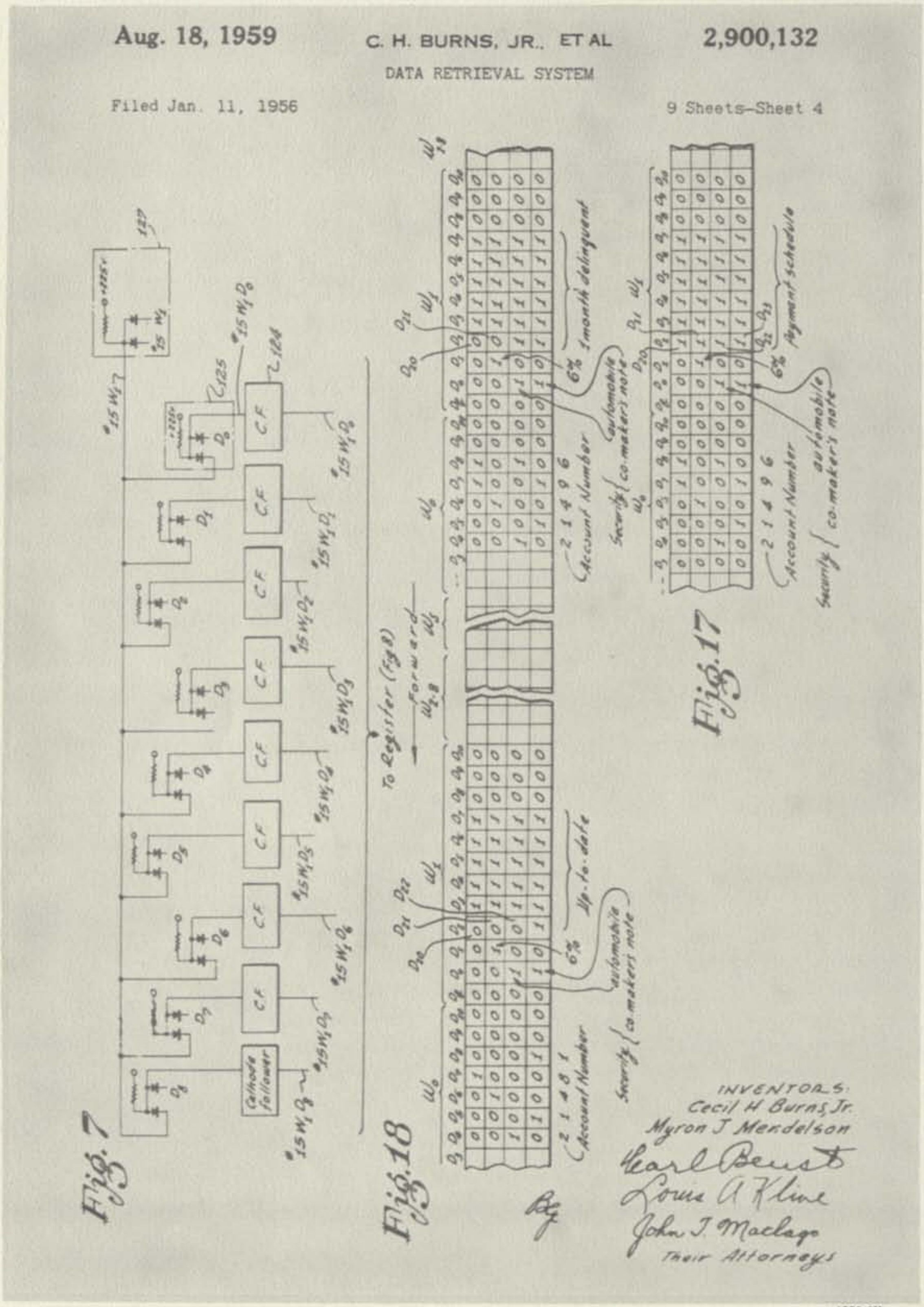


Figure 8. Routes Traveled by Reproductions in Appendix



4298-8N

Figure 9. Reproduction from Input Microfilm

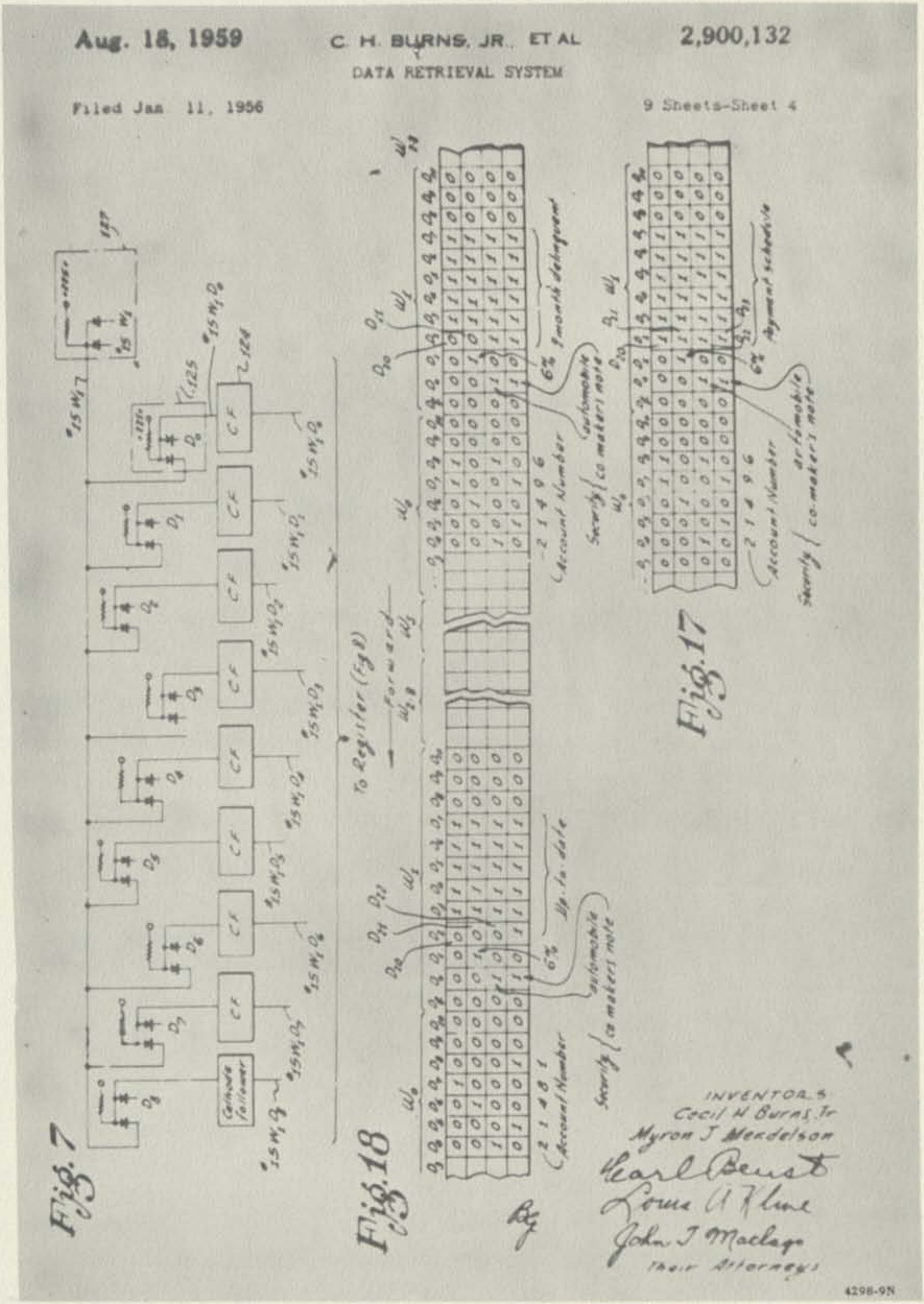
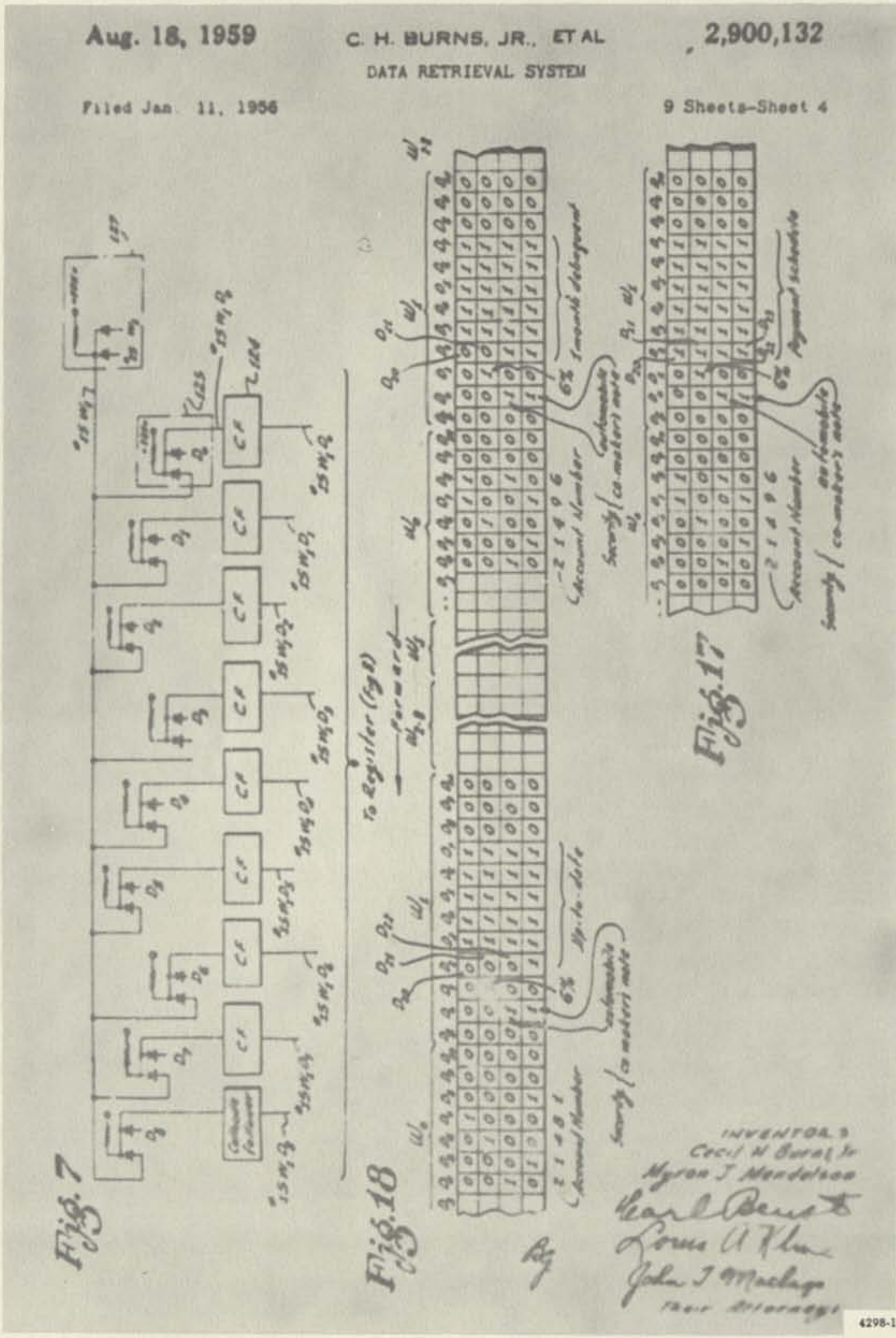


Figure 10. Reproduction from Photochromic Output Microfilm
-200:1 Reduction at Micro-Image



4298-10N

Figure 11. Reproduction from Bulk Transfer Output Microfilm -200:1 Reduction at Micro-Image

4298-11N

Reproduction From Input 35 mm Film

4298-12N

Reproduction From Photochromic Output Microfilm - Micro-Image Dimension, 0.06"

REQUEST FOR VISIT

Date 2 January 1960

TO: John J. Doe
XYZ Corporation
San Francisco, Calif.

Person to be Visited: Sidney Smith

Purpose of Visit: Technical Discussions

Date(s) of Visit: January 15, 1960

	Employee(s)
NAME	Fred Fooley
TITLE	Electrical Engineer
CITIZENSHIP	U.S.A.
ALIEN REG. NO.	
DATE OF BIRTH	20 September 1920
PLACE OF BIRTH	Portland, Oregon
DEGREE OF CLEARANCE	Secret
DATE OF CLEARANCE	15 July, 1953
CLEARING AGENCY	U.S. Air Force

Cognizant Security Agency: Industrial Security Division
Los Angeles Air Procurement District
Bendix Building, 1206 So. Maple Avenue,
Los Angeles 15, California
Phone: Richmond 9-4711, Ext. 1601, 1602, 1603

Contractor Facility Clearance: SECRET, granted 29 March 1956 by
Chief, Provost Marshall Division,
Inspector General's Office
San Bernardino Air Materiel Area
Norton Air Force Base, San Bernardino, California

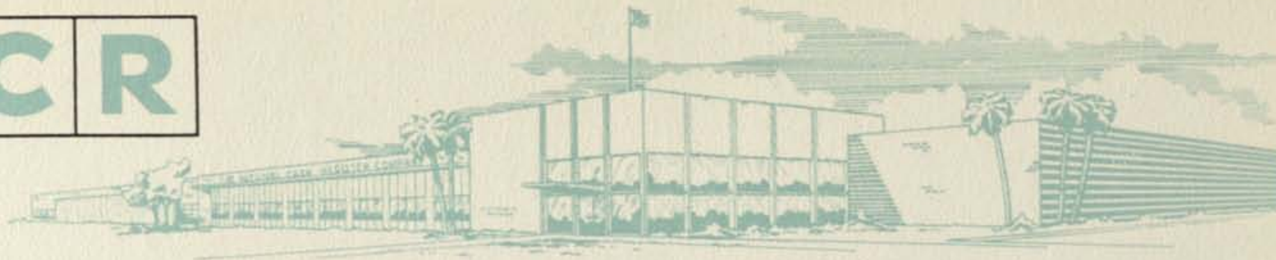
The Contractor hereby certifies that the above statements relative to facility and personnel clearance status are true and correct.

By J. M. Gorman
J. M. Gorman, Security Officer
THE ABC COMPANY
1862 45th Street
Los Feliz, California

4298-13N

Figure 14. Reproduction from Photochromic Output Microfilm -400:1 Reduction at Micro-Image

NCR



ELECTRONICS DIVISION

PHOTOCHROMIC MICRO-IMAGES

A KEY TO PRACTICAL MICRODOCUMENT STORAGE AND DISSEMINATION

By

A.S. TAUBER and W.C. MYERS

Presented at the National Microfilm Association Convention at Washington, D.C., on April 25-27, 1962.

April 1962

THE NATIONAL CASH REGISTER COMPANY

1401 EAST EL SEGUNDO BOULEVARD HAWTHORNE, CALIFORNIA

TABLE OF CONTENTS

ABSTRACT

Recent research and development within The National Cash Register Company has resulted in a new technique for the storage and dissemination of microdocuments. This new technique, Photochromic Micro-Images (PCMI), has made very high-density document storage feasible at linear reductions of 200:1, representing an area reduction of 40,000:1. Features of the PCMI process are described. Next, micro-image system elements are reviewed with respect to their basic functions and potential incorporation into complete micro-image systems. Finally, some potential future applications of micro-images in the fields of document storage and retrieval, libraries, and microform publishing are discussed and explored.

PHOTOCHROMIC MICRO-IMAGES

A KEY TO PRACTICAL MICRODOCUMENT STORAGE AND DISSEMINATION

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Electronics Division
The National Cash Register Co.
Hawthorne, California

INTRODUCTION

Recent research and development within The National Cash Register Company has resulted in a new technique for the storage and dissemination of microdocuments. This new technique, photochromic micro-images (PCMI), (1) has made very high-density document storage feasible on a practical basis at linear reductions of 200:1, representing an area reduction of 40,000:1. Using this technique, it would be possible to record a 300 page book within a square inch of film.

PCMI does not replace conventional microfilm. As a matter of fact, high-quality microfilm is used as the input media. The NCR PCMI process is used to extend the dimensions of micro-storage by an order of magnitude over that available with standard microfilm. In a sense, the process is one of microfilming microfilm.

This paper will have three major parts. First, the PCMI process itself will be described. Next, micro-image system elements will be discussed. Finally, the paper will explore just a few of the potential applications made possible by the future availability of relatively low-cost micro-images which can be easily duplicated and disseminated (or published).

THE PCMI PROCESS

Microfilm technology has existed for more than a century, and it has been possible to make micro-images of documents at a reduction ratio of greater than 100:1 since 1839. (2) However, the practical limitations of straight photographic techniques have discouraged the development of devices capable of producing large quantities of micro-images at these high reduction ratios. To accomplish this implies the laying down of multiple images on a common surface and exposing them individually by some form of step-and-repeat technique.

The major difficulty in using a straight photographic-type process results from the relatively high probability of an error occurring at some point in the process. An error, for example, might be an improperly focused image, or an imperfect microfilm master negative. It might also result from a piece of dirt either in the optical system or upon the film emulsion itself. In many cases it is simply "human error". Basically, there exists no satisfactory inspection procedure to detect, as well as correct, errors before the final development of the master matrix. Therefore, correction of one or more imperfect images would require the re-recording of the entire matrix of images. Experience has shown that the higher the reduction ratio attempted, the more severe the "error problem" becomes.

One of the major accomplishments of the NCR PCMI process is that it not only permits inspection to occur at any step of the process, but it also allows the operator to correct errors. Therefore, by using the PCMI process, it is now feasible to produce original master matrices of micro-images at 200:1 reductions that contain images numbering in the thousands.

What is the PCMI process, and why does it permit such a large jump in the effectiveness of microdocument storage and dissemination above that available with more conventional technologies ?

First, let us take a brief look at photochromic materials. (3) (4) By definition, (5) photochromic compounds exhibit <u>reversible</u> spectral absorption effects (i. e., color changes) resulting from exposure to radiant energy in the visible, or near visible, portions of the spectrum. For example, one class of photochromic materials consist of light-sensitive organic dyes. (6) NCR photochromic coatings consist of a molecular dispersion of these dyes in a suitable coating material. Photochromic coatings are similar to photographic emulsions in appearance and in other properties. They can be made to retain two-dimensional patterns or images which are optically transferred to their surface. They can be coated, in general, on the same types of substrates as photographic emulsions, and they can exhibit excellent resolution capabilities. In addition, both positive-to-negative and direct-positive transfers are possible.

However, photochromic coatings differ from photographic silver-halide emulsions in a number of important respects. The coatings are completely grain-free, low gamma (excellent gray scale characteristics), and exhibit inherently high resolution. The image becomes immediately visible upon exposure and no development process is required. Further, because the coatings are reversible, the information stored can be optically erased and rewritten repeatedly.

The image appears when the individual molecules are switched from either the colored or the colorless state by radiation (light) of the proper wavelength. All of the NCR coatings now in use switch to the colored state when near ultraviolet radiation is used. Switching to the colorless state can be accomplished by using either heat or visible light of the proper wavelength.

Information stored on photochromic coatings is semi-permanent in contrast to developed photographic film which is relatively permanent. This is a result of the reversible nature of the photochromic coating. The life of the photochromic micro-image is dependent upon the ambient temperature of the coating. At room temperature, image life is measured in hours, but as the temperature is lowered, life can be extended very rapidly to months and even years.

Obviously, this temperature-dependent decay of image life prohibits the use of photochromic micro-images in their original form for archival storage. To overcome this problem, means have been developed for transferring the photochromic micro-images to a high-resolution photographic film. This transfer step is a simple operation and results in permanent micro-images.

Mechanization of the NCR PCMI process is simple in principle. The original document is first transferred to high-quality conventional microfilm. Properly filtered, near-ultraviolet radiation is directed through the transparent microfilm and into the micro-image optics. This forms a miniature image on the photochromic coating. Consider, for example, a photochromic plate 3 x 5 inches in size. The size of each micro-image would be 0.0425 x 0.0550 inch, so that a matrix with up to 2,625 micro-images could be placed on each 3 x 5 plate.

When all of the micro-images are formed, and have been properly inspected to see that no errors have been made, the entire contents of the photochromic plate are then transferred in one step as micro-images to a high-resolution photographic film by contact printing. The photographic film is then developed under highly controlled conditions, and the result is a 3 x 5 photographic micro-image master plate.

This 3 x 5 photographic micro-image master can then be used to perform a most important function. It can be used to "publish" any desired number of duplicate 3 x 5 micro-image cards by using a contact printing process, again upon photographic film. Using photographic film provides image permanency as well as potentially low-cost dissemination.

MICRO-IMAGE SYSTEM ELEMENTS AND CONSIDERATIONS

Micro-image system elements and supplies can be broadly classified into two groups. One group consists of the elements and materials required to produce the micro-images, while the other group contains those items involved in the use of micro-images.

The most important system element in the first group is called the PCMI Camera-Recorder. (See Figure 1.) Reels of 35 mm, high-quality microfilm serve as the input media for the PCMI Camera-

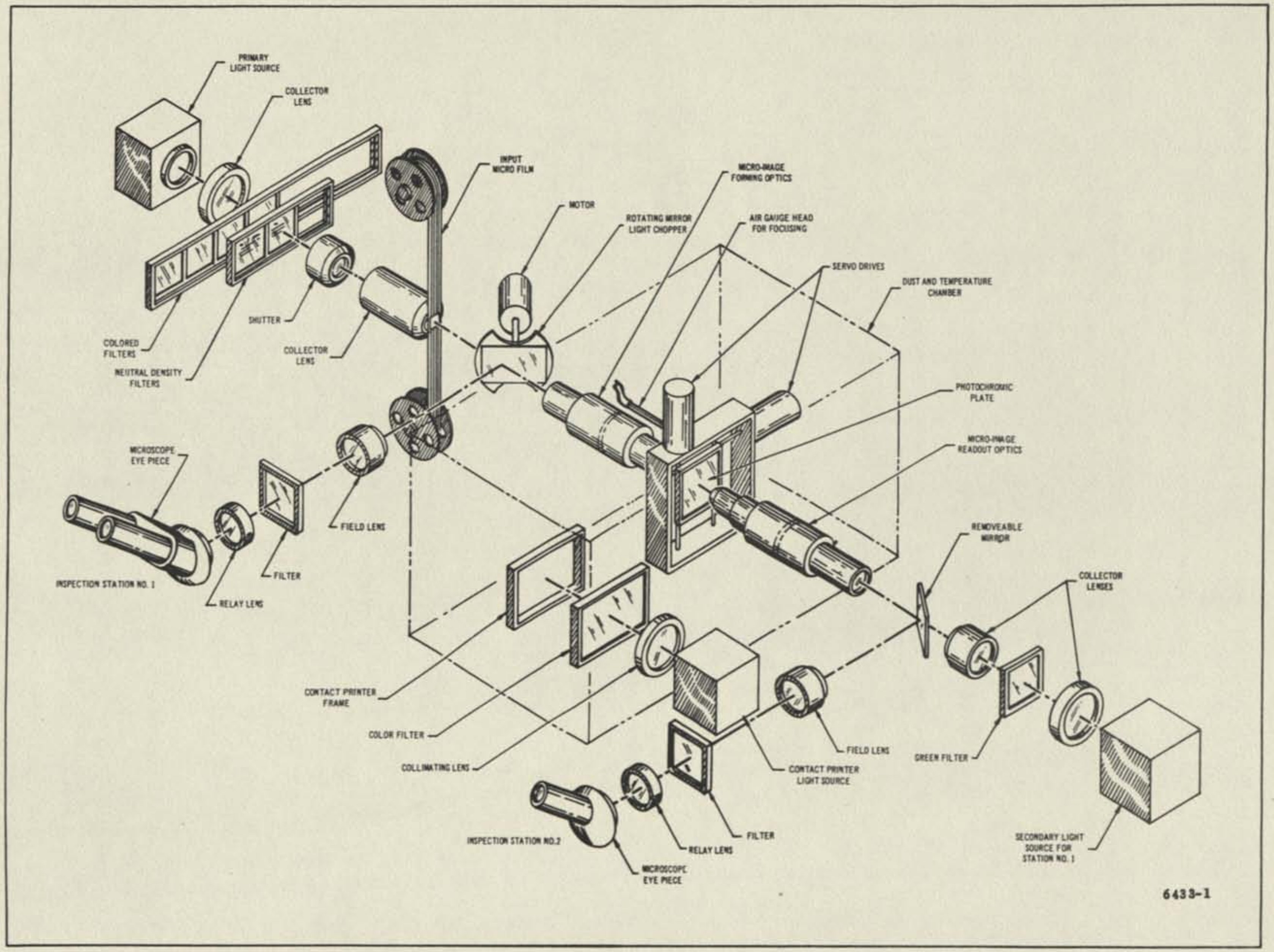

Figure 1. PCMI Camera-Recorder.

Recorder. As can be seen in Figure 1, the photochromic film is enclosed within an environmental chamber.

This chamber maintains the ambient air temperature below 0° and also filters out all dust particles above one-third micron in size. The micro-image focusing optics can be adjusted by a specially designed air gauge to an accuracy of ± 15 μinches. Field diameter of the micro-image is 68 mils.

Micro-images are recorded upon the photochromic film in a step-and-repeat manner. Consecutive pages are written in a horizontal line. The images can be either continuously inspected during the recording process, or the Camera-Recorder can be placed in automatic operation with inspection occurring at a later point in the process. Before the contents of the photochromic film are printed out, a thorough inspection can be made, if desired, to detect any errors that have occurred. Errors are then simply corrected by erasing the imperfect image and rewriting it on the photochromic film.

After a perfect micro-image matrix has been prepared on the photochromic film, the next step of the PCMI process is a bulk transfer of this PCMI matrix to a high-resolution photographic film by contact printing. This procedure also takes place within an environment of dust-free air.

Figure 2 is a view of the laboratory breadboard model used to make the first 200:1 micro-images by means of the NCR photochromic process.

For micro-image systems which have a need to store the PCMI master plate, an off-line refrigerated file is provided. For example, such systems might require periodic updating of portions of the original file. Therefore, it might be more economical to keep the original PCMI master plate, and when necessary, erase only those micro-images that need to be replaced, instead of preparing an entirely new PCMI master each time an updating is required.

Still another important system element used for producing micro-image cards is the off-line contact printer. Input for this unit is the photographic micro-image (PMI) master film prepared by the PCMI Camera-Recorder. High resolution photographic film is used as the output media of this unit. The off-line contact printer performs the important job of micro-image publishing mentioned earlier in the paper. This unit makes low-cost dissemination of micro-image cards possible.

Of all the system elements which might be required to use micro-image cards, the most important unit is the micro-image viewer or reader. It is expected that eventually there will exist a family of micro-image viewers from which to choose. Viewers might range from manually-operated, desk-top models to semi-automatic consoles. Choice will, of course, depend both upon the complexity of the specific micro-image system involved and the particular user's requirements or needs.

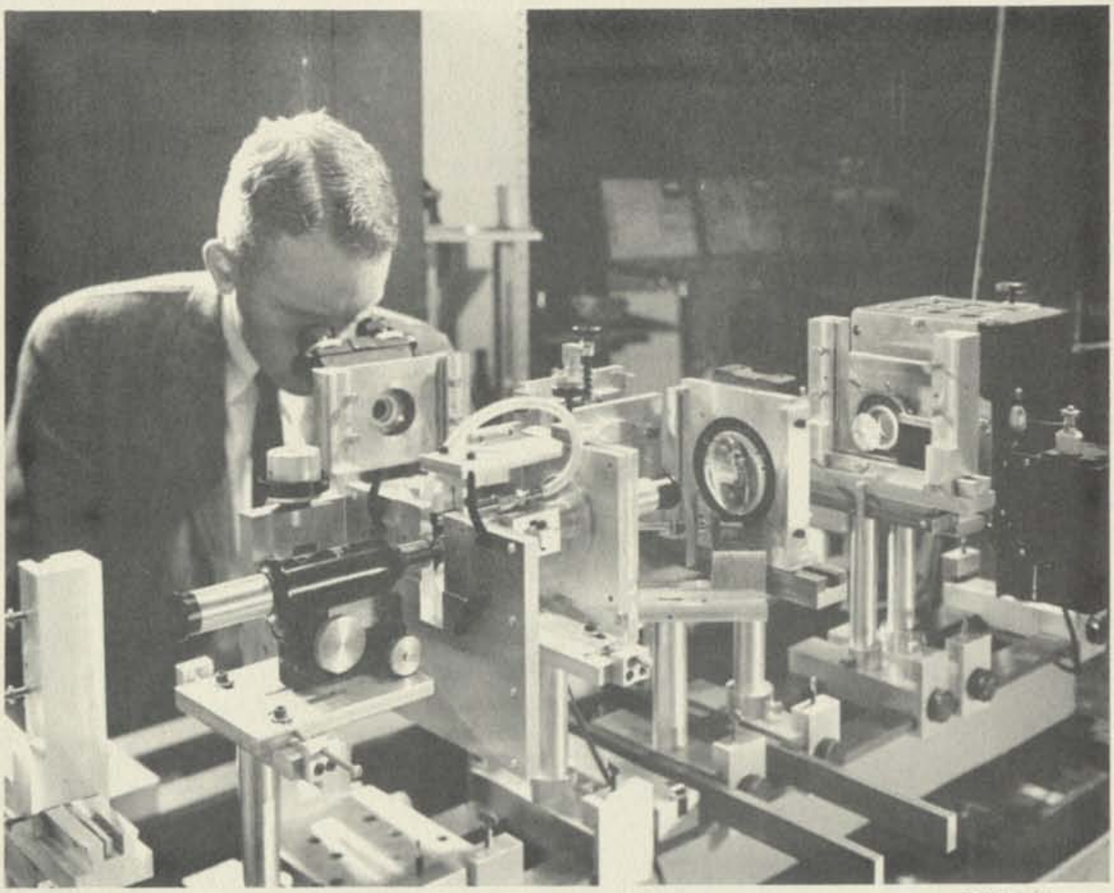
2474-1

Figure 2. Research Breadboard Model of PCMI Camera-Recorder

As with many microfilm systems in use today, there will also be a requirement for hard copy print-out of enlarged micro-images. This will be accomplished by combining both viewing and printing into a dual-purpose unit called a micro-image Viewer-Printer.

The final element needed to complete a micro-image system will be a file. As an example, if 3 x 5 inch cards have been chosen as the basic unit media of the micro-image system, then, chances are, all that will be required is a simple, manual 3 x 5 card file cabinet. Consider the fact that a file of one million document pages could be stored in micro-image form (at 200:1 reduction) on less than 400 three by five cards. This represents a stack of cards about four inches high. For so few cards it would be very difficult to justify the expense of automatic retrieval equipment. Of course, each micro-image system application would have to be analyzed and system engineered for its own specific requirements. Figure 3 summarizes the micro-image system elements that we have just described.

From the previous discussion of the various system elements used to produce and use micro-images, it can readily be seen that a high degree of system flexibility is available to the potential user.

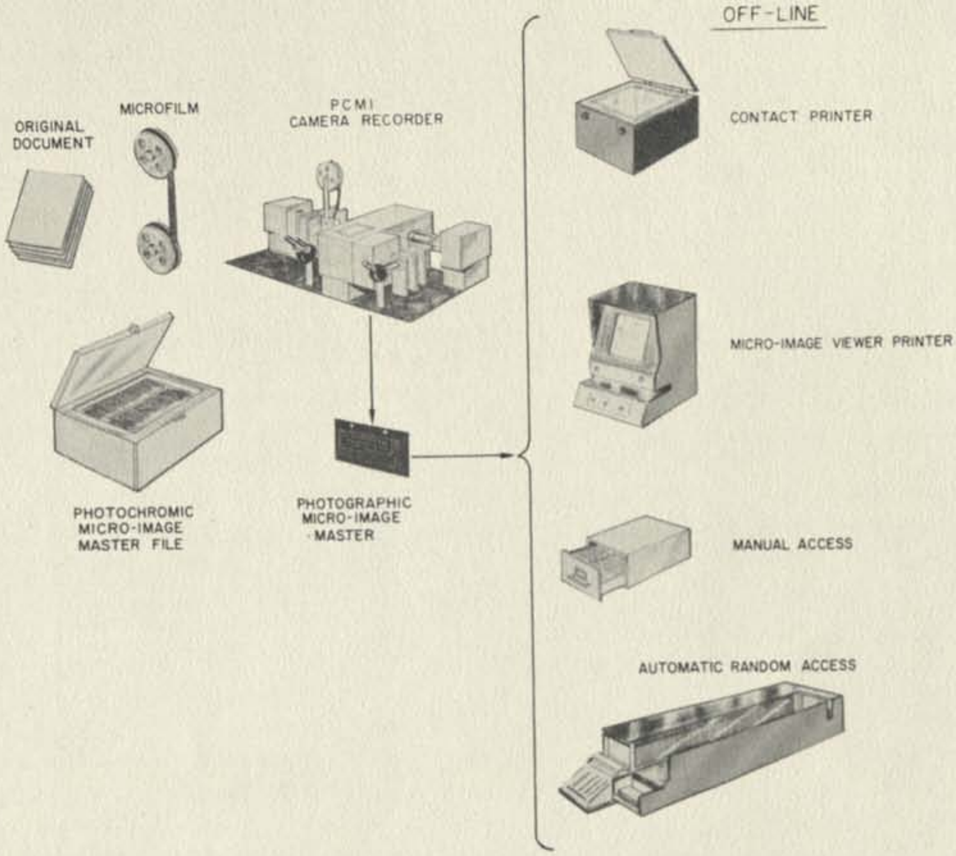

Figure 3. Micro-Image System Concepts

Since each application will vary in the size of its file, the frequency of its activity, the retrieval complexity of its search questions, and the requirements for human-file interaction, there turns out to be no typical user.

A preliminary analysis indicates that only a relatively small percentage of potential micro-image users would need to acquire a PCMI Camera-Recorder. The great majority of users would probably find it much more economical to obtain at least their photographic micro-image master cards from a PCMI service center. It is not at all unreasonable to expect that today's dealer in high-quality, volume microfilming will become the micro-image supplier of the future.

Because PCMI storage and dissemination systems readily lend themselves to a modular approach, the potential user can exercise considerable freedom of choice in his system component selection. This provides the possibility of continuous equipment compatibility with micro-image system growth.

SOME POTENTIAL APPLICATIONS OF MICRO-IMAGES

Except for the most trivial cases, almost any document storage, dissemination, or retrieval problem lends itself to potential mechanization by a micro-image system. An examination of the information retrieval (IR) field has led us to the conclusion that the original document, or its facsimile in the form of either microfilm or micro-image, will almost always be required.

Let us next consider a few potential applications for micro-images. First, we would like to look at the duplicating library concept proposed by Dr. Heilprin, (7) (8) of the Council on Library Resources. Dr. Heilprin drew the following distinction between the present circulating library, and the duplicating or "D" library of the future. In the circulating library, material is in conventional form, and normally it physically circulates in and out of the library. In a "D" library of the future, material would be stored on "microform" masters. Dissemination of material would be one way, i. e., non-returnable. Duplicates of the "microform" masters would be expendable.

Very little imagination is required at this point to see the potential application of NCR's micro-image technology to Dr. Heilprin's "microforms" and the "D" library of the future. For example, the "D" library could be stored on 3 x 5 micro-image cards. At a 200:1 reduction ratio, each card could contain from eight to ten average-size books. This represents approximately one square inch of micro-images per book. Anyone requesting a book could have it duplicated in micro-image form from the master micro-image card on file at the "D" library. It is expected that this could be accomplished on demand while the user waited. Further, full-size, hard copy print-out from the micro-image master could also be made available to the user if the need arose.

By using PCMI technology, every branch library would have the potential of maintaining as large a collection as the main library. Reservations would no longer be necessary for the more popular books. In a "D" library only one master copy of the original material would have to be stored, but this master copy would be in a form suitable for easy duplication. The master copy would never circulate or leave the library since user requests would be filled by duplicates which would be expendable.

Simple, potentially inexpensive duplication at the micro-image level, using contact printing techniques made possible by PCMI, offers an entirely new dimension to the high-density storage process. Dr. Heilprin calls this new dimension multiplication! (8) Further, he states that, "This degree of freedom has vast implication for the replenishment of lost and destroyed libraries in underdeveloped areas, and the interchange of collections of files." (8)

Perhaps the most serious problem remaining to be solved before the duplicating library can become a reality is not a technical one at all but the legal problem of copyright. This legal problem must be resolved on an equitable basis for both the author and the original publisher.

This leads into the next potential application area for micro-images we would like to review, namely, the publishing of scientific, professional, and academic publications. A significant, as well as pertinent, current trend in this field is index publishing. In parallel with index publishing is the need for publication of the document set being indexed as a microform. A recent manifestation of this trend is the publication of the Thomas Register Micro-Catalog in conjunction with the Thomas Register Index to manufacturers.

Index publishing is being actively sponsored by many professional societies. For example, in 1961 the American Institute of Chemical Engineers set up a standard for indexing articles of permanent value that appear in all publications of the Institute. Magazines in the chemical industry such as Petroleum Refiner and Chemical Engineering Progress are publishing the index terms for each article which is arranged for convenient reproduction by photocopying. Similar programs are also in operation by the American Society for Metals, the American Institute of Electrical Engineers, and the American Chemical Society. Another example of index publishing is a program sponsored by the Council on Library Resources called Project Law Search.

The importance of this current work in indexing is related to the fact that the information retrieval problem is a very complex one. For example, the ability to economically and reliably produce, store, and duplicate micro-images does not represent the complete answer. Adequate techniques for indexing and searching the micro-image file must also be worked out. However, as the examples just cited indicate, indexing techniques can be developed for document retrieval which are relatively independent of the document storage approach employed. In one sense, indexing and document storage are complementary problems.

Because of the enormous expansion of published material, increasing publishing costs, and rapidly rising library expenses for the storage and later use of this material, there is an increasing need for some type of microform publishing. One approach that might be considered would be to publish and disseminate a book or journal in micro-image form. One potential advantage of this approach to publishing is that it would provide publishers and authors with the economic freedom to publish greater amounts of information. A most interesting example of a current journal that is being successfully published in microform is Wildlife Disease. During the past few years this publication has increased its number of subscribers and has demonstrated the feasibility of microform publishing. Another significant point is that microform publishing has made possible a journal that previously could not be supported in a conventional printed form because of the very limited number of subscribers. It is entirely conceivable that in the future publishers will offer books and journals in both conventional and micro-image form.

Still another potential area of application for micro-images is on-demand printing. Today, various organizations, such as the National Library of Medicine, ASTIA, and the United States Patent Office, have to provide the means for handling a considerable amount of mail-order requests for documents. Copies of documents from very large collections have to be supplied within a relatively short period of time. Activity rate, defined as the number of pages retrieved per day divided by the total number of pages in the file, is very low, on the order of one-half of one per cent. It seems reasonable to expect that economic, as well as storage space, pressures will eventually force the conversion of present systems to some type of microform system. The kind of duplication, or re-creation, of the original document that would be used for dissemination would depend upon system factors such as the type of microform used for storage and the needs of the user.

NCR micro-image techniques, as discussed in this paper, offer some interesting possible solutions to this problem. One possibility would be to store the entire document collection on 3 x 5 micro-image master cards in a system configuration that would provide the amount of retrieval required. Further, if you will recall, it was pointed out that the ability of the PCMI process to easily duplicate micro-image cards by contact printing provides a new system freedom--that of document dissemination. Therefore, another possibility would be to consider the decentralizing of large document collections to various regional areas. Of course, detailed system studies would have to be made in each case to determine the relative advantages and disadvantages of decentralization over the centralized file. However, the important factor is that PCMI techniques permit the possibility of decentralizing large master document files. The economics of more conventional storage and dissemination techniques almost automatically preclude this possibility.

In 1945, Vannevar Bush presented the documentation field with the concept of Memex. (9) He envisioned Memex as a possible future device comprising a sort of mechanized private file and library for individual use. Memex was to be a desk-type unit equipped with a viewing screen and a selection keyboard. It could store on film, at reductions of 100:1 or better, a tremendous volume of books, journals, newspapers, correspondence, notes, and photographs. In addition, the unit would have an indexing tool that would allow the user to locate the stored material.

The combination of NCR's micro-image techniques for document storage and interrogation units tied into a central computer to provide indexing capability comes close to achieving the original Memex concept. Theoretically, at least, it is now possible for every user to obtain every document in his field of interest in micro-image form so that it can be easily stored, retrieved, displayed for viewing, and reproduced in enlarged form as hard copy when desired.

SUMMARY AND CONCLUSIONS

Before concluding this paper, we would like to briefly review the most important characteristics which make NCR's micro-image technology unique in its field:

1. Photochromic films provide very high resolution with no grain.

2. Photochromic films permit the storage of images containing a wide contrast of gray scale because they are inherently low gamma and grain-free.

3. Photochromic films provide immediate visibility of the image upon exposure. No development process is required.

4. Photochromic films provide both erasing and rewriting functions. This permits the powerful processes of editing, updating, inspection, and error correction to be incorporated into systems.

5. The PCMI process incorporates the ability to effect a bulk-transfer read-out of micro-images at the 200:1 reduction level by contact printing.

6. Use of high-resolution silver halide films provides both permanency for the storage of micro-images and economical dissemination of duplicates.

7. The very high density of 200:1 micro-images offers the possibility of using some form of "manual retrieval" techniques for many applications. This eliminates the normal requirement in systems of this size for expensive and complex random access hardware.

In conclusion, we would like to propose that NCR's micro-image technology offers the following new horizons to the microform business of tomorrow:

a. It offers many fascinating system possibilities to the infant storage and retrieval field.

b. It offers, among many other advantages, the powerful new system freedom of document dissemination and file decentralization to the libraries of the future.

c. It offers scientists, scholars, and professionals in all intellectual fields many advantages from new technologies such as microform publishing and perhaps even their own personalized form of Vannevar Bush's Memex.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the many helpful discussions and criticisms of this paper by other staff members of NCR. In particular, they would like to thank Carl Carlson, Ty Abbott, Sam Lebow, and Henry Kent. The authors would also like to acknowledge the important role in this program of Lowell Schleicher and his staff at the NCR Fundamental Research Department in Dayton, Ohio. This group has supplied us with the photochromic coatings used in the PCMI process, and has also provided us on many occasions with valuable research back-up.

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POTENTIAL MARKETS FOR PCMI IN MICROFORM PUBLISHING AND LARGE FILE APPLICATIONS

Prepared for:

ELECTRONICS DIVISION
NATIONAL CASH REGISTER COMPANY
HAWTHORNE, CALIFORNIA

March 1963

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SRI Project No. IE-4239

Approved:

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H. E. ROBISON, DIRECTOR
INDUSTRIAL ECONOMICS DIVISION

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I INTRODUCTION

The National Cash Register Company, long a major supplier of many types of office machines, is developing a unique high resolution, high density photographic technique for storing, retrieving, and disseminating both written and graphic information. The technique, called "photochromic micro-image" (PCMI), uses the special characteristics of certain photochromic dyes as a storage medium. These materials change color when exposed to light; are immediately visible upon exposure; can be edited, erased, and reused; and have high resolution.

As presently envisioned, images in microfilm form would be reduced further and recorded on photochromic plates. The unique reversibility characteristics of the photochromic material would allow the images to be corrected for errors , erased , and rewritten if necessary. In order to preserve the photochromic images, the film containing the photochromic dyes must remain at a low temperature (approximately 0^{o} Centigrade). Permanent copies of the film images may be made by contact printing with conventional silver-halide film using standard photographic methods. The permanent copies may then be placed in equipment which will permit selection and viewing of a specific image as well as reproduction of the image, if desired, in the form of a hard copy print-out.

Prior to the research documented in this report, the National Cash Register Company (NCR) developed laboratory equipment for use with the PCMI materials and also undertook a project to build an experimental viewer for a Navy parts catalog system. The company also explored to a limited extent potential markets for PCMI systems. In addition, company announcement and institutional-type advertising had evoked considerable interest from a variety of sources. After completing these preliminary programs in the development of PCMI, NCR asked Stanford Research Institute to undertake this study to assist the company in determining classes of potential applications and the nature of the market for PCMI systems.

Objectives and Scope

The basic objective of this study was to determine the nature of the potential market for general purpose PCMI systems being developed by NCR for use in the storage, retrieval, and dissemination of information. Specific objectives were to:

1. Categorize and describe the functional requirements of major classes of applications that appear to be potential markets for the systems.

2. Estimate the present potential U.S. market for this system, including the market for camera recorders, contact printers, viewers, and viewer printers.

3. Estimate the present potential annual market for the photochromic film and hard copy papers used with this system.

4. Describe additional products that may be desirable, in addition to the above, to fulfill the market needs of potential users.

5. Indicate the effect of variations in the pricing and performance of equipment and materials upon the market potential.

6. Describe the type of market organization that could effectively distribute this system to potential users.

7. Describe the principal competing document storage and retrieval systems and indicate their relative importance.

At the outset of this project, it was mutually agreed between the project team and the NCR staff that the study would concentrate on obtaining information in two major application areas--microform publishing and large files for document storage. Applications investigated in the microform publishing field included publications for the general public, such as books, theses, periodicals, and newspapers; and publications for restricted user groups, such as technical reports of NASA, AEC, and ASTIA, catalog applications; and on-demand printing applications.

Large document storage file applications studied included examples of both high activity and low activity files. High activity files contain documents that are used as part of the current business operation, such as in retail sales, credit agencies, and personnel records. Low activity files consist of documents kept for legal or historical use, such as in banks and insurance companies.

In addition to the two major application areas mentioned above, it was mutually agreed that a brief examination of possible applications for PCMI in the areas of military command-control systems and photo-etching would be worthwhile.

Specifically excluded from the scope of this study was the use of PCMI in the storage or reproduction of engineering drawings, in office and convenience copying, in the graphic arts, in photography, in image storage or processing in computers, in dynamic displays, and in long- or short-line data transmission. The potential use of PCMI in applications that would require custom-designed equipment were identified only as they were uncovered during the course of the research aimed at investigating potential classes of application in microform publishing and large-file storage.

Method of Approach

The project team first made a literature search covering the fields of document storage, retrieval, and dissemination, with emphasis on current techniques and problems. Attention was then turned to the results of NCR's research in PCMI techniques, which included both the development of a general PCMI technology and the design of a specific system using this technology. The relationship between the general PCMI technology and the specific system design embodying this technology is shown in Figure 1.

The general characteristics of the PCMI technology (left-hand box, Figure 1) were used to help determine which application areas should be studied, while the characteristics of a specific PCMI system (right-hand box, Figure 1) were used as a basis for analyzing the suitability of PCMI for specific application areas. Product engineering (center box, Figure 1), which relates the characteristics of the PCMI technology to a specific PCMI system design, although important, was not a part of this study.

Thus, the research did not attempt to prescribe what equipment design was most capable of matching PCMI technology to the requirements of specific classes of potential applications for the technology. The research could only attempt to uncover those applications that were suited to the characteristics of the PCMI system specified by NCR. From the analysis of the PCMI technology, the list of potential application areas that were to be investigated during the study was compiled and was mutually agreed upon by SRI and NCR.

A contact list consisting of representative organizations for each application area was then drawn up by the SRI project team and reviewed with the NCR staff. Organizations to be contacted were selected on the basis of two criteria: (1) Were the problems of the organization representative of the application area under study? and (2) Was the organization progressive enough to have become aware of its own problems and of

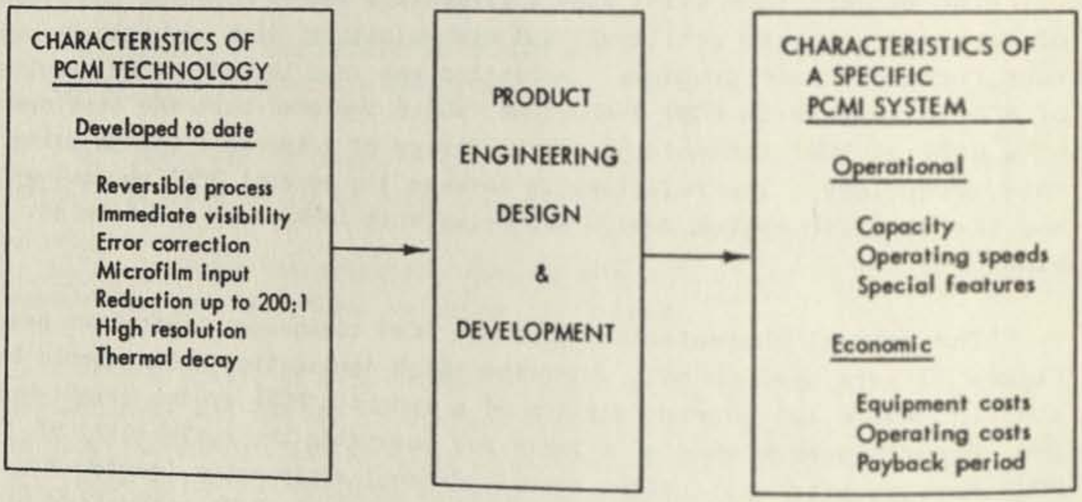

FIGURE 1

RELATIONSHIP BETWEEN GENERAL TECHNOLOGY
AND A SPECIFIC SYSTEM

possible methods for solving them? The purpose of the field interviews was to obtain as complete information as possible from well-informed sources, rather than to generate a large amount of data solely for statistical analysis.

An effort was made to contact people within the selected organizations who were at a level of management where both technical and economic aspects were equally considered. Thirty-seven interviews were conducted. They lasted from a quarter of an hour to several hours, depending upon the willingness of the interviewee to discuss the subject and the amount of information he made available. A considerable part of each interview was spent in obtaining a description of the user's requirements and problems, as well as in obtaining his reactions to both the general PCMI concept and the specific system proposed.

The PCMI system design proposed by NCR as shown in Appendix C was used as a basis for analyzing the relative suitability of PCMI for the application areas investigated. In order to conduct a meaningful analysis, it was necessary to use specific data supplied by NCR on the proposed PCMI system's cost and performance. Wherever possible, parametric curves have been drawn to show the effects of varying these system parameters.

Acknowledgements

The study was administered in the Institute's Industrial Economics Division. Research on the potential uses of PCMI in the field of microform publishing was conducted by Charles Bourne of the Systems Engineering Department. Research on the potential application of PCMI to large document files was conducted by Arthur Dana, Jr., who also served as project leader. Administrative assistance and guidance were furnished to the project team by Richard Randall and Allan E. Lee.

Outstanding cooperation was received from the members of the staff of NCR in providing information on the development of PCMI technology and systems and on the applications investigated for their use. The generous amount of time and effort given by Mr. W. C. Myers, Mr. S. Lebow, Mr. T. Abbot, and Mr. C. Carlson in assisting the research team was particularly appreciated.

II SUMMARY AND CONCLUSIONS

Present Market

The PCMI technology, as presently developed by NCR, exhibits several unique and dramatic characteristics, such as reversibility, high resolution, and high reduction. However, based upon the findings of the research, it is estimated that there is no market at present for the present PCMI system in the fields of general microform publishing, on-demand printing, or large files for document storage. These findings are directly attributable to the inability of the present PCMI system to meet the minimum operational and economic requirements of users in these fields.

The research did uncover one potentially attractive but limited special application area for PCMI--that is, large-volume catalog or other publication systems having annual requirements for providing approximately 2,000 copies of 400,000 pages each. These are unusual requirements and there appear to be only a few applications of this type. On the basis of these findings, it is estimated that the annual market potential for the present PCMI system is either 0 or $4 million,* depending upon whether one large-volume catalog application suitable for PCMI can be identified and sold.

The U.S. Navy Bureau of Supplies and Accounts (BuSandA) application is the only potential one that was identified during the research. However, the reason for estimating that PCMI would be the most suitable method for BuSandA was based upon an analysis of operating costs for four alternative methods (paper, Microcard, Recordak, and PCMI) of implementing catalog systems. The estimate did not consider other factors such as compatability with other systems, cash flow, investment required, maintenance, and reliability, which may be overriding, or other alternatives such as teletype communications, which may be more attractive. Thus, further investigation of the BuSandA application is needed before the likelihood of selling a PCMI system can be predicted. However, if one large PCMI catalog system were sold, its sales value of $4 million would represent approximately 20 percent of the annual value of the existing microform equipment market.

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* Based upon 1 camera-recorder, 2 printers, and 2,000 viewers.

Microform Publishing

Microform publishing is a modest but growing field, with an estimated total annual sales of $5 million. Most of the work is done by five major organizations. Expansion of the market is hampered by the unpleasantness associated with the use of microform readers and restrictions of current copyright laws.

The present PCMI system is the least economical of the four major systems studied* for publishing and disseminating information (except for the special case already mentioned). For most applications, the relatively high cost of the PCMI viewer keeps the system from being competitive with other alternatives. In addition, the present PCMI system's high reduction ratio (200-to-1) conflicts with a user desire for a single viewer, compatible with industry standards (in the range of 20-to-1 to 30-to-1), which would allow him to view microform material from many sources.

The present PCMI system is not competitive with Xerox Copyflo or other equipment now being marketed for on-demand printing applications, because the cost per page for the PCMI system is roughly double that of competing systems.

Large Files for Document Storage

Users of large files for document storage have four basic operational requirements, which can be stated in terms of activity rate, access time, update cycle time, and unit record size. For high activity files the present PCMI system satisfies two of these requirements (activity rate and access time), but fails to meet minimum requirements for the other two (update cycle time and unit record size). The update cycle time achievable with the present PCMI system is too long by a factor of roughly 25. This is crucial, since the length of the update cycle limits the timeliness of information in the file. By comparison, the present PCMI unit record size (too large by a factor of roughly 5) is a minor problem.

Even if the present PCMI system could be redesigned to meet the basic operational requirements, the system would still have a longer payback period (from 2 to 10 times longer) than that of other competing high

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* Paper, Microcard, Recordak, PCMI. The cost of the viewer in the cost of the Microcard, Recordak, and PCMI systems was included in the analysis.

activity file systems, making the PCMI system economically unattractive to the user.

The present PCMI system meets the major operational requirements of low activity file users but has a longer payback period (from 4 to 10 times longer) than other competing low activity file systems. This effectively prevents entry of the present PCMI system into the low activity file market, where a premium is placed on low cost.

In both cases (high activity and low activity), it is the high cost of conversion of the present PCMI system (4 to 12 times that of competitive systems), which is caused primarily by the need for specially processed microfilm input, that raises the total system cost to an uncompetitive level. In addition, the need for special precautions (e.g., silver-halide reprints, special handling) due to thermal decay of the PCMI image in the present system makes the cost and complexity of updating in a high activity file unacceptably high.

Other Applications

The market in the photo-etching industry for photochromic materials is estimated to be quite small (a maximum of $50,000 per year) in relation to the extensive development work needed to meet the custom requirements of this application.

So far as this research effort was able to determine, there is no general class of military command-control applications suitable for the present PCMI system. In the foreseeable future, the basic requirements of military command-control systems appear to be for digital storage (i.e., binary information) rather than document or graphic storage.

III MARKET INFORMATION

It was not possible to assemble market data directly related to applications suitable for the present PCMI system since, with the exception of large-volume catalog publication, no application was found for the present PCMI system in microform publishing and large files for document storage. Further exploration of the large-volume catalog market would require identifying individual potential customers, and thus would involve a magnitude of field work beyond the scope of this study.

It was possible, however, to gather information on the size of the present and potential microform publishing industry and upon present and potential applications for large file storage systems, as an indication of the number and magnitude of future potential markets in these two areas. This information is discussed below under the headings Microform Publishing and Large Files for Document Storage. Information on the present market for microform equipment, supplies, and services was also gathered, as well as a description of the competitive structure of the market. Both are discussed in this section of the report to provide insight into the resources, product lines, and marketing efforts that companies have found to be necessary for the successful development of these markets.

Microform Publishing

There are currently about 45 U.S. organizations that could be called microform publishers for the general public (see Appendix A). However, only a few of these can be considered to be actual microform printers. Also, most of them represent very special and narrow subject interests (e.g., a single publication, or the literature of a very narrow subject area) and are relatively small contributors to the microform publishing business. In terms of their volume of publication business, the major ones are the five described in Table I. The total U.S. microform publishing business is estimated to be a maximum of $5 million per year and is less than 1/2 percent of the total U.S. book publishing business (which is an estimated $1.129 billion per year).

In addition to microform publication for the general public, there is some microform publication for a restricted group of users. Current examples are the reports published in microform by the AEC, NASA, and

Table I

MAJOR U.S. MICROFORM PUBLISHERS AND PRINTERS

Organization	Estimated Annual Sales	Estimated Value of Fixtures and Equipment	Estimated Number of Employees
University Microfilms, Inc. (Div. of Xerox Corp.)	$1,860,000	$200,000	110
Micro Photo, Inc. (Div. of Bell & Howell)	1,000,000	100,000	60
Microfilm Service and Sales Co.	220,000	25,000	11
Microcard Editions, Inc.	200,000	n.a.	n.a.
Microcan, Inc. (affiliate of J. S. Canner & Co., Inc.)	100,000	20,000	n.a.

n.a. = not available.

ASTIA, and the manufacturers' catalogs and part specifications published in microform by Thomas Publishing Co., Vendor Specs Micro File, and the Army Missile Command (see Table II). A few other organizations are actively considering the possibility of publishing in microform. The important point to be made here is that the number of such organizations is relatively small, and most of them are having their work done for them by the printers and publishers listed in Appendix A.

Large Files for Document Storage

Although there has been a great deal of publicity during the past seven years about the development of large mechanized file systems, only a few of these have been sold to date. Table III shows an estimate of the sales of large mechanized retrieval systems since 1955. Two systems, Minicard (5 sales) and WALNUT (1 sale) account for 75 percent and 15 percent, respectively, of the roughly $6.75 million total sales over the seven-year period, and the remaining systems shown in the table account for the other 10 percent of total sales. In any case, the average annual market for the seven-year period is something under a million dollars.

There have been at least 10 manufacturers that have marketed large mechanized image systems, some of them for over five years. However, since 1958, the total number of these units sold in the United States has been just a little more than the total number of manufacturers. Many suggestions or hypotheses can be made as to why this kind of equipment has not been more commercially successful, and the suggestions seem to be directed toward three equally important areas: system economics, performance characteristics, and customer service.

With regard to system economics, it seems that in most cases, there are alternative approaches that are economically more attractive than mechanized image systems. This is partly due to the relatively high cost of the mechanized equipment, but it is also due in large measure to the high conversion and operating costs of mechanized systems. For some of the large manual file systems currently in operation, for example, conversion costs would be on the order of a million dollars--mainly to develop the data base needed for a mechanized system. There do not appear to be many applications that can show a direct cost saving that would justify the change-over to a mechanized image system.

With regard to performance characteristics, there appear to be a limited number of users that could use the presently available mechanized equipment--even if it were given to the user free of charge. This is

Table II

EXAMPLES OF MICROFORM PUBLICATIONS FOR RESTRICTED GROUPS OF USERS

Publications	Microform	Number of Users	Number of Items Published per Year	Reference (see below)
Thomas Register	4" x 6" microfiche	3,500	50,000 pages for 1963 100,000 to 125,000 pages for 1964	1
Vendor Specs Micro-File	16mm film cartridge	100	75,000 pages	2
Army Missile Command reports	16mm film cartridge	35	140,000 pages est.	3
OTS technical reports	Roll microfilm	12	n.a.	4
AEC technical reports	Microcard	300	n.a.	5
NASA technical reports	5" x 8" microfiche	125 (may go to 200)	25,000 to 30,000 reports (1.25 to 1.5 million pages)	6

n.a. = not available.

References:
1. Discussion with vice-president of Thomas Publishing Corporation.
2. Trade literature from Vendor Specs Micro-File.
3. Electronic News, p. 30 (December 17, 1962).
4. Description of 12 regional centers established by OTS to provide copies of unclassified ASTIA, AEC, and NASA reports to the general public.
5. Publications by the Microcard Corporation.
6. D. P. Waite, "Microfilm Card is Information Medium for Space Agency," Systems Management, pp. 27-29 (November 1962).

Table III

U.S. SALES OF LARGE MECHANIZED RETRIEVAL SYSTEMS SINCE 1955

Manufacturer	System	Approximate Sales Price	Installed Number	Estimated Total Sales
FMA, Inc.	Filesearch	$ 115,000	3	$ 345,000
J. Samain	Filmorex	25,000	1	25,000
Benson-Lehner	FLIP	45,000	2	90,000
Magnavox	MEDIA	35,000	2	175,000
Eastman Kodak	Minicard	Over 1,000,000 (est.)	4 or 5	5,000,000
IBM	WALNUT	Over 1,000,000 (est.)	1	1,000,000
Ferranti-Packard	Rapid-Access Look-Up System	17,000	7	120,000
RCA and Ampex	Video File	n.a.	0	0
Info. for Industry	CRIS	25,000	n.a.	n.a.
AVCO Corp.	Verac 903	n.a.	0	0
Total				$6,755,000

n.a. = not available.

Table IV

MAJOR POTENTIAL APPLICATIONS FOR LARGE FILE SYSTEMS

Organization or Application	Approximate Number of Organizations in the U.S.	Reference (see below)
Government hospitals (patient records)	1,650	1
Non-government hospitals (patient records)	3,500	1
County recorders (legal records)	3,047 counties	2
Title insurance companies (legal briefs)	2,500	3
County assessor (property and tax records)	3,047 counties	2
Security and commodity brokers (general business records)	5,800	4
Life insurance companies (251 million policy briefs)	1,400	5
Fire and casualty insurance companies (policy briefs)	350	6
Credit reporting agencies (credit ratings)	3,300	7
Credit agencies (other than banks)	22,700	4
Banks (old checks)	16,200	4
Manufacturers (general business records)	2,000 with over 1,000 employees	8
Newspaper and magazine publishers (morgues of past issues)	20,000 publications	9
Special libraries (technical information)	2,500	10
Public libraries	11,000	11
Industrial research labs	5,000	12
Local police files	20,000 municipalities	2
Employment agencies (personnel records and requirements)	4,000	13
Advertising agencies (copy and art work)	8,000	13
Federal and state agencies	n.a.	

n.a. = not available.

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1. 1960 American Medical Directory, American Medical Association, 535 North Dearborn Street, Chicago, Illinois.
2. Governments in the United States, Vol. I, No. 1, 1957 Census of Governments, U.S. Dept. of Commerce, Bureau of the Census.
3. "1960 Directory of American Title Association," 3608 Guardian Building, Detroit, Michigan.
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13. "1958 Census of Business, Selected Services, U.S. Summary," BC 58-SA1, the U.S. Dept. of Commerce, Bureau of the Census.

because the equipment, operating as a complete system, will not provide the necessary performance with regard to such quantitative characteristics as update cycle time, individual search response time, and search throughput rate. These mechanized systems also fail to meet the desired performance requirements with regard to such subjective characteristics as ease and speed of error correction and file maintenance, ease and speed of access for single or multiple users for parallel searching or browsing, convenience to the user of the forms and media of the search products, capability to handle a variety of forms and types of input materials, ease and speed of framing a search question for the system. In addition, the mechanized systems ordinarily perform only the central function of storage and retrieval, whereas most applications require a variety of other functions (e.g., sorting, merging, listing). On the other hand, several of the mechanized systems can conduct rather complex search questions with their built-in logical capability, but not all large image files need this type of capability. And those that could use this capability probably could still achieve it to an acceptable degree with an expansion of their present manual system. One further shortcoming of most present mechanized systems is their limited capability to incorporate a variety of classifications or indexing systems.

If the equipment is purchased as a means of solving a particular operational problem within a user's organization, then the prospective user expects to receive assistance in system design and conversion, personnel training, and possibly other assistance, such as service bureau facilities for file conversion. Manufacturers have not always provided these services in the past and have probably had some disgruntled customers as a result.

Table IV is a list of major potential applications for large general purpose file systems, together with the approximate number of organizations in each application area. No attempt has been made to separate the list into high and low activity files, since many organizations have both. The approximate number of organizations in each application can be considered as a rough indication (order of magnitude) of the potential demand in the United States for large general purpose file systems. However, in viewing these figures, several qualifications should be kept in mind:

1. Not all the organizations counted for any given type of application will necessarily have files large enough or important enough to warrant conversion to a mechanized or photo-image system.

Table IV

MAJOR POTENTIAL APPLICATIONS FOR LARGE FILE SYSTEMS

Organization or Application	Approximate Number of Organizations in the U.S.	Reference (see below)
Government hospitals (patient records)	1,650	1
Non-government hospitals (patient records)	3,500	1
County recorders (legal records)	3,047 counties	2
Title insurance companies (legal briefs)	2,500	3
County assessor (property and tax records)	3,047 counties	2
Security and commodity brokers (general business records)	5,800	4
Life insurance companies (251 million policy briefs)	1,400	5
Fire and casualty insurance companies (policy briefs)	350	6
Credit reporting agencies (credit ratings)	3,300	7
Credit agencies (other than banks)	22,700	4
Banks (old checks)	16,200	4
Manufacturers (general business records)	2,000 with over 1,000 employees	8
Newspaper and magazine publishers (morgues of past issues)	20,000 publications	9
Special libraries (technical information)	2,500	10
Public libraries	11,000	11
Industrial research labs	5,000	12
Local police files	20,000 municipalities	2
Employment agencies (personnel records and requirements)	4,000	13
Advertising agencies (copy and art work)	8,000	13
Federal and state agencies	n.a.	

n.a. = not available.

References:
1. 1960 American Medical Directory, American Medical Association, 535 North Dearborn Street, Chicago, Illinois.
2. Governments in the United States, Vol. I, No. 1, 1957 Census of Governments, U.S. Dept. of Commerce, Bureau of the Census.
3. "1960 Directory of American Title Association," 3608 Guardian Building, Detroit, Michigan.
4. "County Business Patterns, Part I, First Quarter 1956," U.S. Dept. of Commerce and the U.S. Dept. of Health, Education and Welfare (1958).
5. "1960 Life Insurance Fact Book," Institute of Life Insurance, 488 Madison Ave., New York, N.Y.
6. Best's Insurance News, (Fire and Casualty issue), Alfred M. Best Co., Inc., 75 Fulton St., New York, N.Y. (April 1960).
7. SRI estimates.
8. Metropolitan Area and City Size Patterns of Manufacturing Industries, 1954, Area Trend Series--No. 4, U.S. Dept. of Commerce, Business and Defense Services Administration, Office of Area Development (June 1959).
9. 1960 Directory of Newspapers and Periodicals, N. W. Ayer and Sons, Philadelphia, Pa.
10. Directory of Special Libraries, 1953, Special Libraries Assoc., 31 E. Tenth St., New York, N.Y.
11. American Library Annual, 1957-1958, Council of National Library Associations, and Library Journal published by R. R. Bowker Co., New York.
12. "Industrial Research Laboratories of the United States, 1956" Publication 379, National Academy of Sciences--National Research Council.
13. "1958 Census of Business, Selected Services, U.S. Summary," BC 58-SA1, the U.S. Dept. of Commerce, Bureau of the Census.

2. Some organizations, such as insurance companies, may need more than one file system because of differences in the requirements of the material to be filed.

3. Many of the potential users of large file systems will convert to EDP rather than to photo-image systems for a number of the reasons mentioned earlier.

4. The PCMI system as presently envisioned is not suitable for use in these applications.

Market for Microform Equipment, Supplies, and Services

Size of the Market

Present annual sales of microform equipment, supplies, and services are estimated to be approximately $250 million, and sales are increasing at a rate of 10 to 15 percent per year. Thus, by the late 1960's, a market of $500 million per year could be realized. Table V divides the estimated sales among equipment, supplies, and services.

Table V

THE MICROFORM MARKET
Estimated 1962 Sales

	Millions of Dollars
Equipment	$ 20
Supplies	60
Services (labor, overhead, conversion)	170
Total	$250

Sources: U.S. Department of Commerce; SRI.

The principal effort to date on PCMI has been in the development of equipment; consequently, the size of the microform equipment market is of particular interest. It can be seen from the table that the estimated sales of microform equipment of $20 million per year account for less than 10 percent of the total microform market.

Approximately one-third of the equipment sales shown in Table V are for engineering drawing applications, an area that was not investigated as part of this study. The remaining two-thirds, or $12-$15 million per year, is divided between microform publishing and office system file applications. Of this $12-$15 million, by far the largest part, probably as high as 90 percent, is in sales of equipment to implement the filing and storage function in office systems, i.e. for the production of film in single copies.

The largest segment of the estimated $60 million dollar annual market for microform supplies is composed of sales of silver-halide film. Since at present, PCMI does not contemplate the production of original images, the 3-to-1 ratio between supplies and equipment, shown in Table V, should not be considered representative of the ratio between supplies and equipment that would be realized in a PCMI system. In large information retrieval systems such as WALNUT, Minicard, or MEDIA, annual expenditures for supplies are estimated to be one-fourth or less of the cost of the original equipment. In diazo or xerographic systems that are dependent upon microfilm for the creation of original images, it is estimated that the annual sales of supplies are less than the annual sales of equipment. Since the PCMI system at present contemplates implementing a silver-halide system in a somewhat similar fashion to the capability of a diazo or xerographic system, it is estimated that the sale of photochromic supplies, such as film and paper, would also be less than the sales of equipment--probably smaller than in a diazo or xerographic system, because of the contemplated higher cost of PCMI equipment.

Table VI divides the estimated sales of microform equipment* by type.

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* Included as microform equipment sales are sales of readers, viewers, and allied equipment for use with both silver-halide processes, and with other processes such as diazo, xerography, and thermography.

Table VI

MICROFORM EQUIPMENT MARKET
Estimated 1962 Sales

Type of Equipment	Number of Units	Millions of Dollars
Readers (including reader-printers, card-to-card printers, roll-to-roll printers)	10 to 15,000	$ 5 to 8
Cameras	3 to 4,000	7 to 10
Large information retrieval systems		0.5 to 1
Accessories & miscellaneous equipment, (cabinets, enlargers, processors, film mounters, etc.)		3 to 5
Total sales		$16 to 24

Sources: U.S. Dept. of Commerce; SRI.

The table shows that about 75 percent of the equipment market is composed of sales of readers, printers, and cameras; camera sales are estimated to be almost one-half total equipment sales. Sales of readers without a printing capability, in the $400-$600 price range, are estimated to account for over 50 percent of the total sales value of readers and printers. The balance is accounted for by sales of reader-printers in the $650-$900 price range and by sales of other printers and copiers in the $750-$25,000 price range. Table VII lists representative selling prices of microform equipment.

Sales of large information retrieval systems such as WALNUT and Minicard have never been large and they have been declining since the initial sale of 4 or 5 Minicard systems prior to 1961. With the exception of one WALNUT system, the study was unable to uncover any evidence that there have been any sales of such large information retrieval systems since 1960. There have been some sales of somewhat more moderately priced information retrieval equipment such as Filmorex, FMA Filesearch, and Magnovox MEDIA. However, total equipment sales for these information retrieval systems are estimated not to exceed $1 million per year.

Table VII

REPRESENTATIVE PURCHASE COSTS FOR COMMON MICROFORM EQUIPMENT

Type of Equipment	Approximate Purchase Cost[a]
Cameras for general business recording	$350 to 2,700
Cameras for precision filming	3,000 to 8,000
Readers	150 to 1,000
Reader-printers	650 to 2,500
Contact printers (roll-to-roll)	1,800 to 3,100
Aperture card copier (slow speed)	750
Aperture card copier (high speed)	25,000
Hard copy printer (high speed printing from aperture cards)	8,000 to 160,000
Aperture card mounter (manual)	700
Aperture card mounter (high speed)	33,000
Microfilm storage cabinet (5-drawer)	200 to 260
Microfilm storage cabinet (10-drawer)	250 to 440

a. H. W. Ballou, Guide to Microreproduction Equipment, Second Edition, National Microfilm Assoc., Annapolis, Md. (1962).

Competitors and Competitive Practices

In assessing the share of the microform market that the PCMI system might obtain, it is worthwhile to review the types of organizations now serving the market and the kinds of services and facilities that these companies have found to be necessary for success.

The microform market is dominated by four companies--Eastman Kodak, Minnesota Mining & Manufacturing, Remington-Rand, and Bell & Howell. These four companies account for an estimated 75 percent of the sales of equipment and supplies, and Eastman Kodak alone accounts for 30 to 40 percent. The other 25 percent of the market is divided among many organizations; Appendix B lists approximately 100 of them. In addition to supplies and equipment, the major companies supplying the microform market have found it necessary to provide many types of services; among these are equipment maintenance, technical advice on the operation of the equipment and the use of film and paper, and advice on how to obtain the optimum results from a microform system. It should be emphasized that most users of microform have little technical knowledge or office systems knowledge and depend upon the supplier to provide the necessary application experience to assure a successful installation. The large companies are able to furnish this assistance through large marketing organizations. For instance, Eastman Kodak markets equipment and supplies through its Recordak division and Minnesota Mining and Remington-Rand through their office system marketing facilities; Bell & Howell has recently created a separate division for the sale of microform equipment and supplies. These companies also have extensive nationwide distributional outlets suitable for serving microform markets, such facilities having been already established for other segments of the firms' businesses. The field is characterized by well-established and skilled marketing organizations that have been created as a part of a very large business enterprise but which are well suited for use in the microform market.

As can be seen by the listing in Appendix B, the microform market is also characterized by the presence of many small manufacturers producing microform equipment for custom installation and by the exploratory efforts of some larger organizations such as Chas. Bruning, Fairchild Camera & Equipment, and Xerox Corp., which participate in the microform market as an adjunct to their main product line. Thus, the competition in the market is quite keen and diverse, ranging from the well-organized and well-funded efforts of Eastman Kodak to the attempts of the small marginal manufacturer to enter the market through the sale of specialized equipment produced in a job-shop operation.

Also participating in the market are microform service bureaus--small service agencies mainly providing microfilming facilities for document storage, but also selling equipment and supplies. Microdealers, Inc. is a national organization to which approximately one-third of these local microform service bureaus belong. These service agencies also provide their customers with a great deal of the application experience and technical competence that is required for the successful use of microform.

IV MICROFORM PUBLISHING

Characteristics of Microform Publications and Publishers

The practice of publishing material in microform such as roll microfilm, microfiche, or Microcards, seems to have started on a significant scale about a decade ago when librarians became increasingly aware of the fact that their book collections were literally falling apart because of age, handling, and the poor materials used in the paper, inks, and binding. This was particularly true of newspaper and magazine collections. The concern for the potential loss of much important reference material was further aggravated by the Second World War and its attendant destruction of cities and their library collections. Consequently, the practice of microfilming library materials was instituted in the thought that for security purposes, at least one copy of the library material would always be available in some safe location. The primary emphasis at this time was placed on filming old newspapers and books that were in danger of falling apart or becoming illegible or being destroyed in some other way. Examples of such old material that was later published in microform are the Journal of the Congress of the Confederate States of America, 1861-1865, The Boston Evening Post, 1735-1775, Irish Newspapers Prior to 1750, Analecta Hymnica Medii Aevi (a collection of medieval Christian hymns in the original Latin text). Thus, this first emphasis was on the use of microform for replacement and security storage.

From this early beginning, the practice of microform publication has now been extended to provide duplicate sets of reference works and collections of information that had not been published previously, and would otherwise have been very difficult for the users to get access to. Examples of such collections are the Transcript of the Trial of Adolph Eichmann, Adams Family Papers, Texas Diplomatic Notes from 1836-1845, Texas Conference Army Muster Roll Cards, and Medical Records of Western U.S. Army Posts from 1845-1900.

Microform publication has also been used as an auxiliary means of publication to provide additional copies of material that was initially published in a limited edition. Examples of microform editions of previously published material are the Annales de la Chambre des Députés, Débats Parlementaires, 1918-40, and the National Bibliography of South America. Examples of microform editions of material that is concurrently published in paper form are the *Official Documents of the Organization of American States*, *Reports of the Atomic Energy Commission*, *French Chemical Patents*, and *Annual Reports of 1084 Members of the New York Stock Exchange*. The *Transactions of the American Nuclear Society* recently initiated the practice of providing a Microcard copy of this publication to accompany every original paper version; this is the first time that a technical journal publication has been sent to all subscribers in a combined paper and Microcard edition, although this has already been done for some books and conference proceedings.

Within the last few years, microform has also been used as a medium for primary publication when it would not be economically feasible to use conventional publication practices. Three examples of recent publications which exist *only* in microform are the *Journal of Wildlife Diseases*, *The First Six Million Prime Numbers*, and the *IGY Weather Records*.

The last major type of application for microform has been the replacement of material that is bulky, expensive to bind, and receives relatively infrequent use. The prime example here is the replacement of files of current newspapers by microfilm editions. Approximately 90 percent of the current U.S. newspapers are now available in microform editions. The usual library practice in these cases is to maintain current subscriptions to both the paper edition and the cumulative microform edition, so that the paper copies can be thrown out when warranted by low frequency of use or lack of storage space. In some cases, it may be more economical for libraries to keep microform backfiles of periodicals than to bind and store the accumulated paper copies. It is argued that the cost of the microform edition may be less than the storage and binding costs of the original material--especially if it is to be stored for an indefinite period. One other argument for microform backfiles is that they represent one way in which a new library can easily acquire a complete set of back issues at a reasonable cost. The entire set of back issues of *Electronics*, for example, from 1930 to the present (representing about 16 feet of shelf space) could be obtained at a cost of about $485. An indication of some of the types of material available in microform, as well as their costs, is given in Table VIII.

Types of material which are generally not published in microform are works which might be called entertainment reading (i.e., children's books, works of fiction, book-of-the-month club selections). The microform publication practice has been restricted to works which are primarily of historical or academic interest and are used by researchers. The availability of material in microform is somewhat restricted by the practice of some publishers (e.g., the American Chemical Society and the

Table VIII

TYPES OF MICROFORM PUBLICATIONS AND REPRESENTATIVE COSTS

Type of Microform	Publication	Approximate Cost per Page (cents)	Total Cost (dollars)	Number of Pages	Reference (see below)
Readex microprint	Biblio. by Medina	0.49¢	$ 75	15,300	1 (p. 69)
	Nat'l Biblio. of Portugal	0.50	42	8,370	1 (p. 68)
	Nat'l Biblio. of Cuba	0.50	40	7,946	1 (p. 68)
	Nat'l Biblio. of So. America	0.51	52	10,280	1 (p. 68)
	Proc. Int'l Conf. on Peaceful Uses of Atomic Energy	0.56	50	9,000	1 (p. 66)
Microcard	First Six Million Prime Numbers (book)	0.73	35	4,800	2
	Proc. Int'l Conf. on Peaceful Uses of Atomic Energy	0.78	70	9,000	1 (p. 60)
	American Documentation	0.79	25	3,157	1 (p. 68)
	Eichmann Trial Transcript	0.82	37	4,500	3
	Annals of German Reichstag	0.87	975	112,000	4
	Annals of French Chamber of Deputies	0.95	950	100,000	4
	Medieval Christian Hymns	2.0	300	15,000	5
Roll microfilm	Short-Title Catalog of Books: 1641-1700	0.55	550	100,000	1 (p. 69)
	Physics Abstracts	0.56	12	2,100	1 (p. 60)
	Dissertations	1.25	--	--	6
	Texas Historical Newspapers	1.32	330	25,000	7
	Mexican Archives	1.66	5,000	300,000	8 (p. 13)
	All American Periodicals prior to 1850	0.45	450	100,000	9
	Current Periodicals	0.25 to 0.33	--	--	9

References:
1. Subject Guide to Microforms in Print: 1962-1963, A. Diaz, Ed., Microcard Editions, Inc., Washington, D.C. (1962).
2. Microcard Bulletin No. 20 (January 1960), Microcard Editions, Inc., Washington, D.C. (1962).
3. Microcard Editions, Inc., brochure 62.8.20, Microcard Editions, Inc., Washington, D.C. (1962).
4. Microcard Editions, Inc., brochure 62.10.19, Microcard Editions, Inc., Washington, D.C. (1962).
5. Microcard Editions, Inc., brochure 62.8.15, Microcard Editions, Inc., Washington, D.C. (1962).
6. Dissertation Abstracts, p. iii (September 1962).
7. Microfilm Service and Sales Co., sales brochure.
8. A Catalog of Selected Microfilms, Micro Photo, Inc., Cleveland, Ohio (September 1962).
9. E. Power (Pres. University Microfilms) stated, "We supply current periodical material at rates which vary from one-fourth to one-third of a cent per page," in "Microfilm--The Versatile Academic Tool," a paper in Microtexts as Media for Publication, pp. 10-26 (Hertfordshire County Council Tech. Info. Service, Hertfordshire, England, 1960).

Institute of Radio Engineers) of not permitting their journals to be published or sold in microform.

One general characteristic of the microform publication practice that should be noted here because of its implication for the PCMI system, is the size of the item (book, report, patent, catalog, etc.) that is to be published, as well as the usual size of the press run or initial distribution. Since the ultimate users of the microform seem to prefer having their material in unit record form (e.g., one report per roll or per Microcard), a study of some of the material to be published would give an indication of the requirements for storage capacity of the PCMI card. Table IX provides some estimates of the average sizes and ranges of sizes of reports, books, and other material, and indicates that the planned PCMI capability of 3,000 page images per card is in excess of most of the present publishing requirements, if the microform is to be used in a unit-record manner. In a corresponding manner, an analysis of the unit-record size of various types of commercial or government file materials leads to the same conclusion (see Table X).

As indicated earlier in Table II, the press runs for microform editions are generally in the scores, or hundreds, but seldom in the thousands.

The Economics of Publication in Microform

It is clear that for many applications, the publishing costs for microform editions may be less than the publishing costs for full-size paper editions. However, under some circumstances the operating costs for the entire information distribution system (including costs of publishing and distributing, as well as costs for viewing equipment and its maintenance) may be higher with a microform system than a conventional paper system. Furthermore, there may be microform systems that are economically more attractive than PCMI. This section of the report discusses some of these economic considerations and provides several comparisons of the costs of publication in PCMI and in other forms.

One of the first tasks of this project was to obtain a complete operating description (see Appendix C) of the proposed PCMI systems, along with the best estimates of elemental operating times and costs that could be established at that time. The next step was to compute estimates of the effective operating costs of the PCMI systems for different sets of operating conditions (e.g., with different degrees of equipment utilization and different numbers of images per card). The basic assumptions and derivations for this analysis are presented in Appendix D. A summary

Table IX

ESTIMATED UNIT RECORD SIZES OF VARIOUS TYPES OF PUBLICATIONS

Type of Publication	Range of Size (pages)	Average Size (pages)	Reference (see below)
Dissertations	34-885	185	1
Patents	1-640, with 99% having less than 25 pages	6	2
Books	2-8,011	296	3
NASA reports	1-1,049	50	4
NASA reports		50	5
NASA reports	80% have fewer than 75 pages		6
ASTIA reports	1-790	50	7
AEC reports	1-601	72	8
Air Force technical orders	1-2,500	50	9

References:
1. Analysis of 620 dissertations described in the September 1962 issue of Dissertation Abstracts.
2. P. Urbach, "A Future Microsystem for the U.S. Patent Office," Proc. 11th Annual Convention of the Nat'l Microfilm Assoc., pp. 153-164, Nat'l Microfilm Assoc., Annapolis, Md. (1962); and "On Demand Patent and Copy Order Fulfillment Program," an undated report of the U.S. Patent Office.
3. Analysis of the 862 new books described in the Pure Science and Technology sections of the October and November 1962 issues of the American Book Publishing Record.
4. Analysis of the 483 reports described in Scientific and Technical Aerospace Reports (NASA), Vol. 1, No. 1 (January 8, 1963).
5. D. P. Waite, "Microfilm Card is Information Medium for Space Agency," Systems Management, pp. 27-29 (November 1962).
6. M. S. Day, "The Scientific and Technical Information Program of the National Aeronautics and Space Administration," in The Literature of Nuclear Science, Report TID-7647 of the AEC Technical Information Division, Oak Ridge, Tennessee.
7. Analysis of the 692 reports described in the section of unclassified reports of the December 15, 1962 issue of the ASTIA Technical Abstract Bulletin.
8. Analysis of the 274 most recent reports received by the AEC Depository at SRI.
9. Figures from a trip report by an NCR staff member.

Table X

ESTIMATED UNIT RECORD SIZES OF VARIOUS TYPES OF FILE MATERIAL

Type of Material	Range of Sizes (pages)	Average Size (pages)	Reference (see below)
VA hospital patient medical records	n.a.	400	1
AF officer personnel records	n.a.	500	2
Army personnel records	100-300	n.a.	3
Credit rating files	1-20	2	4

n.a. = not available.

References:
1. Discussion with a member of the Records Management Department, Veterans Administration, Washington, D.C.
2. Discussion with a representative of the U.S. Air Force Administrative Services Office, Washington, D.C.
3. Discussion with Director of Records Management for U.S. Army Adjutant General's Office, Washington, D.C.
4. Discussion with Manager of Methods and Research of Dun & Bradstreet Co., New York.

illustration of the PCMI printing costs for different operating conditions is given in Figure 2. It can be seen that no single figure can be quoted as a general cost per card or cost per image, although the generalization can be made that for press runs of over 100 copies, the cost per image is less than one-half cent for a PCMI card that contains 300 or more images. From a cost standpoint, there is little advantage to going beyond 3,000 images per card. As previously mentioned and as noted in Tables IX and X, there may also be little operational advantage in going to a PCMI card with more than 3,000 images, since many of the items that might be stored or published ordinarily consist of only a few hundred images.

The printing costs for other microforms such as roll microfilm or Microcards also vary, and are sometimes more, and sometimes less than PCMI costs. An exact comparison depends upon a study of specific applications, some of which were given previously in Table II. An illustration of a general cost comparison of the printing cost of PCMI and several other competitive microforms is given in Figure 3. For most of the current applications, the least expensive form of printing seems to be roll microfilm, followed by Microcard, a microfiche equivalent of the Microcard (not shown in the figure), and roll microfilm in cartridge form. Current estimates of PCMI printing costs are included within the range of these competitive systems, with the specific cost depending upon the application.

It should be noted that the printing or publishing costs alone do not tell the whole story. It is somewhat unrealistic for an entirely new system such as PCMI to be compared with other alternatives solely on the basis of printing or publication and distribution costs. For this reason, two representative systems (the publication and distribution of some of the <u>Thomas Register</u> catalogs and some of the <u>Navy Supply Catalogs</u>) were selected for a comparative analysis of relevant cost factors. These two examples are described below.

The specific assumptions and derivations for the cost analysis of the <u>Navy Supply Catalog</u> are given in Appendix E. The resulting cost estimates for four alternative methods of publication (paper, Microcard, Recordak, and PCMI systems) are summarized in Table XI. These are the equivalent annual costs for publishing a new 3,000-page catalog four times a year and distributing single copies to 2,000 different users. The cost for composing and printing the master copy of each page is not included in this estimate since that cost is common to all of the methods being studied.

This particular analysis shows that from an economic standpoint, the best alternative for the Navy is to stay with the present system of

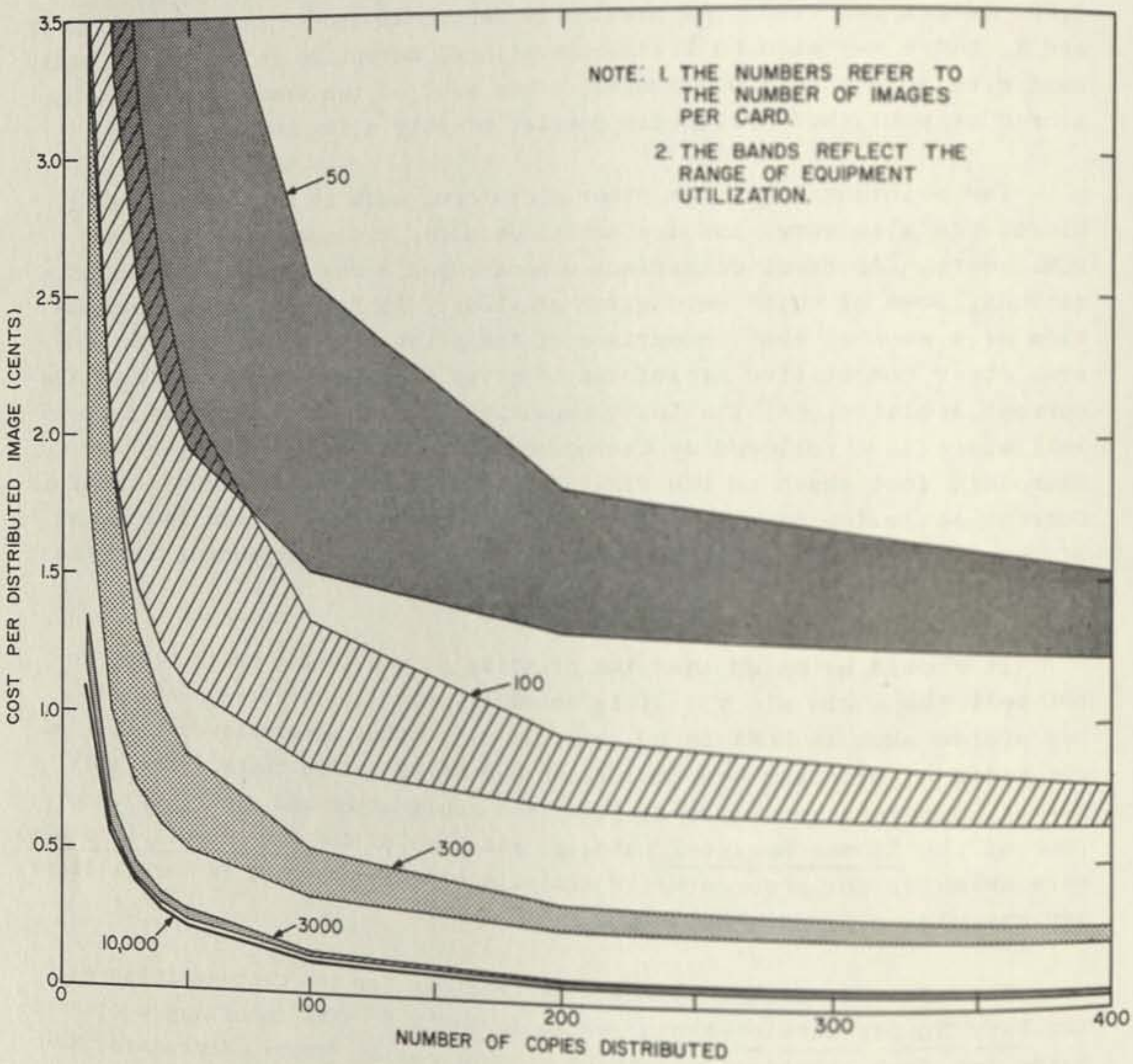

FIGURE 2

COSTS FOR PRINTING IN PCMI MICROFORM

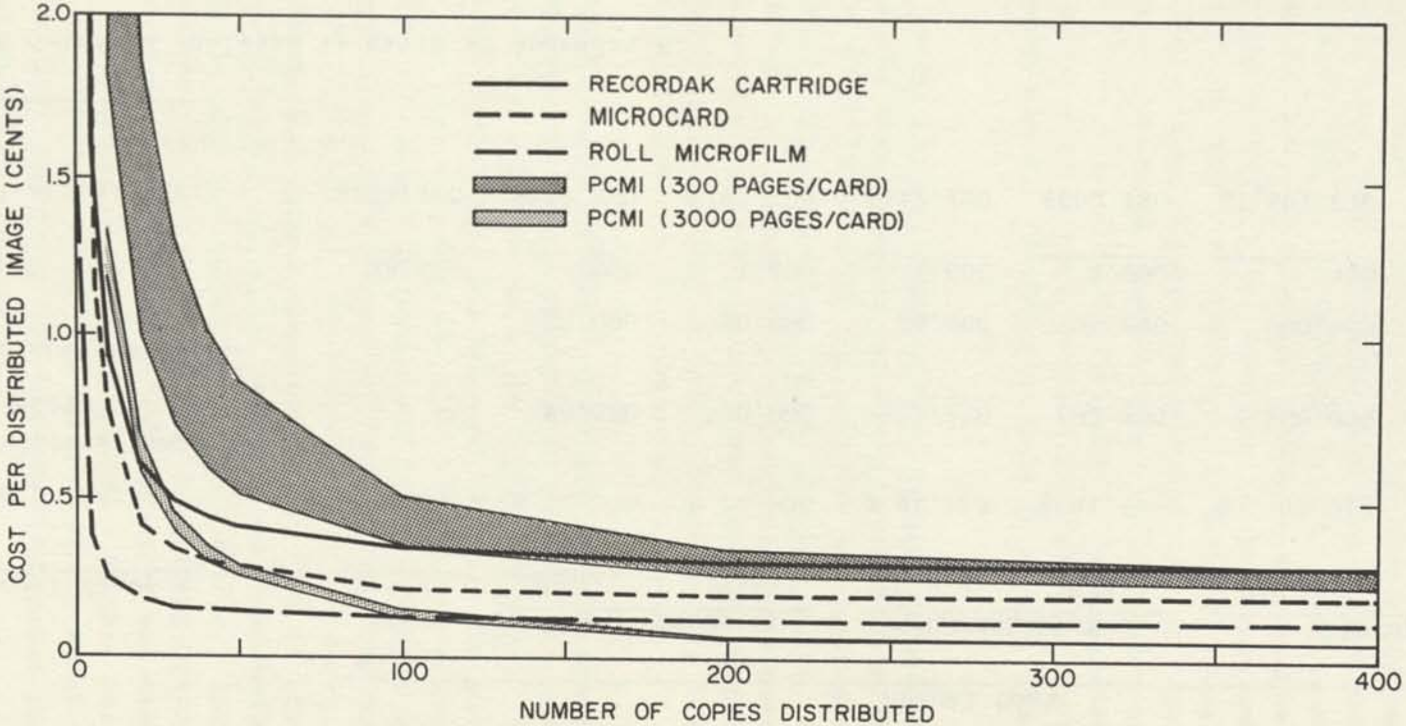

FIGURE 3

COMPARISON OF PRINTING COSTS OF ALTERNATIVE MICROFORMS

Table XI

RESULTS OF COST ANALYSIS OF FOUR ALTERNATIVE METHODS FOR PUBLISHING THE NAVY SUPPLY CATALOG
(A 3,000-page Catalog Published 4 Times a Year and Distributed to 2,000 Users)[a]

	Annual Cost						
	Present Paper System	Microcard System		Recordak System		PCMI System	
Cost Element		(min.)	(max.)	(min.)	(max.)	(min.)	(max.)
Catalog printing	$ 75,000	$ 72,000	$ 72,000	$ 41,130	$ 41,130	$ 41,210	$ 41,210
2,000 viewers, amortized over 3 years	--	86,660	300,000	323,330	663,330	1,200,000	1,666,660
Maintenance for 2,000 viewers	--	20,000	20,000	46,660	96,660	360,000	500,000
Postage	88,320	1,200	1,200	1,600	1,600	400	400
Total annual cost	$163,320	$179,860	$393,200	$412,720	$802,720	$1,601,610	$2,208,270

a. The detailed analysis is given in Appendix E.

full-size paper catalogs and not to publish in microform. If the publishing is to be done in microform, then the most attractive approaches, economically, are the Microcard, Recordak film cartridge, and PCMI systems, in that order. Under the most optimistic circumstances, the PCMI system would still cost six times more than the Microcard system, and about twice as much as the Recordak system. PCMI is clearly not a strong competitor for this application. There is the further fact that in this, and other applications, the total cost of Microcard and Recordak systems may actually be less than that shown in Table XI because of the fact that the user may already possess the required type of viewing equipment, and will not have to charge another viewer to the system cost estimate. This is not the case with the PCMI equipment. An examination of Table XI shows that the major item of cost in the PCMI system is the viewing equipment and its maintenance. The printing cost is a small fraction of the total cost.

All of the analyses done in this report assumed that the entire cost of viewers and their maintenance would be charged to the information system. This would probably be the case for information networks with captive audiences (e.g., the Navy Supply Catalog system, or a system for sending out parts catalogs from automobile manufacturers to their dealers). This Navy catalog example suggests that the cost to the user of the PCMI viewer should be about $200 in order to arrive at a total system operating cost that is the same as the present paper system.

As another illustration to show how the PCMI system compares with other microform systems, a comparative analysis was made for another real application--the publication of the Thomas Register. The specific assumptions and derivations for the cost analysis are given in Appendix F. The resulting cost estimates for four alternative methods of publication (microfiche, Microcard, Recordak, and PCMI) are shown in Table XII. These are the equivalent annual costs for publishing a new 60,000-page catalog annually and distributing single copies to 3,500 users. This particular analysis shows that from a cost standpoint, PCMI is the least attractive of the four different microform systems, and is actually about four times more expensive than the present microfiche system. And even though the PCMI system has the lowest printing or publishing costs of all four systems, this is more than offset by its equipment and maintenance costs, which are the highest of all four systems. In this particular application, the PCMI viewers would have to be sold for about $400 in order to arrive at a total operating cost for the PCMI system that is the same as the present microfiche system.

Because the PCMI system was more costly than the other alternatives in both of these comparisons, even with its relatively low printing costs,

Table XII

COST ANALYSIS OF FOUR ALTERNATIVE METHODS FOR PUBLISHING THE THOMAS REGISTER
(A 60,000-page Catalog Printed Annually and Intended for Distribution to 3,500 Users)[a]

	Annual Cost						
Cost Element	Present Microfiche System	Microcard System (min.)	Microcard System (max.)	Recordak System (min.)	Recordak System (max.)	PCMI System (min.)	PCMI System (max.)
Catalog printing	$315,000	$630,000	$ 630,000	$ 430,050	$ 430,050	$ 80,380	$ 80,380
3,500 viewers, amortized over 3 years	408,330	151,660	525,000	565,830	1,160,830	2,100,000	2,916,670
Maintenance for 3,500 viewers	35,000	35,000	35,000	81,660	169,170	630,000	875,000
Postage	10,500	17,500	17,500	16,800	16,800	350	350
Total annual cost	$768,830	$834,160	$1,207,500	$1,094,340	$1,776,850	$2,810,730	$3,872,400

a. The detailed analysis is included in Appendix F.

it was of interest to find out how the total costs for all the alternatives varied with the amount of printing to be done. Figure 4 shows the total system costs for four alternative systems (paper, Microcard, Recordak, and PCMI) as a function of the number of pages published in each quarterly catalog. This was for an application that required the distribution of single copies to 2,000 users. The specific assumptions and derivations for this cost analysis is given in Appendix G. The costs for the microform alternatives are given as ranges of costs, with the upper and lower bounds reflecting different models of viewing equipment that are available for the various microforms. It can be seen that because of the relatively high fixed costs of the PCMI system, it does not become the most economical system (for 2,000 users) until the system publishes a 100,000- to 150,000-page catalog every quarter. There are probably very few organizations that have this type of publishing load. It can also be seen that, depending upon the volume of material to be published, any of the four alternatives may at some point be the most economical system. There is no single "best" system.

Because this breakeven analysis was only for an application that required copies to be distributed quarterly to 2,000 users, it was of interest to find out how the PCMI breakeven point varied with the volume of publication and the number of users. General expressions were derived (see Appendix G) that described the equivalent annual costs of the paper, Microcard, Recordak, and PCMI systems as a function of the volume of publication and the number of users. These functions were evaluated over a range of values to determine which system was the most economical for different operating situations. This information is summarized in Figure 5, which shows the operating conditions under which the PCMI system is more economical than the other alternatives. Figure 5 is for the most optimistic PCMI equipment costs. It can be seen that generally the PCMI system does not become the most economical system unless there is a requirement to publish the equivalent of a catalog of at least 400,000 pages once a year, and then only under the condition that at least 2,000 copies of this catalog are printed. There appear to be relatively few publishing applications of this magnitude. Examples of a few representative catalog publishing jobs are described in Table XIII (see also Table II). It can be seen from Figure 5 that the PCMI system is the least economical alternative for all but one of these applications.

The main conclusion to be drawn from this study of the relative economics of a total microform publication and dissemination system (i.e., including the cost of providing and maintaining viewers as well as printing and distributing the published material) is that there is a very limited area in which the PCMI system is the most economical of the four alternatives studied. Furthermore, the bounds of this area are such that

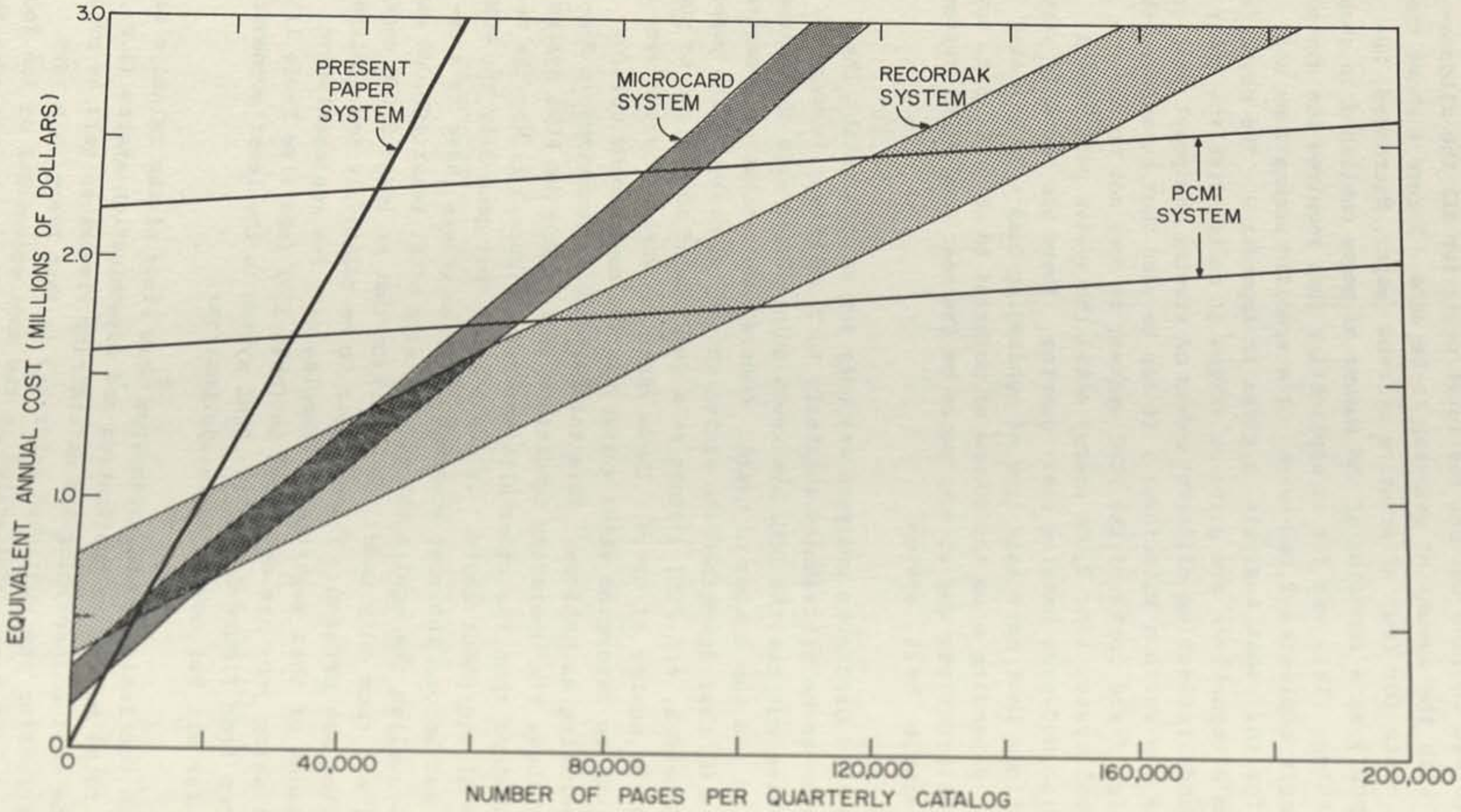

FIGURE 4

TOTAL COSTS FOR CATALOG PUBLICATION IN MICROFORM
(QUARTERLY ISSUES FOR 2,000 USERS)

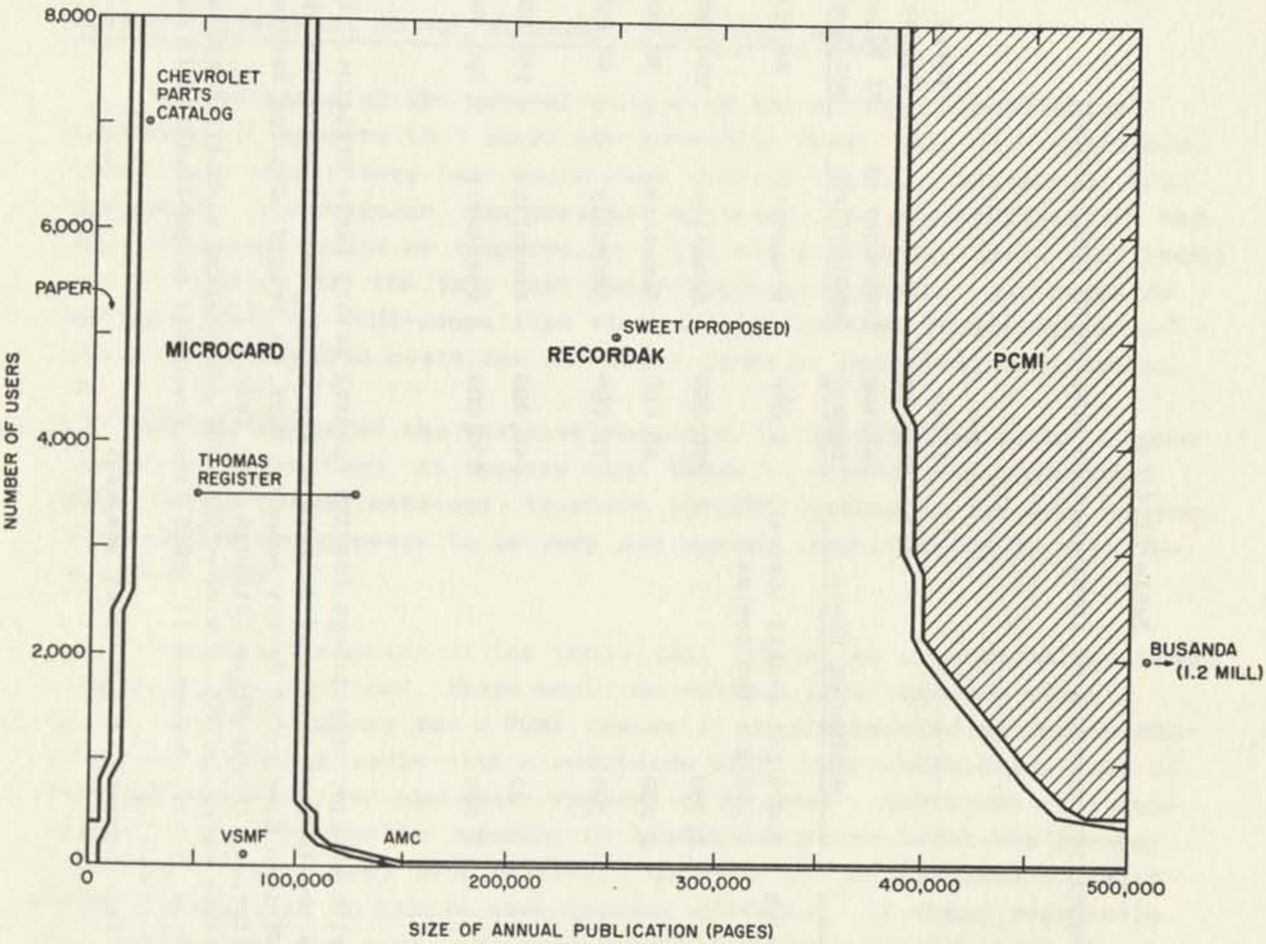

FIGURE 5

FAVORABLE ECONOMIC OPERATING REGION FOR PCMI PUBLICATIONS RELATIVE TO OTHER SYSTEMS

Table XIII

REPRESENTATIVE EXAMPLES OF LARGE CATALOG PUBLISHING APPLICATIONS

Application	Number of Users	Total Size of Catalog (pages)	Frequency of Publication	Total Number of Pages per Year	Reference (see below)
Chevrolet dealers' parts catalog	5,000 get single copies 1,000 get two copies	4,000	Bimonthly	24,000	1
Sweets' Catalog (proposed)	5,000	250,000	Annually	250,000	2
Thomas Register (proposed)	3,500	50,000	Annually	50,000	3
Vendors Specs Micro-File	100	75,000	Annually	75,000	4
Army Missile Command missile parts catalog	35	140,000	Annually	140,000	5
Navy Supply Catalog	2,000	300,000	Quarterly	1,200,000	6

References:
1. Discussion with manager of catalogs for the General Motors Parts Division. The Chevrolet Division has the largest number of dealers of any of the General Motor Divisions.
2. Letter to NCR from Manager of Market Research Dept. of Sweets' Catalog Service, New York.
3. Trade literature of Thomas Micro-Catalogs, New York.
4. Trade literature of Vendor Specs Micro-File, and discussions with its competitors.
5. Electronic News, p. 30, December 17, 1962 (the frequency of publication is not stated, but is assumed to be annually).
6. Information from reports of NCR staff members.

this probably represents only a very few real applications. If the criterion for economic comparison is to be solely printing and distributing costs, and this may not be a realistic comparison, then the PCMI system may, for some special applications, be better than the other alternatives.

Potential for PCMI in the Microform Publishing Market

On the basis of the present volume of the microform publishing business, it appears that there are currently fewer than five microform publishers or printers that would even consider the acquisition of PCMI equipment. Furthermore, the interest of these five organizations in the PCMI equipment would be tempered by: (1) the relatively large (for them) capital costs, (2) the fact that their users or potential customers do not have PCMI or PCMI-compatible viewers, and (3) the relatively unfavorable PCMI system costs for the major areas of potential application.

On the basis of the relative economics of alternative means of publishing in microform, it appears that there is only a very restricted area (large-volume catalogs) in which the PCMI system is the most attractive--and there appears to be very few current applications in this restricted area.

From the viewpoint of the individual library as a potential customer for microform editions, there would be extreme reluctance to spend a great amount of money for a PCMI viewer if an alternative microform edition was also available with a reduction ratio that would allow some of the present and less expensive viewers to be used. Libraries will continue to have a need for viewers to handle microforms with the present reduction ratios (say 18:1 to 30:1), and will not be inclined to add a PCMI viewer just to handle some special editions. It seems reasonable to assume that the same published material may be made available to the libraries in several alternative microforms (e.g., PCMI and roll microfilm) so that the PCMI viewer will not be associated with an exclusive body of material. Consequently, even if one of the major microform publishers marketed PCMI editions of its material, the users might still have, and use, alternative sources of supply for the same material so that they would not have to acquire PCMI viewers.

Potential for PCMI in the On-Demand Printing Market

At the start of the research effort, it was suggested that the PCMI viewer-printer might be usefully employed for on-demand printing. That is, the equipment might be useful for situations in which a full-size paper copy was made, on-demand, of some item in a master file. This type of situation currently exists in the furnishing of copies of U.S. patents, ASTIA reports, out-of-print books, and many other materials, at the time that they are requested. With the advent of less expensive copying equipment, more and more copying work is being done on-demand instead of printing copies in advance and storing them for possible requests.

The PCMI system studied for this application consisted of a viewer-printer equipped to produce hard-copy prints directly from a file of images on PCMI cards. The specific descriptions and cost estimates for this PCMI system are given in Appendix H. Representative costs for alternative methods of on-demand printing are given in Table XIV. An illustrated summary of the relative economics of these alternatives is provided in Figure 6. The unit record sizes for several current on-demand printing operations are given in Table XV. From the data in Figure 6 and Tables XIV and XV it can be seen that the PCMI method is generally more expensive than several other alternatives. Furthermore, this particular analysis did not include the cost of initially preparing the PCMI file cards, which would be more than four or five times the cost of preparing the roll microfilm files. At this point it appears that the PCMI equipment when used in this manner is generally unsuitable for primary use as an on-demand printer.

<u>Restrictions on Microform Publication due to Copyright Laws</u>

The copyright laws put some restrictions on the practice of publication in microform. Since microfilming is essentially a copying operation, it is not permissible to microfilm copyrighted material for private use or for sale, without prior permission from the copyright holder. This restriction has prevented microform publishers from providing a larger selection and catalog of microform editions than might otherwise have been possible. This restriction has also prevented equipment manufacturers from assembling files of certain material in microform (e.g., the last five years of the open source literature in chemistry or electronics) as software to accompany their micro-image equipment.

Some publishers, for example, the American Chemical Society and the Institute of Radio Engineers, will not allow their journals to be published in microform. This is partly because these organizations are reluctant to delegate any of their publication or re-publication privileges to another organization. They would prefer to retain complete control of their material, and they have had very little user interest in microform editions of their works. To provide a significant and attractive catalog

Table XIV

REPRESENTATIVE COSTS FOR ON-DEMAND PRINTING

Type of Service	Form of Source Medium	Approximate Cost per Page (cents)	Reference (see below)
Xerox copies of dissertations	Roll microfilm	4.5¢ including binding	1
Xerox copies (9" x 11") (add. 1.0¢/page microfilm charge if no original film is available)	Roll microfilm	4.25¢	2
Xerox copies on Copyflo equipment (8-1/2" x 11" page, including chopping)	Roll microfilm	4.9-7.1¢	3
Xerox copies of out-of-print books (including binding)	Roll microfilm	3.5¢	4
Xerox copies from bound volumes	Bound volumes	4.0¢	5
Thermofax copies from bound volumes	Bound volumes	7.5¢	6

References:
1. Dissertation Abstracts, p. iii (September 1962).
2. Duopage Price List of Micro Photo Inc., Cleveland, Ohio.
3. Approximate price range from six commercial sources from W. R. Hawken, "Developments in Xerography: Copyflo, Electrostatic Prints, and O-P Books," College and Research Libraries, pp. 111-117 (March 1959).
4. E. Power, "Microfilm as a Library Tool," Special Libraries, Vol. 51, No. 2, pp. 62-64 (February 1960); and "Microfilm--The Versatile Academic Tool," cited earlier.
5. Discussion with Dep. Chief of Reference Services Division of the National Library of Medicine. This cost is based on data collected from the library's 1961 experience in providing 2.2 million pages of photocopied library material. For additional information, see "Survey of the Interlibrary Loan Operation of the National Library of Medicine," by W. H. Kurth, a report of the U.S. Dept. of Health, Education & Welfare. Public Health Service (April 1962).

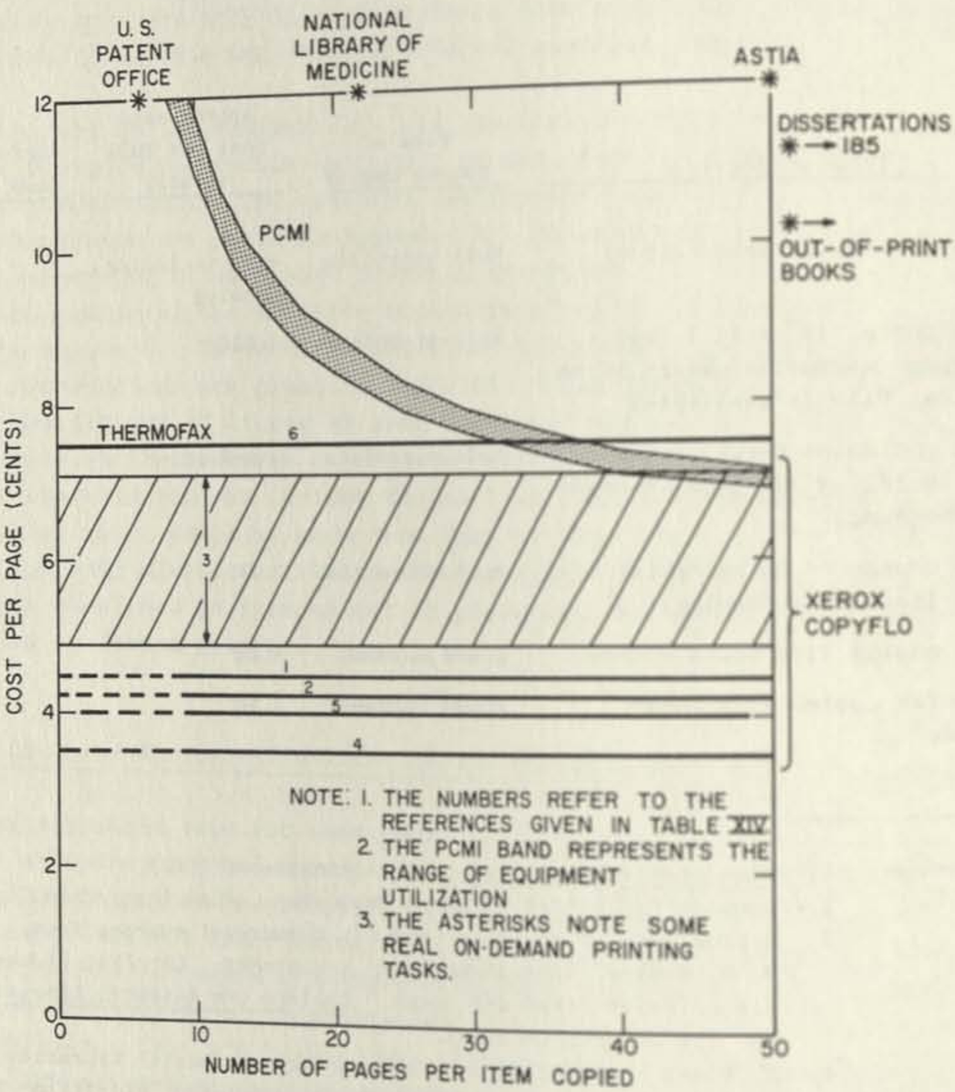

FIGURE 6

ON-DEMAND PRINTING COSTS FOR SEVERAL ALTERNATIVE METHODS

Table XV

REPRESENTATIVE UNIT RECORD SIZES FOR
SOME ON-DEMAND PRINTING APPLICATIONS

Application	Average Size of Item Printed (pages)	Number of Items Printed per Year	Reference (see below)
U.S. patents (U.S. Patent Office)	6	n.a.	1
Technical reports (ASTIA)	50	n.a.	2
Journal articles (NLM)	22	120,000	3
U.S. dissertations	185	15,000 to 30,000	4

n.a. = not available.

References:
1. "On Demand Patent and Copy Order Fulfillment Program," an undated report of the U.S. Patent Office.
2. See Table IX.
3. Discussions with Dep. Chief of the Reference Service Div. of the National Library of Medicine.
4. Table IX, and E. Power, "Microfilm--The Versatile Academic Tool," cited earlier.

of holdings, a microform publisher must go through a considerable amount of effort to contact the various publishers and negotiate for permission to re-publish in microform. In most cases, the microform publisher is actually a re-publisher rather than the prime publisher.

There is also some restriction on the purchase of microform editions. For example, University Microfilms, the largest microform publisher, states that in negotiating its publication rights, it obtains an individual license from each publisher for each journal. Each original publisher is paid a 10 percent royalty and is assured that microform editions will be sold only to those purchasers who provide a statement saying they are already subscribers to the paper edition. This requirement is felt to be necessary to assure the primary publisher that his subscription revenue will not be jeopardized by the microform edition.

It is probably not entirely coincidental that many of the presently available microform publications are for material that: (1) was never copyrighted, (2) is old enough that the copyright has expired, or (3) is from a former enemy national whose copyright was assumed and licensed by the U.S. government. In October 1962, President Kennedy signed Public Law No. 87-846 which includes provisions whereby most copyrights of former enemy nationals now held by the Attorney General are to be returned to the original publishers effective January 21, 1963. This may have the effect of making it even more difficult to obtain permission to provide microform editions of much of this material.

The general availability and use of office copying equipment has led to a great deal of copying of published material without the publishers' permission, and this has disturbed some publishers. But there have been very few instances of duplicating material from microform publications (e.g., duplication of roll microfilm). This is probably because of the technical problems and costs presently associated with making duplicates. Microform publishers would be pleased with the PCMI overcoating arrangement that makes it extremely difficult to make bootleg microform copies of finished PCMI prints.

In any case, many publishers, equipment manufacturers, and users are in one way or another hindered by the present copyright laws. There is currently much interest and growing pressure to change the laws. Current studies by the Council on Library Resources, the National Science

Foundation, and other interested groups should provide more information on this matter.*

Reactions of Readers to Microform Publications

Microform copies are tolerated by users but are seldom preferred. They are tolerated when the original or page-size hard copy is not available, and almost always represent a less attractive alternative to viewing the original. The greatest factor in the lack of popularity of microform systems seems to be the unpleasantness associated with the use of microform readers. For some applications where the information is available only in microform (e.g., some out-of-print books), or where the user is paid to work with this equipment (e.g., some business file systems), the unpleasantness is not such an important factor. However, it does become very important when the user has the freedom to specify other forms of publication.

Until recently, no study had been able to pinpoint the exact source of the unpleasantness, although scores of articles have reported dissatisfaction with the readers.** The recent work done at Battelle on human factor considerations of microform reading pointed out that in addition to the image design parameters over which the system designer normally has no control (e.g., kind of type font and page layout), there are some specific factors over which the designer must exercise careful control.*** These critical design factors are:

Amount of magnification, primarily as it affects the visibility of letters in the projected image

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* L. Heilprin, et al., Bull. of the Copyright Society, Vol. 10, No. 1, pp. 1-36 (October 1962).

V. W. Clapp, "Library Photocopying and Copyright: Recent Developments," Law Library Journal, Vol. 55, pp. 10-15 (1962).

** L. K. Born, "The Literature of Microproduction," American Documentation, Vol. 3, No. 3, pp. 167-187, provides a dozen references that show user dissatisfaction with the viewers.

*** L. E. Walkup, et al., "The Design of Improved Microimage Readers for Promoting the Utilization of Microimages," in Proc. 1962 Conv. of the Nat'l Microfilm Association, pp. 283-310, Nat'l Microfilm Assoc., Annapolis, Md. (1962).

Image sharpness

Image contrast

Uniformity of brightness over the field viewed

Fixity of position of the reader screen

Page brightness

Positive vs. negative projection

Other miscellaneous factors (e.g., color of background and characters, texture of image surface, surrounding brightness)

Because the user and market acceptance of the PCMI equipment may depend, in part, on how well it satisfies the human factors objections of the users, it might be useful here to comment on how well the PCMI viewer satisfies the general design goals that have been established from a human factors standpoint by this Battelle study. Some of these design goals and the corresponding PCMI specifications are listed together in Table XVI.

At this point, it appears that the proposed PCMI equipment satisfactorily overcomes many of the objections and sources of irritation to the users, although there are some requirements, such as image resolution, where the performance is still less than desired.

Table XVI

COMPARISON OF PCMI VIEWER CHARACTERISTICS WITH HUMAN FACTOR DESIGN GOALS

Requirement	PCMI Viewer Characteristic
1. Projected image size should be about 5-1/2" x 9-1/2".	1-4. These are basically characteristics of the source material, over which the PCMI equipment designers have relatively little control.
2. Characters should be dark on a light background of a dull or mat finish.	
3. Characters in projected image should be about the size of 10-point type in height, with a stroke of medium bold width. Acceptable type size is between 8- and 12-point.	
4. Majority of characters should be lower case, not italicized.	
5. Screen illumination should be set for at least 25 foot-candles because this level, established by previous studies, is widely accepted as a minimum for the general reading task.	5. PCMI provides for 40 foot-candles.
6. An opaque screen was suggested (rather than an etched or ground glass translucent screen), primarily to reduce scintillation effects.	6. PCMI has successfully overcome the scintillation problem by using the extra (moving) interference screen.
7. Positive (rather than negative) images are suggested, since for sustained viewing, positive images are felt to be more satisfactory.	7. PCMI system expects to use third-generation positive images as the regular microform.
8. Transparent (rather than opaque) base materials are suggested for the microform because of the problems of projection and hard copy reproduction encountered with opaque materials.	8. PCMI system expects to use images on a transparent base as the regular microform.
9. User must be able to assume various comfortable seated positions while using the reader.	9. This is possible.
10. Projected image must be sharp. A resolution of at least 7 lines per mm is necessary for comfortable viewing.	10. PCMI provides an estimated 4 to 4.5 lines per mm.
11. Reader must be binocular, not monocular.	11. PCMI provides full-screen viewing.
12. Image contrast must be moderately high, 0.7 or better.	12. PCMI image contrast is estimated to be less than 1.0.
13. Brightness of the background of the reading surface should be about the same as the ambient brightness in the room. A means should be provided to allow user to adjust brightness level to match surroundings.	13. No means provided on present model for user to change the level of illumination.
14. Viewer should be usable in the ambient light levels of an average well-lighted room.	14. This is possible.
15. Viewer should be lightweight enough to be held in the lap, and should be truly portable.	15. Not possible now or in the immediate future. Present model may weigh about 100 pounds.
16. Loading of the microform, and operation of the viewer should be simple.	16. This is possible.

V LARGE FILES FOR DOCUMENT STORAGE

In this section the operational characteristics of large files for document storage are first defined, and then they are analyzed in detail with respect to the requirements of high activity file users. The operational characteristics of the present PCMI system are then compared with both user requirements and other competing file systems to arrive at an over-all evaluation of PCMI's competitive ability to meet the operational requirements of high activity file users. The important economic considerations (from the user's point of view) are then defined and used as a basis for evaluating the economic attractiveness of the present PCMI system relative to other competing systems. The same type of analysis is then carried out for low activity files.

General Characteristics of Large Files for Document Storage

Large files are arbitrarily defined as those containing more than a million pages of information. Document storage implies storage of information, written or graphic, in document form rather than in digital (binary bits) form such as in magnetic tape or card storage. Since there is a wide variety of potential file applications, it is useful to classify applications into major categories for purposes of comparison and further analysis.

File applications can be classified either in terms of the information contained in the file such as insurance, personnel, or credit, or in terms of the operational characteristics of the file such as the activity rate, access time, up-date cycle, total number of pages, and accession rate. Preliminary analysis indicated that it would be more meaningful when defining user requirements to think in terms of operational characteristics than in terms of information content. This is because the operational characteristics help determine the economic requirements, and both taken together specify the user's total requirements in terms of what the user wants done and how much he is willing to pay for it.

Activity rate (high or low) was used as the primary criterion for classifying file applications since most users tend to think of their file problems in these terms. Some users have files of both kinds. In contrast, the type of information stored in the file has relatively little impact on user requirements. As an example, an insurance company usually has both a high activity file (for active policies) and a low activity file (for inactive policies and legal records). From the point of view of defining user requirements, an insurance company's active policy file (high activity) corresponds more closely to a credit agency's credit file (high activity) than to the insurance company's inactive policy file (low activity).

Since there are no standardized definitions for operational characteristics, the following arbitrary definitions were adopted for this study:

> Activity rate--Percent of documents retrieved per year. (Number of documents retrieved per year divided by the total number of documents stored in the file.) Activity rate is a measure of file usage.

> Access time--The average time needed to retrieve information from the file. Access time is a measure of the operating speed of the system.

> Update cycle--The acceptable delay for incorporating new information into the file. Length of the update cycle is a measure of the timeliness required of the information in the file. The shorter the update cycle, the more timely the information.

> Accession rate--The number of new entries (pages or fractional pages) added per year divided by the total number of pages in the file. Accession rate is a measure of the growth rate of the file.

> Total number of pages--Equal to double the number of sheets of paper if they have information on both sides.

High Activity Files

High activity files are arbitrarily defined as files having activity rates greater than 1 percent, i.e., more than 1 in 100 documents are retrieved each year. Such files usually contain documents that are used as part of the daily business operations, such as credit ratings in credit agencies, personnel records, patient records in hospitals.

Information used in the day-to-day transactions of business usually must be timely, or up-to-date. Thus, as a general rule, most high activity files also have a high accession rate (high percentage of new information added to present records) as well as a relatively short update cycle (period between successive updatings). The accession rate of a high activity file is in most cases roughly (plus or minus 25 percent) equivalent to the activity rate. One major exception to these generalizations is catalog applications (high activity, long update cycle) which are discussed under microform publishing.

Operational Requirements

The maximum required access time is usually determined by considerations external to the file system itself, such as the desire to provide better service to customers through the utilization of more timely information. An access time below the maximum is usually not specified by the user organization unless there is reason to believe that a lower access time would reduce the over-all cost of information storage and retrieval.

The maximum access time requirements for high activity files usually range from several minutes (for answering telephone requests) to several days for internal and mail requests, although both requests are serviced from the same file. Access time as defined here includes the delays in the system due to spacing of requests during an overload as well as the delay incurred in actually searching for documents in the file. It does not include the time required to determine which documents in the file are relevant to the requestor's inquiry or where the documents are located, but only the time required to physically retrieve them and transfer the desired information to the requestor.

After it has been determined which documents are relevant to the inquiry (through some sort of index) and the specified documents have been retrieved, their contents must be transferred to the requestor. One method is to remove the original copy from the file and lend it to a requestor. This has two disadvantages. First, the original may get lost or be misfiled when it is returned, causing what is known as the "out-of-file problem". Second, even if the original is found or returned at a later date, the file must be accessed again (doubling the total access expense) to replace the document.

Another method is to copy the relevant information from the original onto a slip of paper. This is both time-consuming and susceptible to error when the amount of relevant information is large, but is often the least expensive method when just a few facts are needed and it avoids the out-of-file and double-access problems.

The third approach is to make a "hard copy" of the original through xerographic or other means. The general trend is toward the use of this approach. Hard copy print-out is usually fast and is accurate; but the cost per page can run from 5-20 cents. For high activity files, the cost per page tends to assume greater significance than the capital cost of the printer because of the large number of documents copied.

Purging. The actual operations involved in maintaining a file include the purging of obsolete information and the incorporation of new information (updating). Obsolete information purged from a high activity file is sometimes destroyed, but it is more often transferred to a low activity file. Purging is normally done only once or twice a year, and it is usually accomplished by transferring the entire document (unit record) rather than by removing certain pages.

Growth. The annual growth in total number of pages in a high activity file is usually fairly small (several percent) since the amount of information purged normally about equals the amount of new information incorporated.

Updating. New information is incorporated into a file either by adding to what is already present (add-a-frame), by inserting entirely new documents, or by replacing old material with new (erase and rewrite). Different size forms and varying amounts of information tend to make the updating information vary from whole pages to fractions of a page. Thus in addition to requiring a capability for filing entirely new documents, most users require a capability for updating existing records with either fractional or full-page information.

The task of updating file documents with either fractional or whole page information is easier if the documents are filed in some sort of unit record (i.e., all pages of a specific document are stored, and therefore can be retrieved, as an integral unit). Examples of unit records are folders for paper systems and microfiche or microchips for microform systems.

The unit record size should be large enough to hold the biggest document anticipated as well as future additions (updatings) to that document. On the other hand, if the unit record size is too large, many documents will have to be stored on a single chip and ease of updating, as well as of purging, will be lost. Unit record storage also facilitates random access to the file, since a document can be retrieved directly rather than searching sequentially through the file as is required in roll microfilm files.

Often it is desirable to be able to update a document when it is pulled in connection with an inquiry (for example, credit and retail sales documents). Most manual paper files are updated in this manner.

Update cycle time requirements are usually determined by the same considerations as those determining access time, i.e., external service determines the maximum limit, and economic considerations determine the minimum limit.

The maximum allowable update cycle time for high activity files usually ranges from half a day to several days. Update cycle requirements may, however, vary within this range for different types of information in the same file.

The range of operational requirements of high activity file users is given in Table XVII, together with the operating characteristics of four competitive systems, including the proposed PCMI system. Table XVII shows that the proposed PCMI system fails to meet the update cycle requirements by a factor of 25 to 50 per million pages, i.e., a factor of 250 to 500 for 10 million pages (see Appendix I). This failure is due both to the long setup time (20 minutes each) required by the proposed camera-recorder and printer and to the large number of setups (roughly 400 required to update 1 million pages). The PCMI update cycle time becomes proportionately longer (10 to 50 months) for larger files (10 to 50 million pages), since the number of setups is roughly proportional to the total number of pages in the file.* In contrast, the three other competitive systems, paper, MEDIA, and microfiche, all meet the minimum update cycle time of half a day.

Table XVII also shows that the proposed PCMI unit record size of 2,625 is too large for most applications by a factor of 5 or more, thereby increasing the cost and difficulty of purging the file. In contrast, the paper and MEDIA systems meet the full range of requirements (2 to 500), while the microfiche system covers a substantial portion of the range.

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* Assuming there is at least one update per PCMI plate. For the present size plate, i.e., 2,625 images, and an update cycle of one day, this is equivalent to an annual accession rate of 10 percent--relatively low for a high activity file which is often greater than 100% (see Appendix I).

Table XVII

CAPABILITIES OF HIGH ACTIVITY FILE SYSTEMS AS
COMPARED WITH OPERATIONAL REQUIREMENTS

Operational Characteristic	Normal Range of Requirements	Paper System	Media System	Microfiche System	PCMI System
Activity rate	1% to 300%	Directly proportional to number of clerks	15%/million pages/ viewer[a]	9%/million pages/ viewer[a]	12%/million pages/ viewer[a]
Access time	Several minutes to several days	2 minutes	Less than 1 minute	1 to 2 minutes	1 minute (rough estimate)
Accession rate	1% to 300%	Directly proportional to number of clerks	b	b	b
Update cycle	1/2 day to several days	1/2 day to several days	1/2 day to 1 day	1/2 day to 1 day	1 month with single shift[c]
Minimum quantity of update information	Fractional page to whole page	Fractional page	Single page	Several pages	Fractional page?
Average unit record size	2 pages to 500 pages	Variable in units of 1	Variable in units of 3 pages	Variable in units of 50 or more	2,625 pages at present
Hard copy output	Sometimes	Requires extra equipment and effort	Yes	No	Yes
Total number of pages/average range	1 million to 500 million	Unlimited	Unlimited	Unlimited	Unlimited

a. Directly proportional to number of viewers.
b. Directly proportional to number of cameras.
c. See Appendix I.

Sources: Data from equipment manufacturers; field interviews with users; SRI files.

Thus the PCMI system as presently envisioned does not satisfy user operational requirements or meet competitive standards for high activity files in one crucial area--update cycle--and one minor area--unit record size. The magnitude of the discrepancy between user update cycle requirements and the proposed PCMI capability indicates that substantial changes in the concept and design of the PCMI system will have to be made before PCMI can be competitive in terms of operational requirements.

In assessing the difficulty, direction, and magnitude of the changes in PCMI required, the following points are considered relevant:

1. Total system cost considerations indicate a trend toward lower rather than higher reduction ratios.

2. User operational requirements (for high activity files) dictate the need for reducing rather than increasing unit record size.

3. Items 1 and 2 tend to increase rather than decrease the number of setups required to update a given number of pages, thus increasing the update cycle time.

4. Minimum update cycle requirements are usually governed by considerations external to the file system, such as the need to provide more timely information to outside customers.

5. It would be difficult to convince a user to change minimum update cycle requirements that can be met with other systems unless significant economic advantages not available with the other systems were offered. This does not seem feasible within the foreseeable future, as is demonstrated later in Tables XIX and XX.

Economic Considerations and PCMI Market Potential

As a general rule, after a user finds a system that satisfies his operational requirements (access time, update cycle, activity rate) he then evaluates the system for economic attractiveness. There are, of course, exceptions to this rule. One is specialized real-time military applications, such as intelligence files (not included in this study), where economic considerations are of secondary importance. For most users, however, present document retrieval systems (including the present PCMI system) are neither versatile nor glamorous enough to justify investment on other than a strictly economic basis. (In many cases the failure of highly advertised computer savings to materialize has tended to tarnish the former glamor of expensive information systems for users of these systems.

The user is concerned with two basic types of costs--capital investment (or fixed) costs, and operating (or variable) costs. Essentially the purchase of a document storage system is viewed as an investment opportunity that must show a return on investment comparable with other investment opportunities.

In order for a document storage system to be economically attractive to a user, it must generate sufficient savings in operating costs to equal the fixed-cost-plus-interest, within some predetermined payback period (usually 3 to 5 years).

There are two kinds of capital costs to be considered, the cost of equipment (including the cost of a maintenance contract) and the cost of converting from the present to the proposed system. Of the two, the conversion cost is usually larger by a factor of 2 or more. For example, the cost of converting one million pages to 16mm microfilm at a 30:1 reduction ratio varies from 3/4¢ to 2¢ a page ($7,500 to $20,000 per million pages), depending upon the amount of handling required, while the 5 to 10 readers needed for viewing the images would cost a total of $2,500 to $5,000.

The conversion cost is made up of the actual film and processing cost (about 1/2¢ per image for 16mm film at 30:1 reduction), and the cost of handling or preparing documents to be microfilmed (i.e., removing staples, arranging list pages in proper order, etc.) which is usually 2 to 3 times the filming cost. Preparation of indexes as well as training of personnel in the use of new equipment would substantially increase the conversion costs mentioned above, conceivably doubling them in extreme cases when an elaborate indexing scheme is required.

Operating costs are made up of three main elements--access cost, update cost, and purge cost. Access cost is the average cost per page of retrieving (finding and transferring) information from the file. Access cost usually consists of direct labor and overhead and thus tends to be a direct function of access time. Access cost usually ranges from 6¢ to 16¢ per access. The cost of producing a hard copy must also be considered if this is either the only means of output or the normal means of output. Hard copy cost per page averages 5¢.

The update cost per page of new information is usually greater than the corresponding original conversion cost per page, since additional handling is required to insert the new information into its proper place in the file. The update cost can thus be broken into three parts: (1) converting to image form (conversion cost), (2) locating the proper place in the file (access cost), and (3) actually inserting the information into the file (negligible for paper and unit record systems, expensive for serial systems such as roll microfilm). All three components might be significant, as in roll microfilm systems, or only one might be significant (e.g., access cost in the manual paper systems).

Purging of a file consists of locating the pages to be purged and removing them. Thus, the purging cost is made up of the access cost and the cost of removing the pages to be purged. The cost of removal is negligible when, as is usually the case, a whole document (i.e., unit record) is removed from a unit record system. Therefore, when a whole document is removed, the purging cost is equal to the access cost, i.e., approximately 6¢ to 16¢.

One other operating cost is the cost of floor space occupied by a file system. However, the annual space costs for even the bulkiest file system (manual paper) are relatively small (.02¢ to .2¢ per page per year) when compared with other operating costs (access, update, purge costs) of high activity files.

Table XVIII shows the fixed and variable costs for four high activity file systems including the proposed PCMI system. The conversion cost for the PCMI system exceeds that for the microfiche system by a factor of 3 and for the MEDIA system by a factor of 5.

The estimated PCMI costs for access and purge (8¢ each) are probably on the low side (by a factor of 50 percent or more) since they are both based on an estimated access time of only one minute. It has never been demonstrated that an operator can select the proper PCMI card, insert it in the viewer, find the required image, adjust the focus, make a hard copy, remove the PCMI card, and refile it--all within a minute; or having done this once, continue at the rate of 60 times an hour, 8 hours a day.

The estimated PCMI update cost is also on the low side since it has not been demonstrated that it is even technically feasible to achieve the short update cycle times required. However, to get some indication of the relative economic attractiveness of the PCMI system, it was assumed that a short update cycle could be achieved, which would result in an absolutely minimum cost of 26½¢ to 29½¢. This includes a conversion cost of 8½¢ to 11½¢, an access cost of 8¢, and only 10¢ for material (new disseminable copy) and labor (setup time, etc.).

Table XVIII

HIGH ACTIVITY FILE SYSTEMS--FIXED AND VARIABLE COSTS

Type of Cost	Paper System	MEDIA System	Microfiche System	PCMI System
Fixed cost				
Equipment cost (incl. maintenance/million images)	65 file cabinets, approx. $4,000 total	$25,500/selector-reproducer; less for viewer only	$350 for reader only $650 for reader-printer	$2,500/reader-printer
Conversion cost/million images; no special handling	None	$20,000 (2¢/page)	$30,000 (3¢/page)	$75,000-$115,000 (8.5¢ to 11.5¢/page)
Operating cost[a]				
Access cost/unit record	16¢	6¢	8¢-16¢ (12¢ avg.)	8¢?
Hard copy cost/page	5¢	4¢ paper, 2¢ film	5¢, 10¢ diazo (300 pages)	5¢ paper, 50¢ silver halide (3,000 images)
Update cost/page (access + conversion)	16¢[b]	8¢	11¢ to 19¢	26.5¢ to 29.5¢[c]
Purge cost/unit record	16¢	6¢	8¢ to 16¢	8¢?
Storage cost/page	0.02¢ to 0.2¢	Negligible	Negligible	Negligible

a. Assumes 100% burden on direct labor.

b. In some paper systems, much of the updating is done while accessing the material for information, thus eliminating update cost.

c. Assuming "setup problem" could be solved (see Appendix I), and that material and labor for update would be 10¢.

Sources: Data from equipment manufacturers; field interviews with users; SRI files.

In contrast to the present PCMI system, the costs for the paper, MEDIA, and microfiche systems are based on operating experience and are considered to be fairly accurate. Thus the optimistic nature of the PCMI costs should be kept in mind when comparing the economic attractiveness of the different systems.

Table XIX shows the operating savings or losses that would result by switching from a manual paper system to one of the described microform systems. The equipment cost per million pages for the proposed PCMI system is approximately 1/10 that for the MEDIA system but still 5 to 10* times the cost for a microfiche system. The conversion cost per million pages for the PCMI system exceeds that for a microfiche system by a factor of 3 and that for the MEDIA system by a factor of 5.

Turning to the operating costs, it is seen that the savings in access and purge costs achieved by switching to the PCMI system are roughly 20 percent less than those achieved by switching to the MEDIA system. At the same time the PCMI user would incur an average loss of 12¢ per-page-updated while the MEDIA user would achieve a saving of 8¢ per page.

Compared with the microfiche system, PCMI achieves greater savings in access and purge costs by a factor of 2. However, more than offsetting these savings are the loss in the PCMI system of 12¢ per-page-updated, as compared with a saving of 4¢ for microfiche, and the relatively lower fixed costs of the microfiche system (1/3 the conversion cost, 1/5 to 1/10 equipment cost) compared with PCMI. The effect on investment and payback period of the differences in fixed and operating costs of the three competitive systems (PCMI, MEDIA, microfiche) are shown in Table XX.

Table XX shows the capital investment per million pages and the payback period for different activity rates. A detailed explanation of the calculations is given in Appendix J. As might be anticipated from the previous discussion, the proposed PCMI system has a payback period that is longer by a factor of from $1\frac{1}{2}$ to 10, than that of either the MEDIA or microfiche systems. Thus the return on investment achievable with either the MEDIA or microfiche systems is from $1\frac{1}{2}$ to 10 times greater than that achievable with the proposed PCMI system.

At a 50 percent activity rate, the size of the investment required by the PCMI system becomes roughly equal to that required by the MEDIA system but is still 3 times the investment required for the microfiche

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* Depending upon the activity rate.

Table XIX

HIGH ACTIVITY FILE SYSTEMS
SAVINGS OR ADDITIONAL COSTS RELATIVE TO PAPER SYSTEM

Type of Cost	MEDIA System	Microfiche System	PCMI System
Fixed cost			
Equipment cost/million pages			
At 10% activity rate	\$ 21,500 additional cost	\$ 3,500 saving	\$ 1,500 saving
At 100% activity rate	\$174,500 additional cost	\$ 1,500 additional cost	\$16,000 additional cost
At 300% activity rate	\$506,000 additional cost	\$12,500 additional cost	\$56,000 additional cost
Conversion cost/million pages	\$ 20,000 additional cost	\$30,000 additional cost	\$75,000-\$115,000 additional cost (avg. \$95,000)
Operating costs			
Access cost/access	10¢ saving	4¢ avg. saving	8¢ saving
Update cost/page	8¢ saving	5¢ to 3¢ saving (avg. 4¢)	10.5¢ to 13.5¢ additional cost (avg. 12¢)
Purge cost/unit record	10¢ saving	0¢ to 8¢ saving (avg. 4¢)	8¢ saving
Storage cost/million pages/year	\$200 to \$2,000 saving	\$200 to \$2,000 saving	\$200 to \$2,000 saving

Sources: Data derived from Tables XVII and XVIII.

Table XX

HIGH ACTIVITY FILE SYSTEMS
CAPITAL INVESTMENT AND PAYBACK PERIOD[a] VS. ACTIVITY RATE

Activity Rate	MEDIA System: Investment per Million Pages (dollars)	MEDIA System: Payback Period (years)	Microfiche System: Investment per Million Pages (dollars)	Microfiche System: Payback Period (years)	PCMI System: Investment per Million Pages (dollars)	PCMI System: Payback Period (years)
5%	$ 41,500	4	$26,500	4.8	$ 95,000	38
10	41,500	2	26,500	2.65	95,000	24
50	107,000	1.1	30,700	0.66	103,000	6.5
100	195,000	1.2	31,500	0.3	111,000	3.6
300	526,000	0.92	42,500	0.16	151,000	1.6

a. Based on savings over a manual paper system.

system. At a 300 percent activity rate, the PCMI system requires less than 1/3 the capital investment of the MEDIA system but still roughly 4 times the investment of the microfiche system.

However, the important figure is the payback period, or its reciprocal--return-on-investment.

Therefore, even if the proposed PCMI system could be redesigned to meet operational requirements (update cycle time and unit record size) for high activity files, it would probably still be at an extreme economic disadvantage relative to other high activity file systems, as is shown in Table XX. This conclusion is further strengthened by the fact that the differences in payback period between PCMI and the other two systems, are quite likely greater than Table XX indicates, since the payback period is extremely sensitive to changes in access time.* As access time increases, the number of readers required increases, thus increasing the capital investment. At the same time, operating savings (from access, purge, or update operations) go down. The net result is less money available for paying back a larger investment.

In summary, the PCMI system as presently envisioned is neither operationally nor economically competitive for high activity files with other systems presently available. Specifically, the PCMI systems fails to meet minimum user update requirements or yield a competitive return on investment. On the basis of these findings, it is concluded that there is no market for the present PCMI system in the high activity file field.

Low Activity Files

Low activity files are arbitrarily defined as files having activity rates of less than 1 percent, i.e., less than 1 in 100 documents are retrieved each year. However, the majority of low activity files in fact have activity rates substantially below 1 percent (.001 percent to .1 percent). Low activity files contain documents kept mainly for legal or historical use by, for example, banks, insurance companies, and old business records of industrial firms, etc. Low activity files have been one of the largest application areas for microform file systems, and in particular systems utilizing roll microfilm as the storage medium.

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* The estimate for PCMI access time (one minute) is extremely optimistic and probably low by a factor of 50 percent or more.

Operational Requirements

The minimum access time required for low activity files ranges from several hours to a week or more, with a preponderance of inquiries requiring an access time of several days. As with high activity files, minimum access time requirements may vary within this range for different users of the same file. For example, in one large insurance company, roughly 10 percent of the requests to a low activity file required a minimum access time of several hours, while the remaining 90 percent required several days.

The maximum allowable update cycle for low activity files usually ranges from several days to several months, with most low activity files being updated on a weekly or monthly basis.

New information incorporated into low activity files usually consists of new complete documents or unit records rather than of single or fractional pages to be added to documents already in the file. In addition, low activity files are normally organized on a chronological basis (e.g., all records from first quarter 1962). This greatly simplifies the updating problem, since the new information can be added in a batch to the end of the file, eliminating the need to file each document separately. As a result, low activity files lend themselves to serial (e.g., roll microfilm) methods of storage, which are generally less expensive than the unit record methods required by most high activity files.

In many cases, the update information consists of documents which are transferred to a low activity file after being purged from a high activity file. Since the purge rate of a low activity file is usually extremely low, or even 0, the size (total number of pages) of low activity files tends to grow (average range is 5 to 20 percent per year) as contrasted with high activity files, which tend to remain fairly constant in size for a given level of business effort. As a result, low activity files tend to be roughly an order of magnitude larger in size than high activity files.

One additional operational characteristic required by the low activity file user is the ability to protect his file against damage or loss from fire, theft, flood, decay, misplaced documents, etc. This is particularly important for low activity files since they are kept mainly for legal or historical reasons and are often irreplaceable if lost. The two most common approaches are to use some sort of microform with a duplicate copy stored in a remote location or to maintain the original paper copy in an environmentally controlled mountain vault. Microform storage provides complete protection while vault storage does not entirely eliminate the problem of lost or misplaced documents. Some organizations use both approaches.

The range of operational requirements of low activity file users is given in Table XXI, together with the operating characteristics of three competing types of systems, including the proposed PCMI system.

Table XXI shows that the proposed PCMI system meets all the operational requirements of low activity file users with the minor exception of unit record size. Unit record size, however, is usually relatively unimportant in low activity files, since both updating and purging (if any) is normally done on a "batch" basis.

Economic Considerations and PCMI Market Potential

As mentioned earlier, most users evaluate potential systems in terms of both operational requirements and economic considerations, with economic considerations generally becoming dominant, once the user's minimum operational requirements have been made.

In order for the low activity file to be economically attractive to the user, it must, like the high activity file, generate sufficient savings in operating costs to equal the fixed cost-plus-interest within some predetermined payback period.

Of the two fixed costs, conversion and equipment, the conversion cost usually is greater by a factor of 10 to 20, depending upon the activity rate of the file. Thus, a low activity file with an extremely low rate (.001 percent) requires less investment in viewing or retrieving equipment per million pages than a file with a moderately low rate (.05 percent), although the conversion cost is the same.

This is not true, of course, if the conversion cost is 0 or nearly so, as is the case when a low activity file is essentially a repository for information purged from a high activity file and no change in format or type of storage medium is required. Normally, however, a large part of the information must be converted before being stored in a low activity file, and in these cases the conversion cost usually varies from 3/4¢ to 2¢ a page (16mm reel microfilm). The cost of providing a duplicate security file would probably add .2¢ to .3¢ per image to the conversion cost for a microfilm system. For a paper system, the cost of providing similar but not as complete security would be an operational

Table XXI

CAPABILITIES OF LOW ACTIVITY FILE SYSTEMS AS COMPARED WITH OPERATIONAL REQUIREMENTS

Operational Characteristic	Normal Range of Requirements	Paper System	Roll Microfilm System	PCMI System
Activity rate	.001% to 1%	Directly proportional to number of clerks	4%/million pages/ viewer[a]	12%/million pages/ viewer[a]
Access time	Several hours to several weeks	2 to 5 minutes	3 minutes	1 minute (rough estimate)
Accession rate	1% to 20%	Directly proportional to number of clerks	b	b
Update cycle	Several days to several months	Several days to several weeks	Several days to several weeks	Several days[c]
Minimum quantity of update information	Whole document or series of documents	Document	Document--difficult for single pages	Document
Average unit record size	2 pages to 500 pages (not critical)	Variable	2,000-3,000 pages	2,625 at present
Hard copy output	Sometimes	Requires extra equipment and effort	Yes	Yes
Total number of pages/average range	10 million to 5 billion	Unlimited	Unlimited	Unlimited

a. Directly proportional to the number of viewers.
b. Directly proportional to number of cameras.
c. Assuming batch processing of update material.

Sources: Data from equipment manufacturers; field interviews with users; SRI files.

rather than a fixed cost because of mountain storage vault charges (estimated at .1¢ to .2¢ per image per year).

The update cost per page for a low activity file is normally equal to the conversion cost since unlike high activity files, large numbers of complete documents, in chronological order, can be incorporated into the file in a batch, eliminating the need to file each document or single page separately.

For low activity files, the access cost is relatively unimportant compared with the conversion cost because of the extremely small number of accesses made per page on the average (normally .00001 to .001 annually).

The purge cost also is relatively unimportant compared with the conversion cost since the purge rate is usually extremely low or is 0.

The cost of storage space for low activity files is significant, since the other operating costs, access and purge costs, are low and the files are usually stored for long periods of time (5 to 50 years or more). Annual storage cost per image ranges from .02¢ to .1¢ for paper systems and proportionately less (approximately as the square of the reduction ratio) for microfilm systems. Appendix L shows that negligible savings in storage cost are achieved by using reduction ratios greater than 30:1. Most low activity file paper systems are located in areas where the storage costs are relatively low (i.e., .02 cents per image per year).

Table XXII shows the fixed and variable costs for three low activity file systems, including the proposed PCMI system. Table XXIII shows the operating savings or losses achieved by switching from a manual paper system to one of the described microform systems.

Both the PCMI and reel microfilm systems result in a savings in equipment costs, for two reasons. First, low activity rates usually eliminate the need for more than one reader, thus keeping the investment in equipment relatively low. Second, the use of microfilm eliminates the need for the 65-odd filing cabinets required to store information in the paper system. Although the reel system has a 2-to-1 advantage in equipment savings for the rare case of a minimum system, this disadvantage disappears for the more normal case of larger files, i.e., 5 to 10 million pages.

The combination of equipment savings and low total operating costs (due to low activity rates) makes the cost of conversion the most significant cost in the low activity file. Table XXIII shows that the proposed PCMI system has a conversion cost roughly 7 times that of the roll microfilm system.

Table XXII

LOW ACTIVITY FILES--FIXED AND VARIABLE COSTS

Type of Cost	Paper System	Roll Microfilm System	PCMI System
Fixed cost			
Equipment cost (incl. maintenance/million images)	65 file cabinets, approx. $4,000 total	$400 avg./reader; reader-printer--$700 Approx. one-fourth reader/ million pages at 0.1% activity rate	$2,500/reader-printer Approx. one-tenth reader/million pages at 0.1% activity rate
Conversion cost/million images; no special handling	None	$7,500-$20,000 3/4¢ to 2¢/page	$75,000-$115,000 8.5¢ to 11.5¢/page
Operating cost[a]			
Access cost/unit record	16¢ to 40¢	24¢	8¢?
Hard copy cost/page	5¢	5¢	5¢
Update cost/page	Negligible	3/4¢ to 2¢	8.5¢ to 11.5¢
Storage cost/million pages/year	$200-$400	Negligible	Negligible

a. Assumes 100% burden on direct labor.

Sources: Data from equipment manufacturers; field interviews with users; and SRI files.

Table XXIII

LOW ACTIVITY FILE SYSTEMS
SAVINGS OR ADDITIONAL COSTS RELATIVE TO PAPER SYSTEM

Type of Cost	Roll Microfilm System	PCMI System
Fixed cost		
Equipment cost/million pages		
At .001% activity rate	$3,500 3,500 3,500 } minimum saving $3,975 3,975 3,975 } saving per million pages	$1,500 1,500 1,500 } minimum saving $3,950 3,950 3,950 } saving per million pages
Conversion cost/million pages	$7,500-20,000 additional cost ($13,750 avg.)	$75,000-115,000 additional cost ($95,000 avg.)
Operating cost		
Access cost/access	8¢ cost to 16¢ saving (4¢ avg. saving)	8¢ to 32¢ saving (avg. 20¢)
Update cost/page	3/4¢ to 2¢ additional cost (1.5¢ avg.)	8.5¢ to 11.5¢ additional cost (avg. 10¢)
Storage cost/million pages/year	$200-400 saving	$200-400 saving

Sources: Data derived from Tables XXI and XXII.

As for operating costs, the PCMI system has a 5-to-1 advantage over the reel system in access costs, which, however, is more than offset by a 7-to-1 disadvantage in update-per-page costs.

Table XXIV shows the capital investment required per million pages and the payback period for different activity rates. An explanation of the calculations is given in Appendix K. The proposed PCMI system has a payback period 4 to 10 times greater* than that for the roll microfilm system, or in other words a return on investment 4 to 10 times smaller. In addition, the investment per million pages for the proposed PCMI system is almost 10 times greater than that for a roll microfilm system. In both cases, the poorer showing of the PCMI system is due almost entirely to the higher PCMI conversion costs (7 times greater), since the savings on equipment and access and update costs are relatively negligible.

In summary, the PCMI system meets the major operational requirements of low activity file users but fails to be economically competitive with roll microfilm systems by a factor of from 4 to 10.

This extreme economic disadvantage, together with the premium placed on low costs by the user, leads to the conclusion that there is no market for the present PCMI system in the low activity file field.

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* Depending on the activity rate.

Table XXIV

LOW ACTIVITY FILE SYSTEMS
CAPITAL INVESTMENT AND PAYBACK PERIOD[a] VS. ACTIVITY RATE

	Roll Microfilm System		PCMI System	
Activity Rate	Investment per Million Pages (dollars)	Payback Period (years)	Investment per Million Pages (dollars)	Payback Period (years)
.001%	$10,000	20	$95,000	189
.010	10,000	20	95,000	182
.100	10,000	18.4	95,000	136
1.00	10,000	11	95,000	38

a. Based on savings over manual paper system.

VI OTHER APPLICATIONS

In addition to the two major application areas of microform--publishing and large file document storage--two minor application areas of interest to NCR were examined. Buckbee-Mears Company, a leader in the photo-etching field, was contacted to explore potential application of PCMI to this industry. Buckbee-Mears, in responding to an ad on PCMI expressed strong interest in exploring potential applications of PCMI to the photo-etching process. The rapid growth of military command-control systems (estimated at over $20 billion over the next ten years), together with the requirement of these systems for information storage and retrieval equipment, seemed to warrant a brief examination of PCMI's potential in this area.

Buckbee-Mears Photo-Etching Process

Many of the parts used in Buckbee-Mears photo-etching process are made by drawing a large-scale pattern of the part and then reducing it 100 to 200 times or more, using a step and repeat camera to generate a number of parts on a single pattern. The president of Buckbee-Mears, Mr. Norman B. Mears, thought that the only sizable application area would be in the use of photochromic material rather than silver-halide for the first-generation masters of these reduced patterns. He estimated that even at the most optimistic utilization of material, his company's need for PCMI material would never be over $50,000 a year.

The photo-etching company would be mainly interested in the photochromic material for its high resolution characteristics rather than its erase and rewrite characteristics. Any correction or rework that is done involves changes in placement of one sub-pattern relative to another rather than changes in the content of the pattern itself. The present method is to make changes through step and repeat cameras capable of producing small patterns plus or minus one-half mil.

Although the company would be particularly interested in any further developments, especially the possibility of developing larger-field diameters (i.e., one inch and greater), the relatively small market potential, $50,000, makes the extensive development required unattractive.

Military Command-Control Systems

To date, the capacity of information storage and retrieval systems available has not been completely adequate for the requirements of military command-control systems. It was thought that the high storage density of the PCMI equipment and system, together with its relatively low cost, might be useful for this application.

Military command-control systems are large-scale electronic systems, usually global in scope, that are used to collect and display, in a meaningful manner, information to a military commander, and also to transmit his commands back to the troops. The SAGE Air Defense System, used to protect the United States against foreign air attacks, is perhaps the most widely known system of this type. As advancing technology rapidly decreases the time available to decision-makers for making crucial decisions, more and more money is being spent by the federal government to develop new systems and enlarge old ones.

Command-control systems consist of three basic elements--a sensor network, a communications network, and data processing and display systems. The sensor network consists of radar equipment and other detection equipment such as spy-in-the-sky satellites. The communications network is made up of military and commercial telephone, telegraph, and radio circuits and will include satellite communications when they are developed. The function of the sensor network is to detect and describe changes in the environment that may be of interest to the commander. The function of the communications network is to transmit the information detected by the sensor network to the data processing systems and in turn to transmit back from the commander to the sensors and to forces in the field instructions or commands from the commander.

The data processing and display system usually consists of one or more digital computers for reducing the raw data coming in from the sensor networks into a meaningful form for the commander and of display or output devices for displaying this information to the commander as he desires. The display equipment can be as simple as an electric typewriter operated by the computer, or as complex as a multicolored dynamic display that plots in real time the movement of enemy forces as well as the movements of our own forces. The data processing system must be capable of storing extremely large amounts of information, as well as being capable of retrieving any desired part of the information in a matter of seconds.

Information collected during the course of the project indicated that the main requirement of a command-control system is for the storage of digital information in the form of binary bits rather than for the storage of graphic or alphanumeric information in image form.

Such a storage device would have to be capable of storing billions of bits of binary information in a semipermanent form that might be changed only once or twice a year. Such a storage device would have to have an access time in the millisecond range and cost something under a quarter of a million dollars per unit. In its present configuration it does not appear that PCMI would be applicable.

Table A-1

U.S. MICROFORM PUBLISHERS

Organization	Estimated Cost of One Copy of Each Catalogued Publication (dollars)	Microform	Types of Publications
University Microfilms, Inc. Ann Arbor, Michigan	Over $200,000	Microfilm	Over 50,000 dissertations, many thousands of books, and over 1,600 periodicals and newspapers
Micro Photo (Div. of Bell & Howell) Cleveland, Ohio	Over 200,000	Microfilm	Backfiles of over 2,100 newspapers, some periodicals, some books
Microfilm Service and Sales Co. Dallas, Texas	Over 200,000	Microfilm	Newspapers of the southwest U.S., 400 publications, and over 20 million filmed pages
Microcard Editions, Inc. Washington, D.C.	Over 200,000	Microcard (primarily)	Historical manuscripts, books, special collections (company has distributed over 100 million microcards)
Microcan, Inc. (affiliate of J. S. Canner & Co., Inc.) Boston, Massachusetts	78,000	Microfilm	Approximately 200 journals, AEC reports, and NASA reports
American Jewish Periodical Center Cincinnati, Ohio	24,300	Microfilm	Approximately 100 Jewish newspapers and periodicals (total collection consists of about 1,350 rolls of film)
Consultants Bureau Enterprises, Inc. New York, New York	10,400	Microcard	Approximately 20 Soviet technical journals (Microcards are priced the same as regular printed editions)
Godfrey Memorial Library Middleton, Connecticut	9,550	Microcard	All U.S. chemical patents, annual reports of all U.S. corporations listed on the N.Y. and American Stock exchanges, <u>U.S. Federal Register</u>, <u>U.S. Patent Office Official Gazette</u>, and <u>New York Law Journal</u>
Matthew Bender and Co. Albany, New York	6,250	Microcard	U.S. Supreme Court briefs and records; a few other legal reports
Massachusetts Historical Society Boston, Massachusetts	4,880	Microfilm	Two publications: <u>Adams Family Papers</u> and <u>General Henry Knox Papers</u>
Microlex Corporation (Div. of Lawyers Cooperative Publishing Co., Inc.) Rochester, New York	3,580	Microlex	Approximately 900 volumes of law books
Newsweek Corporation New York, New York	2,580	Microcard	<u>Newsweek</u> magazine
Southern Education Reporting Service Nashville, Tennessee	1,800	35mm microfilm	Collected source information on race relations in the U.S. (total collection consists of 84 rolls of film)
Louisville Free Public Library Louisville, Kentucky	1,290	Microfilm and Microcard	25 publications concerned with Kentucky history and politics
Dakota Microfilm Service Denver, Colorado	890	Microfilm	Approximately 200 musicology titles for time period 1500-1800, plus some recent works
Catholic University of American Press Washington, D.C.	740	Microfilm and Microcard	Approximately 130 dissertations and reports
American Antiquarian Society (affiliated with Micro-Research Corp.) Worcester, Massachusetts	620	6" x 9" readex microprint	18 early American newspapers for time period 1704-1800
Michie Company Charlottesville, Virginia	600	Microcard	<u>Virginia Law Reports</u>
Institute of Paper Chemistry Appleton, Wisconsin	500	Microcard	Pulp and paper patents (U.S. and Canadian)--about 3,200 patents per year

Table A-1 (concluded)

Organization	Estimated Cost of One Copy of Each Catalogued Publication (dollars)	Microform	Type of Publications
Arthur H. Clark Co. Glendale, California	$ 250	Microcard	1 publication--The Philippine Islands: 1493-1898 (55 volumes on 210 cards)
American Bar Foundation Chicago, Illinois	155	Microfilm and Microcard	8 publications: law journals and bulletins
New York Times New York, New York	150	35mm microfilm	New York Times
American Association for Advancement of Science Washington, D.C.	140	Microcard	Science
American Chemical Society Washington, D.C.	135	Microcard	Experimental issue of First Decennial Index to Chemical Abstracts
Meade Natural History Library New Orleans, Louisiana	45	Microcard	Zoology reports
Wildlife Diseases Assoc., American Institute of Biological Sciences Washington, D.C.	4	Microcard	J. Wildlife Diseases, published exclusively in Microcard form, and subscribed to by about 2,000 biologists
Microtext Publishing Corporation New York, New York		Micro-opaque card	Journals, books, ACS monographs
New York Public Library New York, New York	n.a.	Microfilm	N.Y. Times Index and some New York newspapers
Readex Microprint Corp. New York, New York	n.a.		
Peter Smith, Publisher Gloucester, Massachusetts	n.a.		
Society of Exploration Geophysicists Tulsa, Oklahoma	n.a.		
Stechert-Hafner, Inc. New York, New York	n.a.		
Falls City Microcards Louisville, Kentucky	n.a.		
N. A. Kovach, Microfilm Dept. Los Angeles, California	n.a.		
Lost Cause Press Louisville, Kentucky	n.a.		
U.S. National Archives & Records Service Washington, D.C.	n.a.		
Universal Microfilming Corp. Salt Lake City, Utah	n.a.		
University of Alabama University, Alabama	n.a.		
University of Chicago Press Chicago, Illinois	n.a.		
University of Florida Library Gainesville, Florida	n.a.		
School of Health & Physical Education, University of Oregon Eugene, Oregon	n.a.		
University of Kentucky Press Lexington, Kentucky	n.a.		
University of Rochester Press Rochester, New York	n.a.		
University of Wisconsin Press Madison, Wisconsin	n.a.		

n.a. = not available.

Appendix B

U.S. MANUFACTURERS AND DISTRIBUTORS OF MICROFORM EQUIPMENT, SYSTEMS, AND SUPPLIES

CAMERAS

Agfa, Incorporated
Atlantic Microfilm Corp.
Audio Visual Research
Bell & Howell Co.
Charles Bruning Company, Inc.
The De Florez Company
Federal Mfg. and Engineering Co.
Griscombe Products Corp.
Hycon Manufacturing Co.
Ideax Corporation
Keuffel & Esser Co.
E. Leitz, Inc.
Microcard Reader Corp.
Nikon Inc.
Pfaff Development Corp.
Photo Devices, Inc.
Photostat Corp.
Recordak Corp.
Records Service Corp.
Regiscope Corp. of America
Remington Rand Systems,
 Div. of Sperry Rand Corp.

READERS

American Optical Co.
Atlantic Microfilm Corp.
Audio Visual Research
Bell & Howell Co.

READERS (contd.)

The De Florez Company
Documat, Inc.
Erban Products, Inc.
Griscombe Products
Karl Heitz, Inc.
Industrial Design & Service Co.
Keuffel & Esser Co.
The Frederic Luther Co.
Microcard Reader Corp.
Microdealers, Inc.
Microlex Division,
 Lawyers Co-operative Publ. Co.
Minnesota Mining & Mfg. Co.
A & R Specialties Company
Pfaff Development Corp.
Photo Devices, Inc.
Photostat Corp.
Readex Microprint Corp.
Recordak Corp.
Records Service Corp.
Viewlex Inc.
Western Blue Print Co.

HANDVIEWERS

Microcard Reader Corp.
Microreader Mfg. & Sales Corp.
Optics Manufacturing Corp.
Taylor-Merchant Corp.

Source: Administrative Management, "Tools of the Office", November 1962.

PROCESSORS

Allen Products, Inc.
ANA-TEC, Inc.
Burke & James, Inc.
C. F. Russell Co. Inc.
Andre Debrie Mfg. Corp.
Eastman Kodak Co.
Fairchild Camera and Instrument Corp.,
 Industrial Products Div.
Oscar Fisher Company, Inc.
Hi-Speed Equipment, Inc.
Houston Fearless Corp.,
 Westwood Div.
Micro Record Corp.
Milsco Mfg. Company
The Morse Instrument Co.
Nikor Products Co.
General Aniline & Film Corp.
 Ozalid Division
Recordak Corp.
Remington Rand Systems,
 Div. of Sperry Rand Corp.
S.O.S. Photo-Cine-Optics, Inc.
The Stineman System

CONTACT PRINTERS

Burke & James, Inc.
Oscar F. Carlson Company
Federal Mfg. & Engineering Corp.
Microdealers, Inc.
Minnesota Mining & Mfg. Co.
General Aniline & Film Corp.
 Ozalid Division
Photo Devices, Inc.
Photostat Corp.
The Stineman System
Tecnifax Corp.
Uhler: Cine Machine Co.

ENLARGERS

Charles Bruning Company, Inc.
Documat, Inc.
Durst (USA), Inc.
Federal Mfg. & Engineering Corp.
Keuffel & Esser Co.
E. Leitz, Inc.
Microcard Corp.
Microcopy Inc.
Minnesota Mining & Mfg. Co.
Photo Devices, Inc.
Photostat Corp.
Recordak Corp.
Simmon Brothers Inc.
Xerox Corp.

ACCESSORIES & MISCELLANEOUS

Alves Photo Service, Inc.
American Microfilming Service Co.
American Optical Co.
Beil's Photocopy & Microfilm Service
Dakota Microfilm Service
The Frederic Luther Co.
Gaylord Bros.
Graphic Microfilm Corp.
Griswold Machine Works
Hall & McChesney, Inc.
The Harwald Corp.
Hi-Speed Equipment, Inc.
Hollywood Film Co.
Industrial Design & Service Co.
Kalvar Corp.
Paul E. Killion Inc.
Micro Record Corp.
Micro-Seal Corp.
Microfilm Jacket Inc.
The Morse Instrument Co.
Munsell Color Co., Inc.
N. B. Jacket Corp.
Neumade Products Corp.
PEGI
Perma Film Inc.

ACCESSORIES & MISCELLANEOUS (contd.)

Pitney-Bowes Inc.
Prestoseal Mfg. Corp.
Ohio Envelope Co.
Rovico Corp.
Security Steel Equipment Corp.
Serta Film Inc.
Tayloreel Corp.
Wallach & Associates Inc.
Watson Mfg., Co., Inc.
Yawman & Erbe Mfg., Co., Inc.

SPECIALS

Dakota Microfilm Service
FMA Incorporated
General Dynamics/Electronics
Information Retrieval Corporation
The Magnavox Company
Mast Development Company Inc.
Pacific Laboratories
U.S. Industries, Inc.

ADDRESSES OF U.S. MANUFACTURERS AND DISTRIBUTORS OF MICROFORM EQUIPMENT, SYSTEMS, AND SUPPLIES

A & R Specialties Co.
5802 Colfax Ave.
North Hollywood, Calif.

Agfa, Incorporated
516 West 34th St.
N. Y. 1, N. Y.

Allen Products, Inc.
Factory Lane
Milford, Conn.

Alves Photo Service, Inc.
14 Storrs Avenue
Braintree 84, Mass.

American Microfilming Service
44 Laura St.
New Haven 8, Conn.

ANA-TEC, Inc.
1049 Twelfth St.
Santa Monica, Calif.

Atlantic Microfilm Corp.
700 South Main St.
Spring Valley, N. Y.

Audio Visual Research
523 S. Plymouth Court
Chicago 5, Illinois

Bell & Howell Co.
7100 McCormick Road
Chicago 45, Illinois

Biel's Photocopy & Microfilm Service
1045 Ellicott Square Bldg.
Buffalo 3, N. Y.

Charles Bruning Company, Inc.
1800 W. Central Road
Mount Prospect, Illinois

Burke & James, Inc.
321 South Wabash Avenue
Chicago 4, Illinois

Oscar F. Carlson Co.
2600 Irving Park Road
Chicago 18, Illinois

Dakota Microfilm Service
9655 West Colfax Avenue
Denver 15, Colo.

The De Florez Company, Inc.
200 Sylvan Ave., (Route 9W)
Englewood Cliffs, N. J.

Andre Debrie Mfg. Corp.
14-29 112th St.
College Pt. 56, L. I., N. Y.

Documat, Inc.
221 Crescent Street
Waltham 54, Mass.

Durst (USA), Inc.
1140 Broadway (Suite 602)
New York 1, N. Y.

Eastman Kodak Co.
343 State Street
Rochester 4, N. Y.

Erban Products Inc.
134-20 Northern Blvd.
Flushing, N. Y.

Fairchild Camera & Instrument Corp.
Industrial Products Div.
580 Midland Avenue
Yonkers, N. Y.

Federal Mfg. & Engineering Co.
1055 Stewart Avenue
Garden City, N. Y.

Oscar Fisher Co., Inc.
P. O. Box 426
Newburgh, N. Y.

FMA Incorporated
142 Nevada St.
El Segundo, Calif.

Gaylord Bros., Inc.
155 Gifford St.
Syracuse 1, N. Y.

General Dynamics/Electronics
P.O. Box 2449, 1895 Hancock St.
San Diego 12, Calif.

Graphic Microfilm Corp.
115 Liberty St.
New York 6, N. Y.

Griscombe Products, Inc.
133 West 21st Street
New York 11, N. Y.

Griswold Machine Works
412 Main Street
Port Washington, N. Y.

Hall & McChesney, Inc.
Court Street & Genant Drive
Syracuse, N. Y.

The Harwald Co.
1245 Chicago Avenue
Evanston, Illinois

Karl Heitz, Inc.
480 Lexington Avenue
New York 17, N. Y.

Hi-Speed Equipment Inc.
73 Pond St.
Waltham 54, Mass.

Hollywood Film Co.
956 N. Seward St.
Hollywood 38, Calif.

Houston Fearless Corp.
Westwood Division
11801 W. Olympic Blvd.
Los Angeles 64, Calif.

Hycon Manufacturing Co.
700 Royal Oaks Drive
Monrovia, Calif.

Ideax Corporation
150 Fifth Avenue
New York 11, N. Y.

Industrial Design & Service Co.
685 Route No. 17
Paramus, N. J.

Information Retrieval Corp.
1000 Connecticut Avenue, N.W.
Washington 6, D. C.

Kalvar Corp.
909 South Broad St.
New Orleans 25, La.

Keuffel & Esser Co.
Adams and Third Sts.
Hoboken, N. J.

Paul E. Killion, Inc.
80 Maiden Lane
Albany 7, N. Y.

E. Leitz, Inc.
468 Fourth Avenue
New York 16, N. Y.

The Frederic Luther Co.
2803 East 56th St.
Indianapolis 20, Ind.

The Magnavox Company
Fort Wayne, Indiana

Metron Instrument Co.
5300 South Delaware St.
Littleton, Colo.

Micro Record Corp.
487 South Avenue
Beacon, N. Y.

Microcard Corp.
365 Oak St.
West Salem, Wis.

Microcopy, Inc.
3808 W. 54th St.
Los Angeles 43, Calif.

Microdealers, Inc.
1560 Trapelo Road
Waltham 54, Mass.

Microfilm Jackets, Inc.
76 Madison Avenue
New York 16, N. Y.

Microlex Division
Lawyers Cooperative Publ. Co.
1 Graves St.
Rochester 14, N. Y.

Microreader Mfg. & Sales Corp.
2217 N. Summit Ave.
Milwaukee 2, Wis.

Microseal Corp.
6282 North Cicero Avenue
Chicago 46, Illinois

Milsco Manufacturing Co.
2758 North 33rd St.
Milwaukee 45, Wis.

Minnesota Mining & Mfg. Co.
Microfilm Products
900 Bush Avenue
St. Paul 1, Minn.

Morse Instrument Co.
21 Clinton Street
Hudson, Ohio

Munsell Color Co., Inc.
2441 North Calvert Street
Baltimore 18, Md.

N. B. Jackets Corp.
31-31 31st Street
Long Island City 6, N. Y.

Neumade Products Co.
250 W. 57th St.
New York 19, N. Y.

Nikon Inc.
111 Fifth Ave.
New York 3, N. Y.

Nikor Products Co.
179 New Bridge St.
West Springfield, Mass.

Ohio Envelope Co.
Lock Box 86
Cincinnati 19, Ohio

Optics Manufacturing Corp.
170 Eileen Way
Syosset, L. I., N. Y.

General Aniline & Film Corp.
Ozalid Division
Johnson City, N. Y.

Pacific Laboratories
12808 Venice Blvd.
Los Angeles 66, Calif.

PEGI 5924 Birch Avenue
Gary, Ind.

Permafilm, Inc.
723 Seventh Avenue
New York 19, N. Y.

Pfaff Development Corp.
Route 5
Huntington, N. Y.

Philadelphia Air Transport Co.
P. O. B. 27
Norristown, Pa.

Photo Devices, Inc.
33 Litchfield St.
Rochester 8, N. Y.

Photostat Corporation
1001 Jefferson Road
Rochester 3, N. Y.

Pitney-Bowes Inc.
Walnut & Pacific Sts.
Stamford, Conn.

Prestoseal Mfg. Corp.
37-27 33rd St.
Long Island City 1, N. Y.

Readex Microprint Corp.
5 Union Square
New York 3, N. Y.

Recordak Corporation
415 Madison Avenue
New York 17, N. Y.

Records Service Corp.
3808 West 54th St.
Los Angeles 43, Calif.

Regiscope Corp. of America
150 Fifth Avenue (Suite 812)
New York 11, N. Y.

Remington Rand Systems
Div. of Sperry Rand Corp.
122 East 42nd St.
New York 17, N. Y.

Rovico Corp.
318 Market St.
Newark, N. J.

C. F. Russell Co., Inc.
Bay Shore, N. Y.

Schwayder Bros
Denver, Colorado

Security Steel Equipment Corp.
Avenel, New Jersey

Serta Film, Inc.
105 N. Fifth St.
Philadelphia 6, Pa.

Simmon Brothers, Inc.
30-28 Starr Avenue
Long Island City 1, N. Y.

S.O.S. Photo-Cine-Optics, Inc.
602 West 52nd St.
New York 19, N. Y.

The Stineman System
918 Sunset Blvd.
Los Angeles 12, Calif.

The Taylor Merchant Corp.
48 W. 48th St.
New York 36, N. Y.

Tayloreel Corp.
P. O. Box 114
185 Murray St.
Rochester, N. Y.

Tecnifax Corp.
195 Appleton St.
Holyoke, Mass.

Uhler Cine Machine Co.
15762 Wyoming Avenue
Detroit 38, Mich.

U.S. Industries Inc.
250 Park Avenue
New York 17, N. Y.

Viewlex, Inc.
Holbrook,
L. I., N. Y.

Watson Mfg., Co. Inc.
Jamestown, N. Y.

Western Blue Print Co.
2415 W. Peterson Avenue
Chicago 45, Ill.

Xerox Corporation
Rochester 3, New York

Yawman & Erbe Mfg. Co., Inc.
1099 Jay St.
Rochester 3, N. Y.

Appendix C

DESCRIPTION OF PRESENT PCMI SYSTEM

This appendix contains an NCR memorandum describing the functional and economic characteristics of the present PCMI system. Two flow diagrams were added by the project team to further clarify the system description.

SRI PCMI SURVEY

Summary of Data

	Product Goals
Recording rate	1 Second
Per frame inspection	2 Seconds
Per line inspection	1 Second
Setup time	15 Minutes
Rework time	15 Seconds
Contact print time	20 Minutes
% of rework	5% Min. - 10% Max.
Printer paper cost	5 Cents
Viewer printer cost	$1,800 - $2,500 - $3,500
Printer cost	$200 - $300
Viewer service cost	$150 per Year
Supply costs	$100 per Year
Photochromic plate cost	$1.00 - $2.00
Contact film cost	50 Cents Max.
Automatic contact printer	$5,000 - $10,000
File box (incl. standby)	$1,000
Microfilm cost	7 Cents - 10 Cents
Camera-recorder	$75,000 - $100,000

Needed Time Data

Camera-Recorder

1. Recording Rate

The recording rate on the present research machine approximates 2 seconds per image. This time is based on 1/2 second for plate and film movements, 1 second for focusing and timer operations, and 1/2 second for plate return after recording a single row of images.

It is reasonable to expect that this recording time will be reduced to 1 second on a production unit (1/4 second for film advance, 1/2 second for focus, 1/4 second for exposure and plate return).

The 1 second recording rate may be used as a specification which will hold film regardless of the mode of inspection followed.

2. Inspection

At this point, the amount of time required for inspection of images can be no more than an estimate since no experience has been acquired. For the purpose of the SRI study, a time of 2 seconds per image may be assumed, if a visual check is being made after each exposure.

If an inspection is being made after each line, it may be possible to consider 1 second per frame as a norm inasmuch as inspection and plate return may be combined into one continuous operation.

The above times assume that the input microfilm has been pre-inspected. Without the benefit of actual experience it is not possible to evaluate the effect of automatic inspection technique in terms of time-saving. If the SRI Survey indicated that cost per image, as affected by inspection time, is a critical factor, then serious considera-tion would be given the inclusion of one of the state-of-the-art devices available in basic camera-recorder.

3. Setup Time

It is estimated that "make-ready" or "setup" time will consume approximately 15 minutes per card. (Regardless of the number of images to be recorded.) This time would include all housekeeping operation, but would exclude the time for making the contact prints for obtaining the photographic master.

An additional 20 minutes should be added to the above time for the preparation of the photographic masters. This operation involves movement of the photochromic plate into the contact printer, exposing the LIPPMAN card, removing the exposed cards, etc.

4. Error Correction

The times specified here are the times required to change an image after the visual inspection indicates the necessity for a change. The erase time per image may be set at 14 seconds. The re-record time per image is equal to the initial recording time; i.e., 1 second per image. Thus a total time of 15 seconds may be specified.

The above time may be used as a norm regardless of the mode of inspection selected.

5. Time Summary

A summation of the above time parameters would indicate the following:

Minimum	100% Filled Card (2,500 Images)	50% Filled Card (1,250 Images)
Setup	900 seconds	900 seconds
Record	2,500 seconds	1,250 seconds
Inspection (by line)	2,500 seconds	1,250 seconds
Rework (5%)	1,875 seconds	935 seconds
Contact print	1,200 seconds	1,200 seconds
Total	8,975 seconds	5,535 seconds

Minimum	100% Filled Card (2,500 images)	50% Filled Card (1,250 images)
Setup	900 seconds	900 seconds
Record	2,500 seconds	1,250 seconds
Inspection (by image)	5,000 seconds	2,500 seconds
Rework (10%)	3,750 seconds	1,875 seconds
Contact print	1,200 seconds	1,200 seconds
Total	13,350 seconds	7,725 seconds

It appears from the above that a filled card would require from 2-1/2 to 3-3/4 hours for completion, depending upon the mode of inspection and the amount of rework required. A partial card (50%) would require from 1-1/2 to 2-1/4 hours. The fixed time for setup (900 seconds) and contact print (1,200 seconds) would throw a time penalty toward the less dense utilization of the PCMI Card.

Other Data of Interest

1. Amount of Rework

Without benefit of experience it is impossible to determine the nature and amount of rework that will be required. Out-of-focus frames, wrong density, dirt, etc., will all contribute to the total problem, but the degree to which each of these may contribute would be speculation at this time.

For planning and timing purposes, it would be well to consider the effects of both a 5% and a 10% rework factor. These numbers were used in the timing tables developed in paragraph 5, above.

2. Susceptibility to Radiation

The question of susceptibility to damage by radiation has not been explored as a part of the current PCMI Program. Insofar as the silver-halide card is concerned, the same factors exist as are present in all microfilm systems, and this is the most widely dispersed element in the PCMI system.

3. Functional Specifications

Functional description of all elements of the PCMI system are attached as Annex A.

4. AVCO Error Rate

There is no specific information available on the AVCO error or rework rate.

5. Microfilm Specifications

Specifications for the microfilm input to the NCR PCMI system are as follows:

Microfilm Specifications for Micro-Image Input

Media: 35 mm sprocketed microfilm must pass near ultra-violet.

Orientation: Vertical direction of document in line with long direction of film.

Framing: Framed by camera-recorder.

Spacing: Eight perf pull-down.

Developing: Developed for continuous tone, i.e., a gamma of 1.

Background Density: 1.2 density.

Resolution: 80 lines per mm for 9-10 point print.
120 lines per mm for 6-8 point print.

Input Document: 8-1/2" x 11" page.

Reduction: Input document to film, 10:1.

6. Microfilm Costs

Estimate for preparing input microfilm for the NCR PCMI system have been obtained from a local source (Microfilm Corp. of Calif.). However, these costs are subject to many factors, such as setup time, volume of work, degree of handling required for the document to be filmed, etc. For planning purposes, a per frame cost of 7 cents to 10 cents would be justified.

As further background on microfilm costs, a recent estimate received from Remington-Rand Service Bureau for microfilming engineering drawings will be of interest:

Remington-Rand Microfilm Service Costs

Work Being Completed at NCR

	Quantity	Cost Per M
Critical Commercial Microfilm		
1. Engineering drawings	13,250	$125.00 per M frames
2. Double exposure of above		57.00 per M frames
MIL SPEC 9868 Microfilm		
3. Engineering drawings	13,250	368.00 per M frames
4. Double exposure of above		235.00 per M frames
5. Listing for I.B.M.	13,250	217.00 per M cards
6. Keypunch, verify, interpret from listing	13,250	124.00 per M cards
7. Reproduce and interpret additional decks	13,250	5.58 per M cards
8. Diazo Dupl. film 35mm	30 Rolls	6.50 per 100' roll
9. Mounting film into cards	13,250	32.30 per M cards
10. Microseal aperture cards F7001 - Mil D. aperture electrotype plate	13,250	38.75 per M cards

Work Being Completed at Remington-Rand

1. Critical commercial microfilming on a continuous basis	115.00 per M frames
3. MIL SPEC 9868	358.00 per M frames
8. Diazo duplicate film rolls are	6.50 per 100' roll on any quantity up to 100'.

Items 2, 4, 5, 6, 7, 9 and 10 will remain the same amount based on the per 1,000 price.

Needed Cost Data

Viewer-Printer Costs

1. Viewer-Printer

At this point in time, there has not been sufficient work done to permit an accurate cost estimate of this equipment.

Accordingly, it would appear reasonable for SRI to gauge the PCMI viewer market potential based on a range of potential prices; e.g., the following:

$1,800	$2,500	$3,500

Stated in terms of monthly rental, we could consider ranges such as:

$45.00	$62.50	$87.50

It is assumed that the printer contributes $200-$300 to the above figures.

2. Paper Cost

The printer under development in the research phases of the PCMI program utilizes a photographic process employing a paper marketed under the trade name "Polymicro." This paper will cost approximately 5 cents per 8-1/2" x 11" sheet. The process requires the use of chemicals for bringing out the latent image.

There are other printing techniques that could be used, such as electrostatic @ 5 cents per sheet, xerographic @ 3 cents - 5 cents per sheet, but the equipment costs for these dry processes is excessive at this point in time.

However, for the purpose of establishing market interest it may be assumed that a dry process printing technique offering copies @ 5 cents per sheet or less will become available for inclusion in a viewer-printer offered in the time span surrounding the development of the NCR PCMI system.

3. Replacement Costs

The significant replacement problem in the viewer-printer will be the light source. At the present time we are considering the use of a Zenon source which offers sufficient brightness (60 foot lamberts) for 1,600 hours. The price on this light source will approximate $125.00.

4. Maintenance and Service

3 M offers a service policy on its viewers ranging from $65.00 to $125.00 per year depending upon the complexity of the machine under service. In return for this fee the customer is entitled to six (6) inspection calls per year, free replacement of defective parts, and emergency service calls.

Recordak offers the same contract with a reduced number of calls (2 per year).

It may reasonably be expected that a higher figure, e.g. $150.00 per year would be warranted for the PCMI viewer due to the increased complexity of optics, tighter tolerances, etc.

Camera-Recorder Costs

1. Glass Photochromic Plate

The price for the photochromic plate should be nominal, i.e., $1.00-$2.00. This item will be relatively insignificant unless an application calls for storing a large volume of plates for future updating.

2. Contact Film Cost

PCMI contact prints will be made on high-resolution emulsion, 3" x 5" cards. There are two suppliers with the capability of producing these "cards"; however, since the specifications have not yet been finalized, a firm cost has not been established.

For purposes of the SRI survey, a maximum cost of 50 cents may be assumed.

3. Cost of Contact Prints

There are two types of contact prints required in the PCMI system: the photographic master produced from the photochromic plate, and succeeding contact prints made from the photographic master.

Present product objectives envision a machine in the \$5,000-\$10,000 range which will produce both types of masters on an automatic or semi-automatic basis.

If this mechanization proves impractical or infeasible, a separate device will be designed for each purpose--photochromic to photographic, and photographic to photographic. In either event, clean-room or dark-room facilities should not be required.

4. Camera-Recorder Cost

As of this time there has not been sufficient work done to permit an engineering estimate of the cost of a camera-recorder. Indicators point toward a potential selling price in the \$75,000-\$100,000 range, and it would be reasonable to use this range in a market potential survey.

5. Temperature Controlled File Box

The PCMI concept includes the storage of photochromic plates for updating, editing, deletion, etc., of images previously recorded. Thus the requirements for storing these plates under controlled environment exist.

However, since temperature of $-10^{o}F$ are sufficient for this purpose, it is assumed that a "file" with the size and cooling system of a good commercial freezer will be satisfactory.

A figure of \$500 may be used for this piece of equipment.

For standby protection another \$500 may be added to the above cost.

Film Processing Installation

For research purposes it has been found desirable to produce and process contact prints in a "clean-room" environment. Also, the best attainable commercial equipment has been specified for this purpose.

However, in a commercial product designed for use in a "non-professional" environment, the design objective should provide for production of contact print masters in a special machine designed for this purpose, or in the automatic contact printer.

Volume contact prints will be produced on the automatic contact printer which will also contain environmental protection.

Thus, expense for special construction of clean-rooms or investment in darkroom equipment should not be required.

Annex A

Preliminary Functional Specifications of the Photochromic Micro-Image Machinery

Original Document Capability of System

Document Size

8-1/2" x 11" for 200:1 reduction. This is determined by both the microfilm frame size, which is limited to 31/32 inches in width between sprocket holes, and the lens field size of 68 mils in diameter. Larger documents can be handled at greater than 200:1 times reduction.

Print Size

At the 200:1 reduction, the smallest print size that can be handled is 8 point. Most print above this dimension can be handled. The most important factor which limits the print size is the resolution of the system. (The final product should be capable of handling 6 point print.)

Resolution (Research Model)

The input microfilm resolution will be 80 lines/mm minimum. The photochromic plate resolution will be 800 lines/mm. The silver-halide master, which was contact printed from the photochromic plate, will have 720 lines/mm resolution. The positive dissemination copy, the final product of the system, will have 650 lines per mm resolution, which will give a resolution on the screen of the viewer of 3 lines/mm minimum. (Final design objectives should permit 4.5 lines/mm on the viewer.)

Continuous Tone Capability

At each step in the process, the images will be developed so as to retain continuous tone. This is comparable to saying that everything will be developed for a gamma (8) of 1 or nearly 1. This type of processing gives latitude to both the processing techniques and the input documents. The input documents can have different print densities in the printed image, the paper reflectivity can vary, and the source material can vary. The continuous tone capability also allows for photographs to be handled in the system.

The 3"x5" Micro-Image Card

The 3"x5" card will contain 2,625 micro-images arranged in a rectangular array of 75 columns by 35 rows. There is nothing sacred about the number of images or about the layout of the columns and rows. However, it is felt that this leaves sufficient room for indexing and other uses of the card and is only to be regarded as a tentative format to be used for testing the micro-image concept.

Two registration holes will be placed on the card for locating the card in the viewer and other contact printing operations.

The emulsion to be used will be of the Lippman emulsion type, which is capable of resolving 2,500 lines/mm of which we are using 650 lines/mm. The card will be developed for unity gamma to give the continuous tone and latitude mentioned previously. Stable base film is to be used since an acetate base is capable of being one frame off in a particular dimension due to the humidity changes and temperature changes.

The emulsion is to be overcoated both for protection and to place dirt and scratches out of the focal plane. This overcoating is to be 2 to 5 mils thick. It will also give additional rigidity to the card.

Camera Recorder Specifications

The input to the camera recorder will be from 35 mm sprocketed microfilm. This input will be reduced 20 times at the photochromic plate. (Final design should permit input from standard unsprocketed microfilm.)

Photochromic Plate

The material to be used on a photochromic plate will be type P113, which is light erasable and will give us the editing and correcting of bad images capability. The material will be placed on a glass plate backing. This material type will allow us to write images into a clear field or erase images into a colored field.

Recording Sequence

The recording sequence is to be automatically controlled so that an entire plate can be laid down with inspection at various points in the procedure. This means that there will be:

1. Automatic microfilm advance

2. Automatic photochromic plate advance in the x-y direction

3. Automatic focusing

4. Automatic control of exposure time

5. Optional stopping of the cycle before and after recording each image and after a row of images for inspection

All features of the machine can be manually operated so that correction procedures can take place and the machine can be started and stopped.

Recording Time

The research model of the camera recorder was not designed with any thought to making the operation fast. Simple relay logic and cycle timer operation have been used for controlling the sequence of operations. A half second has been allowed for plate movement, microfilm advance, and refocusing times. One second has been allowed for timer operations and a half second has been allowed for the plate return after recording a row of images. These times add up to 2 seconds per frame, or one hour and 25 minutes for the total loading time of a plate. These times do not include the time for inspection and the time for corrections. (Final design should permit a recording time of 1 second per image.)

Environment Chamber

When the photochromic plate is in the recording portion of the camera recorder, it will be in a cold and clean atmosphere. The temperature will be maintained within 10 degrees of a set point. The set point can be changed from 0^{o} to 30^{o}F. The air will be recirculating through an absolute filter which filters out all particles above 0.3 microns in diameter. When the photochromic plate is moved over to the contact printing portion of the camera recorder, it will be in a warmer atmosphere (also clean). The air in this portion of the chamber will come from the colder chamber and will be heated so that the Lippman emulsion will not have to be handled in a cold environment.

There will be a door between the two chambers which will allow the plate to be passed from one to the other. The contact printing operation is to take place adjacent to the printing operation so as to minimize the amount of handling of the photochromic plate.

Viewer-Printer

The viewer-printer development is past the initial design stage and is entering the final design phase. Therefore, these specifications can be regarded as design goals. The major emphasis has been placed upon keeping the cost of the viewer-printer as low as possible. To meet this goal, as much of the machine's operations as could be made manual, have been made manual, such as the indexing of the table, the indexing of the micro-image card, focusing, and insertion of the 3"x5" cards.

The print-out paper has been selected because if its low cost and high quality.

Indexing the 3"x5" Card

The card will be moved in both an x and y direction in the viewer to get to any frame. Independent knobs will be provided for both the x and y direction and both a coarse and fine feed will be provided. Indication will be provided to show which frame is in the viewing position of the viewer. This indication will either be of the Veeder-root counter type or markings on knobs. There will be registration pins on the viewer which the card will be slipped over to locate the card in proper relationship to the x-y counters.

Print-out Paper

The print-out paper and its developing process should have the following specifications:

1. Projection paper speed

2. Exposure and development cycle less than 15 seconds

3. Low cost developing machinery

4. Continuous tone, if possible

5. The paper should be dry enough after development to be handled

6. Paper cost should be less than 6 cents per copy

7. A matte finish

8. If possible, the paper should not exhibit a reversal (i.e., make a negative from a positive image).

Screen

The screen size should be 11" x 11". The screen is to be used in a rear projection manner, therefore, it should diffuse the light striking it from the rear. When observed from the front, the screen should exhibit a minimum of the scintillation effect, and the screen should have the maximum amount of screen gain possible under the above conditions.

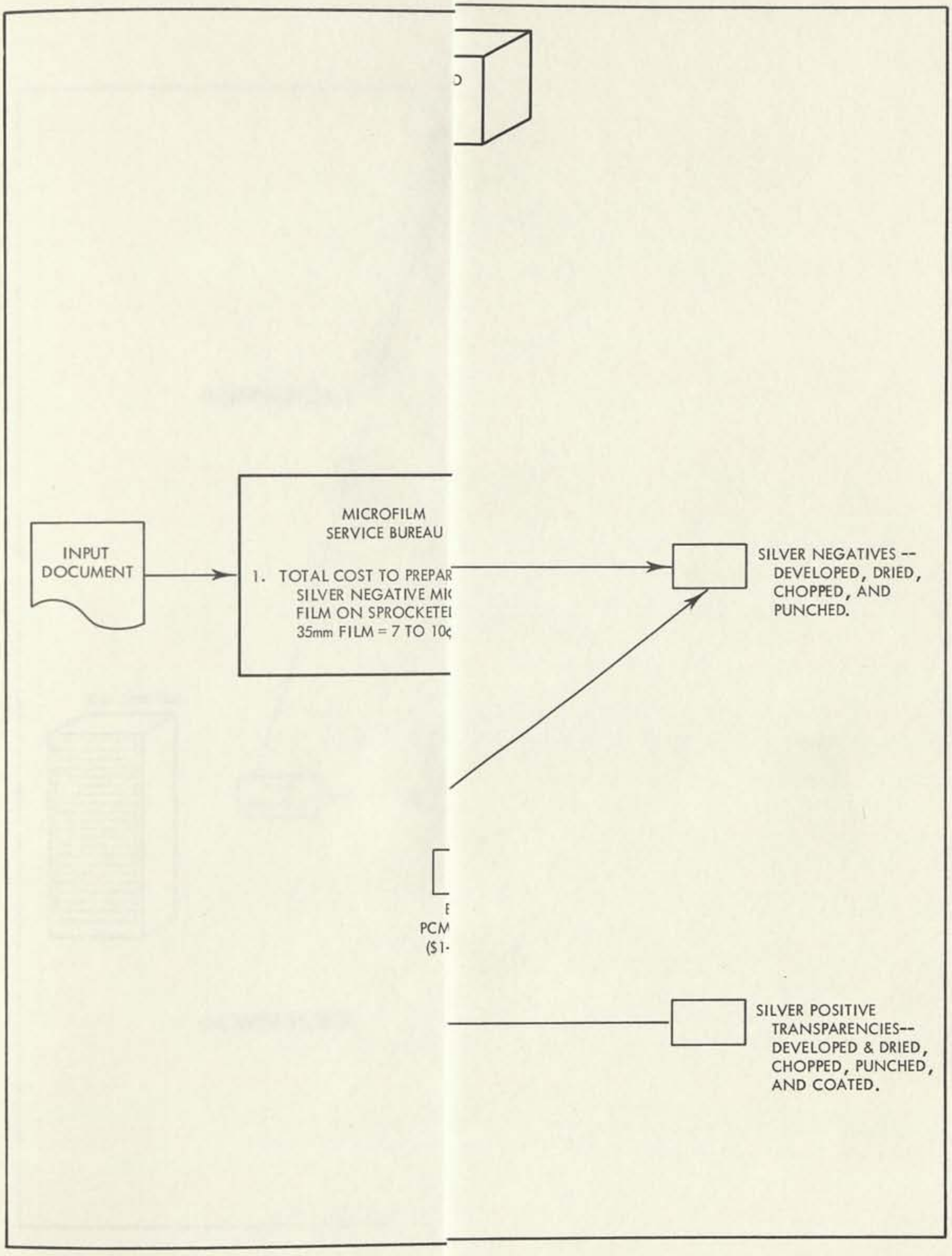

FIGURE C-1

INARY ESTIMATE OF PCMI INPUT RATES AND COSTS

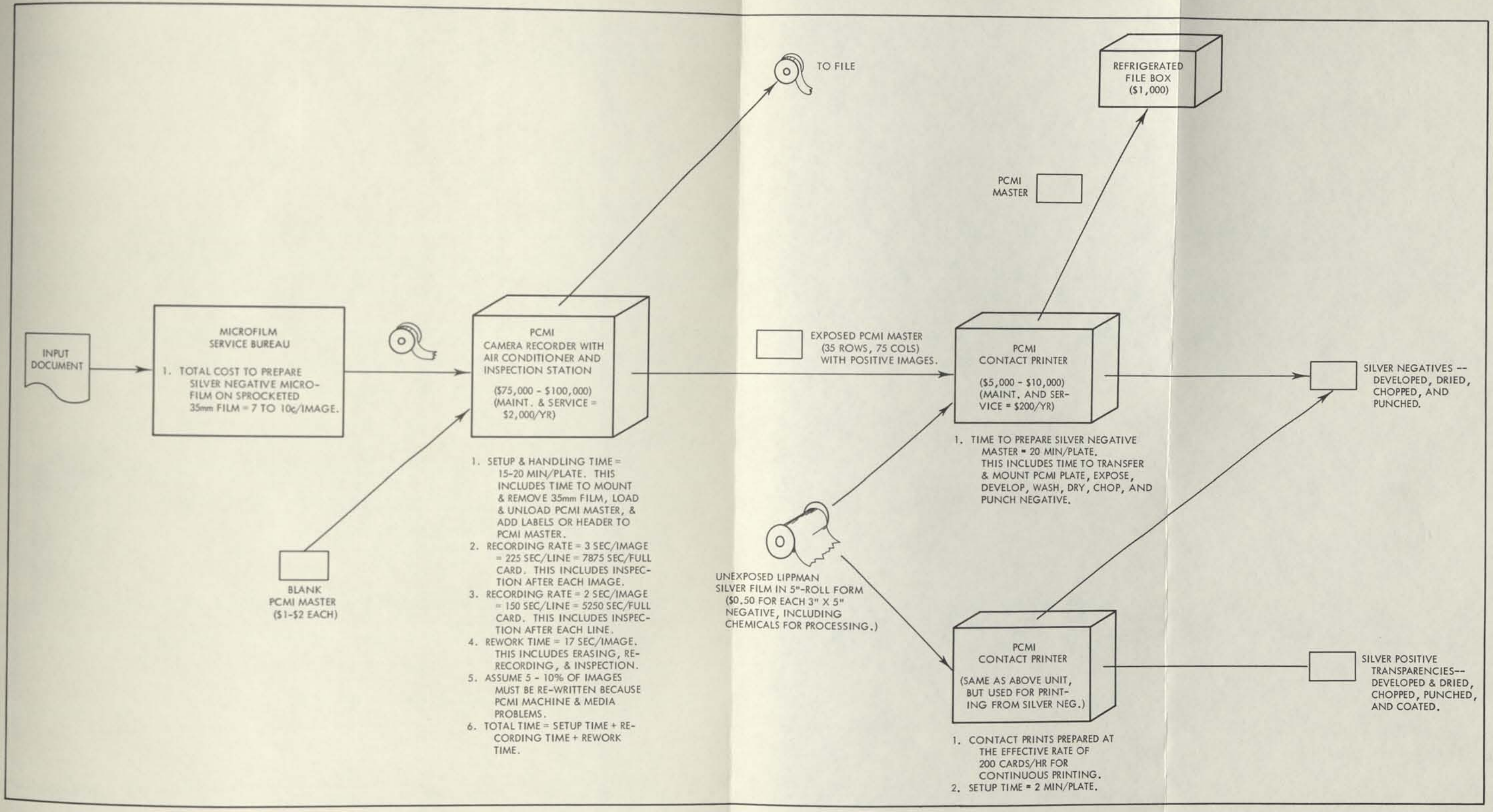

FIGURE C-1

PRELIMINARY ESTIMATE OF PCMI INPUT RATES AND COSTS

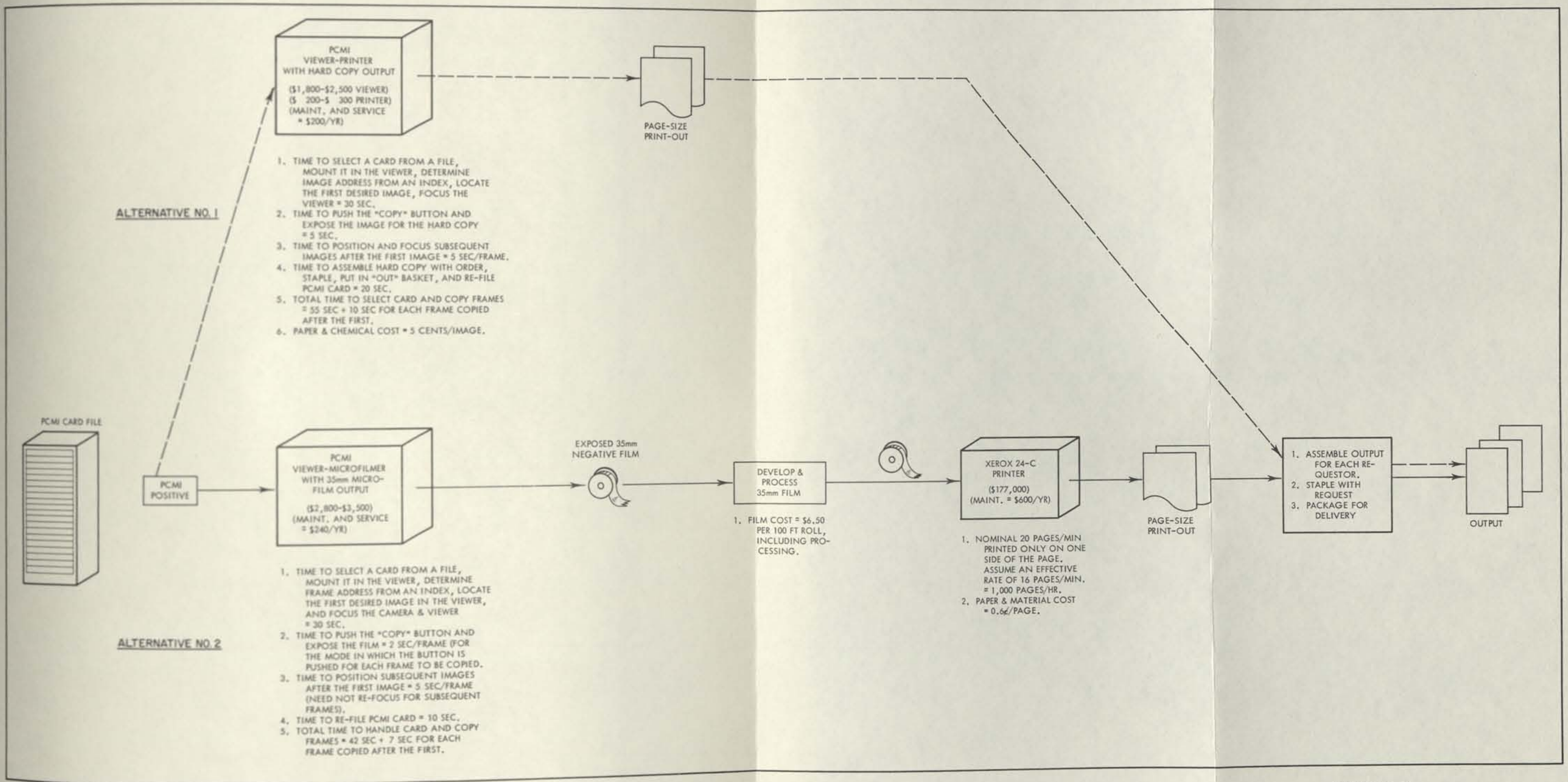

FIGURE C-2

PRELIMINARY ESTIMATE OF PCMI OUTPUT RATES AND COSTS

Appendix D

BASIC ASSUMPTIONS AND DERIVATIONS FOR PCMI COST ANALYSIS

Appendix D

BASIC ASSUMPTIONS AND DERIVATIONS FOR PCMI COST ANALYSIS

General Considerations

1. None of the PCMI units of equipment operate more than 20 hours per day, 22 days per month.

2. The machine operator can work interchangeably on either the camera-recorder or the contact-printer. It will be assumed that he does not have to work on two jobs simultaneously, and the only point of be considered here is the total number of man-hours required to run all of the equipment.

3. The full cost of the equipment will be charged to the cost of preparing the cards, regardless of the degree to which the equipment is used.

4. The recording equipment is to be amortized over a period of 40 months at 0% rate of return.

5. Labor cost will be charged only for the actual time that the operator is required to be with the machine.

6. The equipment will not be run unattended. Each minute of machine time (for each machine) will require a corresponding minute of labor time.

7. Direct Labor Cost = $3.00 per hour for PCMI camera and contact-printer operators, and $2.00 per hour for clerical help if required.

8. Overhead Cost = 200% of the direct labor cost.

9. There are no extra labor costs (premiums) for working second and third shifts.

10. The PCMI equipment operator can perform the necessary minor maintenance of replacements.

11. The assumed equipment, maintenance, and material costs, as well as the equipment operating times, are noted on the system drawings in Appendix C.

Specific Labor Requirements

Define N = No. of images per PCMI plate
C = No. of copies per press run

	Seconds per Plate
1. PCMI Camera-Recorder Operator:	
a. Setup and handling = 20 min/master plate =	1,200
b. Recording and inspection after each line = (2 sec/image) (N images/plate) =	2 N
c. Rework = (17 sec/reworked image) (0.1 N reworked images/plate) =	1.7 N
Total =	(1,200 + 3.7 N) sec/plate
2. PCMI Contact-Printer Operator:	
a. Total time to prepare silver negative master = 20 min/plate =	1,200
b. Setup time for distribution positives = 2 min/plate =	120
c. Effective print time at 200 copies/hr = (1/200)(hr/copies)(3,600 sec/hr) (C copies/print run)(1 print run/plate) =	18 C
Total =	(1,320 + 18 C) sec/plate

3. Misc. labor for handling and packaging = negligible

Specific Equipment Costs

1. Cost of PCMI Camera-Recorder Unit = $100,000.

   For 40 months' amortization at 0% rate of return, this = $2,500 per month.

   A second camera will be required if more than 440 hrs/mo. of recording time are required. The number of master plates that can be recorded in one month by one camera depends upon the number of images recorded in each plate. For recording with a fixed number of images per plate, the maximum production rate for one camera is given by:

   Max. no. of plates recorded per month =

$$\frac{(440 \text{ hrs/mo.})\ (3{,}600 \text{ sec/hr})}{(1{,}200 + 3.7\ N) \text{ sec/plate}}$$

2. Cost of PCMI Contact-Printer (dual-purpose, to print master negatives and distribution positives) = $10,000.

   For 40 months' amortization at 0% rate of return, this = $250 per month.

   A second contact-printer will be required if more than 440 hrs/mo. of printing time are required. The maximum production rate for each printer is given by:

   Max. no. of master plates copies per month =

$$\frac{(440 \text{ hrs/mo.})\ (3{,}600 \text{ sec/hr})}{(1{,}320 + 18\ C) \text{ sec/plate}}$$

3. Total = $2,750 per month

Other Fixed Costs

1.	Cost of refrigerated file box = $1,000.	
	For 40 months' amortization at 0% rate of return, this =	$ 25.00/mo.
2.	Service and maintenance costs of PCMI camera-recorder = $2,000/yr =	166.67
3.	Service and maintenance costs of PCMI contact-printer = $200/yr =	16.67
	Total	$208.34/mo.

Material Costs

1.	Blank PCMI master =	$2.00 /plate
2.	Silver Lippman film for master negative =	0.50
3.	Silver Lippman film for distribution positive =	0.50 C/plate

Appendix E

BASIS FOR COMPARATIVE COST ANALYSIS FOR PUBLICATION OF THE *NAVY SUPPLY CATALOG*

Appendix E

BASIS FOR COMPARATIVE COST ANALYSIS FOR PUBLICATION OF THE NAVY SUPPLY CATALOG

(A 3,000-page Catalog Published Four Times a Year and Distributed to 2,000 Users)

Annual Cost of Present Paper System

Publishing cost[1] = ($18,750/issue)(4 issues/yr) =	$ 75,000
Postage cost[2] = (13.8 lbs/catalog)(2,000 catalogs/issue)(4 issues/yr)(0.8 dollars/lb) =	88,320

Annual Cost of Microcard System

Publishing cost[3] = (3,000 pages/catalog)(0.3¢/page)(1 dollar/100¢)(2,000 catalogs/issue)(4 issues/yr) =	72,000
Viewer cost (minimum system)[4] = 1/3(2,000 viewers @ $130) =	86,660
Viewer cost (maximum system)[5] = 1/3(2,000 viewers @ $450) =	300,000
Viewer maintenance and repair[6] = (2,000 viewers @ $10/yr) =	20,000
Postage cost = (1 oz/10 cards)(30 cards/catalog)($0.05/oz)(2,000 catalogs/issue)(4 issues/yr) =	1,200

Annual Cost of Recordak System

Original microfilming[7] = ($24.75/1,000 pages)(3,000 pages/issue)(4 issues/yr) =	297
Kodamatic indexing[7] = ($7/master roll)(1 master roll/issue)(4 issues/yr) =	28
Contact printing[7] = ($3.50/roll)(2,000 rolls/issue)(4 issues/yr) =	28,000
Magazines and loading[7] = ($1.60/roll)(2,000 rolls/issue)(4 issues/yr) =	12,800
Total printing cost =	$ 41,125

Viewer cost (maximum system)[8] = 1/3 (2,000 viewers @ $995) =	$ 663,330
Viewer cost (minimum system)[15] = 1/3 (2,000 viewers @ $485) =	323,330
Viewer maintenance and repair (maximum system)[9] = 1/3($145/viewer)(2,000 viewers) =	96,660
Viewer maintenance and repair (minimum system)[16] = 1/3($70/viewer)(2,000 viewers) =	46,660
Postage cost = (4 oz/catalog)($0.05/oz)(2,000 catalogs/issue)(4 issues/yr) =	1,600

Annual Cost of PCMI System

PCMI recording equipment cost[10] = (12/40)($111,000) =	33,300
PCMI recording equipment maintenance cost[11] =	2,200
Material costs[12] = (1 master card/issue)($2.50/master card)(4 issues/yr) + (2,000 contact prints/issue)(4 issues/yr)($0.5/contact print) =	4,010
Camera labor[13] = (1,200 + 3.7(3,000))(sec/master card)(4 master cards/yr)(1 hr/3,600 sec) = 13.66 hrs	
Contact printer labor[13] = (1,320 + 18(2,000))(sec/issue)(4 issues/yr)(1 hr/3,600 sec) = 41.47 hrs	
Labor cost[13] = (55.13 hrs)($9/hr) =	496
Original microfilming cost[13] = ($0.1/exposure)(3,000 exposures/issue)(4 issues/year) =	1,200
Total printing cost	$ 41,206
Viewer cost (minimum system)[14] = 1/3(2,000 viewers @ $1,800) =	$1,200,000
Viewer cost (maximum system)[14] = 1/3(2,000 viewers @ $2,500) =	1,666,660
Viewer maintenance and repair (minimum system)[13] = 2,000 viewers @ $180 =	360,000
Viewer maintenance and repair (maximum system)[13] = 2,000 viewers @ $250 =	500,000
Postage cost = ($0.05/card)(2,000 cards/issue)(4 issues/yr) =	$ 400

Notes

1. Publishing cost of $18,750/issue taken from NCR proposal to U.S. Navy, and reports of NCR visit to Navy offices.

2. 13.8 lbs/catalog represents the weight of a 3,000-page telephone book.

3. Total cost of 0.3¢ per distributed page for Microcard publication cost is a Microcard Corporation quotation.

4. Microcard Model Micro-3 viewer amortized over 3 years at 0% rate of return.

5. Microcard Model 7 viewer amortized over 3 years at 0% rate of return.

6. These viewers incorporate no electronics or electromechanical equipment. The major replacement item will be the light bulb. Total maintenance cost assumed to be $10/yr for a viewer.

7. Recordak quotations: $24.75 per thousand exposures for commercial quality 16mm microfilming (100 lines/mm); Kodamatic indexing approximately $7/roll; $3.50 per 100 ft roll for contact printing in volumes over about 50 rolls; $0.95 each for film magazines; $0.65 each to load the film magazines. Assume 3,000 pages/roll.

8. Recordak Model PS Viewer amortized over 3 years at 0% rate of return.

9. Recordak quote for Model PS maintenance: zero for first year, $72.50 per year after that.

10. NCR quotes for camera-recorder ($100,000), contact printer ($10,000), and file box ($1,000) amortized over 40 months at 0% rate of return.

11. NCR quotes for maintenance costs of camera-recorder ($2,000/yr) and contact printer ($200/yr).

12. 3,000 images/card. NCR quotes for film cost.

13. See assumptions for system costs and timing in Appendix C.

14. NCR quotes for viewer costs. Equipment amortized over 3 years at 0% rate of return.

15. Recordak Model Starlet PTA Film Reader amortized over 3 years at 0% rate of return.

16. Recordak quote for Model Starlet PTA Film Reader maintenance: zero for first year, $35 per year after that.

Appendix F

BASIS FOR COMPARATIVE COST ANALYSIS
FOR PUBLICATION OF THE THOMAS REGISTER

Appendix F

BASIS FOR COMPARATIVE COST ANALYSIS FOR PUBLICATION OF THE THOMAS REGISTER

(A 60,000-page Catalog Printed Annually and Intended for Distribution to 3,500 Users)

Annual Cost of Present Microfiche System

Publishing cost[1] = ($0.15/card)(600 cards/catalog) (3,500 catalogs/yr) =	$ 315,000
Viewer cost[2] = 1/3(3,500 viewers @ $350) =	408,330
Viewer maintenance and repair[3] = 3,500 viewers @ $10/yr =	35,000
Postage cost[4] = (600 cards/catalog)(0.1 oz/card) ($0.05/oz)(3,500 catalogs/yr) =	10,500

Annual Cost of Microcard System

Publishing cost[5] = ($0.003/page)(60,000 pages/catalog) (3,500 catalogs/yr) =	630,000
Viewer cost (minimum system)[6] = 1/3(3,500 viewers @ $130) =	151,660
Viewer cost (maximum system)[7] = 1/3(3,500 viewers @ $450) =	525,000
Viewer maintenance and repair[3] = 3,500 viewers @ $10/yr =	35,000
Postage cost[8] = (0.1 oz/card)(1,000 cards/catalog) (3,500 catalogs/yr)($0.05/oz) =	17,500

Annual Cost of Recordak System

Original microfilming[9] = ($24.75/1,000 pages)(60,000 pages) =	1,485
Kodamatic indexing[9] = ($7/master roll)(60,000 pages/ 2,500 pages per roll) =	168
Contact printing[9] = ($3.50/roll)(24 rolls/catalog) (3,500 catalogs/yr) =	294,000
Magazines and loading[9] = ($1.60/roll)(24 rolls/catalog) (3,500 catalogs/yr) =	134,400
Total printing cost =	$ 430,053

Viewer cost (maximum system)[10] = 1/3(3,500 viewers @ $995) =	$1,160,830
Viewer cost (minimum system)[17] = 1/3(3,500 viewers @ $485) =	565,830
Viewer maintenance and repair (maximum system)[11] = 1/3($145/viewer)(3,500 viewers) =	169,170
Viewer maintenance and repair (minimum system)[18] = 1/3($70/viewer)(3,500 viewers) =	81,660
Postage cost = (24 rolls/catalog)(4 oz/roll)($0.05/oz) (3,500 catalogs/yr) =	16,800

Annual Cost of PCMI System

PCMI recording equipment cost[12] = (12/40)($111,000) =	33,300
PCMI recording equipment maintenance cost[13] =	2,200
Material costs[14] = (20 master cards/yr)($2.50/master card) + (20 master cards/yr)(3,500 contact prints/master card)($0.5/contact print) =	35,050
Camera labor[15] = (1,200 + 3.7(3,000))(sec/master card) (20 master cards/yr)(1 hr/3,600 sec) = 68.3 hrs/yr	
Printer labor[15] = (1,320 + 18(3,500))(sec/master card) (20 master cards/yr)(1 hr/3,600 sec) = 357.3 hrs/yr	
Total labor cost[15] = (425.6 hrs/yr)($9/hr) =	3,830
Original microfilming cost[15] = ($0.1/exposure)(60,000 exposures/yr) =	6,000
Total printing cost	$ 80,380
Viewer cost (minimum system)[16] = 1/3(3,500 viewers @ $1,800) =	2,100,000
Viewer cost (maximum system)[16] = 1/3(3,500 viewers @ $2,500) =	2,916,670
Viewer maintenance and repair (minimum system)[15] = 3,500 viewers @ $180/yr =	630,000
Viewer maintenance and repair (maximum system)[15] = 3,500 viewers @ $250/yr =	875,000
Postage cost = (20 cards/catalog)(0.1 oz/card)($0.05/oz) (3,500 catalogs/yr) =	350

Notes

1. $0.15 per card is the cost estimate quoted by Thomas Publishing Co. This is for a card that contains approximately 100 page images.

2. Modified Griscomb Model K6 Filmcard Reader at estimated cost of $350.

3. These viewers incorporate no electronics or electromechanical equipment. The major replacement item will be the light bulb. Total maintenance cost assumed to be $10/yr for a viewer.

4. Approximately 100 pages/card.

5. Total cost of 0.3 cents/distributed page for Microcard publication cost is Microcard Corporation quotation.

6. Microcard Model Micro-3 viewer amortized over 3 years at 0% rate of return.

7. Microcard Model 7 viewer amortized over 3 years at 0% rate of return.

8. Approximately 60 pages per card proposed by Microcard Corporation for this particular application.

9. Recordak quotations: $24.75 per thousand exposures for commercial quality 16 mm microfilming (100 lines/mm); Kodamatic indexing approximately $7/roll; $3.50 per 100 ft roll for contact printing in volumes over 50 rolls; $0.95 each for film magazines; $0.65 each to load the film magazines. Assume 2,500 pages/roll.

10. Recordak Model PS viewer amortized over 3 years at 0% rate of return.

11. Recordak quote for Model PS: zero for first year, $72.50 per year after that. Assume 0% rate of return.

12. NCR quotes for camera-recorder ($100,000), contact printer ($10,000), and file box ($1,000) amortized over 40 months at 0% rate of return.

13. NCR quotes for maintenance costs of camera-recorder ($2,000/yr) and contact printer ($200/yr).

14. 3,000 images/card. NCR quotes for film costs given in Appendix C.

15. See assumptions for system costs and timing in Appendix D.

16. NCR quotes for viewer costs. Equipment amortized over 3 years at 0% rate of return.

17. Recordak Model Starlet PTA Film Reader amortized over 3 years at 0% rate of return.

18. Recordak quote for Model Starlet PTA Film Reader maintenance: zero for first year, $35 per year after that.

Appendix G

DERIVATION OF COST EXPRESSIONS FOR ALTERNATIVE PUBLICATION METHODS

Appendix G

DERIVATION OF COST EXPRESSIONS FOR ALTERNATIVE PUBLICATION METHODS

Define: N = No. of pages in the publication
U = No. of users that receive single copies of the publication

	Cost per Year (dollars)
1. Paper System	
Cost of film negatives	
= ($1.00/page)(N pages/master publication)(1 master publication/year)	= $1.0 N
Cost of film plates	
= ($1.25/page)(N pages/master publication)(1 master publication/year)	= 1.25 N
Cost of paper	
= ($0.002/page)(N pages/publication)(U publications/year)	= 0.002 NU
Cost of postage	
= ($0.8/lb)(0.0046 lb/page)(N pages/publication)(U publications/year)	= 0.00368 NU
Total cost = N [2.25 + 0.00568(U)] dollars per year	
2. Microcard System	
Cost of printing	
= ($0.003/page)(N pages/publication)(U publications/year)	= 0.003 NU
Cost of viewers (min.)	
= 1/3 (U viewers @ $130)	= 43.33 U
Cost of viewers (max.)	
= 1/3 (U viewers @ $450)	= 150.00 U
Cost of viewer maintenance	
= U viewers @ $10/year	= 10.00 U
Cost of postage	
= (0.1 oz/card)(1 card/100 pages)($0.05/oz)(N pages/publication)(U publications/year)	= 5×10^{-5} NU
Total cost (min.) = 53.33 U + (3.05×10^{-3}) NU dollars per year	
Total cost (max.) = 160.00 U + (3.05×10^{-3}) NU dollars per year	
3. Recordak System	
Cost of initial filming	
= ($0.02475/master page)(N master pages/year)	= 0.02475 N
Cost of Kodamatic indexing	
= ($$2.33 \times 10^{-3}$/master page)(N master pages/year)	= 0.00233 N
Cost of contact printing	
= ($$1.166 \times 10^{-3}$/page)(N pages/publication)(U publications/year)	= 1.166×10^{-3} NU
Cost of magazines and loading	
= ($$0.533 \times 10^{-3}$/page)(N pages/publication)(U publications/year)	= 0.533×10^{-3} NU
Cost of postage	
= (1.333×10^{-3} oz/page)($0.05/oz)(N pages/publication)(U publications/year)	= 66.6×10^{-6} NU
Cost of viewers (max.)	
= 1/3 (U viewers @ $995)	= 331.66 U
Cost of viewers (min.)	
= 1/3 (U viewers @ $485)	= 161.66 U
Cost of viewer maintenance (max.)	
= 1/3 (U viewers @ $145)	= 48.33 U
Cost of viewer maintenance (min.)	
= 1/3 (U viewers @ $70)	= 23.33 U
Total cost (min.) = 185 U + N[$27.08 \times 10^{-3} + (1.765 \times 10^{-3})U$] dollars per year	
Total cost (max.) = 380 U + N[$27.08 \times 10^{-3} + (1.765 \times 10^{-3})U$] dollars per year	
4. PCMI System	
Cost of recording equipment and its maintenance	= 35,000
Cost of viewers (max.)	
= 1/3 (U viewers @ $2,500)	= 833 U
Cost of viewers (min.)	
= 1/3 (U viewers @ $1,800)	= 600 U
Cost of viewer maintenance (max.)	
= U viewers @ $250	= 250 U
Cost of viewer maintenance (min.)	
= U viewers @ $180	= 180 U
Cost of postage	
= ($$16.66 \times 10^{-6}$/page)(N pages/publication)(U publications/year)	= 16.66×10^{-6} NU
Cost of original filming	
= ($0.10/master page)(N master pages/year)	= 0.10 N
Cost of PCMI camera labor	
= (1.138×10^{-3} hr/master page)($9/hr)(N master pages/year)	= 10.245×10^{-3} N
Cost of PCMI printer labor	
= ($3.3/card setup)(N/3,000)(setups) + ($0.045/card printed)(N/3,000)(cards printed/publication)(U publications/year)	= N[$1.1 \times 10^{-3} + 15 \times 10^{-6}$ U]
Cost of materials	
= $2.50/master card)(N/3,000)(master cards) + ($0.50/printed card)(N/3,000)(printed cards/publication)(U publications/year)	= N[$0.833 \times 10^{-3} + 0.166 \times 10^{-3}$ U]
Total cost (min.) = 35,000 + 780 U + 0.1122 N + 0.1983×10^{-3} NU dollars per year	
Total cost (max.) = 35,000 + 1,083 U + 0.1122 N + 0.1983×10^{-3} NU dollars per year	

Appendix H

PCMI ON-DEMAND (HARD COPY) PRINTING COSTS

Appendix H

PCMI ON-DEMAND (HARD COPY) PRINTING COSTS

Equipment Costs

1. Cost of viewer-printer with hard copy output = \$2,800.

   For 40 months' amortization at 0% rate of return, this = \$70 per month.

2. Maintenance and repair = \$200/yr = \$16.66 per month.

Labor Requirements

Define n = number of images to be copied for each order.

1. Setup time (read order card, pull master film from file, load master film in viewer, determine first address from index, locate first desired image, focus the viewer) = 3 min/order

2. Cleanup time (remove film from viewer and replace it in master file, collate request with finished product) = 2 min/order

3. Effective printing time = (5 sec/image)(1 min/60 sec)(n images/order)

   Total = (5 + n/12) min/order

4. Maximum number of orders copied/month =

$$\frac{440 \text{ hrs}}{\text{mo.}} \times \frac{1 \text{ order}}{(5 + n/12) \text{ min}} \times \frac{60 \text{ min}}{\text{hr}} = \frac{440(60)}{5 + (n/12)}$$

Material and Supply Costs

1. Paper and chemical cost = 5¢ per page.

Extra Assumptions

1. All information for a given item is on a single card (i.e., ignore the possibility of any extra setup times during the printing of a file item).

2. Each print request is for a single copy (i.e., a press run of one copy).

3. The cost of initially providing the file of PCMI cards is not included in this analysis.

4. Total labor cost is $6/hr.

Appendix I

UPDATING OF PCMI UNIT RECORDS

Appendix I

UPDATING OF PCMI UNIT RECORDS

Assumptions

1. Add-a-frame only, no purge or rewrite.
2. Unit record size = 2,625.
3. Annual update rate of at least 10%, i.e., daily rate of at least 400/million pages.
4. Records to be updated at any one time are randomly distributed.
5. On the average, each plate will have at least one update (see items 3 and 4).
6. PCMI camera-recorder setup time = 15 min.
7. PCMI printer setup time = 15 min.
8. Time to record images negligible in comparison with camera-recorder setup time.
9. Time to print one contact print is negligible compared with printer setup time.
10. Time to arrange pages in proper sequence, expose, and process input microfilm not considered.

Analysis

1. For each plate

	Setup
	15 min PCMI camera-recorder
	15 min PCMI contact-printer
	30 min total setup

2. 400 plates hold 1 million images.
3. At least 1 update per plate.
4. 400 x 30 min = 200 hrs/update cycle/million pages.

5. Length of update cycle/million pages increases as unit record size is reduced below 2,625 and annual update rate increased above 100%.

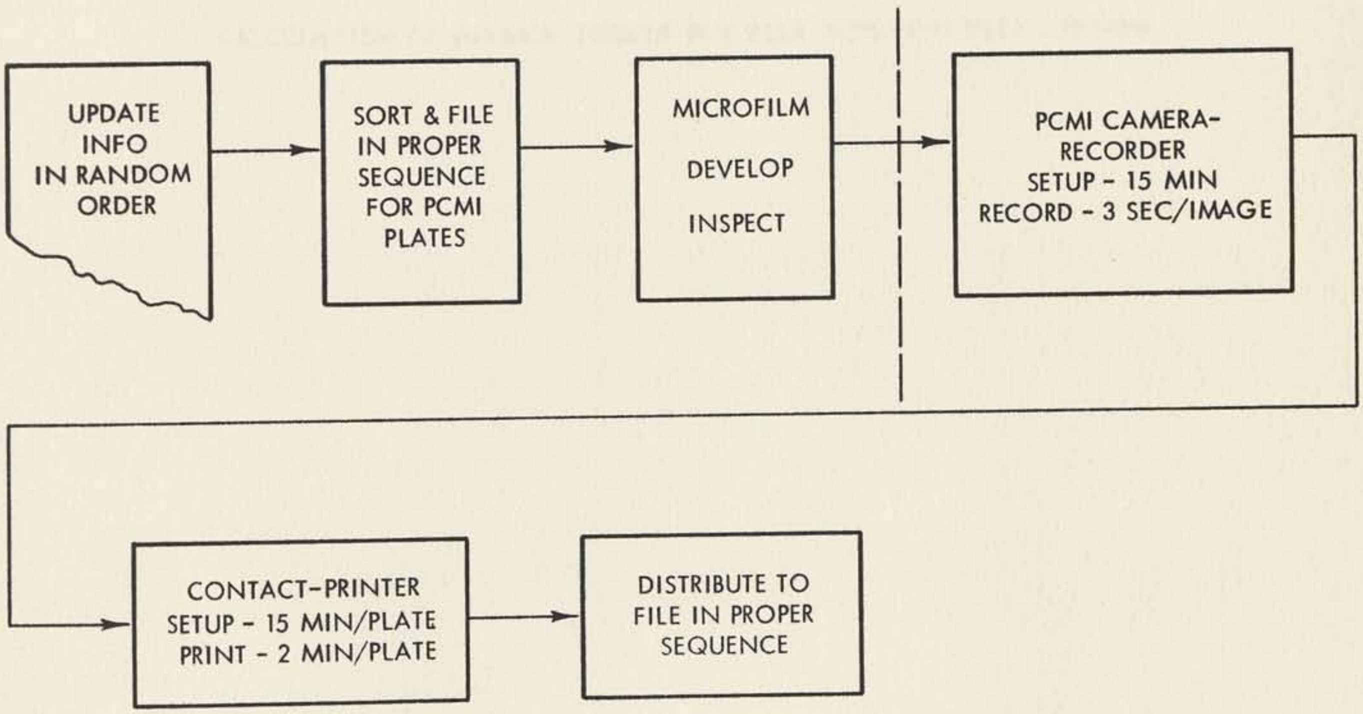

FIGURE I-1

UPDATING OF PCMI UNIT RECORDS

Appendix J

CALCULATION OF PAYBACK PERIOD FOR HIGH ACTIVITY FILE SYSTEMS

Appendix J

CALCULATION OF PAYBACK PERIOD FOR HIGH ACTIVITY FILE SYSTEMS

Assume:

1. Cost of camera (depreciation and maintenance) included in conversion cost
2. Interest rate = 0%
3. Accession rate = 1/2 activity rate (conservative)
4. Purge rate = 1/4 accession rate = 1/8 activity rate

Then:

$$C_t = P \left[A\ (S_a + 1/2\ S_u + 1/8\ S_p) + S_s \right]$$

$$C_t = P \left[A\ (S_o) + S_s \right]$$

where,

C_t = Total fixed cost per million pages = $C_c + C_e$

C_c = Conversion cost/million pages

C_e = Equipment cost/million pages

P = Payback period in years

A = Activity rate x 10^6

S_u = Savings/page updated over present system

S_a = Savings/access, over present system

S_p = Savings/page purged over paper system

S_s = Annual savings in storage/million pages

S_o = $(S_a + 1/2\ S_u + 1/8\ S_p)$

All savings and costs in dollars..

	PCMI	MEDIA	Microfiche
S_a	+8¢	+10¢	+4¢
$1/2\ S_u$	-6	+8	+1
$1/8\ S_p$	+1	+1.25	+4
S_o =	+3¢	+19.25¢	+9¢
=	$+\$3 \times 10^{-2}$	$+\$19 \times 10^{-2}$	$+\$9 \times 10^{-2}$

$S_s = \$1{,}000 \text{ avg.} = \$1 \times 10^3$

C_t for Activity Rate	PCMI	MEDIA	Microfiche
10%	\$ 95,000	\$ 41,500	\$26,500
50	103,000	107,000	30,700
100	111,000	194,500	31,500
300	151,000	526,000	42,500

(See Table XIX)

$P = C_t \div A \cdot S_o + S_s$

A	PCMI	MEDIA	Microfiche
5×10^4	$P = \frac{95 \times 10^3}{(1.5 + 1)10^3} = 38$	$P = \frac{41.5 \times 10^3}{(9.5 + 1)10^3} = 4$	$P = \frac{26.5 \times 10^3}{(4.5 + 1)10^3} = 4.8$
10^5	$P = \frac{95 \times 10^3}{(3 + 1)10^3} = 24$	$P = \frac{41.5 \times 10^3}{(19 + 1)10^3} = 2$	$P = \frac{26.5 \times 10^3}{(9 + 1)10^3} = 2.65 = 2\text{-}2/3 \text{ yr}$
5×10^5	$P = \frac{103 \times 10^3}{(15 + 1)10^3} = 6.5$	$P = \frac{107 \times 10^3}{(95 + 1)\times 10^3} = 1.1$	$P = \frac{30.7 \times 10^3}{(45 + 1)\times 10^3} = .66$
10^6	$P = \frac{11.1 \times 10^4}{(3 + 1)10^4} = 3.6$	$P = \frac{19.5 \times 10^4}{(19 + 1)10^{+4}} = 1.2$	$P = \frac{3.15 \times 10^4}{(9 + .1)10^4} = .3$
3×10^6	$P = \frac{15.1 \times 10^4}{(9 + .1)10^4} = 1.6$	$P = \frac{52.6 \times 10^4}{57 \times 10^4} = .92$	$P = \frac{4.25 \times 10^4}{27 \times 10^4} = .16$

Appendix K

CALCULATION OF PAYBACK PERIOD FOR LOW ACTIVITY FILE SYSTEMS

Appendix K

CALCULATION OF PAYBACK PERIOD FOR LOW ACTIVITY FILE SYSTEMS

Assume:

1. Cost of camera (depreciation and maintenance) included in conversion cost
2. Interest rate = 0%
3. Updating treated as conversion; see Section V, "Low Activity Files"
4. Cost of providing security not considered here

Then: $C_t = P\left[A(s_a) + S_s\right]$

where,

C_t = Total fixed costs per million pages = $C_c + C_e$

C_c = Conversion cost/million pages

C_e = Equipment cost/million pages

P = Payback period in years

A = Activity rate x 10^6

S_a = Savings/access, over paper system

S_s = Annual savings in storage/million pages

All savings and costs in dollars.

$P = C_t \div A(S_a) + S_s$

C_t for Activity Rate (see Table XXIII)	PCMI	Roll Microfilm
.001%	$95,000	$10,000
.010	95,000	10,000
.100	95,000	10,000
1.00	95,000	10,000

(See Table XXII)

PCMI $\frac{S_a}{\$2 \times 10^{-1}}$

Roll microfilm $\$4 \times 10^{-2}$

$S_s = \$5 \times 10^2$ average

A	PCMI	Roll Microfilm
10	$P = \frac{95 \times 10^3}{(.002 + .5)\times 10^3} = 189$	$P = \frac{10 \times 10^3}{(.0004 + .5)\times 10^3} = 20$
10^2	$P = \frac{95 \times 10^3}{(.02 + .5)\times 10^3} = 182$	$P = \frac{10 \times 10^3}{(.004 \times .5)10^3} = 20$
10^3	$P = \frac{95 \times 10^3}{(.20 + .5)10^3} = 136$	$P = \frac{10 \times 10^3}{(.04 + .5)10^3} = 18.4$
10^4	$P = \frac{95 \times 10^3}{(2.0 + .5)10^3} = 38$	$P = \frac{10 \times 10^3}{(.4 + .5)10^3} = 11$

Appendix L

ANALYSIS OF ANNUAL STORAGE SPACE COST AS A FUNCTION OF REDUCTION RATIO

Appendix L

ANALYSIS OF ANNUAL STORAGE SPACE COST AS A FUNCTION OF REDUCTION RATIO

Assumptions:

1. 8-1/2" x 11" documents
2. Filing cabinet--4-drawer, requiring 15" x 30" floor area
3. 4,000 sheets/drawer; 1 image/sheet
4. Aisle space = 2/3 of floor space used for filing cabinet
5. Space required roughly proportional to area reduction ratio

Analysis for One Million Pages:

4,000 sheets/drawer x 4 drawers/cabinet = 16,000 sheets/cabinet

$\frac{1,000}{16}$ = 62.5 cabinets, or 63 cabinets

Each cabinet 1-1/4' x 2-1/2" = 3.13 sq ft

Aisle space = 2/3 of 3.13 = 2.1 sq ft

Total space per cabinet = 3.13 sq ft
2.12 sq ft
5.25 sq ft

63 cabinets x 5.25 sq ft = 331 sq ft ≈ 335 sq ft (this could be reduced 25% by using 5-drawer files)

It is important to note that although we have assumed one image/page, we could double number of images, i.e., put one on each side without increasing storage space required.

Cost of Space Required Using Microfilm:

Linear Ratio	Area Ratio	100 Million Pages	10 Million Pages	1 Million Pages
1:1	1:1 at $5.00 sq ft	33,500 sq ft $168,000	3,350 sq ft $16,800	335 sq ft $1,680
10:1	100:1	335 sq ft $1,680	33.5 sq ft $168	3.35 sq ft $16.80
20:1	400:1	84 sq ft $420	8.4 sq ft $42	0.84 sq ft[a] $4.20
30:1	900:1	37 sq ft $185	3.7 sq ft $18.5	0.37 sq ft[a] $1.85
100:1	10,000:1	3.35 sq ft $16.80	0.335 sq ft[a] $1.65	0.0335 sq ft[a] $0.16
200:1	40,000:1	0.86 sq ft[a]	0.086 sq ft[a]	0.0086 sq ft[a]

a. Numbers below one sq ft are significant only for planning, since viewer and other equipment take up more room than this.

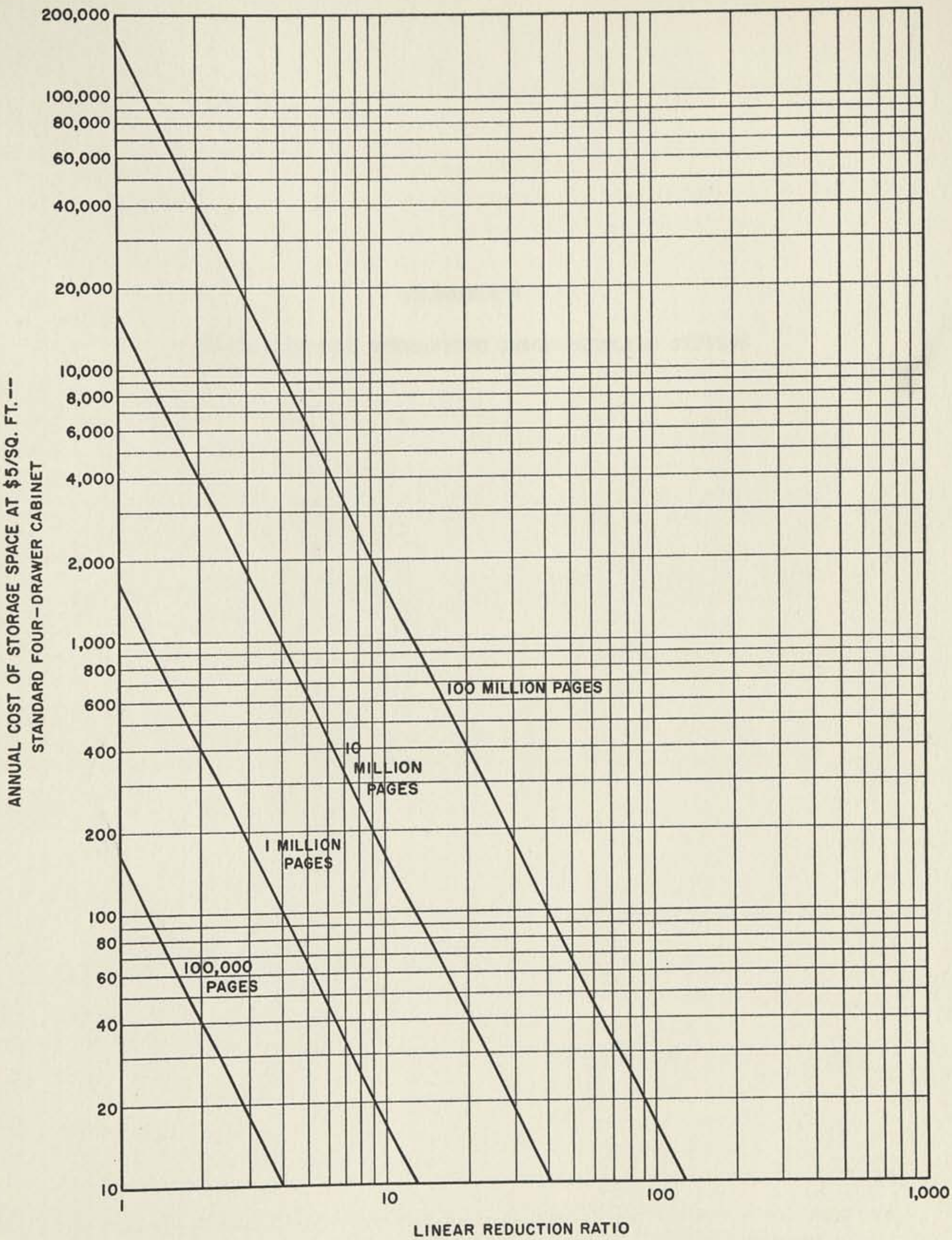

FIGURE L-1

ANNUAL STORAGE COSTS VS LINEAR REDUCTION RATIO

Appendix M

REPRESENTATIVE MECHANIZED IMAGE-HANDLING SYSTEMS

Appendix M

REPRESENTATIVE MECHANIZED IMAGE-HANDLING SYSTEMS

FMA Filesearch System

This equipment is an up-to-date commercial version of the Rapid Selector. The file medium is a 1,000-foot roll of 35mm film, with a maximum of 32,000 document pages per roll. The pages are recorded at a reduction of 25:1, and optically encoded indexing information accompanies each film frame. With this reduction ratio, 32 legal-size pages can be recorded on each foot of film. It is estimated that a single camera operator can photograph about 4,000 pages a day.* Space is provided on the film for a total of 56 alphabetic or 84 decimal characters of indexing data on each frame, plus some marks for machine checking. The indexing data can take any general alphabetic or numerical form.

The system consists primarily of a recording unit and a search unit. The recording unit uses a 35mm planetary camera to record both the document page and the indexing data on the same frame at the same time. To speed up the generation of the indexing code pattern for filming, the indexing data are first put in punched card form, so the cards can subsequently be used to set up the patterns quickly and automatically during the filming operation.

The search operation consists of typing a search descriptor or index number in a punched card, then using the card to set up the search pattern in the machine. The system is capable of simultaneous handling of up to six requests having a moderate degree of logic complexity. The file is searched at the rate of 6,400 pages (200 feet) per minute, and at the user's option, the selected frames are either displayed on a viewing screen, printed as full-size hard copies, or copied on another roll of microfilm. Five minutes or more would be required to search the entire 32,000-page file.

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* R. A. Condon, "The FMA Filesearch System," paper presented at a Symposium on Information Processing, Los Angeles Chapter of the American Documentation Institute, Los Angeles, California (September 1961).

Three Filesearch systems have been installed to date since their first announcement in 1960 (two at the Navy's Bureau of Ships, and one at a classified Air Force installation). The Bureau of Ships installation has already recorded about 1½ million pages on roll microfilm, at an estimated conversion cost (for filming, indexing, etc.) of about 25¢ per page.

Benson-Lehner FLIP

The Benson-Lehner FLIP (Film Library Instantaneous Projection) equipment currently operates as an automatic selector for viewing purposes.* Each frame of 16mm roll microfilm contains a single image and 32 bits of binary coded indexing information to describe the contents of that frame. A 1,200-foot roll with 72,000 images is searched at a rate of 300 to 600 frames per second. The minimum scan speed is 60 inches per second. The equipment for the operator consists essentially of a keyboard interrogation device and a large display screen. The keyboard positions correspond to the coding positions on the film so that the inquiry can be keyed into the system via the keyboard. After the inquiry has been entered, the film is transported at a high rate of speed until a frame is located which satisfies the search criteria. The film is then stopped and positioned so that the chosen frame is displayed on the viewing screen. No provisions have been made for reproducing the selected frame, and no general purpose equipment is currently available to prepare the original film record with the coded indexing information.

Only two of these units have been installed since their initial announcement in 1958.

The Eastman Kodak Minicard System

The Minicard System was developed by Eastman Kodak with U.S. Air Force support for application to specific military information problems

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* P. K. Worsley, "Data Retrieval with Especial Application to Use of Film Library Instantaneous Presentation (FLIP) in Literature Searching," a section of the book Modern Trends in Documentation, M. Boaz, Ed., pp. 70-73, Pergamon Press, New York (1959).

rather than for application to documentation problems in general.* It comprises one of the largest and most expensive collections of equipment ever developed specifically for information storage and retrieval. Primarily because of its cost, its use has been restricted to a few special government file problems. The first complete system went into operation late in 1958.

In this system, the unit record or film chip is a 16mm by 32mm piece of film which normally includes one or more images and their associated indexing data. Images are stored at a reduction of up to 60:1 and up to twelve legal-size pages can be recorded on a single chip. Single maps up to 18"x22" can be recorded at a 38:1 reduction, and single photographs up to 9"x9" can be recorded at a 20:1 reduction. The amount of indexing data on each chip may range from 252 to 2,730 bits, roughly corresponding to 42 to 455 alphanumeric characters. Because of their small size, it has been found convenient to carry the chips on a skewer in groups of 2,000 or less when manual handling is necessary.

The system includes a camera that photographs the original documents on 16mm film and inserts the coding information on the same frame as the related image, using data provided on punched paper tape. Approximately 500 pages of graphic material can be recorded in an hour, assuming an average of 6 pages and 210 characters of code on each film chip. A 200-foot-film magazine will record approximately 1,800 film records. After

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* A. W. Tyler, W. L. Myers, and J. W. Kuipers, "The Application of the Kodak Minicard System to Problems of Documentation," American Documentation, Vol. 6, pp. 18-30 (January 1955).

J. W. Kuipers, A. W. Tyler, and W. L. Myers, "A Minicard System for Documentary Information," American Documentation, Vol. 8, No. 4, pp. 246-268 (1957); this is also published as Chap. 7 in Information Systems in Documentation, J. H. Shera, et al, Ed., Interscience, New York (1957).

Anon., "More Instant Literature," (Minicard description), Chemical and Engineering News, pp. 82-83 (June 29, 1959).

W. L. Myers and G. L. Loomis, "The Minicard Film Record as a Common-Language Medium," Chapt. 20 in Information Retrieval and Machine Translation, Part 1, A. Kent, Ed., Interscience, New York (1960).

A. L. Effros, "The Minicard System for Storage and Retrieval of Documentary Information," paper presented at a Symposium on Information Processing, Los Angeles Chapter of the American Documentation Institute, Los Angeles, California (September 1961).

the film is processed (about 30 minutes per magazine) and checked for image quality, it is chopped into individual chips by a film cutter that can cut an entire film magazine into about 2,000 chips in less than 4 minutes. These original film negatives are used to produce second-generation positives for the working file. The original negatives are then put away for security storage and are not used for any file searching operations. The second-generation positive chips are produced in an automatic duplicator, one for each input document, and one for every subject heading or file category to be used. They are then inserted into the file under the respective categories. This procedure serves to partition the file so that searches can be confined to scanning selected portions of the file, instead of requiring a scan of the complete contents of the file. The input chips are automatically routed to their respective magazines at the rate of 1,000 chips per minute by a sorting machine.

File searching is done by an automatic selector at the rate of 1,200 chips per minute. The question statements are supplied on paper tape and the question logic is stated with plugboard wiring. The records that satisfy the search criteria are copied on third-generation negatives and delivered to the inquirer. Equipment is available for viewing, or for producing hard copy at the rate of 540 prints per hour. The film chips cannot be conveniently handled, viewed, or reproduced by any equipment except the equipment developed for the Minicard system.

A total of four or five systems have been delivered for military and government installations; however, there have been no additional installations since their first commercial announcement in 1958.

The Filmorex System

The Filmorex system is a photographic unit record system which has been under development since 1952 by Dr. Samain in Paris, France.* Over 10 of these systems have been delivered to European users. The unit record is a film chip (60mm lengths of 35mm film) with half binary coding and half text, similar to the format used in the Minicard system. Special equipment is available to search, view, or produce hard copy photolistings of the cards. Documents up to 30 by 45 cm (approximately

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* J. Samain, "Documentation by the Filmorex Technique," Chap. 26 in Information Systems in Documentation, J. H. Shera, *et al*, Interscience Publishers, New York (1957).

12"x18") can be photographed on one-half of the microfilm card. The coding half of the card will hold a binary pattern for up to 25 six-digit numbers that can be used to index or describe the contents of that card.

The original microfilming is done by photographing "coordinate cards" with a special camera unit. The coordinate cards are cards for each indexing term which have the appropriately coded pattern printed on the edge of the card. In this manner, the digital coding for a document could be displayed for photographing by shingling the appropriate coordinate cards next to the document. This is a very simple method for inserting the coding terms on a document, and could certainly be applied to other microfilm systems. The searching is performed by a Selector unit which reads the cards at a rate of 600 cards per minute. When the Selector recognizes a coding combination that it has been instructed to watch for, the card containing this code is shunted into a separate pocket. A hard copy listing of the selected cards may be obtained by running the cards through the Photolister unit. With the exception of one experimental installation at USAF Rome Air Development Center, there have been no installations in this country since the first commercial announcement here in 1958.

Video Storage

Image storage systems designed both by RCA and by Ampex, and referred to as the Video File, store graphic images such as documents, maps, or drawings, on video magnetic tape in much the same manner as a video tape recording system. Each frame or image on the tape is accompanied by digital data giving the file number or address of the image. The RCA system has a resolution four times greater than commercial television and can store a page-size document on about 3 square inches of videotape surface. A 7,200-foot roll of tape could store up to 36,000 pages. The documents are initially recorded on tape by a scanning TV camera which, with automatic page-feeding equipment, can operate at about 120 documents per minute. The file tape can be searched at the rate of 300 inches per second, and selected images can be displayed on a monitoring screen or printed out by an Electrofax printer.

This equipment has been proposed by both companies but not used yet for any operational information system.

Recordak Lodestar with Counting Accessory

The regular Recordak microfilm viewer can be augmented with a special accessory that counts the number of frames since the beginning of the roll. If the location or sequence number of a document on a roll of film is known the number can be entered on a keyboard and the drive motor set to unwind the film automatically until it arrives at or near the desired address. The operator need not monitor the viewing screen during this scanning operation and is free to concentrate on other tasks. This file look-up device is admittedly crude but relatively inexpensive.

Ferranti-Packard Rapid Access Look-Up System

The Ferranti-Packard equipment scans a continuous loop of 16mm film at moderate speed (over 40 inches per second) to achieve a moderate random-access time. One installation has a single loop of 440 film frames, giving an average frame selection time of 1.5 seconds. Larger loops are possible with a consequent increase in time; for example, a 5,000-frame loop would give an average access time of about 18 seconds. Each film frame contains space for a small amount of indexing data, arranged in much the same manner as in the Rapid Selector. The search criterion is a single number, such as a page number, and is entered on a keyboard device. The selected frame is displayed on a viewing screen. Equipment is being developed to print full-size copy from the selected frames.

Seven units of this equipment were custom built for the Ellicott Drug Company in Buffalo, New York. The equipment is used for calling up RAMAC numbers assigned to a 25,000-item drug product inventory. Nine of these units have been built since they were first announced in June 1960.

CRIS

The CRIS (Command Retrieval Information System) developed by a subsidiary of Information for Industry, as an outgrowth of some earlier work done by Avakian in 1956.* This system stores images photographically on

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* E. Avakian, "AMFIS--The Automatic Microfilm Information System," Special Libraries (April 1957).

P. W. Larson, "CRIS (Command Retrieval Information System)," Proc. 11th Annual Conv. of the Nat'l. Microfilm Assoc., pp. 41-50, Nat'l. Microfilm Assoc., Annapolis, Maryland (1962).

a scroll of microfilm 400 feet long by 17 inches wide, and containing over 500,000 page-size images or over 28,000 large drawings per scroll. A keyboard device is used to enter a CRIS address, and the image at that address is displayed to the operator or provided in aperture card form. The average time to retrieve any desired image is under 20 seconds, and the retrieval time for sequential images is even faster. An aperture card copy of the displayed frame can be made in about 20 seconds. The scroll material is a Mylar base with a Kalfax emulsion, and is usually prepared by contact printing from strips of microfilm that were obtained by conventional procedures.

The system was first announced in 1961.

Magnavox MEDIA

The MEDIA (Magnavox Electronic Data Image Apparatus) system was first demonstrated by Magnavox in 1961.* This photographic unit-record storage system uses a combination of manual and machine search techniques. The basic film chip is a 16mm by 32mm card that contains up to two 9"x15" page images or three 8½"x11" page images at a reduction of 30:1, and an information field of up to 17 encoded and human readable digits to identify the image. These digits usually describe the document number as well as some other codes. The documents are photographed on 100-foot rolls of microfilm using a special camera unit, processed, and cut into cards at the rate of 240 per minute. The cards are kept in capsules or cartridges containing up to 200 cards. These capsules are stored in regular file cabinets and are handled and selected manually. The chips are usually not stored in order within a capsule, and the contents of each capsule may be run through a sorting device to extract specific chips from the capsule. To retrieve a specific file item (e.g., document no. 1234598) a clerk selects capsule number 12345 from the file cabinet, mounts it in the selector unit, and keys in the last two digits (98). The cards are then scanned at the rate of 600 cards per minute to

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* D. D. Jenkins, "Magnetic Indexing, Microfilm Storage and Information Retrieval," in Proc. 11th Annual Conv. of the Nat'l. Microfilm Assoc., pp. 205-212, National Microfilm Association, Annapolis, Maryland (1962).

R. L. Laurent, "Magnacard--Magnavue--Media," paper presented at a special conference of the Los Angeles Chapter of the American Documentation Institute, Los Angeles (September 1961).

select the desired card. This unit can provide a page-size blowback of the card image if desired. A browsing unit is also available; with this, the user can view the cards in a capsule one at a time in a regular microfilm viewer-printer, and can transfer selected copies to hard copy form.

Two MEDIA systems have been installed since their commercial announcement in 1961. One of these installations is the International Association of Machinists in Washington, D.C., and the other is at the Home Insurance Company in New York City.

AVCO Corp. VERAC 903

The AVCO Manufacturing Corporation developed a single prototype model of a mechanized photographic storage system in 1959 with support from the Council on Library Resources.* This system, the VERAC 903, has not been operated yet in a real library environment. The equipment was designed to alleviate some of the storage problems of conventional library systems. Three main pieces of equipment have been developed: (1) a microphotographic memory, (2) a camera system to generate micro-images from the input documents, and (3) an output system to display and reproduce selected portions of the micro-image file. The photographic storage element was designed for a capacity of 1,000,000 reduced page images, with an access time between 0.3 and 2.0 seconds to any page in the memory. The images are stored at relatively high reduction ratios, 70:1 or 140:1. The output consists of a cathode ray tube display or a microfilm reproduction of the images selected from specific addresses or page numbers.

IBM WALNUT

WALNUT is a code name for a complex, mechanized, micro-image storage and retrieval system (IBM 9603 Image File) developed for a federal agency

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* K. Bowker, et al, "Technical Investigation of Elements of a Mechanized Library System," Final Report EW-6680 of the AVCO Corp., Crosley Div., Electronics Research Laboratory, Boston, Massachusetts (January 1960).

by the IBM Corporation.* The system consists primarily of a file of microfilm strips stored in bins, and a mechanical selection device that can quickly go to a specified bin, mechanically select a strip of microfilm, and copy images from that strip onto aperture cards. The basic image file unit contains a total of 990,000 page-size images (200 plastic cells of 50 strips each, with 99 images on each strip) stored at a 35:1 reduction. This is equivalent to about 3,000 books or the contents of about 100 filing cabinets. Given an image number and page count, the random-access selection equipment can locate the desired image in less than 5 seconds, and transfer the image to a blank frame of Kalfax film mounted in an aperture card. The Kalfax film is exposed with an ultraviolet lamp and heat-developed by the basic file unit. The aperture card has positions for four images, reduced 27.2 times from the original document. The equipment can provide images from this file, on demand, at the rate of about 500 aperture cards per hour. The aperture cards can be viewed, or used to print copy on any of several models of commercially available microfilm viewer-printers. The original address of the image was given to the file in punched card form, and could have been the direct result of a computer file search of some master index.

Another piece of equipment which accompanies the basic file unit is the IBM 9403 Image Converter. This unit serves as the file input device by transferring images from conventional 35mm sprocketed silver microfilm (at an original reduction of 15.8:1) to the Kalfax file strips at a further reduction of 2.2:1. The file strips utilize Kalfax film that has an image resolution on the order to 550 to 600 lines/mm. The Image Converter operates at a maximum rate of 1,500 frames per hour, to transfer

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* R. W. Porter, "A Large-Capacity Document Storage and Retrieval System," in Large-Capacity Memory Techniques for Computing Systems, M. C. Yovits, Ed., pp. 351-360, Macmillan Co., New York (1962).

N. A. Vogel, "WALNUT Document Storage and Retrieval System," Proc. 11th Annual Conv. of the Nat'l. Microfilm Assoc., pp. 27-39, Nat'l. Microfilm Assoc., Annapolis, Maryland (1962).

P. D. Bradshaw, "The WALNUT System: A Large Capacity Document Storage and Retrieval System," American Documentation, Vol. 13, No. 3, pp. 270-275 (July 1962).

J. H. Veyette, Jr., "Photo-Image Storage: Its Role in Modern Business," (includes a description of the IBM WALNUT system) Business Automation, Vol. 6, No. 4, pp. 16-21 (October 1961).

images to the file strips, assign addresses, and punch these addresses into a tab card.

Only one of these WALNUT systems has been installed, and this was at the Central Intelligence Agency. There have been no other installations since the equipment was first announced in 1961, and there are no units on order. Specific information regarding the cost and nature of application is classified, and hence is not available for this project.

Representative Costs for Mechanized Image Systems

Following is a summary of representative costs of 14 mechanized image systems:

Equipment	Current U.S. Purchase Cost (Approximate)
Benson-Lehner FLIP	$ 40,000 to 50,000
FMA Filesearch	167,000
Ferranti-Packard Rapid Access Look-Up System	17,000
Eastman Kodak Minicard	over 1,000,000
Filmorex System	25,000
IBM WALNUT System	500,000 to 1,000,000
AVCO Corp. VERAC 903	over 100,000
Video Tape System	500,000 to 1,500,000
Recordak Lodestar with Counting Accessory	4,600
CRIS (Information for Industry)	25,000
CRIS Scroll Preparation Unit	10,000
Magnavox MEDIA Camera	8,500
Magnavox MEDIA Film Cutter	1,500
Magnavox MEDIA Selector-Reproducer	25,500

Appendix N

CONTACT LETTER

Appendix N

CONTACT LETTER

Dear Mr.

Stanford Research Institute requests your help in a study it is conducting for a major data processing equipment manufacturer. The Institute has been asked to perform a product planning and application study to define the needs of industry and government relating to a new high-density optical technique for storing, retrieving and disseminating both written and graphic information.

I would appreciate a chance to visit with you or a knowledgeable member of your systems staff to discuss possible applications of this technique to some of your organization's information handling problems. I am particularly interested in obtaining a description of your present requirements (written or graphic) for the storage, retrieval and dissemination of information, as well as any present or planned methods of meeting these requirements.

Current plans should bring me to your city between and . I will telephone your secretary to arrange a more precise time for my visit when I arrive in the vicinity.

We hope our visit might prove as stimulating to you as we are sure it would be to us.

Sincerely yours,

Arthur W. Dana, Jr.
Systems Analyst

AWD:jh

Appendix O

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Appendix O

ORGANIZATIONS CONTACTED

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Hawthorne, California

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TITLE POTENTIAL MARKETS FOR PCMI IN MICROFORM PUBLISHING AND LARGE FILE APPLICATIONS

AUTHOR A. W. Dana, Jr., and C. P. Bourne

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The potential for reducing the storage space required for books and documents, through use of NCR's Photochromic Micro-Image (PCMI) technique, is graphically portrayed in this photo. Marlene Wess holds in her right hand a piece of PCMI film which contains the contents of eight copies of the books she is holding in her lap. The same books, reproduced on microfilm, are shown on the wall behind.

Photochromic Micro-images

New process for storing tiny images "microfilms" microfilm.

By A. S. Tauber and W. C. Myers

RECENT RESEARCH AND DEVELOPMENT by The National Cash Register Company has resulted in a promising new technique for the storage and dissemination of micro-documents.

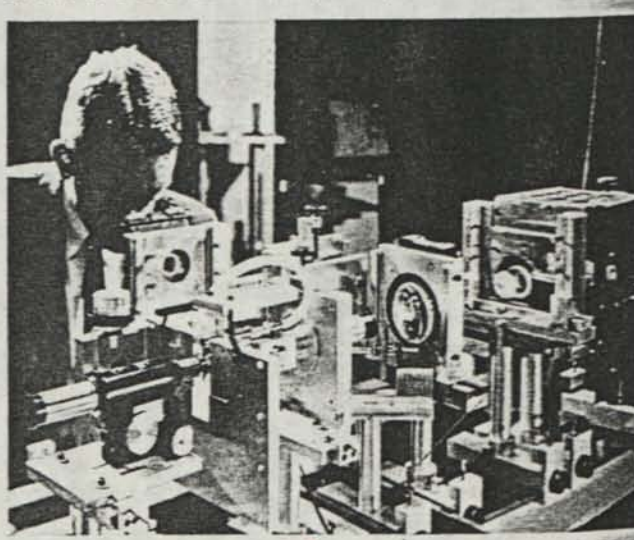
This new technique, called photochromic micro-images (PCMI), has made very high density document storage feasible at linear reductions of 200:1, representing an area reduction of 40,000:1. Using this technique, it would be possible to record a 300 page book within a square inch of film.

PCMI does not replace conventional microfilm. As a matter of fact, high quality microfilm is used as the input media. The new process is used to extend the dimensions of micro-storage over that available with standard microfilm. In a sense, the process is one of "microfilming" microfilm.

The major difficulty in using a regular photographic type process for micro-image storage is the probability of an error occurring at some point in the process. An error, for example, might be an improperly focused image, or an imperfect microfilm master negative. It might also result from a piece of dirt, either in the optical system or upon the film emulsion itself. In many cases it is simply "human error".

Basically, there is no satisfactory inspection procedure to detect, as well as to correct, such errors before the final development of the master

A research "breadboard" model of a PCMI camera-recorder in use at NCR's Hawthorne, Calif., electronics division.



matrix. Therefore, correction of perfect images requires the re-... entire matrix of images. Experience has shown that the higher the reduction ratio attempted, the more severe the "error problem" becomes.

One of the major advantages of the new process is that it not only permits inspection to occur at any step of the process, but it also allows the operator to correct errors.

Photochromic coatings

What is the PCMI process, and why does it potentially permit such improvement in the effectiveness of micro-document storage and dissemination above that available with more conventional technologies?

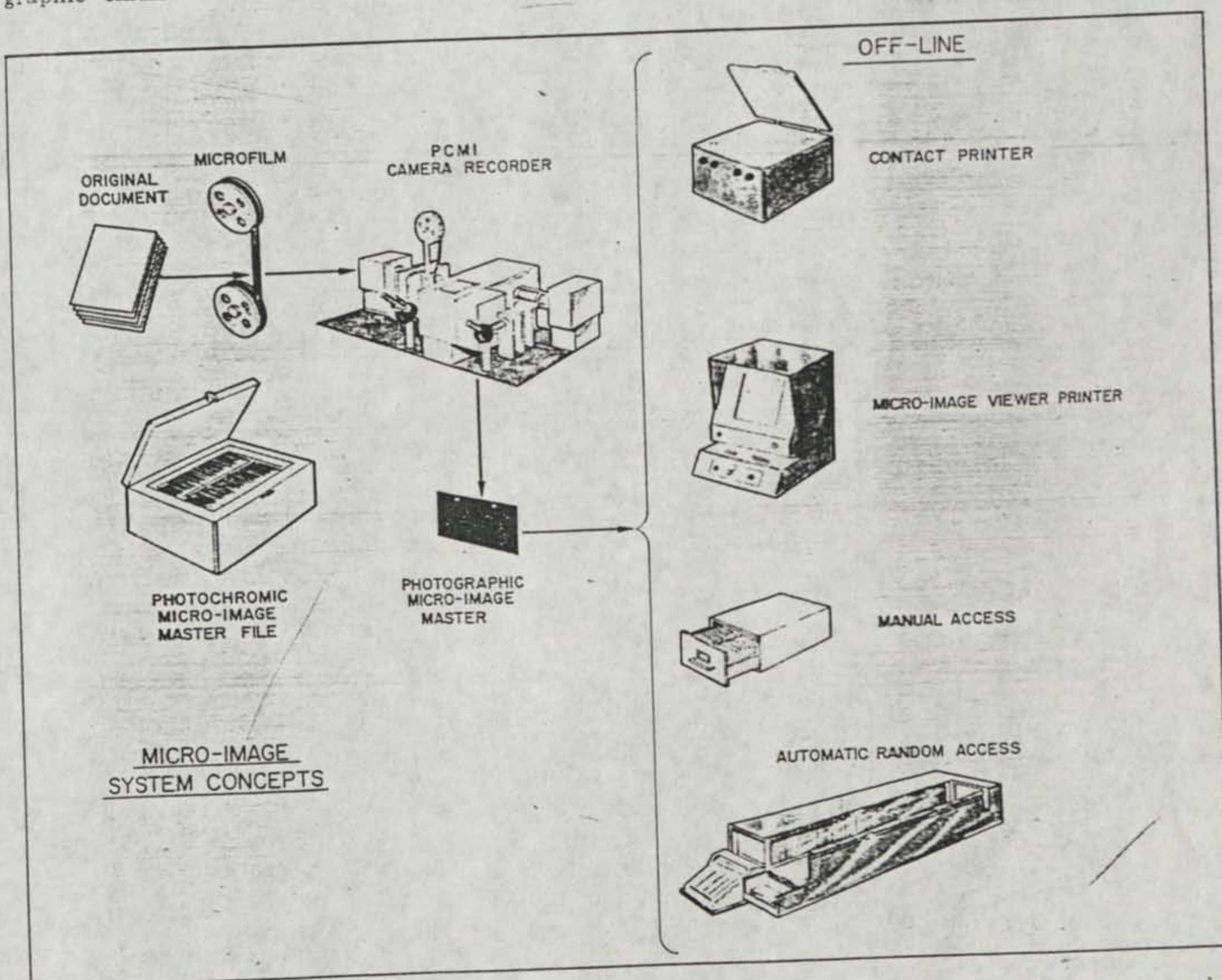
Photochromic compounds exhibit color changes when exposed to radiant energy in the visible, or near visible, portions of the spectrum. For example, one class of photochromic materials consists of light sensitive organic dyes. NCR photochromic coatings consist of a molecular dispersion of such dyes in a suitable coating material.

Photochromic coatings are similar to photographic emulsions in appearance and in other ...es. They can be made to retain two-dimensional patterns or images which are optically transferred to their surface. They can be coated, in general, on the same types of material as photographic emulsions, and they have excellent resolution capabilities. In addition, both positive-to-negative and direct-positive transfers are possible.

However, photochromic coatings differ from photographic silver-halide emulsions in a number of respects. The coatings are completely grain free and exhibit inherently high resolution. The image becomes immediately visible upon exposure and no development process is required. Further, because the coatings are reversible, the information stored can be optically erased and rewritten repeatedly.

The image appears on a PCMI plate or film when the individual molecules are switched from either the colored or the colorless state by light of the proper wave length. All of the NCR coatings now in use switch to the colored state when near ultra-violet radiation is used. Switching to the colorless state can be accomplished by using either heat or visible light of the proper wave length.

Information stored on photochromic coatings is



semi-permanent in contrast to developed photographic film which is relatively permanent, the result of the reversible nature of the photochromic coating. The life of the photochromic micro-image is dependent upon the temperature of the coating. At room temperature, image life is measured in hours, but as the temperature is lowered, life can be extended to months and even years.

This decay of image life prohibits the use of photochromic micro-images in their original form for archival storage. To overcome this problem, NCR has developed ways to transfer the photochromic micro-images to a high resolution photographic film. This transfer results in permanent micro-images.

PCMI process

In utilizing the PCMI process, the original document is first transferred to high quality conventional microfilm. Near-ultraviolet light is directed through the transparent microfilm and into the micro-image optics. This forms a miniature image on the photochromic coating. When all of the micro-images are formed, and have been properly inspected to see that no errors have been made, the entire contents of the photochromic plate are then transferred in one step as micro-images to a high resolution photographic film by contact printing. The photographic film is then developed, and the result is a photographic micro-image master plate.

This master can then be used to "publish" any desired number of duplicate micro-image cards by using a contact printing process, again upon photographic film. Using photographic film provides image permanency as well as potentially low cost dissemination of the stored information.

For micro-image systems which have a need to store the PCMI master plate, an off line refrigerated file can be provided. For example, some systems might require periodic updating of portions of the original file. In such cases, it might be more economical to keep the original PCMI master plate and, when necessary, erase only those micro-images that need to be replaced, instead of preparing an entirely new PCMI master each time an updating is required.

Storage

Many document storage and dissemination problems potentially lend themselves to mechanization by a micro-image system; for example, libraries of the future where books could be stored on small cards and duplicates of these cards given to library patrons for reading at home on compact viewing devices.

By using PCMI technology, every branch library would be able to maintain as large a collection as the main library. Reservations would no longer be necessary for the more popular books. Only one master copy of the original material would have to be stored, but this master copy would be in a form suitable for easy duplication. The master copy would never circulate or leave the library since user requests would be filled by the duplicates, which would be expendable.

However, the use of PCMI for complex information retrieval systems will necessitate a great deal more developmental work, NCR scientists point out. For example, the ability to economically and reliably produce, store, and duplicate micro-images does not represent the complete answer to realizing the full potential of PCMI. Adequate automatic techniques for indexing and searching the micro-image file have yet to be fully developed.

Despite such problems, this new micro-image technology does offer the following new horizons:

1. New system possibilities in the information storage and retrieval field.

2. Document dissemination and file decentralization for the libraries of the future.

3. Advantages to scientists, scholars, and professionals in all intellectual fields, such as relatively inexpensive microform publishing of their work, and easier and more thorough access to the work of others. ■

NCR – PCMI

copy to Tauber

Recent research and development within The National Cash Register Company has resulted in a new technique for the storage and dissemination of microdocuments. This new technique, Photochromic Micro-Images (PCMI), had made very high-density document storage feasible at linear reductions of 200:1, representing an area reduction of 40,000:1. Features of the PCMI process are described. Next, micro-image system elements are reviewed with respect to their basic functions and potential incorporation into complete micro-image systems. Finally, some potential future applications of micro-images in the fields of document storage and retrieval, libraries, and microform publishing are discussed and explored.

Photochromic Micro-images, A Key to Practical Microdocument Storage and Dissemination[1]

Received 28 May 1962

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• Introduction

Recent research and development within The National Cash Register Company has resulted in a new technique for the storage and dissemination of microdocuments. This new technique, photochromic micro-images (PCMI) (1), has made very high-density document storage feasible on a practical basis at linear reductions of 200:1, representing an area reduction of 40,000:1. Using this technique, it would be possible to record a 300-page book within a square inch of film.

PCMI does not replace conventional microfilm. As a matter of fact, high-quality microfilm is used as the input medium. The NCR PCMI process is used to extend the dimensions of micro-storage by a magnitude over that available with standard microfilm. In a sense, the process is one of microfilming microfilm.

This paper will have three major parts. First, the PCMI process itself will be described. Next, micro-image system elements will be discussed. Finally, the paper will explore just a few of the potential applications made possible by the future availability of relatively low-cost micro-images which can be easily duplicated and disseminated (or published).

• The PCMI Process

Microfilm technology has existed for more than a century, and it has been possible to make micro-images of documents at a reduction ratio of greater than 100:1 since 1839 (2). However, the practical limitations of straight photographic techniques have discouraged the development of devices capable of producing large quantities of micro-images at these high reduction ratios. To accomplish this implies laying down multiple images on a common surface and exposing them individually by some form of step-and-repeat technique.

The major difficulty in using a straight photographic-type process results from the relatively high probability of an error occurring at some point in the process. An error might be, for example, an improperly focused image, or an imperfect microfilm master negative. It might also result from a piece of dirt either in the optical system or upon the film emulsion itself. In many cases it is simply "human error". Basically, there exists no satisfactory inspection procedure to detect, as well as correct, errors before the final development of the master matrix. Therefore, correction of one or more imperfect images would require the re-recording of the entire matrix of images. Experience has shown that the higher the reduction ratio attempted, the more severe the "error problem" becomes.

One of the major accomplishments of the NCR PCMI process is that it not only permits inspection to occur at any step of the process but it also allows the operator to correct errors. Therefore, by using the PCMI process, it is now feasible to produce original master matrices of micro-images at 200:1 reductions that contain images numbering in the thousands.

What is the PCMI process, and why does it permit such a large jump in the effectiveness of microdocument stor-

[1] Paper presented at the April 1962 meeting of the National Microfilm Association.

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age and dissemination above that available with more conventional technologies?

First, let us take a brief look at photochromic materials (3, 4). By definition (5), photochromic compounds exhibit *reversible* spectral absorption effects (i.e., color changes) resulting from exposure to radiant energy in the visible, or near visible, portions of the spectrum. For example, one class of photochomic materials consists of light-sensitive organic dyes (6). NCR photochromic coatings consist of a molecular dispersion of these dyes in a suitable coating material. Photochromic coatings are similar to photographic emulsions in appearance and in other properties. They can be made to retain two-dimensional patterns or images which are optically transferred to their surface. They can be coated, in general, on the same types of substrates as photographic emulsions, and they can exhibit excellent resolution capabilities. In addition, both positive-to-negative and direct-positive transfers are possible.

However, photochromic coatings differ from photographic silver-halide emulsions in a number of important respects. The coatings are completely grain-free, low gamma (excellent gray scale characteristics), and exhibit inherently high resolution. The image becomes immediately visible upon exposure and no development process is required. Further, because the coatings are reversible, the information stored can be optically erased and rewritten repeatedly.

The image appears when the individual molecules are switched from either the colored or the colorless state by radiation (light) of the proper wavelength. All of the NCR coatings now in use switch to the colored state when near ultraviolet radiation is used. Switching to the colorless state can be accomplished by using either heat or visible light of the proper wavelength.

Information stored on photochromic coatings is semi-permanent, in contrast to developed photographic film which is relatively permanent. This is a result of the reversible nature of the photochromic coating. The life of the photochromic micro-image is dependent upon the ambient temperature of the coating. At room temperature image life is measured in hours, but as the temperature is lowered life can be extended very rapidly to months and even years.

Obviously, this temperature-dependent decay of image life prohibits the use of photochromic micro-images in their original form for archival storage. To overcome this problem, means have been developed for transferring the photochromic micro-images to a high-resolution photographic film. This transfer step is a simple operation and results in permanent micro-images.

Mechanization of the NCR PCMI process is simple in principle. The original document is first transferred to high-quality conventional microfilm. Properly filtered, near-ultraviolet radiation is directed through the transparent microfilm and into the micro-image optics. This forms a miniature image on the photochromic coating. Consider, for example, a photochromic plate 3 x 5 inches in size. The size of each micro-image would be 0.0425 x 0.0550 inch, so that a matrix with up to 2,625 micro-images could be placed on each 3 x 5 plate.

When all of the micro-images are formed and have been properly inspected to see that no errors have been made, the entire contents of the photochromic plate are then transferred in one step as *micro-images* to a high-resolution photographic film by contact printing. The photographic film is then developed under highly controlled conditions, and the result is a 3 x 5 photographic micro-image master plate.

This 3 x 5 photographic micro-image master can then be used to perform a most important function. It can be used to "publish" any desired number of duplicate 3 x 5 micro-image cards by using a contact printing process, again upon photographic film. Using photographic film provides image permanency as well as potentially low-cost dissemination.

• Micro-image System Elements and Considerations

Micro-image system elements and supplies can be broadly classified into two groups. One group consists of the elements and materials required to *produce* the micro-images, while the other group contains those items involved in the *use* of micro-images.

The most important system element in the first group is called the PCMI Camera-Recorder (Fig. 1). Reels of 35 mm, high-quality microfilm serve as the input media for the PCMI Camera-Recorder. As can be seen in Figure 1, the photochromic film is enclosed within an environmental chamber.

This chamber maintains the ambient air temperature below 0°C and also filters out all dust particles above ⅓ micron in size. The micro-image focusing optics can be adjusted by a specially designed air gauge to an accuracy of ±15 μinches. Field diameter of the micro-image is 68 mils.

Micro-images are recorded upon the photochromic film in a step-and-repeat manner. Consecutive pages are written in a horizontal line. The images can be either continuously inspected during the recording process or the Camera-Recorder can be placed in automatic operation with inspection occurring at a later point in the process. Before the contents of the photochromic film are printed out, a thorough inspection can be made, if desired, to detect any errors that have occurred. Errors are then simply corrected by erasing the imperfect image and rewriting it on the photochromic film.

After a perfect micro-image matrix has been prepared on the photochromic film, the next step of the PCMI process is a bulk transfer of this PCMI matrix to a high-resolution photographic film by contact printing. This procedure also takes place within an environment of dust-free air.

Figure 2 is a view of the laboratory breadboard model

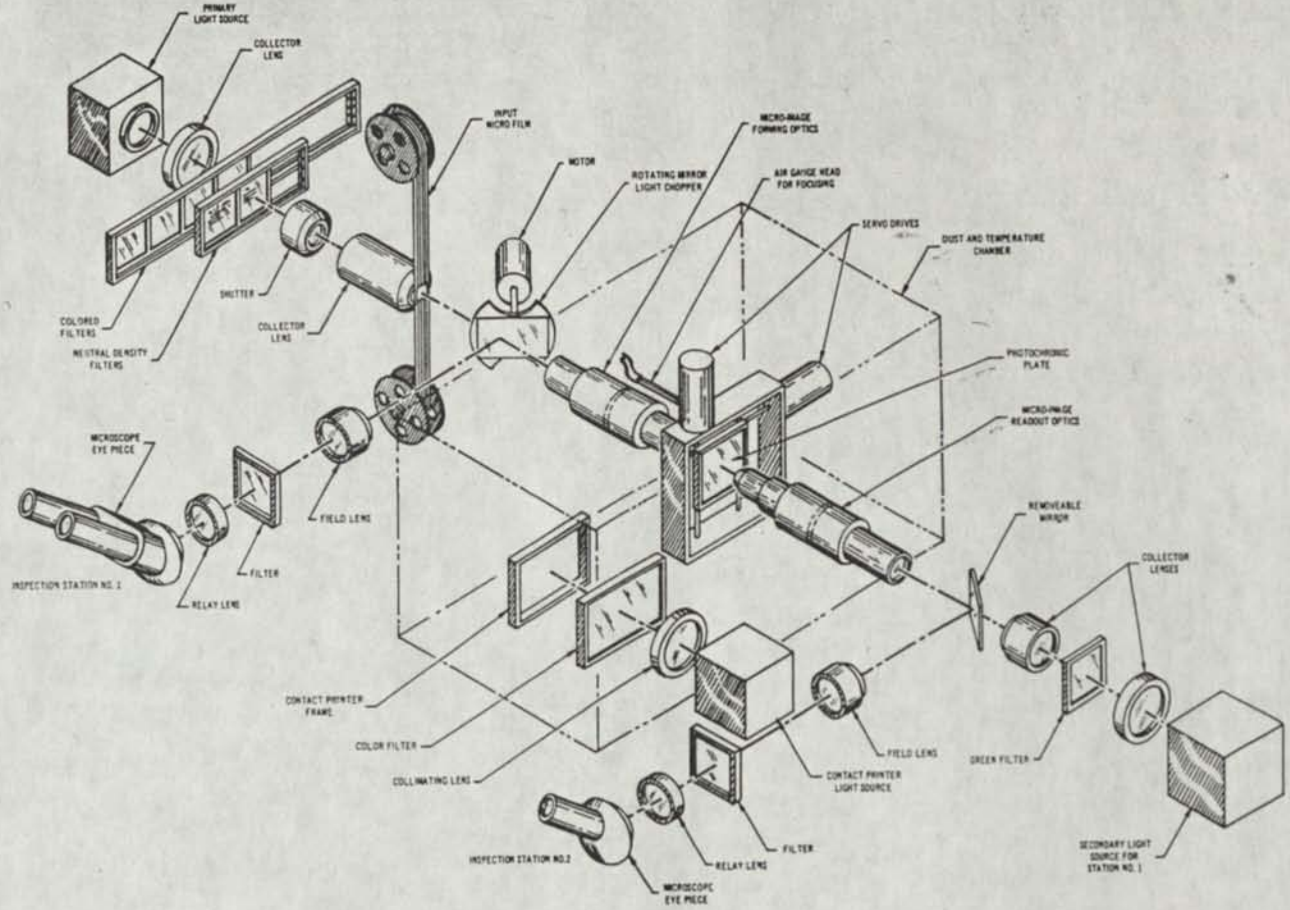

Fig. 1. PCMI Camera-Recorder.

used to make the first 200:1 micro-images by means of the NCR photochromic process.

For micro-image systems which have a need to store the PCMI master plate, an off-line refrigerated file is provided. For example, such systems might require periodic updating of portions of the original file. Therefore, it might be more economical to keep the original PCMI master plate and, when necessary, erase only those micro-images that need to be replaced, instead of preparing an entirely new PCMI master each time an updating is required.

Still another important system element used for producing micro-image cards is the off-line contact printer. Input for this unit is the photographic micro-image (PMI) master film prepared by the PCMI Camera-Recorder. High-resolution photographic film is used as the output medium of this unit. The off-line contact printer performs the important job of micro-image publishing mentioned earlier in the paper. This unit makes low-cost dissemination of micro-image cards possible.

Of all the system elements which might be required to use micro-image cards, the most important unit is the micro-image viewer or reader. It is expected that eventually there will exist a family of micro-image viewers from which to choose. Viewers might range from manually-operated, desk-top models to semi-automatic consoles. Choice will depend, of course, both upon the complexity of the specific micro-image system involved and the particular user's requirements or needs.

As with many microfilm systems in use today, there will also be a requirement for hard copy print-out of enlarged micro-images. This will be accomplished by combining both viewing and printing into a dual-purpose unit called a micro-image Viewer-Printer.

The final element needed to complete a micro-image system will be a file. As an example, if 3- x 5-inch cards have been chosen as the basic unit medium of the micro-image system, then, chances are, all that will be required is a simple, manual 3 x 5 card file cabinet. Consider the fact that a file of one million document pages could be stored in micro-image form (at 200:1 reduction) on less than 400 three by five cards. This represents a stack of cards about 4 inches high. For so few cards it would be very difficult to justify the expense of automatic retrieval equipment. Of course, each micro-image system application would have to be analyzed and system-engineered for its own specific requirements. Figure 3 summarizes the micro-image system elements that we have just described.

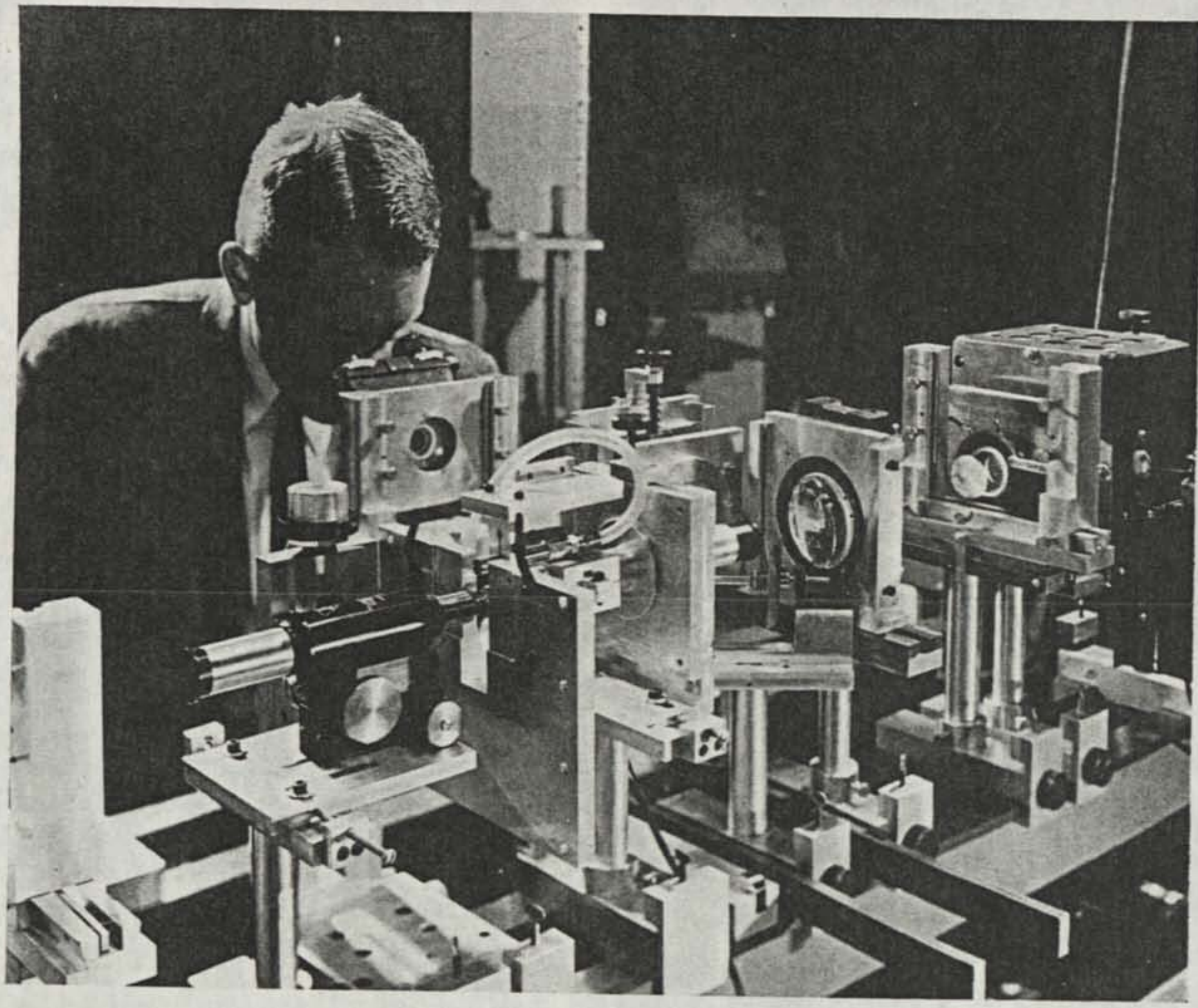

FIG. 2. Research Breadboard Model of PCMI Camera-Recorder.

From the previous discussion of the various system elements used to *produce* and *use* micro-images, it can readily be seen that a high degree of system flexibility is available to the potential user. Since each application will vary in the size of its file, the frequency of its activity, the retrieval complexity of its search questions, and the requirements for human-file interaction, there is no typical user.

A preliminary analysis indicates that only a relatively small percentage of potential micro-image users would need to acquire a PCMI Camera-Recorder. The great majority of users would probably find it much more economical to obtain at least their photographic micro-image master cards from a PCMI service center. It is not at all unreasonable to expect that today's dealer in high-quality, volume microfilming will become the micro-image supplier of the future.

Because PCMI storage and dissemination systems readily lend themselves to a modular approach, the potential user can exercise considerable freedom of choice in his system component selection. This provides the possibility of continuous equipment compatibility with micro-image system growth.

• Some Potential Applications of Micro-images

Except for the most trivial cases, almost any document storage, dissemination, or retrieval problem lends itself to potential mechanization by a micro-image system. An examination of the information retrieval (IR) field has led us to the conclusion that the original document, or its facsimile in the form of either microfilm or micro-image, will almost always be required.

Let us next consider a few potential applications for micro-images. First, we would like to look at the duplicating library concept proposed by Dr. Heilprin (7, 8) of the Council on Library Resources. Dr. Heilprin drew the following distinction between the present circulating library and the duplicating or "D" library of the future. In the circulating library, material is in conventional form, and normally it physically circulates in and out of the library. In a "D" library of the future, material would

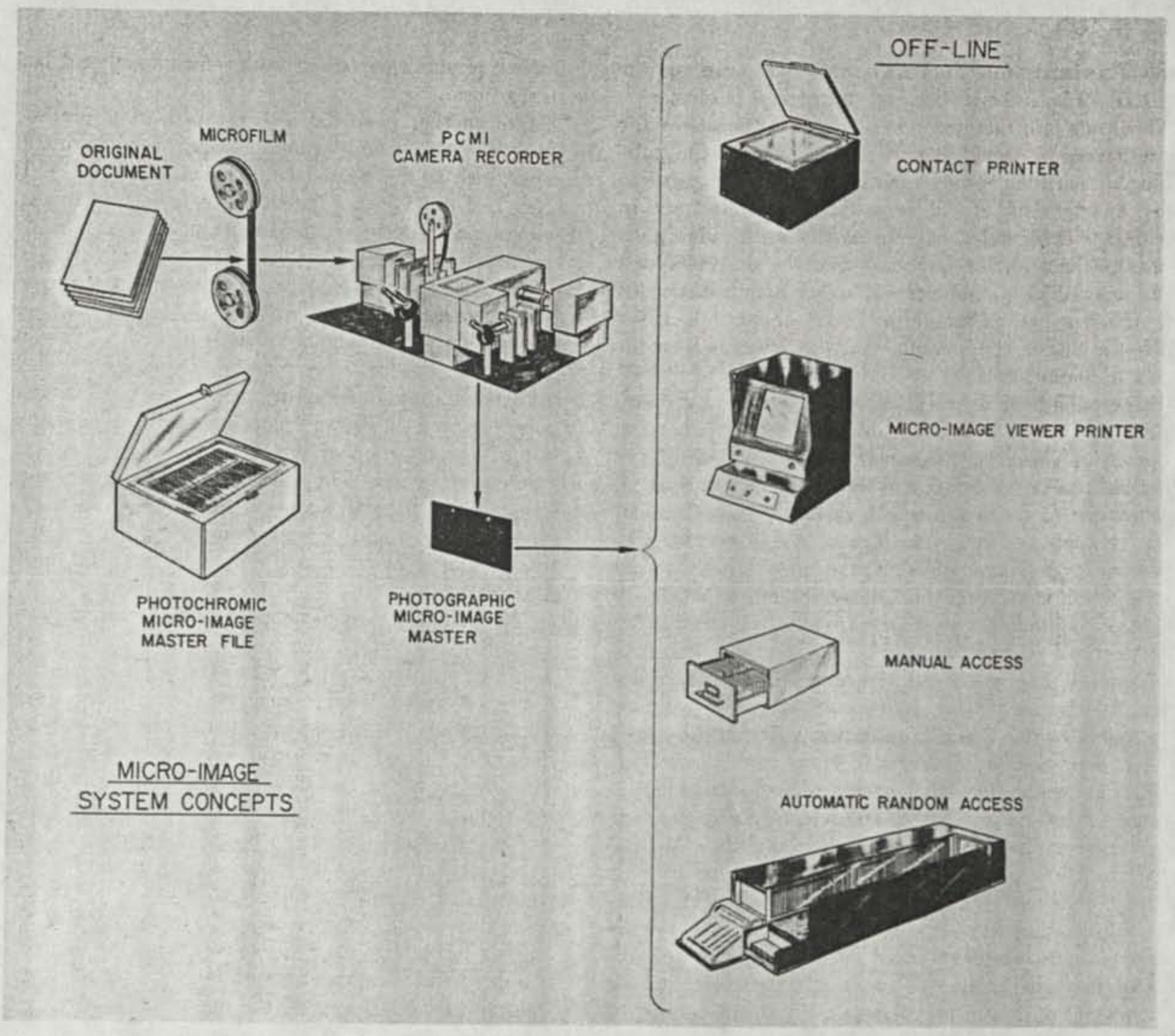

FIG. 3. Micro-image System Concepts.

be stored on "microform" masters. Dissemination of material would be one way, i.e., non-returnable. Duplicates of the "microform" masters would be expendable.

Very little imagination is required at this point to see the potential application of NCR's micro-image technology to Dr. Heilprin's "microforms" and the "D" library of the future. For example, the "D" library could be stored on 3 x 5 micro-image cards. At a 200:1 reduction ratio, each card could contain from eight to ten average-sized books. This represents approximately one square inch of micro-images per book. Anyone requesting a book could have it duplicated in micro-image form from the master micro-image card on file at the "D" library. It is expected that this could be accomplished on demand while the user waited. Further, full-size, hard copy print-out from the micro-image master could also be made available to the user if the need arose.

By using PCMI technology, every branch library would have the potential of maintaining as large a collection as the main library. Reservations would no longer be necessary for the more popular books. In a "D" library only one master copy of the original material would have to be stored, but this master copy would be in a form suitable for easy duplication. The master copy would never circulate or leave the library since user requests would be filled by duplicates which would be expendable.

Simple, potentially inexpensive *duplication at the micro-image level*, using contact printing techniques made possible by PCMI, offers an entirely new dimension to the high-density storage process. Dr. Heilprin calls this new dimension multiplication (8). Further, he states that "This degree of freedom has vast implication for the replenishment of lost and destroyed libraries in underdeveloped areas, and the interchange of collections of files" (8).

Perhaps the most serious problem remaining to be solved before the duplicating library can become a reality is not a technical one at all but the legal problem of copyright. This legal problem must be resolved on an equitable basis for both the author and the original publisher.

This leads into the next potential application area for micro-images we would like to review, namely, the publishing of scientific, professional, and academic publications. A significant, as well as pertinent, current trend in this field is *index publishing*. In parallel with index publishing is the need for publication of the document set being indexed as a microform. A recent manifestation of this trend is the publication of the Thomas Register Micro-Catalog in conjunction with the Thomas Register Index to manufacturers.

Index publishing is being actively sponsored by many professional societies. For example, in 1961 the American Institute of Chemical Engineers set up a standard for indexing articles of permanent value that appear in all publications of the Institute. Magazines in the chemical industry such as *Petroleum Refiner* and *Chemical Engineering Progress* are publishing the index terms for each article which is arranged for convenient reproduction by photocopying. Similar programs are also in operation by the American Society for Metals, the American Institute of Electrical Engineers, and the American Chemical Society. Another example of index publishing is a program sponsored by the Council on Library Resources called Project Law Search.

The importance of this current work in indexing is related to the fact that the information retrieval problem is a very complex one. For example, the ability to produce, store, and duplicate micro-images economically and reliably does not represent the complete answer. Adequate techniques for indexing and searching the micro-image file must also be worked out. However, as the examples just cited indicate, indexing techniques can be developed for document retrieval which are relatively independent of the document storage approach employed. In one sense, indexing and document storage are complementary problems.

Because of the enormous expansion of published material, increasing publishing costs, and rapidly rising library expenses for the storage and later use of this material, there is an increasing need for some type of microform publishing. One approach that might be considered would be to publish and disseminate a book or journal in micro-image form. One potential advantage of this approach to publishing is that it would provide publishers and authors with the economic freedom to publish greater amounts of information. A most interesting example of a current journal that is being successfully published in microform is *Wildlife Disease*. During the past few years this publication has increased its number of subscribers and has demonstrated the feasibility of microform publishing. Another significant point is that microform publishing has made possible a journal that previously could not be supported in a conventional printed form because of the very limited number of subscribers. It is entirely conceivable that in the future publishers will offer books and journals in both conventional and micro-image form.

Still another potential area of application for micro-images is on-demand printing. Today, various organizations, such as the National Library of Medicine, ASTIA, and the United States Patent Office, have to provide the means for handling a considerable amount of mail-order requests for documents. Copies of documents from very large collections have to be supplied within a relatively short period of time. Activity rate, defined as the number of pages retrieved per day divided by the total number of pages in the file, is very low, on the order of one-half of one per cent. It seems reasonable to expect that economic as well as storage space pressures will eventually force the conversion of present systems to some type of microform system. The kind of duplication, or re-creation, of the original document that would be used for dissemination would depend upon system factors such as the type of microform used for storage and the needs of the user.

NCR micro-image techniques, as discussed in this paper, offer some interesting possible solutions to this problem. One possibility would be to store the entire document collection on 3 x 5 micro-image master cards in a system configuration that would provide the amount of retrieval required. Further, if you will recall, it was pointed out that the ability of the PCMI process to easily duplicate micro-image cards by contact printing provides a new system freedom—that of document dissemination. Therefore, another possibility would be to consider the decentralizing of large document collections to various regional areas. Of course, detailed system studies would have to be made in each case to determine the relative advantages and disadvantages of decentralization over the centralized file. However, the important factor is that PCMI techniques permit the possibility of decentralizing large master document files. The economics of more conventional storage and dissemination techniques almost automatically preclude this possibility.

In 1945, Vannevar Bush presented the documentation field with the concept of Memex (9). He envisioned Memex as a possible future device comprising a sort of mechanized private file and library for individual use. Memex was to be a desk-type unit equipped with a viewing screen and a selection keyboard. It could store on film, at reductions of 100:1 or better, a tremendous volume of books, journals, newspapers, correspondence, notes, and photographs. In addition, the unit would have an indexing tool that would allow the user to locate the stored material.

The combination of NCR's micro-image techniques for document storage and interrogation units tied into a central computer to provide indexing capability comes close to achieving the original Memex concept. Theoretically, at least, it is now possible for every user to obtain every document in his field of interest in micro-image form so that it can be easily stored, retrieved, displayed for viewing, and reproduced in enlarged form as hard copy when desired.

• Summary and Conclusions

Before concluding this paper, we would like to review briefly the most important characteristics which make NCR's micro-image technology unique in its field:

1. Photochromic films provide very high resolution with no grain.
2. Photochromic films permit the storage of images containing a wide contrast of gray scale because they are inherently low gamma and grain-free.
3. Photochromic films provide immediate visibility of the image upon exposure. No development process is required.
4. Photochromic films provide both erasing and rewriting functions. This permits the powerful processes of editing, updating, inspection, and error correction to be incorporated into systems.
5. The PCMI process incorporates the ability to effect a bulk-transfer read-out of micro-images at the 200:1 reduction level by contact printing.
6. Use of high-resolution silver halide films provides both permanency for the storage of micro-images and economical dissemination of duplicates.
7. The very high density of 200:1 micro-images offers the possibility of using some form of "manual retrieval" techniques for many applications. This eliminates the normal requirement in systems of this size for expensive and complex random access hardware.

In conclusion, we would like to propose that NCR's micro-image technology offers the following new horizons to the microform business of tomorrow:

a. It offers many fascinating system possibilities to the infant storage and retrieval field.
b. It offers, among many other advantages, the powerful new system freedom of document dissemination and file decentralization to the libraries of the future.
c. It offers scientists, scholars, and professionals in all intellectual fields many advantages from new technologies such as microform publishing and perhaps even their own personalized form of Vannevar Bush's Memex.

• Acknowledgments

The authors gratefully acknowledge the many helpful discussions and criticisms of this paper by other staff members of NCR. In particular, they would like to thank Carl Carlson, Ty Abbott, Sam Lebow, and Henry Kent. The authors would also like to acknowledge the important role in this program of Lowell Schleicher and his staff at the NCR Fundamental Research Department in Dayton, Ohio. This group has supplied us with the photochromic coatings used in the PCMI process, and has also provided us on many occasions with valuable research back-up.

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May 1967

A NEW PUBLICATION METHOD

THE PCMI MICROFORM SYSTEM

pcmi

TRADEMARK

MAY 29 1967

NCR THE NATIONAL CASH REGISTER COMPANY • DAYTON, OHIO 45409
DATA PROCESSING • ACCOUNTING MACHINES • CASH REGISTERS • ADDING MACHINES • SERVICE • SUPPLIES

May 24, 1967

DAYTON, OHIO 45429
INDUSTRIAL PRODUCTS DIVISION
3100 Valleywood Drive
1167

Mr. Charles P. Bourne
Director, Advanced Information Systems Division
Programming Services, Inc.
493 Middlefield Road
Palo Alto, California 94301

Dear Mr. Bourne:

In response to your inquiry, I am enclosing some descriptive material which deals with the PCMI* Microform System in some detail. If after reviewing this material you have additional questions or if we may be of other assistance, please contact:

Mr. J. P. Roche
Account Manager
Microform Systems Sales
Industrial Products Division
2815 W. El Segundo Blvd.
Hawthorne, California 90250
(213) 777-7866

We thank you for your interest in the PCMI System.

Sincerely,

J. L. Glanville
J. L. Glanville
Assistant to the Marketing Manager
INDUSTRIAL PRODUCTS DIVISION

JLG:btt

Enclosures

*PCMI is a trademark of The National Cash Register Company.

THE NCR CLASS 455 PCMI® TRANSPARENCY READER UNIT

The new NCR Class 455 Reader has been developed to provide a low cost, high quality device for viewing information in micro image form. Fullest attention has been given to every detail of design and human engineering. The result is an outstanding product which is efficient in use and virtually maintenance free.

It may be operated by nearly anyone after a brief introduction to its simple access mechanism. A PCMI transparency containing up to 3200 images is inserted between a hinged pair of glass plates. The glass plates perform the dual function of 1) holding the transparency in a plane, and 2) acting as a heat sink to afford an extra measure of protection against heat damage. An almost effortless operator movement will allow the entire cover glass assembly to be moved in the x or y direction, singly or in combination, until the desired image has been positioned for viewing. Throughout this movement, the optical system has mechanically "tracked" the image plane so that only a touch of the fine adjustment ring may be required to bring the entire image into sharpest focus.

The illuminating source is an advanced design quartz-iodine cycle incandescent lamp. The life of this lamp contrasts favorably with conventional light sources and, because it is not subject to the usual internal blackening, its brightness is constant throughout.

The 11" by 11" coated screen is designed to assure image detail clarity and uniform brilliance. As an option, an adjustable cover assembly can be provided to shield the screen from ambient glare sources.

In consideration of the unique requirements for magnifying and projecting images above 100 power, a special lens system was designed exclusively for use in the Class 455. The design and construction specifications for the fine optical system are representative of the overall quality and precision inherent in this unit.

NCR

INDUSTRIAL PRODUCTS DIVISION

DAYTON • NEW YORK • WASHINGTON • LOS ANGELES • TOKYO

AMSTERDAM • FRANKFORT • LONDON • MILAN • STOCKHOLM • PARIS

SPECIFICATIONS:

Construction:	A quality optical mechanism integrated into a durable frame.
Size and Weight:	26" high, 16" wide, and 24" deep; Shipping weight - 48 pounds (approx.) Net Weight - 40 pounds
Viewing Screen:	
Size:	11" x 11" with 1-1/4" radiused corners with added visual facility for row/column indication.
Type:	Rear projection, translucent, diffused surface type for sharp high contrast, brilliant and clearly illuminated images.
Color:	White
Illumination Source:	150-watt, 21-volt long-life quartz-iodine cycle incandescent source. Gives high intensity, even illumination. A quiet and efficient cooling fan is in operation whenever light source is operating.
Focus Control:	Lens system "tracks" the image plane so that gross focus is always maintained. Fingertip controlled fine focus accomplished with conveniently placed knurled ring.
Optical System:	Choice of precision microscope type 115X or 150X specially designed, plano-optical system. Heat absorption glass protects film against heat damage.
PCMI Transparency Input:	Positive images for maximum clarity. Plastic laminated transparencies 105 mm. x 148.75 mm.
Access Mechanism:	Manually operated, inverted T arrangement allows transparency holder to glide smoothly on Teflon-coated bearings to any desired X-Y position. Simple, efficient and trouble-free direct access.
Electrical:	Single phase power source 47 to 63 cps at 90 to 127 volts 47 to 63 cps at 200 to 260 volts
Environment:	
Operating:	Between 32°F. and 115°F. Between 5% and 98% relative humidity
Non-Operating:	Between -40°F. and 180°F.

*PCMI is a trademark of The National Cash Register Company.

A NEW PUBLICATION METHOD
THE PCMI MICROFORM SYSTEM

Breakthrough! NCR introduces practical paperless publishing!

A microform system that lets you publish 3200 pages on a 4"x6" transparency, send it anywhere for a nickel, and read it full size when it gets there, again & again.

PCMI* MICROFORM SYSTEM

NCR announces a significant advance in the field of information storage and dissemination. The new PCMI Microform System should not be thought of as a kind of second generation microfilm; it would be more accurate to term it a new publishing technique.

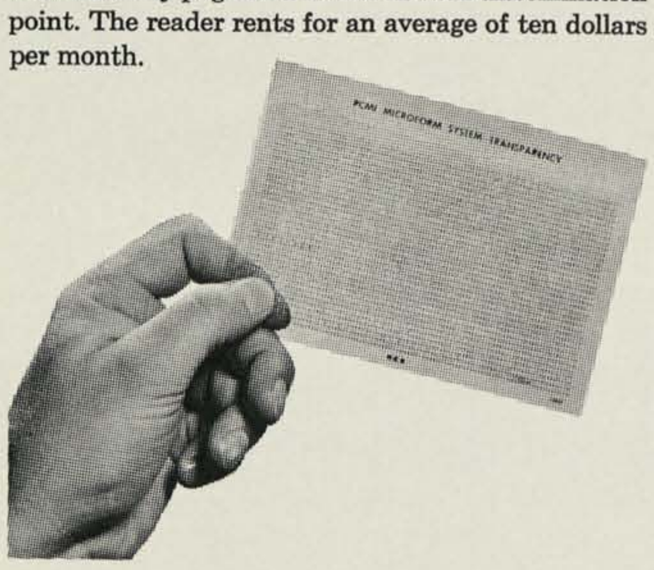
With PCMI you can:

1. Put up to 3200 8½" x 11" pages of data on a single 4" x 6" transparency.

2. Reproduce dissemination copies of that transparency for about a dollar each.

3. Mail this 4" x 6" transparency anywhere in the U.S. and Canada for a nickel. It is practically indestructible and cannot be counterfeited.

4. Read every page on a reader in each dissemination point. The reader rents for an average of ten dollars per month.



A PCMI transparency can contain up to 3200 8½" x 11" pages of copy, line and halftone art.

Who can use the PCMI Microform System?

Any company which has a lot of information which must be sent to a lot of places. Currently testing the technique are Ford Motor Company (parts catalog), The Boeing Company and National Airlines (727 maintenance manual), a number of educational societies, a legal reference firm and the Masel and Brucha Microform Corporation (which wants to disseminate classic Hebrew writings to scholars, libraries and—eventually—Jewish laymen).

How does the PCMI Microform System work?

The amazing science of photo-chromics permits the non-photographic reproduction of incredibly small images. The technique, unlike photography, is reversible, so mistakes can be corrected during the recording process. By visually checking each image as it appears, NCR can produce a flawless PCMI master. Then a photographic master negative is prepared, checked and duplicate positives made and laminated. A simple but optically sophisticated reader returns the images to the original (or preferred) size for easy reading.

How does this system compare with microfilm?

Microfilm is basically a storage technique; the PCMI Microform System is a publishing process since, in the main, it replaces printed documents. With microfilm you get an inexpensive first copy with copies almost as costly as the original. The PCMI master is more expensive but you can produce copies of a 3200 page document for about $1.00 each.

How long will the transparency last?

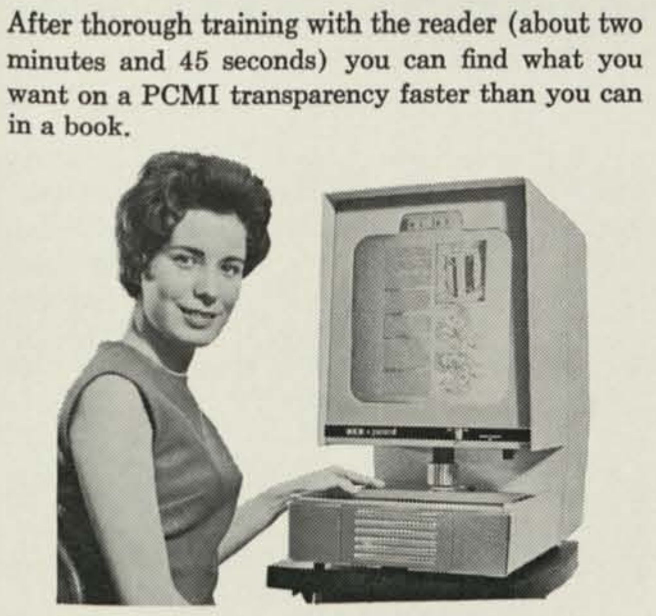
Indefinitely. The transparency is laminated front and back. Scratches on the laminates, even dirt and grease cannot obliterate the message. The laminate also protects you from having the entire microform reproduced by a competitor. Publishers will find this can protect their copyrighted material.

Can you make hard copies of individual pages?

Yes. Shortly after the shipment of our first production readers, NCR expects to announce a machine to produce hard copies of any page desired. For example, this will permit a mechanic to take a parts diagram to the car or plane for positive identification.

How quickly can you find information?

After thorough training with the reader (about two minutes and 45 seconds) you can find what you want on a PCMI transparency faster than you can in a book.



Many units are currently on field test and, even before public announcement, NCR has orders for more than 26,000 PCMI readers.

What about updating?

To update most conventionally printed catalogs, price sheets or manuals, only the revised pages are sent to dissemination points. This practice requires costly, time-consuming manual replacement of individual sheets. Because of the time involved, changes often are never made, resulting in expensive errors, potentially dangerous mistakes and lost orders. With the PCMI Microform Systems, the data is updated and a complete new transparency replaces the old, virtually eliminating the chances of error.

How can your company test the PCMI Microform System?

Write to NCR, Industrial Products Division, Dayton, Ohio 45429. Tell us the amount of information you have, and the number of copies you need. We will contact you as quickly as possible.

Let's dream a little

The possibilities are endless. Technical and scientific reference libraries are prime applications. Educational use of the PCMI system can be extended into the computer-aided instruction field. Extremely inexpensive home viewers are in the offing. The complete works of Shakespeare, the great recipes of the world, an unabridged dictionary would each fit a single transparency. An encyclopedia would take only eight. These and all the great books of the world can be stored in the corner of a desk drawer.

What's your idea? Revolutionize something!

**PCMI is a trade mark of the National Cash Register Company*

NCR®

THE NATIONAL CASH REGISTER COMPANY, DAYTON, OHIO

A NEW PUBLICATION METHOD - THE PCMI* MICROFORM SYSTEM

A new process which makes it possible to reproduce in excess of 3200 8-1/2" x 11" pages on one small transparency has been developed by The National Cash Register Company. In addition, any desired number of dissemination copies can then be read on specially designed reader units.

NCR believes that this process, the PCMI Microform System, is an answer to the problem of storing and disseminating the enormous quantity of books, pamphlets, reports and documents being produced today.

A new type of film is used in NCR's PCMI process. It consists of a molecular dispersion of photochromic (light-sensitive) dye on a suitable substrate. Normally transparent, the molecules of photochromic dye become opaque when exposed to ultraviolet light. If an image is projected on the photochromic film, it is immediately visible, without a development process.

Unlike conventional photographic film, photochromic films are completely grain-free, and are capable of very high resolution. They will retain images with resolution greater than 1000 lines per millimeter.

At the reduction ratios achieved, the equivalent of eight average books can easily be recorded on one 105mm x 148mm piece of film. This means that a file of 1,000,000 book pages can be contained in a stack of film cards less than six inches high. A library of 60,000 volumes could be stored in one drawer of a file cabinet.

The light sensitive reaction of NCR photochromic dyes is reversible. After being changed to an opaque state by exposure with ultraviolet light, the molecules of photochromic dyes will revert to their normal transparent state upon the application of heat or visible light. Thus, if a defect occurs in forming a micro-image, the image can be erased and corrected.

* PCMI is a trademark of The National Cash Register Company.

process to reproduce tones and thus handle photographs allows creation of micro-images from a wide range of input documents.

Figure 1 depicts the significant steps in the process of creating PCMI microforms. A two-step reduction technique is employed; it begins with the creation of high quality microfilm. At present 35mm sprocketed microfilm is used at a reduction ratio which is most compatible with the input document size, the nature of the data recorded on the document, and the physical limitations of the microfilm itself. For 8-1/2" x 11" documents which contain no printed characters smaller than 10 point size, a reduction of about 12:1 is quite satisfactory. Quality control, a critical consideration throughout the process, begins here since it is obvious that maximum detail and clarity must characterize the microfilm if the ultimate micro-image is to be acceptable. The microfilm is processed and inspected for defective images, water marks, and the like, and retakes are made as necessary. The retakes are spliced into position, replacing the original defective images, and a single input reel is created. This input reel contains the two to three thousand frames required to fill a PCMI master plate.

The second reduction step is accomplished by means of a device known as a Camera-Recorder. Within this device is a glass plate coated with photochromic material. The reel of microfilm is mounted on the Camera-Recorder and near ultraviolet light is passed through each frame. The image from each frame is further reduced either 10 or 20 times and the resulting micro-image is focused on the photochromic master plate. For each image, the Camera-Recorder also projects an appropriate row-column number to facilitate indexing. Automatic mechanisms position the photochromic coated glass plate and advance the microfilm on a step and repeat basis until the entire micro-image matrix has been created on the plate. A binocular microscope, integrated into the Camera-Recorder, permits the operator to inspect the micro-images, either as they are being formed or after the plate has been completed. The entire Camera-Recorder operation for a 2,000-image matrix requires about two hours.

Owing to the nature of the photochromic material, the micro-images are only semi-permanent in nature. Therefore, to provide permanent master or "printing" plates, several high resolution photographic masters are contact printed from the photochromic master plate. These photographic master plates are processed and inspected. They are then utilized in automatic contact printers which produce the desired number of dissemination copies. The rolled output is processed and a protective laminate is applied. The film is cut to standard dimensions (105 x 148mm), inspected and prepared for customer shipment.

Although the primary purpose of the laminate is to protect the photographic emulsion from involuntary damage (e.g., dirt, scratches, harmful atmospheric elements, etc.), several other benefits accrue from it. The resulting transparency is quite rugged and requires no additional mounting or frame to facilitate handling or file manipulation. Further, dirt, fingerprints, and scratches on the surface of the laminate are beyond the extremely short depth of focus which characterizes high magnification systems. Such surface defects do not, therefore, adversely affect the projected micro-image to any significant degree.

Copy Protection

The dissemination copies combine the archival properties of high quality silver halide images with the physical protection of plastic laminate. Perhaps more important when considering PCMI as a publication medium, the laminate on each dissemination copy positively precludes contact printing of any additional microform copies. Individual pages may be duplicated, one at a time, as with any other publishing medium. But to do so beyond a few pages would not be competitive with the cost of obtaining an entire transparency from the publisher. This positive control over unauthorized and illegal duplication affords ample protection to the publisher.

Results

Although resolution is by no means the sole determinant of image quality, it does provide a convenient means for objective evaluation.

For microfilm input, NCR has specified 120 lines per millimeter as minimum if high quality micro-images are to result. Owing chiefly to optical limitations within the Camera-Recorder and to two subsequent generations of contact printing, dissemination copies typically afford resolution of 650 to 750 lines per millimeter. Using these figures, a PCMI microform at 150x reduction provides image quality comparable to high quality microfilm at 30:1.

Cost

Of the many attributes which make the PCMI system an attractive micro publishing media, perhaps the most relevant and certainly the most practical is cost. As might be assumed for the detailed and highly critical nature of the process involved, the cost of creating the photographic master printing plate is appreciable. The exact price depends upon the number of master plates required and upon the number of images per master plate. The price of each dissemination copy is constant regardless of the number of images thereon.

The economic advantage of the PCMI system exists where there is a requirement for a large number of copies. The cost of preparing the master plate may then be prorated over the number of copies and the per copy cost approaches one dollar as a lower limit. Figured on a cost per image basis, the cost is usually 1/20th of a cent or less per page.

Reading Equipment

Reductions well beyond 250:1 (62,500 times area reduction) are practical to attain with PCMI. However, information on microfilm has little practical value if suitable reader equipment is not available. Some of the factors considered when designing PCMI reader equipment were:

1. Optical magnification desired
2. Screen brightness
3. Screen size
4. Image quality
5. Lamp life
6. Reader unit cost

The combination of these parameters which NCR feels will fulfill the requirements common to most users were built into low-cost readers. One of these has a fixed magnification of 115 times. This allows storage of over 2,000 micro-images on a single transparency (assuming documents which are 8-1/2" x 11" and a full-size image of the original on the screen). The open aperture screen brightness on this model is in excess of 60 foot-lamberts when measured axially at a distance of 15 inches from the screen. The screen size is 11" square to accommodate an 8-1/2" x 11" image oriented either vertically or horizontally. A low monthly rental cost of the 115x has been established, depending upon the rental period and upon whether or not full service coverage is included. NCR feels that this combination of performance versus price will find broad acceptance in application areas where wide dissemination of volume data is required.

Another reader features 150x magnification which allows more than 3200 images per transparency.

We are aggressively continuing our research efforts to enable us to find a satisfactory combination of such factors as screen brightness, lamp life and image quality to enable us to provide readers with magnifications well beyond our current capabilities.

As A Publishing Media

What are the principal implications of the PCMI Microform System as a publishing media? They fall into two general classes of publishing, in-house and commercial.

By in-house is meant the publication of material for internal use by any large organization which does business on a widely decentralized basis. In addition to utilizing the PCMI system as previously described, i.e., hard copy to microfilm to PCMI, recent developments in computer technology give rise to some fascinating new systems possibilities.

Consider the information handling pattern which came about during the early years of electronic data processing. Information from field business locations was delivered to a centralized EDP installation where it was sorted, manipulated and combined to produce important new reports. Suddenly there was more information in a more useful form than had ever been available prior to EDP. These reports were produced and disseminated, but only on a limited basis, due to the time and cost of producing multiple copies. Indeed the output of this information by means of high speed line printers sometimes took longer than did its creation. Even the best line printer currently available is limited to under 10 legible copies produced from a single printing operation. Dissemination copies produced in this fashion must be decollated and possibly bursted and bound.

It has become evident to business management that although there is more information available within their EDP installations, the maximum benefit can be derived only when this information is made available to the field locations where it can be acted upon. EDP equipment manufacturers responded to this need with a dazzling array of data communication networks, on-line systems, and the like. But the cost to disseminate vast quantities of information to a large number of field locations by such a system is often staggering. Besides, the speed afforded by these systems is not always required.

Several years ago, a significant development occurred in the area of computer output. Devices became available which could, at the rate of thousands of characters per second, accept information from either a computer or from magnetic tape, display this data on a cathode ray tube, and trigger a microfilm camera to record the CRT display. The microfilm could then be used as 1) the dissemination copy itself, 2) a master copy from which dissemination microfilm copies could be contact printed, or 3) input to a device which would produce the required hard copy for distributional purposes.

The PCMI system adds an important alternative in this connection. Computer-generated microfilm can be produced which is suitable for input to the PCMI process. PCMI microforms thus provide a most economical vehicle for transmitting this information to decentralized locations.

User Acceptance

With regard to commercial publishing, some significant points relative to economic feasibility, protection against unauthorized duplication, etc., have been previously discussed. What about user acceptance? Here the question is not whether the user will accept microforms as readily as books, but, rather whether the user will resist this change to the extent of making its implementation impossible.

Certainly a great missionary effort is involved in attempting to bring about so dramatic a change in form as from books to PCMI microform. But there is ample reason and cause to attempt it. The so called "information explosion" is much publicized and widely lamented by frustrated researchers, managers, educators, librarians, and other professional people. The situation is compounded by a second "explosion" represented by our burgeoning population. Volumes of statistics have been cited which indicate that these problems are critical today and are certain to get progressively worse. Recently enacted federal legislation recognizes the problem as both national and international in scope. Microphotographic storage such as the PCMI system has the following strong economic and logical reasons for its inclusion in any proposed solution:

1. Conversion of existing literature would be simplest and most economical.
2. Information stored in this form could be indexed with equal facility by nearly all present indexing systems.
3. Maximum storage density is achieved.
4. Graphic, photographic, and alphanumeric information may be stored with equal ease.
5. The mechanics of retrieval are greatly simplified by having data in such compact form.

Additionally, the PCMI Microform System alone offers the following unique combination of capabilities:

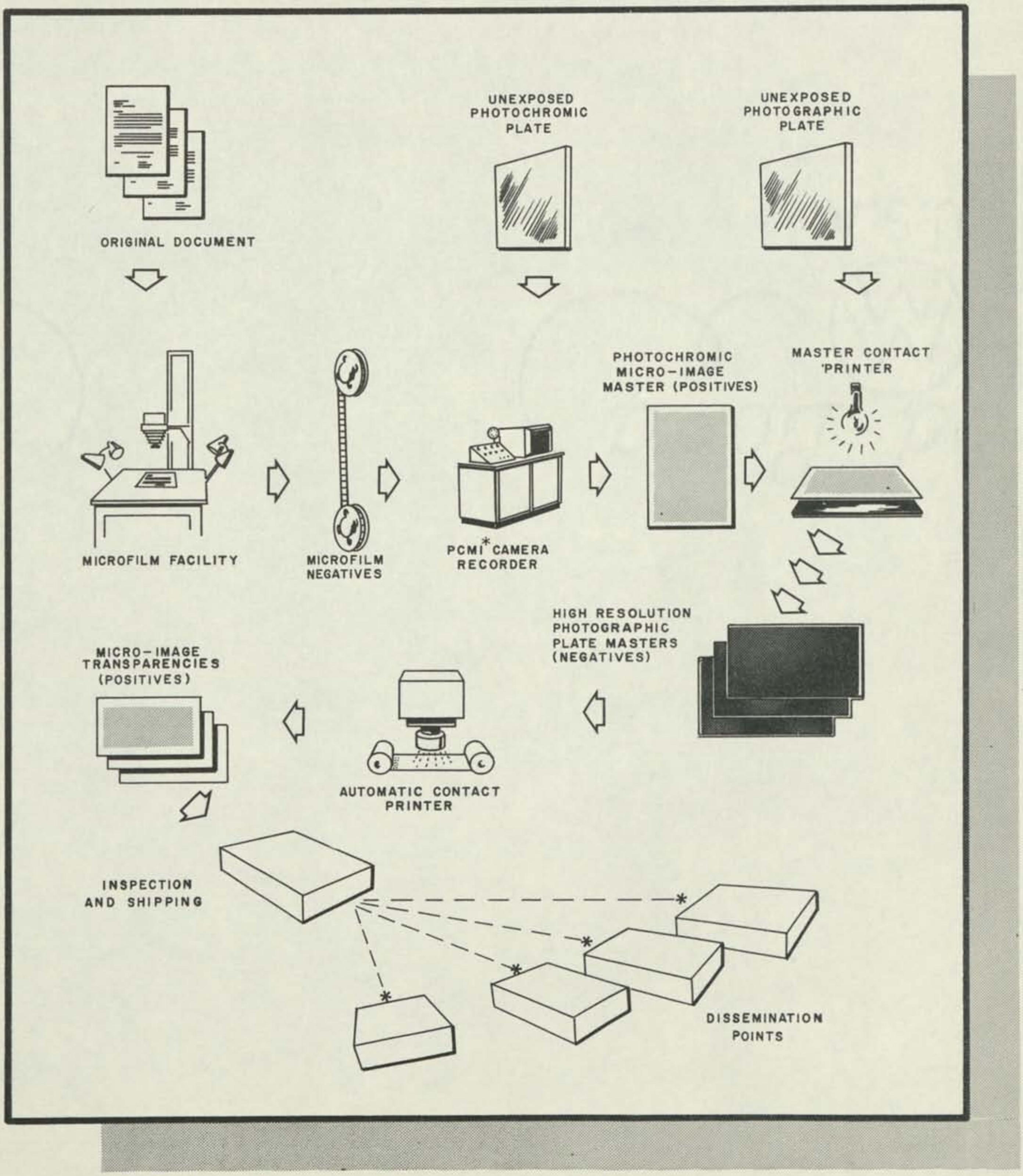
1. NCR photochromic films provide very high resolution capability.
2. Images created using photochromic film are immediately visible upon exposure.

3. Images created using photochromic materials may be erased and rewritten, thus providing a facility for updating, editing, and error correction.
4. A wide range of alphanumeric, graphic, and photographic documents can be effectively stored.
5. The PCMI process provides permanent silver halide dissemination copies on an economical mass production basis.
6. The very high storage density intrinsically reduces the problems of data access and manipulation.

The PCMI Microform System will make a significant contribution to the task of making more information more readily available to more people. This, after all, is the basic function of publishing.

FIGURE 1

NCR MICROFORM PROCESSING CENTER



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THE NATIONAL CASH REGISTER COMPANY

ELECTRONICS DIVISION

The young lady above is holding a film chip containing an entire copy of the Bible. On this 2 inch by 2 inch frame are stored 1245 pages of text. The 2000 copies shown in the picture represent a document collection of 2,500,000 pages. This display dramatizes the storage and dissemination capabilities of NCR's new photochromic micro-Image technology.

INVITATION

The National Cash Register Company has developed a photochromic micro-image (PCMI) process that provides, for the first time, the practical means for the recording and dissemination of a plurality of micro-images with very high packing density. PCMI concepts and technology will be demonstrated in the NCR suite at the Benjamin Franklin Hotel in Philadelphia during the 1964 National Microfilm Association Convention, April 28, 29 and 30.

You are invited to stop in and see a PCMI demonstration and to consider this technology for possible application to your micro-image system needs. Some of the potential application areas for PCMI techniques are information storage, retrieval and dissemination, microform publishing, on-demand printing, and specialized library uses.

Further inquiry may be directed to The National Cash Register Company, Electronics Division, Edmund F. Klein, Manager, Military Department, 2815 W. El Segundo Boulevard, Hawthorne, California, area code 213, 757–5111.

April 17, 1964

Photo-Chromic Micro Image

A NEW TECHNIQUE FOR DATA RECORDING AND DATA DISSEMINATION

NCR

WILBUR C. MYERS
DIRECTOR OF RESEARCH

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TELEPHONE 757-5111

NCR THE NATIONAL CASH REGISTER COMPANY, ELECTRONICS DIVISION

PHOTOCHROMIC MICRO-IMAGE

A NEW TECHNIQUE FOR DATA RECORDING AND DATA DISSEMINATION

by

Wilbur C. Myers

Presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) and Society of Information Display (SID) joint workshop on "New Technologies in Data Recording and Data Display" in Los Angeles, California 1, 2 June 1964.

To receive additional copies of this technical paper, direct requests to the Technical Publications Department, Electronics Division, The National Cash Register Company, 2815 W. El Segundo Blvd., Hawthorne, California.

Technical Publications No. 2596

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ABSTRACT

Development of the photochromic micro-image (PCMI) process by The National Cash Register Company provides, for the first time, the practical means for the recording and dissemination in quantity of a plurality of micro-images with very-high packing density. Linear reductions from 100-to-1 to greater than 200-to-1 (representing area reductions from 10,000-to-1 to greater than 40,000-to-1) have been successfully demonstrated by using a variety of image formats, such as printed materials, photographs, drawings, and fingerprints. Key factors in the success of the PCMI process are the following capabilities: a) inspection and error-correction at the micro-image level; b) high-resolution contact printing of micro-images on a mass production basis; and c) simple, effective retrieval and utilization of micro-images by means of specially designed viewers.

A basic PCMI system, consisting of a camera-recorder, automatic contact printer, and a micro-image viewer, has been completed and is operational. Development studies are underway with this equipment to accumulate data for system application studies. Some of the potential application areas for PCMI techniques are information storage, retrieval and dissemination, microform publishing, and specialized library uses.

INTRODUCTION

For several years The National Cash Register Company has conducted research and development in advanced microdocument technology. This has resulted in the development of the photochromic micro-image (PCMI) process[1,2,3] which provides the means for the first time of practically achieving the storage, publication, and dissemination of a plurality of micro-images with very high packing density. Linear reductions from 100-to-1 to greater than 200-to-1, representing area reductions from 10,000-to-1 to greater than 40,000-to-1, have been successfully demonstrated by using a variety of image formats, such as printed materials, photographs, drawings, and fingerprints. Prototype equipment has been completed which demonstrates how these very high-density micro-images can be mass produced economically, i.e., published, for easy dissemination, and subsequently retrieved and utilized by means of a micro-image viewer.

To illustrate the PCMI capability, a complete 1245-page Holy Bible[4,5] was prepared in micro-image form upon a single film substrate. The linear reduction ratio used was 220-to-1, representing an area reduction of 48,400-to-1. The area of the micro-image Bible text was 1.95 square inches. Figure 1 shows a set of 2000 micro-image Bibles prepared by contact printing from the same photographic micro-image (PMI) master plate. This represents a publishing operation of 2.5 million pages.

2596-1

Figure 1. The Holy Bible in Micro-image Form

HISTORICAL BACKGROUND OF MICRO-IMAGES

The origin of micro-images generated by means of microphotographic techniques dates back to 1839, the same year that the first two successful photographic processes were announced to the world[8]. Two men dominate the first few decades of microphotography. John Benjamin Dancer, the English scientist, inventor, and optical manufacturer deserves the credit for making the first microphotograph in the autumn of 1839. For this purpose, Dancer used the newly invented daguerreotype photographic process. He was also responsible for carrying on many of the experiments which ultimately resulted in making microfilm a practical medium for reproducing and storing printed and pictorial documents. The responsibility for establishing microfilm on a commercial scale belongs to the French chemist, inventor, and portrait photographer, Rene Dragon.

Dr. G. W. W. Stevens[7], a world authority on microphotography, suggests several logical reasons for the slow adaptation of microphotography to practical problems. First, the work of Dancer and Dragon demonstrated the potential of micro-images produced by photographic techniques, rather than the immediate practicality of the new process. Second, general and extensive use of a process requires that economical and reliable methods must be developed for producing large numbers of micro-images. Third, it has only been within the past three decades that technology began to provide such important related items as transparent and flexible film bases, better emulsions, and appropriate illuminants for micro-document viewers.

This thesis is very much supported by Hawkins'[6c] review of the subject. In fact, Hawkins says that 1936 was the turning point in the acceptance of microcopying as a practical library technique.

Stevens[7], as well as many others, further points out that only within the last generation has the need for microform documents become really pressing. Today this need has become urgent! Webster[8] defines "document" as "an original or official paper relied upon as the basis, proof, or support of anything else; in its broadest sense including any writing, book, or other instrument conveying information". Documents no longer exist today in just one form, but in two – the original or facsimile thereof, and/or a micro-image of the original. As a matter of fact, micro-image processes and systems, together with electronic data processing (EDP) systems, encompass virtually the entire field of information handling. The striking anomaly in this comparison of micro-image systems with EDP is that EDP applications, hardware, and systems far outstrip those of micro-images, in spite of the fact that EDP is commercially less than 15 years old! Evidence is rapidly accumulating, however, that this gap between micro-image and EDP in applications and system sophistication is beginning to narrow. Today, micro-images in a wide variety of forms are widely used not merely for their dead record preservation function but as a highly active intermediate process in numerous live applications as well.

It is probable that the single most important impetus to the trend of live micro-image systems was the approval and subsequent publication in 1960 by the Department of Defense of a group of specifications covering a DOD engineering data microreproduction system. Four of these documents[9] were directly related to 35 millimeter microfilm and aperture cards. In late 1962, these specifications were revised[10] and now serve as a very important standard for the entire microfilm industry.

Prior to this action by the Department of Defense, there had been an appalling lack of standardization as well as variation in uniformity and quality in the microfilm industry as a whole. Since then, other steps towards standardization are being taken in the industry. One of the most recent and important standardization moves concerns the publication[11] in 1963 of a microfiche standard specification for documents 8.5 by 11 inches and smaller.

Microfiche, which are sheets of film containing sequences of micro-images usually with a caption legible to the unaided eye, are not new. They have been in use in a variety of formats for many years. In Europe, microfiche are widely used for scholarly books and for similar library purposes. The technique was not applied in the United States to anywhere near the same extent until very recently. It was then discovered that microfiche offered a potentially practical solution to the increasingly important and complex problem of publishing and disseminating scientific and technical documents. This requirement is strongest within the government, and the need is literally for millions of micro-images.

The increasing attention to and awareness of standards by the microfilm industry is a healthy and optimistic sign that it may well be on the threshold of spectacular growth. Another indication in this direction is the rapidity with which the micro-image field is changing with respect to new techniques, processes, hardware, and systems. Much work, however, remains to be done, particularly in the systems area, before micro-image technology begins to deliver more than a small fraction of the potential predicted for it over 100 years ago.

REQUIREMENTS FOR THE MASS PRODUCTION OF MICRO-IMAGES

Systems utilizing micro-images in the range of 25-to-1 reduction ratio are commercially available for a rapdily growing variety of records management and library-type applications. Both production and office-type micro-image equipment, such as cameras, contact printers, viewers, viewer-printers, and allied devices, have been in general use long enough for adequate economic data to be available to anyone who must make decisions for setting up and operating such a system. However, practical limitations of normal photographic technology (also including non-silver halide, non-reversible image-forming processes) have discouraged the development of devices capable of producing and using large quantities of micro-images much greater than 25-to-1 reduction ratio[12].

To understand why this has been the case, it will be instructive to examine the general requirements for mass producing micro-images[16-21]. Any process for this purpose implies laying down multiple images on a common surface and exposing them individually by some form of step-and-repeat technique. The process will also involve a detailed consideration and careful control of most, if not all, of the following factors.

- Nature of the input document.
- Final image quality required.
- Reduction ratio employed.
- Exposure conditions.
- Film processing.
- Contact printing and number of generations involved when multiple copies are needed.
- Inspection and quality control procedures used throughout the process.

A much more intangible factor, but perhaps one that is most important to the end results achieved, is related to the actual people responsible for doing the work. Satisfactory end results depend upon a strict fidelity to specified process conditions. Each of the previously listed factors will now be examined briefly (for a more detailed treatment, refer to References 16 through 21).

NATURE OF THE INPUT DOCUMENT. The degree of ease or difficulty in producing usable micro-images is enormously affected by the properties of the original documents to be copied. The number of different kinds of documents that a system has to handle is also very important. Typical examples of input material might be printing, photographs, handwriting, maps, and line drawings.

IMAGE QUALITY REQUIRED. Process tolerances will of necessity be influenced by the fidelity to which the micro-images are required to reproduce the original upon blow-back (i.e., viewing). Any photographic-copying process must cause a finite amount of image degradation with each successive generation of copying. The degree of loss might range from barely detectable with a microscope to complete illegibility. Contrast level used in the process is also important for working tolerances. There is an understandable tendency for the micro-image user to judge results by the appearance of the final blow-back without making proper allowance for the properties of the original document. In practice, best results are obtained by adjusting until the darkest black of any one document is recorded as not quite black, while the whitest background is recorded as light grey. Such copies will then record the entire tonal range of all the documents to be copied without an appreciable loss in legibility.

REDUCTION RATIO EMPLOYED. Various practical factors limit the degree of reduction that can be effectively used. With high reduction ratios, imperfections in the film materials become increasingly important, although modern manufacturing methods and associated rigid quality control measures have effected a very marked quality improvement in commercially available high-resolution films. More serious is that the smaller the micro-images become, the greater will be the number of images normally recorded on a single substrate, and the greater will be the cost if even one image on a substrate is defective. Equipment for producing and using high-reduction ratio micro-images also demands higher precision. Verry[22] states that micro-image system designers should remember that the user normally reads microfilm by necessity instead of by choice, and is not interested in technical achievement per se. Therefore, the user judges the value of micro-images by his ability to read them without strain. Added to this, of course, must be the economic and system trade-offs involved as reduction ratios become higher and higher. To paraphrase Stevens[23]: A micro-image process should be operated with the largest-sized images consistent with the system design requirements of the user.

EXPOSURE. A critical stage in the micro-image production process is the exposure of negatives[21]. This is intimately related to image quality and can be essentially thought of as two problems, namely, the copying of documents with varying contrast or brightness range, and those with varying line widths. As previously stated under image quality, small changes in exposure conditions produce disproportionately greater changes in the negative because of the typical microfilm high contrast characteristics of the emulsion. In essence, for a positive, underexposure gives a reduced line width whereas overexposure causes a broadening of the lines and a coarsening of the image.

FILM PROCESSING. Once a satisfactory set of film processing conditions have been found for the particular micro-image variables involved, the principal problem becomes one of deciding whether manual or automatic processing will be used. While this is partially an economic determination, it is highly preferable, from an engineering viewpoint, to utilize continuous-processing equipment wherever possible because strict attention to details is mandatory. Exacting controls must be placed upon the time, temperature, cleanliness, and the integrity of all solutions and materials used in each step of the process, and this is more readily accomplished on a production basis by using automatic equipment.

CONTACT PRINTING AND NUMBER OF COPY GENERATIONS. Attention is directed at this point to the entire emphasis placed in the preceding sections upon the mass-production methods which are essential for economically producing very large numbers of micro-images. These processes must operate under such conditions that the probability of any image proving unsatisfactory is very small. It is not particularly difficult to make excellent micro-images with much smaller dimensions than those normally used for commercial purposes, and, from time to time, it has been variously suggested that greater reduction ratios should be employed. However, to the best of the author's knowledge, contact printing to film on a mass-production basis of large quantities of high-reduction ratio micro-images on a single substrate has been neither reported in the literature nor demonstrated in fact prior to the development of the PCMI process by NCR[24].

INSPECTION AND QUALITY CONTROL PROCEDURES. From the preceding discussion, it should be apparent that the technical approach to producing high-reduction ratio micro-images on a production basis needs to be quite different from that used for normal commercial microfilming. The micro-image process should be organized for effective image inspection as well as for maximum use of modern quality control techniques. It is not only interesting but highly significant that the necessity for inspection of microscopic images has been repeatedly described in the literature as far back as 1865[25]. This requirement derives from the relatively high probability of error occurring at some point in the micro-image process. An error might be, for example, an improperly focused image, or an imperfect input image. It might also result from dirt in the optical system or from dirt on the film. In most cases, Ives[26] found it to be one form or another of human error. When non-reversible image forming techniques are used, the heart of the inspection problem results from the fact that there exists no known inspection procedure to detect errors before final development takes place. Thus, error-correction of one or more imperfect images requires re-recording of the entire matrix of images. Experience has shown[26] that the higher the reduction ratio used, the more acute the error problem becomes.

One of the major attributes of the PCMI process is that it not only permits inspection to occur at any step in the production of the photochromic micro-image master matrix, it also gives the operator error-correction capability. Therefore, by using the PCMI process, it is now practical to produce master matrices of micro-images at reduction ratios ranging from 100-to-1 to 200-to-1 that contain usable images numbering in the thousands. In addition, new techniques for contact printing with these master matrices of micro-images have been developed which allow the future dissemination of micro-images to be considered on an unprecedented scale.

PHOTOCHROMICS AND THE PCMI PROCESS

What is the PCMI process, and how does it permit such a large jump in the effectiveness of micro-image storage and dissemination above that available with more conventional technologies?

First, let us take a brief look at photochromic materials[27]. By definition[28], photochromic compounds exhibit reversible spectral absorption effects (i.e., color changes) resulting from exposure to radiant energy in the visible, or near visible, portions of the spectrum. For example, one class of photochromic materials consists of light-sensitive organic dyes[29]. NCR photochromic coatings consists of a molecular dispersion of these dyes in a suitable coating material. Photochromic coatings are similar to photographic emulsions in appearance and in certain other properties. They can be made to retain two-dimensional patterns or images which are optically transferred to their surface. They can be coated on the same type of substrates as photographic emulsions, and they can exhibit excellent resolution capabilities. In addition, both positive-to-negative and direct-positive transfers are possible.

Photochromic coatings differ, however, from photographic silver-halide emulsions in a number of important respects. The coatings are completely grain-free, have low gamma (excellent gray scale characteristics), and exhibit inherently high resolution. Figure 2-A shows a photograph reproduced from a 35-millimeter negative film. Figure 2-B shows the same photograph reproduced from a photochromic reduction of the 35-millimeter negative to an image with a dimension of 0.06 inch. The image becomes immediately visible upon exposure and no development process is required. Further, because the coatings are reversible, the information stored can be optically erased and rewritten repeatedly.

A. 35MM REPRODUCTION FROM FILM

B. REPRODUCTION FROM 1½MM PHOTOCHROMIC MICRO–IMAGE

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Figure 2. Micro-image Reproductions

The image appears when the individual molecules are switched from either the colored or the colorless state by radiation (light) of the proper wavelength. All of the NCR coatings now in use switch to the colored state when near-ultraviolet radiation is used. Switching to the colorless state can be accomplished by using either heat or visible light of the proper wavelength.

Information stored on photochromic coatings is semi-permanent, in contrast to developed photographic film which is relatively permanent. This is a result of the reversible nature of the photochromic coating. The life of the photochromic micro-image is dependent upon the ambient temperature of the coating. At room temperature, image life is measured in hours, but as the temperature is lowered, life can be extended very rapidly to months, and even years.

The temperature-dependent decay of image life obviously prohibits the use of photochromic micro-images in their original form for archival storage. To overcome this problem, means have been developed for contact printing the photochromic micro-images to high-resolution photographic emulsions in order to obtain permanent micro-images.

In principle, the PCMI process is performed by the following series of operations. The original (input) document is first transferred to good-quality microfilm [30] at a reduction ratio of approximately 10-to-1. Properly filtered, near-ultraviolet radiation is then directed through the transparent microfilm and into the micro-image optics. This optical train effects a second reduction of the image resulting in the desired reduction ratio and also focuses the micro-image upon a photochromic coating. The micro-image thus formed becomes immediately visible and is available for inspection. If a defective micro-image is found upon inspection, the cause of the error is located and corrected.

The defective micro-image is erased from the photochromic plate by properly filtered light containing an erasing waveband. The correct micro-image is re-recorded in the same location by repeating the writing sequence of operations and inspection is performed again. This sequence of operations is performed in a step-and-repeat manner until the entire matrix of photochromic micro-images is complete and without visible errors.

The entire contents of the photochromic micro-image plate are then transferred (as micro-images) in one step by contact printing onto a high resolution photographic plate. The photographic plate is next developed under highly controlled conditions resulting in a photographic micro-image (PMI) master plate. Micro-image dissemination (duplicate) films are prepared in a similar manner using the PMI master plate to contact print onto high-resolution photographic film.

A more detailed discussion of the techniques and equipment required to produce high-reduction ratio micro-images using the PCMI process is discussed in the following paragraphs.

THE BASIC PCMI SYSTEM

PCMI system elements can be classified into two essential groups. One group consists of the hardware and materials required to produce micro-images, whereas the other group contains the items necessary to use micro-images. The basic PCMI system is illustrated in Figure 3, and represents the minimum number of elements required to produce and use micro-images. Since PCMI systems differ from one another principally in their use of micro-images, the following discussion will be limited to the basic PCMI system shown in Figure 3. Later portions of the paper will explain how this basic system can be easily expanded to meet a wide variety of micro-image system applications and requirements.

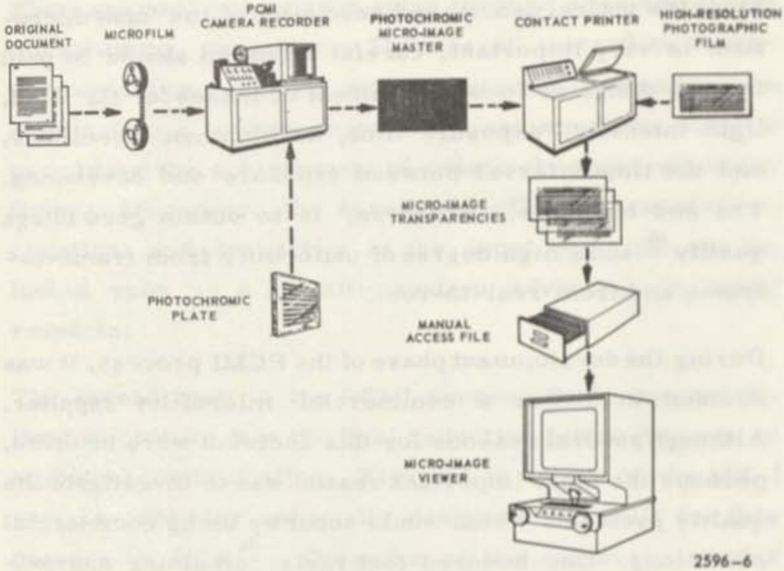

Figure 3. Basic PCMI System

The first step in the PCMI process is to convert the original documents to standard 35-millimeter (sprocketed) microfilm. This microfilm, typically a 10-to-1 reduction, becomes the input to the camera-recorder. Because of the many considerations cited earlier, the properties of the input microfilm are very important and require close control and inspection before use in the camera-recorder. If this is not done, not only will the image quality of the system micro-images suffer, but the microfilming step can quickly become the major source of trouble in the PCMI process[26].

Since the optical density and resolution of the input microfilm is very important, careful attention should be paid to such things as focus, alignment of lenses for flat field, light intensity, exposure time, development conditions, and the time interval between exposure and developing. The end objective, of course, is to obtain good image quality[30] and a high degree of uniformity from frame-to-frame and from reel-to-reel.

During the development phase of the PCMI process, it was decided to utilize a commercial microfilm supplier. Although several reasons for this decision were involved, perhaps the most important reason was to investigate the quality problems which would occur by using commercial conditions. One-hundred-foot reels containing approximately 600 frames were processed and inspected by the vendor. Resolution charts and step wedges were placed at the beginning and end of each reel to assist in inspecting the film against the desired specifications. Defective frames were noted on retake sheets and reprocessed on later reels. Upon delivery to NCR, the microfilm was subjected to inspection again. (It is interesting to note that, in spite of the vendor's previous inspection, many additional quality defects were found by NCR incoming inspection.) Eventually, sufficient microfilm was spliced together to record an entire micro-image photochromic master from a single reel. The reel was then carefully stored for later use in the camera-recorder.

There are good reasons for going through an intermediate microfilming operation. The use of microfilm transparency with an efficient optical system allows an intense actinic image to appear on the final emulsion surface permitting the achievement of relatively short exposure times. Moreover, the associated off-line preparation, collation, and inspection of the input material can be looked upon as a definite system advantage in many respects.

The second step in the PCMI process is to convert the input microfilm into the final reduction micro-images on a photochromic coating. Figure 4 is a view of the MK-I camera-recorder especially designed and built for this purpose by NCR[31]. Operation of the camera-recorder can be either manual or semiautomatic; however, in either operating mode, a trained operator is required to use the equipment.

Micro-images are recorded upon the photochromic coating in a step-and-repeat manner. Consecutive pages are written in a horizontal line. The images can be either continuously inspected during the recording process, or the camera-recorder can be placed in automatic operation with inspection occurring at a later point in the process. Before the contents of the photochromic film are printed out, a thorough inspection is made to detect any errors that have occurred. Errors are then corrected by erasing the imperfect image and rewriting it on the photochromic coating.

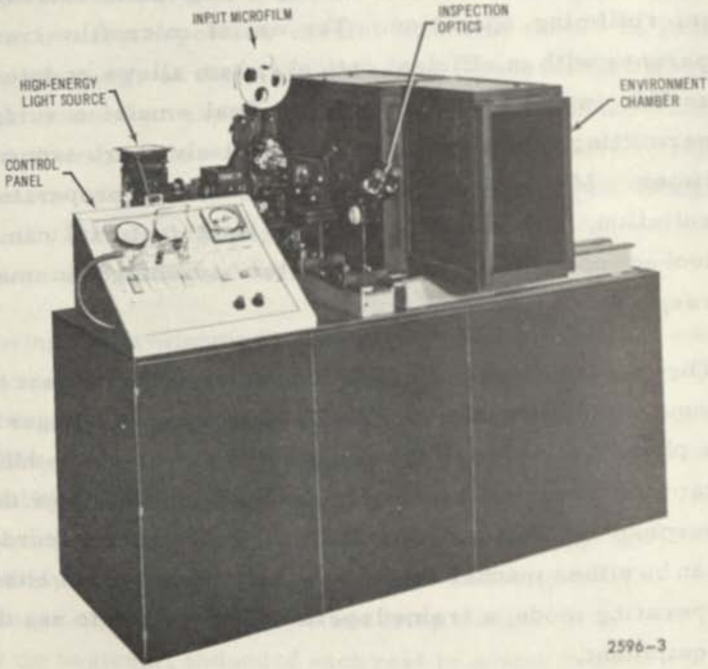

Figure 4. NCR Model ED MK-I PCMI Camera-Recorder

The first major assignment for the PCMI camera-recorder was to produce 30,000 micro-image Allowance Parts Lists (APL) for the Navy[32]. The format of the APL matrix is 72 columns by 35 rows placed on 1.6-millimeter (1/16 inch) centers vertically and horizontally. Thus, a total of 2520 micro-images at 220-to-1 are easily contained on a 76 by 127-millimeter (3 by 5 inch) film transparency.

A full row of micro-images was exposed and then inspected on the return cycle. The procedure of exposing a row, stopping at the end of a row, inspecting on the way back, and starting the next row is a routine but very monotonous job. In practice, the operator inspects an image for about half a second before pushing a button to move to the next image. When print uniformity exists, the operator can detect both faulty exposure and dirt particles larger than one half the character height at the same time. A focus inspection takes approximately 2 seconds and a page number check requires 3 to 4 seconds. Character lines blurred to double their normal width are easily detectable within the 0.5-second inspection time because lines tend to be blurred horizontally or vertically, but not both.

The second major assignment for the camera-recorder was to produce two complete matrices of the Bible [4, 33], side by side, on the same photochromic coating. The individual Bible format was 50 columns on 0.8-millimeter (1/32 inch) centers horizontally by 25 rows on 1.3-millimeter (1/20 inch) centers vertically, resulting in a total of 1250 micro-images (including five blank pages) on a 51 by 51-millimeter (2 by 2 inch) film chip.

The third step in the PCMI process is to convert the photochromic master matrix to permanent micro-images by contact printing onto a high-resolution photographic emulsion. The result is a photographic micro-image (PMI) master matrix which is then used to contact print the micro-image dissemination transparencies. Throughout the contact printing and subsequent photographic development processes, extreme care must be taken to maintain strict controls on the processing conditions used. For obvious reasons, cleanliness is very important, so that clean room conditions are used wherever possible when handling the photochromic coatings and high-resolution photographic emulsions.

Successful techniques for both manual and automatic contact printing of large-area, high-resolution micro-images have been developed by Carl Carlson and Frank Scherr of NCR. A manual technique is used to contact print the PMI masters while an automatic contact printer is employed to prepare the dissemination copies when more than just a few copies are required.

The high-resolution photographic film can also be processed and developed either manually or automatically. Small quantities of film were developed in-house in a specially equipped combination clean-room dark-room. For larger quantities, such as required in the micro-image Bible program, 100-foot rolls of film were contact printed and sent out for commercial processing in automatic, high-speed equipment. Excellent results were obtained by exercising very close liaison with the vendor, and by mutually arriving at the final process conditions and controls necessary to do the job.

In spite of the stringent demands on the contact printing process, yields are very good. For example, over 24 useable PMI masters can easily be prepared from the same PCMI master (and more can be prepared if required).

Using the automatic contact printer, each PMI master is capable of producing well over 2000 dissemination transparencies [34] at the rate of 10 copies per minute. This means that, should the need arise, over 50,000 micro-image dissemination copies can be prepared from the original PCMI master, which in turn represents a micro-form publishing of 125 million pages. That these figures are more than just optimistic extrapolations of laboratory data is illustrated by the successful production of over 25,000 micro-image Bibles for use at the NCR Pavilion at the 1964 New York World's Fair.

The following experimental results [34] are typical current capabilities of the PCMI process. Resolution of images on the photochromic film were measured at approximately 1000 lines per millimeter with the limitation resulting primarily from the optical system used in the MK-I camera-recorder and not from the recording medium used. Contact printing the PCMI master to the PMI master resulted in 800 lines per millimeter on the PMI master. Using the PMI master to contact print dissemination copies on high-resolution photographic film resulted in 650 to 750 lines per millimeter on the dissemination transparency. From this data, it can be seen that a sizable safety factor exists in the PCMI process, since the minimum resolution normally required for usable high-reduction ratio micro-images is 500 lines per millimeter. Experiments were also conducted which indicated that contact printing further generations of micro-image copies from dissemination copies would result in additional 6 per cent loss in resolution for each succeeding generation produced.

Although the PCMI techniques and equipment used to date have provided very satisfactory result, we are confident upon their analysis that they can be significantly improved upon in the future. Higher performance and yields concurrently achieved at over-all lower costs appear at this time to be primarily a matter of applied engineering.

The fourth and final step in the PCMI process for preparing micro-images is the application of a protective coating to the dissemination transparency prior to placing the transparency in circulation and use. The requirement for protecting the dissemination copy is essential since ordinary photographic film is easily scratched and damaged in handling unless special protective coatings are used. This is a common problem in the microfilm industry [48] and of course becomes potentially much more serious as reduction ratios increase and the information packing density becomes greater.

Early attempts to solve this problem consisted of applying various organic polymer protective coatings to the dissemination transparency and was similar in principle to techniques currently employed with microfilm [35]. Although partially successful, this approach was found to be expensive and to yield a final product with considerably less than optimum handling characteristics. A very effective, and inexpensive solution to the problem was found by

Eliot Stone[36] of NCR. The answer was to laminate the dissemination transparency between two thin sheets of a special plastic material. The final product can now be readily handled, and fingerprints and dirt can be wiped off without fear of damaging the film emulsion. Scratches on the surface of the plastic coating cause very little trouble in practice since they are out of the field of focus at the reduction ratios used in the PCMI process.

With ordinary microfilm, copyright protection and the prevention of counterfeit microform editions from originally disseminated microfilms is very difficult. However, in the case of PCMI dissemination copies, overcoating positively prevents a dissemination copy from being duplicated by contact printing.

Within the framework of the basic PCMI system, the only important equipment required to use micro-images is a viewer. Since the literature on this subject[37] is very extensive, it contains much conflicting information. It has only been within the past few years that most micro-image viewer manufacturers have begun to realize that something more was needed than cheap equipment. There is little question that the forward progress of the microfilm industry has been somewhat impeded because of the general unavailability of high quality viewers until very recently. It has been false economy in the long run to have sacrificed optical quality for the sake of cost. Happily, the current trend in micro-image viewers is definitely towards higher performance and better quality.

Unfortunately, the legacy of this earlier lack of attention to viewer design and quality is an almost universal resistance on the part of the user to the extension of micro-image techniques into broader application areas. At the present time, it is probably fair to say that a large part of the future success of microform systems is dependent upon the formation of positive attitudes towards their application by prospective users.

The viewer designed for use in the PCMI program had as a primary design objective the achievement of high optical quality images on the viewer screen. Figure 5 shows the

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Figure 5. NCR Model ED 200B Micro-image Viewer

first micro-image viewer produced as a result of this work and the general specifications are listed in Table 1.

TABLE 1. NCR MODEL ED 200B VIEWER SPECIFICATIONS

CHARACTERISTIC	SPECIFICATION
Screen Size	11 by 11 inches
Screen Brightness	Sufficient for viewing in well-lighted room (40 fl) 200 times
Transparency Positioning Table	Manual drive for 35 rows and 75 columns; Vacuum transparency holder; 3 by 5 inch transparency table; Row and column position indicator
Controls	Row and column drive knobs; manual focus adjustment; transparency insert lever; on-off switch; lamp start switch
Resolution	Sufficient for viewing 8-point print
Light Source	Zenon, 150 watts
Cabinet Dimensions	27-1/4 inches high by 18 inches wide by 29-1/2 inches deep
Weight	150 lbs
Power Requirements	110 volts ac, 350 watts

Additional design goals were simple mechanical access to the desired micro-image, and reliability of operation. A great deal of experimentation and study of the human factors involved in viewer use was also conducted and is still continuing.

Comparison of the Model 200B viewer specifications and operating characteristics against the human factors design goals for micro-image viewers as listed by a recent Battelle Institute study[37d] shows the following.

- The 200B provides for 40 foot-lamberts of illumination versus a suggested minimum requirement of 25 foot-lamberts for the general reading task.

- The PCMI system utilizes positive (rather than negative) images which coincides with Battelle's recommendation for more comfortable sustained viewing.

- The 200B uses transparent (instead of opaque films) as recommended by Battelle which simplifies projection of the image.

- The user of the 200B can easily assume various comfortable seated positions while using the reader.

- The 200B provides full-screen viewing.

- The 200B provides resolution on the screen sufficient to resolve 8-point print[39].

- Image contrast of the 200B is greater than the 0.7 minimum recommended by Battelle.
- The 200B can be comfortably used in the ambient light levels of an average well-lighted room.
- Loading and positioning of the micro-image transparency is simple on the 200B.
- Access to the desired image is simple and rapid with the 200B.
- The 200B is not readily portable as recommended by Battelle; however, portable PCMI viewers have been built and are described later in the paper.

From the preceding comparison, it is clear that the performance of the Model 200B viewer more than meets the original design objectives.

The final element used to complete a basic PCMI system is a micro-image file. For example, if 3 by 5-inch micro-image transparencies are used, it is possible to store one million document pages in microform (at 200:1 reduction) on less than 400 transparencies. This represents a stack of films less than 6 inches high, and chances are, all that will be required is a simple (manual) 3 by 5 file cabinet. Since automatic retrieval equipment can be built to use only a few hundred transparencies, the system economics in many cases will make such equipment difficult to justify over the manual approach. In any event, each PCMI application should be system-engineered for specific requirements.

FUNCTIONAL EXPANSION OF PCMI SYSTEMS

Since the basic PCMI system is somewhat limited in image processing capabilities, it is important to examine how PCMI systems can be functionally expanded in order to provide the broadest possible system flexibility for solving different types of application problems. Typical functions involved in image processing include the file-maintenance procedures of data collection, sorting, collating, purging, classification, indexing, and up-dating, and the file-use procedures of dissemination, storage, search, retrieval, viewing, copying, selective distribution, and display. In addition to providing PCMI systems with functional flexibility, it is also important to consider flexibility of format. The large variety of printed and graphic material in use today dictates that no single format can be selected which would be suitable for all types of application.

Since each image processing application will vary in file size, the frequency of activity, the retrieval complexity of search questions, and in requirements for human-file interaction, there is no typical PCMI user or system. Thus, the fundamental thesis for the balance of this discussion is that micro-image systems are defined by the user needs, not by hardware. This is analogous to describing a particular configuration of computer equipment as a system. In a manner similar to computers, a small number of PCMI building blocks (or modules) can be used in different combinations to form a large number of widely different systems.

Returning to the basic PCMI system as shown in Figure 3, it can be seen that we are primarily concerned with expanding the functional capabilities of those elements of the system required to use micro-images rather than those elements involved in micro-image production. While each prospective PCMI user should give serious consideration to establishing an in-house primary microfilming operation[40], a preliminary analysis indicates very few users would want to acquire a camera-recorder. The majority of users would find it more economical to obtain micro-images from a PCMI service bureau. Therefore, let us examine what can be done to upgrade both the functional specifications and the performance of the viewer and the file.

The NCR Model ED 200B Viewer (refer to Table 1) is a heavy-duty, manually-operated unit with no output capability other than visual display (blowback) on the screen. In principle, a number of things can be done to the viewer, either singly or in combination, to increase the screens potential value to a PCMI system. Consider the following examples.

- Provision for hard copy output of the image shown on the screen.
- Provision for microfilm output of the image shown on the screen.
- Automatic positioning of the micro-image transparency to the desired image location.

- Reduction of the physical size and weight of the unit (to enhance portability).

Of very special significance for the broad dissemination of micro-images would be the design of a portable, easy to use, manually-operated viewer which could be manufactured in large quantities at very low cost and sold for "home" use. Here the technical problems [37c, 37d] are admittedly formidable but are not currently considered to be insurmountable in view of what has been learned to date on the PCMI program.

As pointed out earlier, the manual PCMI storage file not only is capable of large storage capacities but the file is also very inexpensive. However, for some systems there will be a need to automate this file and this can be accomplished in various ways. As one example [41], consider a file drawer which serves as both the storage cabinet and the means for selecting the desired micro-image transparencies.

The transparencies are coded (using any desired code) and filed in the drawer in a random manner. Selection of the desired card or group of cards is accomplished by using a simple keyboard.

Some illustrations will now be given to demonstrate a few of the variations possible with PCMI system configurations. The manual PCMI system shown in Figure 6 has both a manual file and a manual viewer. The viewer can have an optional feature of either hard copy or microfilm output. Starting from this relatively simple arrangement

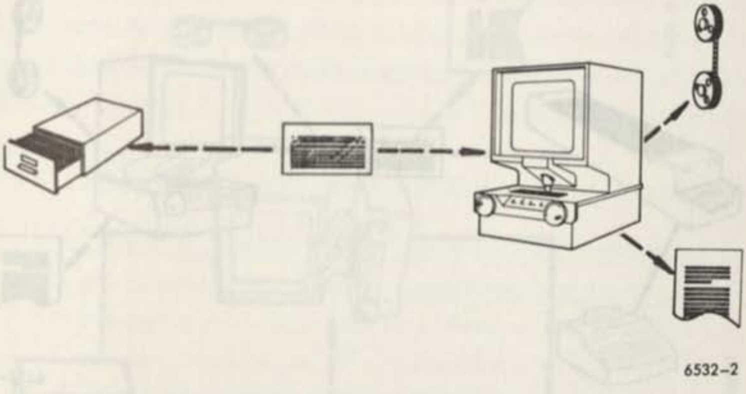


Figure 6. Manual PCMI System

of PCMI elements, various degrees of system automation can be gradually built up on a modular basis. Figure 7 illustrates the combination of an automated viewer with a manual file whereas Figure 8 shows the reverse case of an automated file used with a manual viewer.

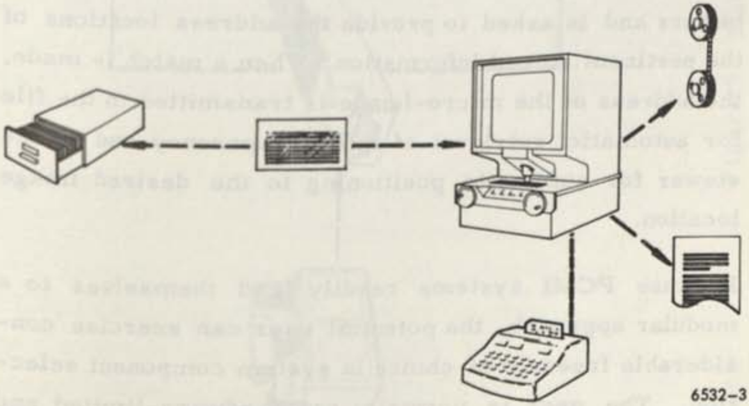


Figure 7. Automated Viewer PCMI System

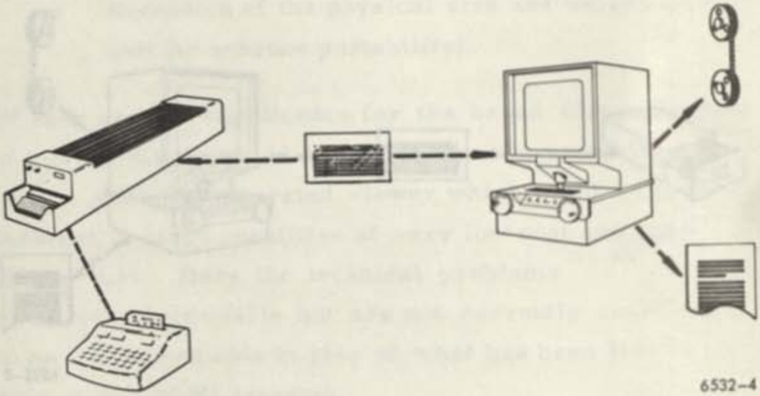
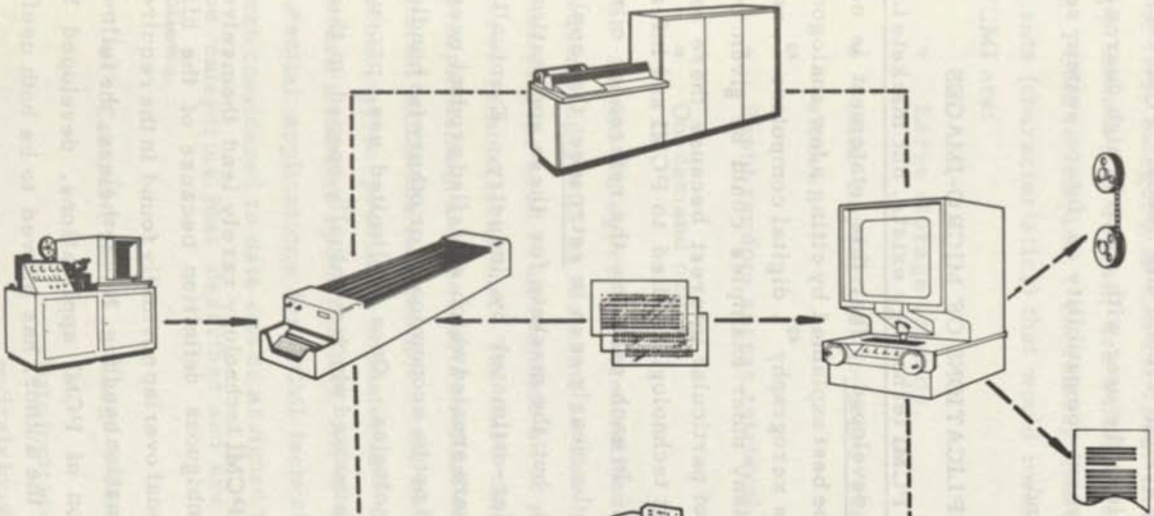


Figure 8. Automated File PCMI System

A fully-automated PCMI system is shown schematically in Figure 9. In this case, both the viewer and the file are automated and operation is controlled by means of either a general-purpose or a special-purpose computer. In principle, the computer is given a set of search parameters and is asked to provide the address locations of the pertinent stored information. When a match is made, the address of the micro-image is transmitted to the file for automatic retrieval of the transparency and to the viewer for automatic positioning to the desired image location.

Because PCMI systems readily lend themselves to a modular approach, the potential user can exercise considerable freedom of choice in system component selection. The user is normally not hardware-limited and can properly apply himself to the problem of designing



6532-5

Figure 9. Fully-Automated PCMI System

the micro-image system around his needs. PCMI technology also provides the user with a fairly high degree of continuous equipment compatibility as future system requirements expand.

POTENTIAL APPLICATIONS OF MICRO-IMAGES

Applications for PCMI technology exists, but markets for PCMI must be developed. That this statement is not paradoxical can be best explained by citing a few analogous examples such as xerography[42], digital computers[43], and microfilm[44]. Many other examples could be given but these three are of particular interest because these examples represent technologies allied to PCMI and information handling. In each case, as the references cited document, it can be clearly seen in retrospect that applications did exist, but the markets for these applications were badly under-estimated by industry. Eventually, large markets were created which satisfied product needs that simply could not be economically or otherwise handled with prior technologies. Once in limited use, product demands were generated which eventually opened up their own markets.

Applications of PCMI technology rarely lend themselves to simple, unambiguous definition because of the high degree of functional overlap normally found in the requirements for information handling. Nevertheless, the following classification of PCMI applications, developed by Sam Lebow and the author, has proved to be both useful and instructive when considering PCMI systems.

The first category is central files. Not all central file applications, of course, are suitable for mechanization by PCMI techniques. Therefore, central file requirements (characteristics) that would make it attractive to PCMI are:

- Large storage capacity.
- Data impractical to store entirely by digital stores.
- Rapid random access retrieval.
- On-demand output.

The second category is decentralized files. The file requirements will be the same as that listed for central files plus the need to disseminate all or part of the master file to remote locations. The third category is microform publishing, and the fourth and final category is termed special situations (an example would be the use of PCMI technology to provide a miniaturized map-data viewer aboard a manned space vehicle). All of the many specific potential applications for PCMI technology which have been considered to date can be assigned to one or more of the categories just described and are summarized as follows.

• Central File	Large storage capacity
	Data impractical to store entirely by digital stores

	Rapid random access retrieval
	On-demand output
• Decentralized Files	Same requirements as Central Files plus need to disseminate all or part of the master file to remote locations
• Microform Publishing	
• Special Situations	

From an examination of the proceding summarized categories, it should be evident that PCMI technology can be potentially applied to a wide variety of information processing problems within the fields of information storage and retrieval (ISR), microform publishing, libraries, and for certain specialized military and space applications. While a discussion of PCMI applications is beyond the scope of this paper, a detailed treatment of the subject has been completed by the author for early publication as a companion paper. However, a section of the PCMI applications paper dealing with military and space applications will be included here because it permits some graphic examples to be given of PCMI capabilities.

Military and space applications of micro-images will be restricted for the purpose of this discussion to only those problems requiring the use of a compact, portable viewer as an integral part of their system solution. Development of successful miniaturized micro-image viewers for military and/or space programs could have valuable fall out benefits on a variety of future commercial applications of micro-images, especially microform publishing for mass markets. Typical applications might be data viewers for use aboard submarines, small ships, high-performance military aircraft, manned orbiting satellites, and manned space probes. Compression of size and/or weight is important in all of the aforementioned examples.

Some idea of the enormous potential PCMI techniques have to offer can be obtained by its comparison in Table 2 with a 16-millimeter microfilm space library[45] currently being exhibited at the New York World's Fair. Of

TABLE 2. SPACE LIBRARY OF 2,500,000 PAGES

CHARACTERISTIC	16 MM MICROFILM	PCMI 220:1 MICRO-IMAGES
Original Material	books, reports etc.	2000 Bibles
Weight of original material[46]	8000 lbs	3920 lbs
Weight or reduced material	295 lbs	4.4 lbs

course, to be more meaningful, such a comparison should also include the viewers available to use the microform images. This cannot be done accurately on a one-to-one basis since no quantitative data is available on the microfilm viewer[47] used at the Fair, and the NCR Model ED200B Viewer described earlier (see Figure 5 and Table 1) is plainly not suitable for space applications. However, recent NCR research[48] on miniaturized viewers for manned space flight applications can be described to show some of the progress that has been made so far.

As originally defined, the problem was to design a compact, light weight, low-power micro-image viewer that could be used aboard a manned space vehicle. The viewer would have a self-contained, fixed reference file of up to 50,000 pages of information, such as navigational charts, planetary and sapce data, and checkout, maintenance, and emergency procedures. Rapid access to stored information was also a desirable feature. Two miniaturized viewers have been designed, built, and delivered on this program to date. The NCR model ED MK-II Miniaturized Micro-Image Viewer[49] is shown in Figure 10 and the specifications are given in Table 3.

While much more development work remains to be done before a functionally satisfactory and military specification viewer is available, the results achieved to date have been extremely encouraging.

2596-5

Figure 10. NCR Model ED MK-II Miniaturized Micro-image Viewer

A careful comparison of the viewer specifications as listed in Table 3 readily suggest that much can be accomplished by applied engineering to significantly improve the performance specifications of commercial-type micro-image viewers. This is certainly apparent in the parameters of size and weight. Further, recent developments in the

TABLE 3. NCR MODEL ED MK-II MINIATURIZED MICRO-IMAGE VIEWER SPECIFICATIONS

CHARACTERISTIC	SPECIFICATION
Screen Size	4 by 5 inches
Brightness	Sufficient for viewing in normal ambient lighting
Magnification	120 times
Transparency Positioning	Manual row and column drive; less than 5.5 seconds access time per foot of film length
Controls	Manual focus; on-off switch
Resolution	Sufficient for viewing 8 point print
Storage Media	35 mm film (non-sprocketed)
Self-Contained Storage Capacity	9600 images per foot of film length; 25 images per row across the film; extendable in length to 20 feet of film equal to 192,000 images

TABLE 3. (CONT)

CHARACTERISTIC	SPECIFICATION
Light Source	Tungsten, 7 volt, 15 watts
Cabinet Dimensions	2-1/8 inches high by 9-1/2 inches wide by 11-3/4 inches deep
Weight	5 lb 14 oz

commercial availability of low-cost microscope optics[50] may have an important influence on the ultimate cost of commercial viewers. Thus, the prospects of having compact micro-image viewers available in the near future for both commerical and military space applications are bright.

In 1945, Vannevar Bush presented the documentation field with the concept of Memex[51]. He envisioned Memex as a possible future device comprising a sort of mechanized private file and library for individual use. Memex was to be a desk-type unit equipped with a viewing screen and a selection keyboard. Memex could store on film, at reductions of 100-to-1 or better, a tremendous volume of books, journals, newspapers, correspondence, notes, and photographs. In addition, the unit would have an indexing tool that would allow the user to locate the stored material.

The combination of the NCR micro-image techniques for document storage, and interrogation units connected into a central computer to provide indexing and search capability, comes to achieving the original Memex concept. Theoretically, at least, it is now possible for every user to obtain every document in his field of interest in micro-image form so that the document can be easily stored, retrieved, displayed for viewing, and reproduced in enlarged form as hard copy when desired.

SUMMARY

The most important characteristics which make PCMI technology unique in its field can be summarized as follows.

- NCR photochromic coatings provide very-high resolution with no grain.
- NCR photochromic coatings permit the storage of images containing a wide range of gray scales because the coatings are inherently low gamma and grain-free.
- NCR photochromic coatings provide immediate visibility of the image upon exposure.
- NCR photochromic coatings permit both erasing and rewriting functions. This permits the powerful processes of editing, updating, inspection, and error correction to be incorporated into PCMI systems.

- The PCMI process incorporates the ability to effect a bulk-transfer readout of micro-images with over a 200-to-1 reduction ratio by contact printing, and can accomplish this on a mass production basis.

- Use of high-resolution silver-halide emulsions provides both permanency for the storage of micro-images and economical dissemination of duplicates.

- The very-high storage density of 100-to-1 to 200-to-1 micro-images offers the possibility of using some form of manual retrieval techniques for many applications. This eliminates the normal requirement in systems of this size for expensive and complex random access hardware.

The invention of the PCMI process by NCR scientists, and its current availability for broad application, should prove to be a most timely and important contribution to the state-of-the-art of information processing. New techniques and imaginative approaches to better handle information are urgently needed. The following intrinsic properties of PCMI appear to be attractive for this purpose.

- Adaptability to unit media-type information handling.

- Fast, random access retrieval.
- Extension to very large capacity storage.
- Economical file dissemination.
- Economical file decentralization.
- On-demand output capability.

Admittedly, PCMI does not solve the intellectual problems of how to classify and retrieve information; however, its unusual combination of properties and inherent flexibility does appear to offer some fascinating future opportunities for truly creative system engineering.

ACKNOWLEDGMENTS

The invention of PCMI technology and its subsequent reduction to practice as described in this paper was the end result of many individuals working both singly and together as a research team. Space unfortunately does not permit recognition of everyone who had a hand in the development of PCMI; however, the author gratefully acknowledges the critical reading of the manuscript performed by Carl Carlson, and wishes to thank Ty Abbott, Sam Lebow, John Hammond III, Dave Ives, Frank Scherr, Eliot Stone, and other members of the NCR staff for many helpful discussions on the subject of PCMI. The photochromic coatings used in the work described were supplied by Lowell Schleicher and his staff at the NCR Fundamental Research Department in Dayton, Ohio, and they played a most important part in our program. Partial support of this work was sponsored by the Bureau of Supplies and Accounts, Department of the Navy.

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3. "PCMI: Photochromic Micro-Image System Description," NCR, ED Technical Publication No. 7564, 19 pp, March 1964

4. The Holy Bible, Authorized King James Version (Old and New Testaments), 1245 pp (page size: 6-1/2 by 9-1/2 inches), type format: World Indo-Text, Bible No. 711, The World Publishing Company, Cleveland 2, Ohio

5. NCR's micro-image Bible, as well as micro-image viewer to read the Bible, will be exhibited at the NCR Pavilion at the New York World's Fair starting 22 April 1964

6. For a detailed account of the history of microphotography, the following references are highly recommended and contain extensive bibliographies on the subject.

a) Luther, F., Microfilm - A History 1839-1900, 195 pp, The National Microfilm Association, Annapolis, Md., Barre Publishing Co., Barre, Mass., 1959

b) Stevens, G. W. W., "Microphotography since 1839," Photographic J., 90B, 1950, p 150

c) Hawkins, R., Production of Micro-Forms, Volume 5, Part 1, The State of the Library Art, edited by Ralph R. Shaw, 208 pp, The Rutgers University Press, New Brunswick, New Jersey, 1960

7. Stevens, G. W. W., Microphotography: Photography at Extreme Resolution, 326 pp, John Wiley and Sons Inc., New York, 1957 (See especially Chapter 12, pp 232-277, "Document Microphotography.")

8. Webster's New Collegiate Dictionary, G. & C. Merriam Co., Publishers, Springfield, Mass., 1960

9. "New DOD Specifications for Microfilming: A Panel (Discussion)" Francis R. Borden, Chairman, Proceedings 1962 Convention, Volume 12, National Microfilm Association, pp 82-90, Ed. by Vernon Tate, NMA, Annapolis, Md., 1963

10. "DOD Engineering Data Microreproduction Standards and Specifications," NMA Informational Monograph No. 1, 151 pp, 1962 (available from the National Microfilm Association, P. O. Box 386, Annapolis, Md.)

11. The National MICRO-NEWS, Number 66, Official Journal of The National Microfilm Association, October 1963 (Entire issue devoted to the new NMA Microfiche Standard Specification and the background leading up to its adoption.)

12. In addition to the PCMI system of NCR, only two operational micro-image systems have been announced which utilize reduction ratios higher than 25-to-1. The first system, Minicard[13], was developed by Eastman Kodak starting in 1954 for the Department of Defense, and was first publicly demonstrated 17 November 1958. It employs micro-images at a reduction ratio of 60-to-1. Minicard is not only a storage medium but also a family of equipment[14]. namely, the Camera, the Duplicator, the Sorter, and the Selector. In almost every respect, Minicard represented an extension in the state-of-the-art, e.g., high reduction ratio, unitized cards, high transport rates, complex logical processing, and high densities of coded data. However, the system's capabilities have yet to be tested for general applications since the equipment has not been made commercially available.

The second system, Walnut[15], was developed by IBM for the CIA and uses micro-images at a 35-to-1 reduction ratio. Development started in 1958 and the first prototype was announced in July 1961. This system is also not commercially available.

13. Tyler, A. W. et al, "The Application of the Kodak Minicard System to Problems of Documentation," American Documentation, 6, January 1955, pp 18-30

14. Kuipers, J. W. et al, "A Minicard System for Documentary Information," Ibid, 8, October 1957, pp 246-268

15. Bradshaw, P. D., "The Walnut System: A Large Capacity Document Storage and Retrieval System," Ibid, 13, July 1962, pp 270-275

16. Stevens, G. S. S., opus cited, pp 247-257

17. Lewis, C. M. and W. H. Offenhauser, Jr., Microrecording: Industrial and Library Applications, 456 pp, Interscience Publishers, Inc., New York, 1956, Chapters IV through VII, pp 67-233

18. Hawkins, R., opus cited, especially the section, "Quality Factors," pp 77-94

19. Rudd, R. G., "Some Factors Influencing the Quality of Microfilm Images," Proc. National Microfilm Association, Vol. 2, 1953, pp 44-58

20. Fromm, H. J., "The Quality of Microfilm Images," Ibid, Vol. 12, 1963, pp 175-182

21. Rubin, Jack, "An Historical Survey of Line Density Approach to Exposure Control," Reproduction Methods, 4, April 1964, pp 33-37, 59-60 (a highly informative, well written and illustrated article)

22. Verry, H.R., "Report of an Enquiry concerning Micro-photography, Part (ii) in the U.S.A.," U.N.E.S.C.O., 1951, p 13

23. Stevens, G. W. W., opus cited, p 248

24. For a detailed discussion of the problem areas surrounding the contact printing of high-reduction ratio micro-images, see Stevens, G. W. W., opus cited, Chapter 10 and pp 255-257

25. Willemin, M., "Micro-Photography," Brit. J. Phot., Vol. 12, p 152 (1865) (For other examples, see Stevens, G. W. W., opus cited, pp 256-257.)

26. Ives, H. D., private communication

27. The following references on photochromism have been selected and annotated for the reader desiring more detailed information on this subject.

a) Brown, Glenn H. and W. Shaw, "Phototropism" (Photochromism), Rev. Pure Applied Chem; 11, 2, 1961 (contains a literature review dating from 1880 to 1959)

b) Lewis, Gilbert N. and David Lipkin, "Reversible Photochemical Processes in Rigid Media; The Dissociation of Organic Molecules into Radicals and Ions," Am. Chem. Soc. J., Vol. 64, December 1942, pp 2801-2808 (The first paper reporting that some colorless organic compounds form reversible colored modifications upon exposure to ultraviolet light.)

References c through i cite the pioneer work on photochromic spiropyrans performed by the late Yehuda Hirshberg.

c) Fisher, E. and Y. Hirshberg, "Formation of Coloured Forms of Spirans by Low-Temperature Irradiation," J. Chem. Soc. of London, Part 4, October-December 1952, pp 4522-4524

Carlson's paper[1] described the NCR research program to build such a memory and it was from this basic work that the PCMI process[2] was derived.

o) J. Phys. Chem., 66, December 1962, pp 2423-2579 (contains 34 papers presented at an International Symposium on Reversible Photochemical Processes, held at Durham, North Carolina, 16-18 April 1962)

References p and q were published last year and propose further application areas for photochromic compounds.

p) Dorion, G. and L. Weissbein, "Photochromism," Discovery, February 1963

q) "Triplet State May be Basis for Useful Photochromics," Chem. and Eng. News, 3 June 1963, pp 53-57

The final reference is a recent review article.

r) Hammond, G. S. and N. J. Turro, "Organic Photochemistry," Science, Vol. 142, 20 December 1963, pp 1541-1553

28. Brode, W. R., "Chemical Spectroscopy," Proc. ASTM, Vol. 50, 1950, pp 513-560 (refer to p 550)

29. Berman, E., et al, "Photochromic Spiropyrons. I. The Effect of Substituents on the Rate of Ring Closure," J. Am. Chem. Soc., Vol. 81, Part 4, 5 Nov-1959, pp 5605-5608

30. It is recommended that the DOD microfilm standards cited in Reference 10 be used as a minimum guide to establishing specifications for PCMI input microfilm.

31. Ty Abbott was the NCR Project Engineer responsible for the development of this equipment and he was materially assisted by Dave Ives, Carl Carlson, and Ron Rondas.

32. Micro-image APL's were produced as a part of Navy contract Nonr-3865(00). The APL document is a Navy catalog form printed on a high-speed printer. The paper measures 11-5/8 by 10 inches, whereas the printed text occupies an area of 11-1/2 inches by 8-1/2 inches. The printing is quite non-uniform in density. The character height is approximately 0.10 inch with fairly uniform stroke width.

33. The World No. 714 Bible page measured 6-1/2 by 9-1/4 inches with a printed area of 5-1/2 by 8-1/2 inches. The diagonal of the printed area is 10.1 inches. The microfilming of the Bible was done at a reduction ratio of 11-to-1, which would reduce this diagonal to 0.92 inches. A further reduction in the camera-recorder of 20-to-1 reduces this to 0.046 inch which will fit into the 0.068-inch field diameter of the objective with some tolerance left to be distributed through the system. The overall reduction is 220-to-1. The text at this reduction is 0.025 by 0.039 inch, which in the matrix area of 0.031 by 0.050 inch leaves a horizontal tolerance of ±0.003 inch and a vertical tolerance of ±0.005 inch. The area on the film chip consumed by the text is 1.95 square inches (1-1/4 by 1-9/16 inches).

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35. Peiz, Gladys T., "Film Coatings--Do They Really Protect Microfilm?", The National MICRO-NEWS, No. 67, December 1963, pp 125-139

36. Stone, E., private communication

37. The following recent references provides a comprehensive introduction to the historical background and current status of micro-image viewers and viewer-printers.

a) Born, Lester K., "The Literature of Microreproduction," Am. Doc., Vol. 3, No. 3, 1952, pp 167-187

b) Steward, Jean, et al, Reading Devices for Micro-Images, Vol. 5, Part 2 of The State of the Library Art, Ed. by Ralph R. Shaw, The Rutgers University Press, Rutgers, N.J., 1960

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f) Ibid, Vol. 3, No. 4, April 1963, pp 36-41

g) Guide to Microreproduction Equipment, Ed. by H. W. Ballon, National Microfilm Association, Annapolis, Md., 1962, pp 99-225

h) Hawken, Wm. R., Enlarged Prints from Library Microforms: A Study of Processes, Equipment, and Materials, 131 pp, American Library Association, Chicago, Ill., 1963

i) Boyett, D., "Microfilm Readers and Reader-Printers," The National MICRO-NEWS, No. 68, February 1964, pp 174-188

38. The 200B Viewer was developed as a partial fullfillment of Contract Nonr 3528(00) with the U.S. Navy Bureau of Supplies and Accounts (BUSANDA). Ty Abbott was the NCR Project Engineer responsible for the technical development of the Viewer.

39. There is a large amount of subjectiveness normally encountered in the practical evaluation and analysis of image quality. For example, during research on the PCMI program it was found that using NBS resolution test charts alone as a measure of image quality obtained at various stages of the process could be highly misleading when compared against the literature and against various independent human observers. Image quality on the 200B viewer screen is an example of this. The Battelle study [37] states that a resolution of at least seven lines per millimeter is necessary for comfortable viewing. The report further states that characters in the projected image should be 10-point print with an acceptable size range of 8- to 12-point print. The 200B achieves approximately three lines per millimeter resolution but it

can easily be used to read 8-point print. This supports the above argument that the evaluation of image quality is not a simple task. For the reader interested in further information on this subject, the following excellent review articles are recommended.

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40. Luther, Fredrick, "The Economics of Microfilming: A Comparison Between Contracted Services and a Do-It Yourself Program," Proc. NMA Conv., 1961, pp 33-40

41. Randomatic TM3000, pushbutton card file, Randomatic Data Systems, Inc., Trenton, N. J.

42. Bixby, William E., "Applications of Microxerographic Techniques to Information Recording," Proc. NMA Conv., 1962, pp 229-247 (contains an account of the early difficulties in selling the concept of xerography)

43. Many accounts have appeared in the literature describing the early days of computer technology. In virtually every case cited, industry drastically underestimated the future market for computers. As one example, compare the story of the founding and early history of Engineering Research Associates (later bought by Remington Rand) as told by Engstrom with the recent Fortune and Business Week articles on computer.

a) Engstrom, Howard T., "Electronics and Documentation," American Documentation, Vol. 13, January 1962, pp 119-122

b) "New Tool, New World," Business Week, 29 February 1962, pp 70-90 (Special Report on Computers--How they're Remaking Companies.")

c) Burck, Gilbert, "The Boundless Age of the Computer," Part 1, Fortune, Vol. LXIX, March 1964, p 101

d) ----, "On Line in Real Time," Part 2, Ibid, April 1964, p 141

e) Pfeiffer, John, "Machines That Man Can Talk With," Part 3, Ibid, May 1964, p 153

44. The following two references describe the history of microfilm applications and also offer predictions for future markets and uses.

a) Mayberry, R. E., "Microfilm--A Means, Not an End," Proc. NMA Conv., 1962, pp 137-141

b) Taubes, Ernest P., "Microfilm as a Systems Tool," The National MICRO-NEWS, No. 68, February 1964, pp 151-169

45. Description of Recordak exhibit in the Kodak Pavilion, News Bulletin of BEMA (Business Equipment Manufacturer's Association), 30 March 1964, p 4

46. Note: The Bible was printed upon thin onion skin paper which is one-half the weight of regular or bond paper. This explains the apparent discrepancy in the weights of the original documents since the overall comparison is made on the same number of pages.

47. The Recordak exhibit has been inspected at the Fair by NCR technical personnel familiar with micro-image technology and no evidence was found to indicate that the 16-millimeter viewer employed was

significantly different than the Recordak Lodestar, magazine loading film reader. The Lodestar viewer is similar in exterior dimensions to the NCR Model ED 200B viewer. Although it is not as heavy as the 200B, it is definitely not a portable unit.

48. "Electronics Division Delivers Miniature Map Data Viewer for Astronauts Use," NCR-Editor, Vol. 4 No. 2, February 1964, p 1, (a house publication of the NCR, Electronics Division, Hawthorne, California)

49. Details of the Model MK-I miniaturized viewer are not given since the MK-II is functionally much superior. However, much was gained from the testing and evaluation of the MK-I Model and it may be of interest to cite that it was also a tungsten lamp viewer and weighed only 3 pounds.

50. Scholastic Series Microscopes - Reference Manual, Bausch & Lomb Incorporated, Rochester, N.Y., 1964 (See especially models ESM100 (100X) and STZ200 (50-200X) which represent a whole new approach to low-cost, high-quality precision optical instruments.)

51. Bush, Vannevar, "As We May Think," Atlantic Monthly, 1945, pp 101-108

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MICROFORM SYSTEM

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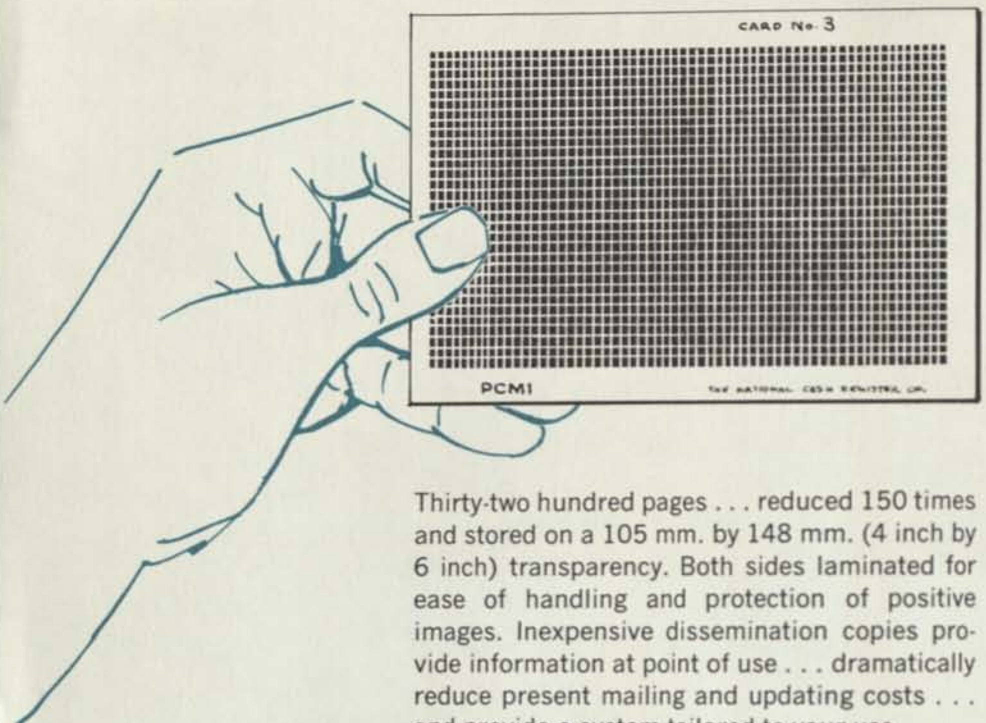

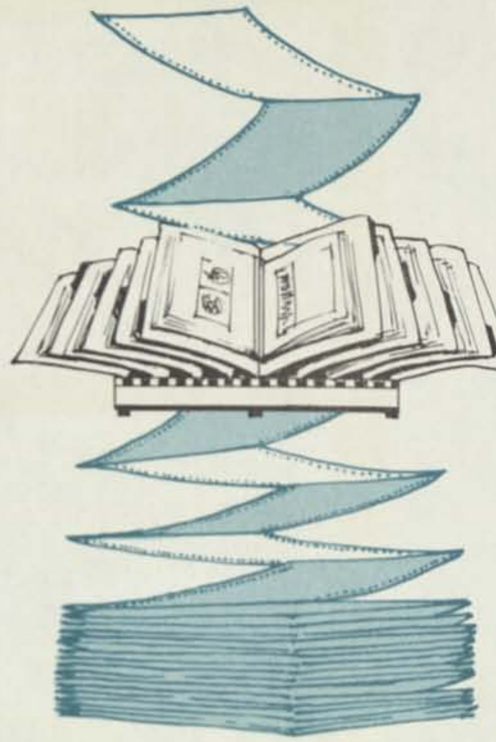

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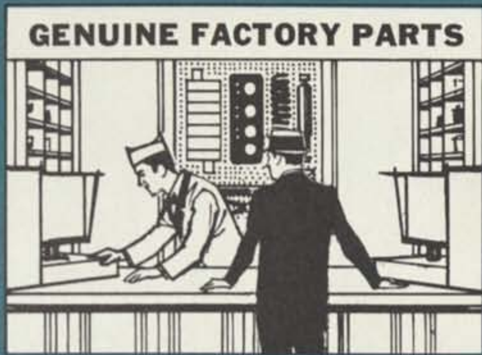
Automatic Contact Printer generates dissemination copies . . . Quality control and clean room facilities assure optimum results.

Individual transparencies may then be sent to all terminal locations for use. This NCR Distribution Center presently has a production capability of 3 million transparencies per year.



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- Reduces mass-storage requirements
- Reduces communication costs
- Effectively increases computer service capacity
- Reduces inquiry traffic

ADMINISTRATIVE

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- Current operating data
  - Sales
  - Credit
  - Inventory
  - Price schedules

PCMI SYSTEM FEATURES

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- Dramatically reduces present mailing and updating costs
- Handles alphanumeric, graphic or photographic material
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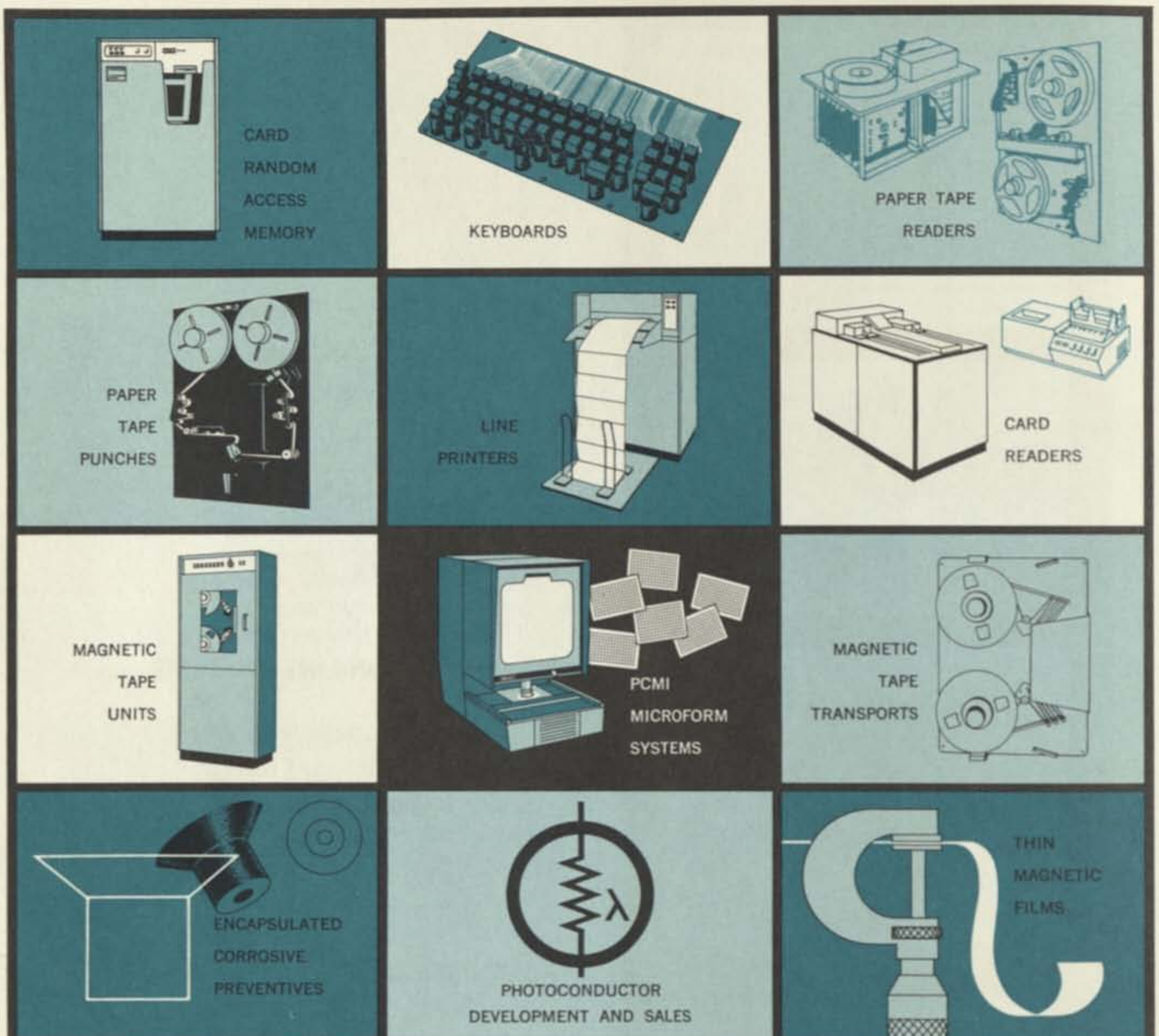

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PHOTOCHROMIC INFORMATION STORAGE

by JOSEPH BECKER

While most microfilm or micro-image applications now in use employ either silver halide or diazo film as the recording medium, The National Cash Register Co. has announced a process called photochromics which also provides a practical means for high-density storage of textual and graphic images.

NCR photochromic coatings are similar to photographic emulsions in appearance and other properties. They can be coated on the same type of surfaces as photographic emulsions and exhibit excellent resolution capabilities. The basic principle behind the photochromic process is the ability of individual molecules in the coating to switch alternately from a colored to a colorless state. The materials switch when subjected to near ultraviolet radiation and back to the colorless state when subjected either to heat or visible light. The concept of PCMI is a fresh idea in the field of information storage and retrieval. The PCMI process is now out of the laboratory and available from NCR for special applications on a contract basis.

brief history of micro-images

In 1839, John Benjamin Dancer, an Englishman, coupled photography with microscopy for the first time to produce microphotographs of a page of text. He employed the Daguerreotype photographic process in his experiments. Twenty years later, Sir David Brewster further disclosed how microphotographs could be concealed in small places like an ink blot. The German Army, in World War II, adopted this principle in a technique called "microdot." It transmitted information to its agents by hiding microphotographs of secret messages in the punctuation marks contained in book print.

The French government, during the Franco-Prussian War, used microphotography to communicate dispatches into Paris when the city was under siege. As many as 3,000 messages could be photographed and reduced on one collodian plate. A surface layer called a "pellicle" was then peeled from the plate as a thin film. This lightweight film was rolled into a scroll, slipped into a quill, and attached to a pigeon's tail feather. When the pigeon reached Paris, the film was recovered from the quill, projected, and the messages copied by hand. "Pigeon Post" was the forerunner of the familiar V-mail process employed by the U.S. in World War II.

Microfilm is the principal method known to man for compressing graphic and textual data without alteration of information content. Libraries use it extensively for space reduction of archival files of newspapers, periodicals, and books. In addition to compacting passive files, industry and government are using microfilm more and more as the keystone of active and dynamic information systems. As long as information can be stored more densely on microfilm than on magnetic tape, microphotography will be an attractive and important medium for micro-recording printed and graphical data.

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properties of other film recording media

Silver-Halide is the most popular photo-recording medium. It is fast, grainy, exposed with white light, and developed wet. It is used widely in the home and for commercial purposes. *Diazo* film was introduced many years ago. It consists of a Mylar base coated with a photosensitive dye. It is slower than silver, exposed with ultraviolet light, and developed by ammonia vapor. Ultra violet light disintegrates portions of the dye compounds and ammonia vapor brings out the remaining dye in the coating. Since the dye imbeds itself in the film, the intelligence at once becomes visible to the human eye. More recently another recording medium was introduced, called *Kalvar*. In the Kalvar process a plastic film is coated with microscopic gas bubbles. On exposure, the bubbles are excited by an ultraviolet light source. The film is developed dry by heating it at a temperature equivalent to that of a warm iron. Heat caused the excited bubbles to burst and form light scattering centers. The unaffected coating that remains on the surface ,provides the intelligence for the picture.

Diazo and Kalvar are quick, dry, and offer acceptable resolution characteristics for most applications. That both processes are dry gives them an important advantage over the silver-halide family of films which still require chemical development and fixing.

Silver-halide, diazo and kalvar film are used in many different forms. Microfilm images can be rolled into spools, cut up into strips and inserted in jackets, contained on sheets of film called *microfiche*, or scotch taped into the window of an *aperture card*. These are translucent forms. The results of microfilming can also be applied to opaque forms. Images can be contact printed onto *microcards*; or contact printed onto adhesive-backed strips known as *microtape*; or projected and burned into a multilith plate for offset runs onto paper called *microprint*.

All of the forms described above require a viewer to help the user inspect and use selected micro-images. Some

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of these viewers are combination printers, permitting a user to make a paper enlargement (i.e., hard copy) on the spot after selecting his micro-image. When microfilm is combined with xerography, entire paper files can be recreated from the film automatically at high production speeds. Further, several sophisticated devices have been manufactured to facilitate the automatic retrieval of microimages from a large file.

description of the pcmi process

Photochromics derived from NCR's chemical research in the fields of encapsulation and dye chemistry. NCR photochromic materials are light-sensitive organic dyes. The dyes can be placed as a molecular dispersion in suitable coatings and applied to almost any surface. With photochromics, the molecular coating can be exposed with ultraviolet radiation and erased with white light. It is this reversible characteristic that gives PCMI a powerful advantage in film technology. It is grain free, thus permitting the recording of very high density micro-images. It also exhibits excellent gray scale characteristics which facilitates the recording of both textual and graphic information in the same medium. The reversible feature enables inspection, error detection and correction, and at the same time provides a method for adding and subtracting information. Photochromics brings to film technology some of the same power that magnetic recording brought to computer technology.

High-density microrecording is feasible with PCMI at linear reductions of 200 to 1, representing an area reduction of 40,000 to 1. One limitation of the photochromic coating is its semi-permanency. PCMI coatings are sensitive to ambient temperature. Coatings kept at lower temperatures have a longer life than others. Room temperature image life is normally measured in minutes or hours, whereas a drop of 30 to 40 degrees will rapidly extend this life to months.

As a general rule microform systems require exacting quality controls at all stages of processing—in the optics at the time of filming, in the storage medium, and in subsequent stages of film duplication.

In the PCMI process the user's original documents are first photographed under strict quality control conditions to conventional 35 mm (sprocketed) microfilm. Computer output generated on 35 mm microfilm using an SC 4020 can also be made compatible as input to the PCMI process. A machine, called a Camera Recorder, then accepts the 35 mm microfilm as its input. Ultraviolet light is projected through each microfilm frame to a glass plate coated with the photochromic emulsion. The optical train between the film and the plate produces the desired reduction ratio by focusing the image on a controlled coordinate location on the glass plate. After each exposure, the image becomes immediately visible for inspection. Thereafter, in a step and repeat fashion, successive images can be exposed one at a time, or automatically until an entire matrix is produced. Inspecting for errors is done a frame at a time, or by backspacing the exposed matrix. When an imperfect image is detected, light in the appropriate erasing waveband erases the image and the ultraviolet projection is repeated.

After exposure, the photochromic plate is contact printed on a second plate coated with a high-resolution silver-halide emulsion; a bulk transfer of the images in the matrix occurs. The latter plate is used as a master to produce subsequent transparency copies after appropriate chemical development and fixing. Finally, the copies are laminated between two protective plastic sheets.

Copy resolution achieved with PCMI is above normally accepted standards for viewing and enlarging. Contact printing to film on a mass production basis of large quantities of high reduction ratio micro-images on a single substrate is unique with PCMI.

A reduction ratio of 200 to 1 allows for the storage of 2,500 pages on one 3x5 transparency. Four hundred 3x5 transparencies, representing a file of 1,000,000 pages, occupies only six linear inches. A shoebox file of transparencies can therefore hold as many as 3,000,000 images!

At present, the PCMI process to produce micro-images is available at NCR to customers on a service bureau basis. Production cost for a single 3x5 photographic master plate is estimated to be $250. The cost of subsequent dissemination transparency copies, produced by contact printing, ranges from $.50 to $1 each depending on quantity. High density micro-images can, therefore, be mass produced with unprecedented economy. At the rate of 50 pages per penny the concept for disseminating whole libraries of information grows extremely appealing. A relatively low-cost high-performance viewer has also been developed to the pre-production prototype stage to facilitate the retrieval and utilization of the micro-images.

Apart from the revolutionary advance which PCMI brings to film technology, it also introduces a new dimension into information processing system design. Its principal advantage rests with the ability to mass produce micro-image dissemination files economically. Thus far, document retrieval systems have tended in the direction of providing a central store of images that could be placed on-line with users through remote consoles. Though technically feasible, such schemes have been uniformly thwarted by prohibitive cost. PCMI, for the first time, makes the decentralized file concept appear as an attractive alternative. For example, unique special collections in the library of one country could be filmed and the resultant micro-images disseminated to other repositories all over the world. A similar idea would be applicable to industry and government where decentralized operations rely heavily on the ability to possess the same information in the field as is available at headquarters. Since micro-image files can be produced so inexpensively, it is also conceivable that entire libraries may eventually be available for home use as well.

The ultimate success of a micro-image dissemination system will rest with the user. Since he is the one who must handle and view the film product, his attitude toward the system is important. His acceptance will hinge on how "comfortable" he feels with film as a reference medium. Accordingly, studies have been made of his habits, and a great deal of experimentation has been conducted with viewer equipment. Design goals for a PCMI viewer include high optical quality, eight-point print resolution on the screen, simple mechanical access to the desired image, easy loading and unloading, portability, and hard copy printout capability. If such a viewer is eventually to be sold for home use, it will also need to be manufactured in quantity at low cost.

In summary, PCMI represents a unique capability in the field of information storage and retrieval. While the level of this technical development is high, its principal areas of potential application remain to be explored. It does, however, appear destined to have an impact on microfilm publishing methods associated with the mass production of a plurality of images for dissemination purposes.

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