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16. Abstract

An experimental and analytical study has been conducted to establish the feasibility for scanning and digitizing electrocardiogram records. The technical requirements and relative costs for two systems are discussed herein. One is designed to automate the analysis of current electrocardiograms submitted in accordance with the FAA Aeromedical certification regulations. The other is designed for retrieval and scanning of the FAA file of microfilmed electrocardiogram records.

A cost-benefit analysis of the two systems is also presented.

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PREFACE

The work described herein has been performed at the Transportation System's Center (TSC) as part of a program designed to establish the feasibility for scanning and digitizing electrocardiograms stored on strip charts or microfilm. This program is sponsored by the Department of Transportation through the Federal Aviation Administration (FAA), Office of Aviation Medicine.

Currently, the FAA processes an average of 35,000 electrocardiograms per year. Approximately 1,000,000 records are stored in an active file of FAA microfilm cards. The primary objective of the program at TSC is to provide the technology necessary to allow gradual conversion of these FAA records to a form suitable for processing and analysis by digital computer with medical backup.

We would like to acknowledge the help received from Mr. A. Iannini who contributed significantly to the experimental portions of this work. Mr. Iannini was responsible for the modifications made to the optical-scanner system.

1. INTRODUCTION

The Federal Aviation Administration requires, under Regulation Part 67.13, Medical Standards and Certification, First Class Medical Certification, that each applicant for license must be free of, or have no established medical history, nor clinical diagnosis of (a) myocardial infarction, or (b) angina pectoris or other evidence of coronary heart disease. To insure compliance with this regulation, each applicant must submit electrocardiograms (ECG's) taken by designated Aviation Medical Examiners (AME's) to the FAA Aeromedical Certification Branch for review by a cardiologist. These electrocardiograms are required initially, at age 35, and annually after age 40. At present, the Aeromedical Certification Branch is processing on the order of 35,000 ECG's per year and has approximately 1,000,000 active microfilm accounts in its total files. These ECG records are presently analyzed manually, a tedious procedure which requires highly skilled medical personnel to spend much of their time studying ECG's which contain no abnormalities.

During the past decade, a variety of computer programs have been written[2-7] for the purpose of automating this analysis. A number of ECG instrumentation carts have been developed. These carts are commercially available for use in digitizing the ECG, while being taken, and performing on-line analysis for prescreening purposes. However, these existing systems do not have provisions for scanning and digitizing either the incoming ECG records in strip chart form (analog) or the current records in the FAA files. Any proposed system to handle the ECG data as they exist must include some means for optical scanning, so that the records may be converted to a form which is suitable for input to a digital computer.

Two separate aspects of the problem must be considered; they are examination of (a) strip-chart ECG records as recorded on standard machines, and (b) ECG microfilm files. There will be differences both in terms of system requirements (accuracy, speed, and degree of automation) and hardware availability and costs.

During fiscal year 1972, the Transportation Systems Center (TSC) of the Department of Transportation conducted a study to analyze the system requirements for scanners to determine technical feasibility and cost-benefits for practicable systems. The findings of this study are contained herein.

2. SYSTEM REQUIREMENTS

There are two basic problems which must be considered in analyzing and determining detailed system requirements for new instrumentation, such as the ECG optical scanner: First, the data format which may be necessary to allow entry into the ECAN-D computer analysis program; Second, technical constraints which are imposed by the forms that the raw data take. This last consideration is more limiting, and as such has received more attention in this study.

2.1 ECAN-D DATA FORMAT

The ECAN-D (ECG Analysis, version D) program is the computer program currently being considered for use in automated screening of the ECG data.[1] The only aspects of concern herein are the input requirements since they determine some of the scanner specifications. These requirements are as follows:

ECAN-D INPUT FORMAT

Data Format	10-bit digital samples
Sampling Rate	500 samples per second
Signal Length	1856 samples (3.72 seconds) maximum

The sample length of 3.72 seconds was selected so that a minimum of three cardiac cycles were included. Minor modifications to the program might be made to allow for processing of shorter signals in certain cases.

2.2 FORMS OF ELECTROCARDIOGRAM DATA

Since the scanning problem has two separate parts (see above) constraints imposed by specific presentation of the ECG for each application must also be considered individually.

2.2.1 Original ECG Strip-Chart Records

ECG strip-chart records are presently submitted to the OAM by over 7,000 Aviation Medical Examiners (AME's). They are sent to OAM attached to the form shown in figure 2-1. This form specifies the length of each of the twelve traces, and also asks that the original tracings be submitted. However, there are no other requirements. Such factors as accuracy or type of recording paper are not specified.

The traces are then mounted, together with the lower part of the form, in preparation for microfilming, (figure 2-2). In this example the nine short traces each contain only two cardiac cycles, which is one less than the three required by the present ECAN-D program. This problem can be overcome by relatively minor modifications to the computer program.

The present size of the three long traces before microfilming is 2 by 6 inches (I, II, and III in figure 2-2), and 2 by 2 inches for the nine short traces (AVR, AVL, AVF, and V1 through V6 in figure 2-2). Since there is not a stated requirement, the colors of the chart paper and the tracing may vary. Often however, both are of the same color; i.e., black or dark gray. When the traces are mounted, no attempt is made to keep the axes of the various traces perpendicular to each other, or to the edge of the microfilm frame.

2.2.2 Microfilmed ECG Records

After the ECG tracings are mounted as shown above, they are microfilmed. The original tracings are then discarded. These microfilms are black and white negatives of the original records. Accordingly, any color present in the grid or tracings of the original ECG's is lost. The total reduction in size of the tracings is approximately 25 times, resulting in a full-frame size of approximately 1/2 by 3/4 inch.

OAM maintains one clear plastic storage card for each airman whose records are kept in the files. Such a card is large enough to contain the airman's complete ECG history. Although it provides a convenient means of filing and storing ECG data, the card can be

★ GPO : 1967 OF—266-461

← *Guide for length of leads AVR, AVL, AVF, V1 through V6* ↑

← *(Guide for length of leads I, II, and III)* →

INSTRUCTIONS FOR PREPARATION AND SUBMITTAL OF ELECTROCARDIOGRAM

1. Submit only original ECG tracings. Photostats are not acceptable.
2. ECG must be taken within 90 days prior to FAA physical examination.
3. Chest electrode placement as follows:
   V-1—At the 4th right interspace at the sternal border.
   V-2—At the 4th left interspace at the sternal border.
   V-3—Halfway between leads V-2 and V-4.
   V-4—At the 5th left interspace on the midclavicular line.
   V-5—Halfway between V-4 and V-6.
   V-6—On a line dropped perpendicularly from V-4 to the midaxillary line.
4. Show standardization on leads I and V-1.
5. Cut leads I, II, and III six inches long; leads AVR, AVL, AVF, and all V leads two inches long. (Guide provided above for measurements.)
6. Arrange leads in the order shown in line 3 above; mark lead number in upper left hand corner on the front of each segment.
7. Print applicant's name on the FRONT of the lead I portion of tracing.
8. Staple all tracings to identification card below at point indicated; tear off identification card along perforation; attach to Form FAA-8500-8, and mail to:

FEDERAL AVIATION ADMINISTRATION
Aeromedical Certification Branch
P.O. Box 25082
Oklahoma City, Oklahoma 73125

TYPE OR PRINT ALL IDENTIFYING INFORMATION REQUIRED BELOW

PILOT'S NAME (Last, First, Middle)		PILOT'S CERTIFICATE NO.	DATE OF BIRTH
MEDICAL EXAM. CLASS–	DATE OF ECG	EXAMINER'S NAME AND SERIAL NO.	
FAA USE ONLY MED. ID NO.			

STAPLE HERE

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
ELECTROCARDIOGRAM

FAA Form 8065-1 (6-67)
Supersedes previous edition

Figure 2-1. Form Used in Submitting ECG's to FAA scratched and marred when handled. Also, the individual frames may move slightly within the storage card, so that the traces are no longer oriented to each other or the entire card.

2.2.3 Possible Improvements

The shortcomings of the microfilmed data have been indicated in the discussion above. In the future, microfilm should be used only for storage and the scanner used to digitize the original tracings. This will ease the resolution requirements by a factor of 25 and will circumvent some of the previously mentioned handling problems.

As an aid in scanning the incoming full-size records, ECG's might be submitted on chart paper with the grid pattern printed in a specified color. Such paper is available at no extra cost over paper with only a black grid. The scanner could then view the tracings through a filter of the same color as the grid, thus resulting in removal of the grid.

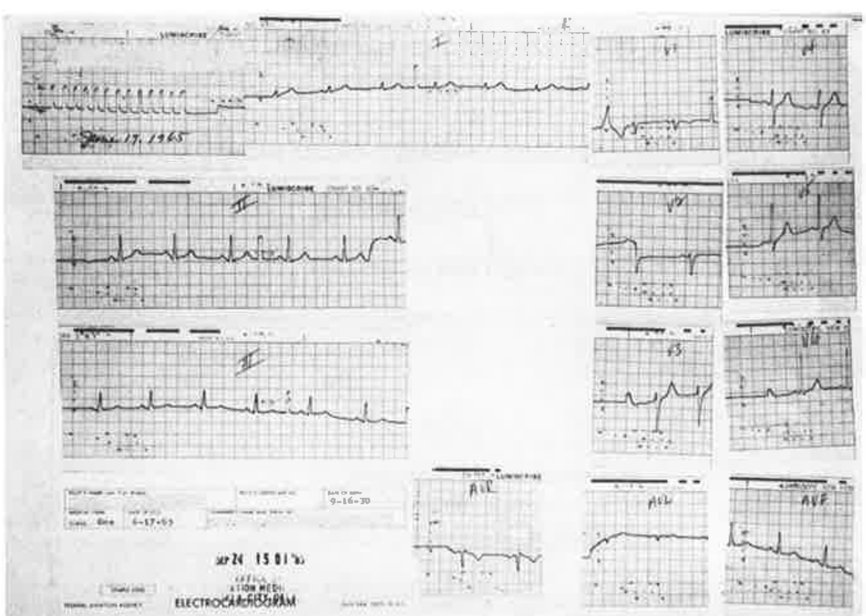


Figure 2-2. Example of ECG, Mounted

3. SCANNING SYSTEMS

3.1 CURRENT SCANNING METHODS

There are two different methods which are currently used for image tracing and scanning and for which equipment is available; they are (a) the X-Y digitizer, and (b) scanning microdensitometer. A detailed technical description of a version of the latter device which has been tested experimentally at TSC is given in the appendix.

3.1.1 X-Y Digitizer

All X-Y digitizers operate on the same principle; i.e., they use a mechanical or electrical transducer to determine the exact position of a cross-hair (or similar cursor) with respect to a fixed X-Y coordinate system. To digitize many points on a line, as the ECG system requires, a controller must be included in the system to issue sampling commands at regular intervals. For ECG tracings, these intervals must correspond to uniform intervals of time since the ECAN-D program assumes that data have been taken at 500 uniformly spaced samples per second. In addition, if the data are on microfilm, a projector must be added to the system to increase the image size into the resolution range of the digitizer.

As noted directly above the X-Y digitizer must be able to resolve 500 samples per second on the original tracings. The tracings are usually scaled at 1 second per inch in the time coordinate, so that the digitizer must have a resolution of 0.002 inch per sample. There are digitizers available with a resolution as low as 0.001 inch per sample. Also, there are digitizers available with projection systems to handle microfilm.

The principal objection to the use of an X-Y digitizer is the relative importance of the operator. Some of the most important parts of the ECG traces are the sharp "peaks" and their slopes; i.e., the points on the trace where tracing accuracy is most critical. It is at these very points that the operator tends to make his errors. Also, the relative importance of the operator has a corollary in the relative unimportance of the controller unit of the system. In an X-Y digitizer, the controller exists only to regulate the sampling rate and to store the samples onto a permanent recording medium, usually magnetic tape. Accordingly, there is little to be gained in having one large controller for several digitizers.

3.1.2 Scanning Microdensitometer

The operation of a scanning microdensitometer may be compared to that of a television camera. The image may be considered as having a fine grid placed over it. Then the device can scan the area to obtain the image brightness (or "gray level") at each point. Unlike a television camera, which sweeps the image at a regular rate, the scanning microdensitometer can be set to measure individual points or parts of the image under control of a computer. This property can be used for analyzing ECG microfilms since the operator could set a "window" over the ECG trace to be analyzed. It might prove possible for the operator to have greater control, by setting the window to expose only that part of a trace containing the actual ECG signal (on the long traces, see figure 2-2), and scanning only the required number of cardiac cycles.

Let us consider the resolution required of such a system. On microfilm, the 25x reduction in size reduces the longest trace (lead I) to 1/4 inch with a scale factor of one millimeter per second. Since we require 500 samples per second, the scanner resolution must be:

$$r = \frac{\text{1 millimeter/per second}}{\text{500 samples/per second}} = \text{2 microns/per sample.}$$

where r = resolution.

This resolution is not obtainable using available equipment. The TSC device which is discussed later in the appendix can take 2048 samples in 3 inches; giving a resolution of approximately 40 microns/per sample, and which is typical of the state-of-the-art for scanning microdensitometers. If the microfilm is blown up to its original size, the resolution required can be mulitplied by a factor of 25, yielding a required resolution of 50 microns/per sample which is possible.

The advantage of the scanning microdensitometer is that the actual scanning process is completely automatic, eliminating operator error. However, the device cannot discriminate between the various dark lines on the ECG tracing, which can be signal, grid, identification, or stray marks (see section 3.2 below).

Another advantage can be realized if the operating speed of the scanning microdensitometer is relatively slow compared to that of the controlling computer. The computer can then be used to control several units in a time-sharing manner. It may also be possible to have the operator divide his attention between two or more devices.

3.2 PROCESSING OF SCANNER OUTPUT

If the controller can properly regulate the sampling rate, the output of an X-Y digitizer can be used as input into the ECAN-D program with no further processing. For most digitizers surveyed however, the samples are not taken at a uniform rate along one axis (i.e., the time axis); instead, they are taken at a rate which depends on the rate of motion of the cursor. Therefore, an algorithm must be worked out which could convert a set of unevenly spaced time samples to 500 evenly spaced samples per second.

The data from a scanning microdensitometer require more processing because it describes not only the line of the ECG trace, but all the points of the graph. A line-discrimination program must therefore be used to determine which of the digitized points belong to the actual signal. Experimental tests of several line-discrimination techniques on sample data have indicated that it will be necessary to use a more sophisticated pattern-recognition technique. Such a technique is the ADAPT, a clutter subtraction technique,* which treats the scanner data as a signal in which the

*Springfield, F., Avco Systems Division, Wilmington, MA, Personal Communication.

grid can be an easily recognizable noise component to be removed by an advanced form of Fourier filtering. The ADAPT system is a "learning" method; it scans a number of ECG's to recognize and isolate the grid. The system has been applied to other similar problems in extracting signals from background noise.

Since processing of the scanner data can be done off-line, it might be possible to use one computer to process the output of several scanners. This might allow greater efficiency in the scanning operation since the amount of processing necessary at that time could be minimized.

4. DISCUSSION

4.1 POSSIBLE SYSTEMS

In the earlier sections, the technical considerations for various scanner systems have been presented and discussed. As a result of an analysis of these systems, it has become clear that two separate applications must be considered. One involves a system for processing and analyzing current incoming ECG records. Features and costs for this system must be compared, with those of the current practice of manual analysis by FAA cardiologists. The other involves a system for digitizing the ECG microfilm files and storing the computerized analysis in easily retrievable form. In light of these requirements, three possible systems have been proposed and a comparative cost analysis has been performed.

4.1.1 System A

System A has been designed to replace the current manual-screening procedures for reading incoming ECG's. The need for this system will decrease as direct digitizing of the ECG's, using central processing stations increases. System A consists of the following components (figure 4-1): (a) a strip chart reader which optically scans the ECG tracings, removes the grid lines through optical filtering, and produces a digital output comparable to that of the digital ECG carts; (b) a digital formatter and interface; and (c) a magnetic-tape recorder.

An operator will be required to enter the appropriate data from the FAA submission form and to insert the ECG tracings into the machine. It may be possible to reduce the overall cost of the scanning systems by using a single computer to operate several scanners on a time-sharing basis. As mentioned previously use of this system will only be possible if the ECG tracings are recorded on strip charts with specified grid colors.

4.1.2 System B

The primary purpose of System B is to scan, digitize, and analyze the current FAA file of microfilmed ECG's. If the predicted scanning times are achieved, then it is expected that the current file of 1,000,000 records can be processed in a 11-year period (assuming the processing of new records is handled by another system). System B consists of the following components (figure 4-2): (a) computer-controlled film scanner, (b) a display for use by the operator in setting initial conditions, (c) a data-entry and scan-control console, and (d) a digital magnetic-tape deck. The microfilm records will have to be removed from the storage jackets and then enlarged, before scanning.

The overall feasibility for system B can only be determined after the successful demonstration of the software for removal of the microfilm grid lines.

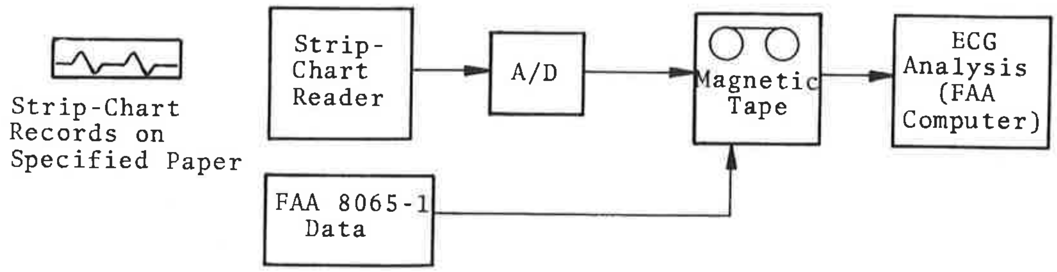
4.1.3 System C

The final system is designed to combine features and components of both system A and system B. Specifically, system C is designed to handle all of the incoming ECG strip charts and a portion of the microfilm records. In addition, system C includes a complete analysis computer which will allow a gradual phase over to use of directly digitized ECG's.

Figure 4-3 indicates the major components required to implement this system. It is expected that the system could be purchased in two phases to allow testing, debugging and validation before making a total commitment. The phase I portion is designed to process up to 15,000 strip charts and 5,000 microfilms each year. Phase II will add the analysis computer and additional strip chart scanners so that all of the strip charts can be digitized.

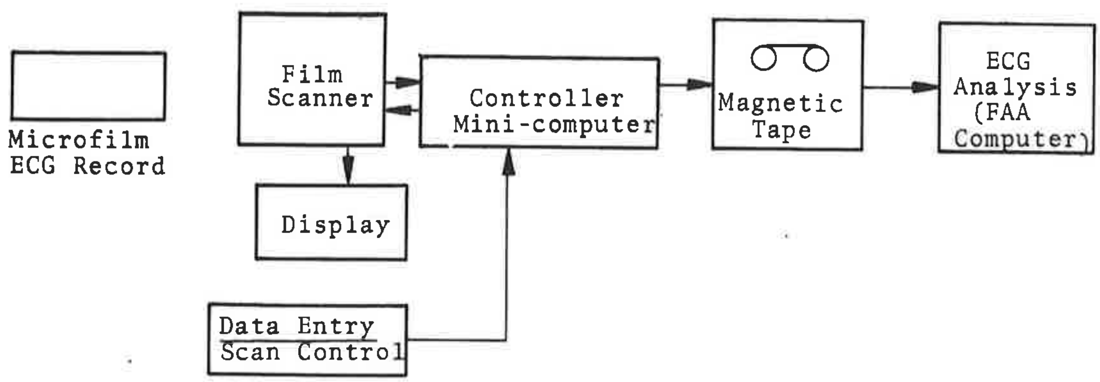
4.1.4 Cost Comparisons

Cost comparisons for the three systems have been prepared for the 1973-1983 time period. These estimates are based on an extrapolation of the projected volume of incoming records as



Scan Time: 5 minutes per ECG
ECG's Scanned per hour: 12
ECG's Scanned per year: 20,000
Operator's Function: Insert chart, enter data from FAA form, Initiate scan.

Figure 4-1. System A - Block Diagram



Scan Time: 5 minutes per frame
Records Scanned per year: 25,000
Systems required for annual rate of 100,000 ECG's: 4
Operator's Function: Insert record, enter data from FAA form, select scan area, align frame, initiate scan

Figure 4-2. System B - Block Diagram

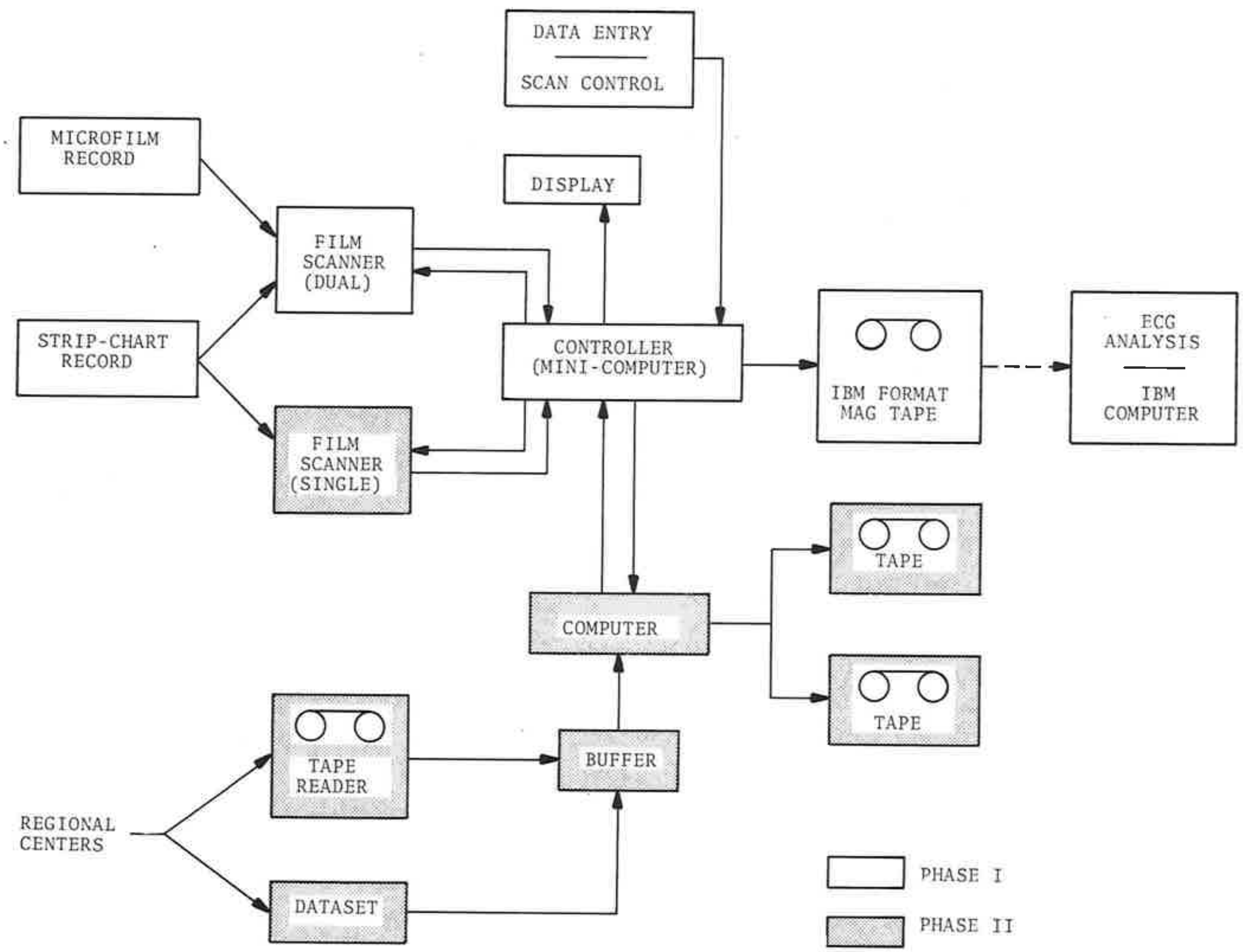


Figure 4-3. System C - Block Diagram

reported by Communications Services, Inc., in their report [1]. Figure 4-4 shows the volume increasing from 34,100 ECG's in 1973 to a projected volume of 84,000 in 1983.

Table 4-1 gives a projection of the costs incurred by the present approach involving the manual screening of ECG's by FAA cardiologists. Since systems A and C are being proposed as possible alternatives to this approach it will be necessary to compare their annual and total costs.

Table 4-2 lists the costs for system A over the same time period. Microfilming costs have been included in the table since these costs are being considered independently of system B. If system B is adopted and the assumption is made that the microfilm file will be abolished, obviously the microfilming of the new records will be unnecessary. System B reduces the total cost by $204,500 and reduces the unit cost to $5.09/per ECG.

Table 4-3 lists the estimated costs for system B for the time period required for digitizing the entire microfilm library. The unit cost of $4.03 per ECG represents the cost for scanning, digitizing, and performing the computer analysis, using the ECAN-D program. However, it does not include the cost of the cardiologists time.

Table 4-4 lists the estimated costs for system C assuming gradual phasing in of directly digitized ECG's (starting in fiscal year 1978).

One factor that is not shown in this analysis is the effect of inactivation of files. If the rate of transfer of files from an active status to an inactive status is 10 percent per year, the total number of files is reduced to 900,000. Thus, the unit cost is raised by 10 percent, unless the scanner-processing speed could be increased from 25,000 to 30,000 ECG per year. At this latter rate, the required number of scanners could be reduced to three, and the unit cost drops to approximately $3.96 per ECG.

TABLE 4-2. SYSTEM A--COST ANALYSIS

ITEM / FISCAL YEAR	73	74	75	76	77	78	79	80	81	82	83	TOTAL
Personnel — MD	30.2	32.0	33.4	35.4	37.5	39.7	42.1	44.6	47.1	49.7	52.5	444
Personnel — ECG Clerks	19.5	20.6	23.7	27.1	32.8	36.9	46.1	58.6	61.9	65.3	69.0	462
Microfilming	10.5	11.6	12.6	14.0	15.4	17.0	18.7	20.5	22.2	24.0	25.8	192
Equipment (filing)	1.3	-	-	5.4	-	-	-	5.4	-	-	-	12
Space	12.2	12.2	12.2	14.0	14.0	14.0	14.0	17.5	17.5	17.5	17.5	163
Computer Analysis/Reporting — Machine Time	28.7	31.1	33.7	36.5	39.6	43.2	47.0	51.2	55.6	59.7	63.3	490
Computer Analysis/Reporting — Personnel	69.8	73.9	74.1	79.6	83.3	88.3	97.1	102.9	108.7	114.7	121.2	1014
Equipment — Scanners(1)	40.0	-	20.0	-	-	-	20.0	-	-	-	20.0	100
Equipment — Storage tapes(2)	8.5	9.4	10.3	11.3	12.5	13.7	15.1	16.6	18.1	19.5	21.0	156
Equipment — Maintenance	1.0	1.0	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.5	18
Equipment — Personnel(3)	16.0	16.0	25.8	27.3	28.8	30.4	40.1	42.4	44.7	47.3	57.9	378
Total(4)	237.7	208.7	247.3	252.1	265.4	284.7	342.2	361.7	377.8	399.7	450.7	3429
Electrocardiograms Processed(5)	34.1	37.5	41.3	45.4	49.4	54.9	60.4	66.4	72.3	78.1	84.0	624

Notes:
(1) 1 scanner per/20,000 ECG's
(2) $0.25/ECG
(3) 1 clerk/per each scanner $80,000
(4) Costs in thousands of dollars
(5) ECG's in thousands processed

TABLE 4-3. SYSTEM B -- COST ANALYSIS

ITEM / FISCAL YEAR	73	74	75	76	77	78	79	80	81	82	83	TOTAL
Personnel[1]												
Analyst	15.0	15.8	-	-	-	-	-	-	-	-	-	31
Operator/Tech	15.0	15.8	16.7	17.7	18.6	19.7	20.8	22.0	23.2	24.5	25.9	220
Clerks	-	32.0	33.8	35.7	37.7	39.8	42.0	44.4	46.8	49.4	52.2	414
Space	-	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	50
Computer Analysis/Reporting												
Machine Time[2]	-	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	700
Personnel[3]		130.0	137.3	145.0	153.1	161.7	170.7	180.3	190.4	201.0	212.3	1682
Equipment Scanners[4]	480.0	-	-	-	-	-	-	-	-	-	-	480
Storage Tapes	-	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	250
Maintenance	-	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	50
Software	55.0	-	-	-	-	-	-	-	-	-	-	55
Preprocessing	-	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	100
Total[5]	565.0	308.6	302.8	313.4	324.4	336.2	348.5	361.7	375.4	389.9	405.4	4031
Electrocardiograms Processed[6]	-	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1000.

Notes:
(1) 1 analyst $15,000
1 operator/technician $15,000
4 clerks $8,000 each
(2) $5,000 for records
$0.70 per ECG for analysis
(3) $30,000 for records
$1,000 ECG for analysis
(4) 4 scanning at $120,000
(5) Costs in thousands of dollars
(6) ECG's in thousands processed

TABLE 4-4. SYSTEM C -- COST ANALYSIS

ITEM / FISCAL YEAR		73	74	75	76	77	78	79	80	81	82	83	TOTAL
Personnel [1]	MD	60.4	64.0	33.4	35.4	37.5	39.7	42.1	44.6	47.1	49.7	52.5	506
	ECG Clerks	19.5	20.7	33.8	35.7	37.7	39.8	42.0	44.4	46.8	49.4	52.2	422
	Operator/Tech		15.8	16.7	17.7	18.6	19.7	20.8	22.0	23.2	24.5	25.9	205
Microfilming		10.5	11.6										22
Filing Equipment		2.0											2
Space		12.2	12.2	17.2	19.0	19.0	19.0	19.0	22.5	22.5	22.5	22.5	208
Computer: Analysis/Reporting													
	Machine Time	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	55
	Personnel	34.9	37.0	37.0	39.3	41.6	44.1	48.5	51.5	54.4	57.4	60.6	506
Equipment	Scanners	120	150										270
	Storage Tapes(2)			4.5	5.0	5.5	7.5	8.0	8.0	8.7	9.3	9.4	66
	Maintenance		1.0	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.5	18
	Software	25											25
Total		289.5	317.3	149.1	158.6	166.4	176.3	187.4	200.0	209.7	219.8	230.6	2305
ECG'S Processed	Incoming Current	34.1	22.5										57
	Sys. C		15.0	41.3	45.4	49.4	22.0	24.2	26.0	28.9	31.2	33.6	317
	Direct						32.9	36.2	39.8	43.4	46.9	50.4	250
	Microfilm		5.0	5.0	5.0	5.0	20.0	20.0	15.0	15.0	15.0	10.0	115

(1) MD: 2 ea-73,74; 1 ea-75 on
Clerk: 2 ea-73, 74; 3 ea-75 on

(2) $0.10/ECG

CURRENT SYSTEM | SYSTEM C 100% | SYSTEM C (40%) DIRECT DIGITIZING (60%) →

Table 4-5 compares the total costs for the current system, system A and system C. The total number of ECG's processed includes both the incoming strip charts (624,300) and a portion of the microfilms (115,000). The unit cost of $3.12 per ECG, though obviously sensitive to changes in the assumptions that have been made, should represent a good comparative estimate. The annual costs for the same three systems are plotted in Figure 4-5. The lower costs for system C (after initial hardware procurement) are due to the reduction of personnel required during the later years (compared to the current system) and to the use of a self-contained analysis computer (compared to system A).

TABLE 4.5. TOTAL COST COMPARISON FOR 1973-1983 PERIOD

	CURRENT INPUT		CURRENT FILES
	PRESENT SYSTEM	SYSTEM A	SYSTEM B
	(costs in $K)		(costs in $K)
Capital Equipment	12	112	480
Personnel	2059	1283	2346
Computer Analysis	55	490	770
Other	353	1497	435
Total Costs	2479	3429	4031
Average Cost Per Year	225	312	366
Electrocardiograms Processed (total)	624,300	624,300	1,000.000
Unit Cost ($Per ECG)	$ 3.97	$ 5.54	$ 4.03

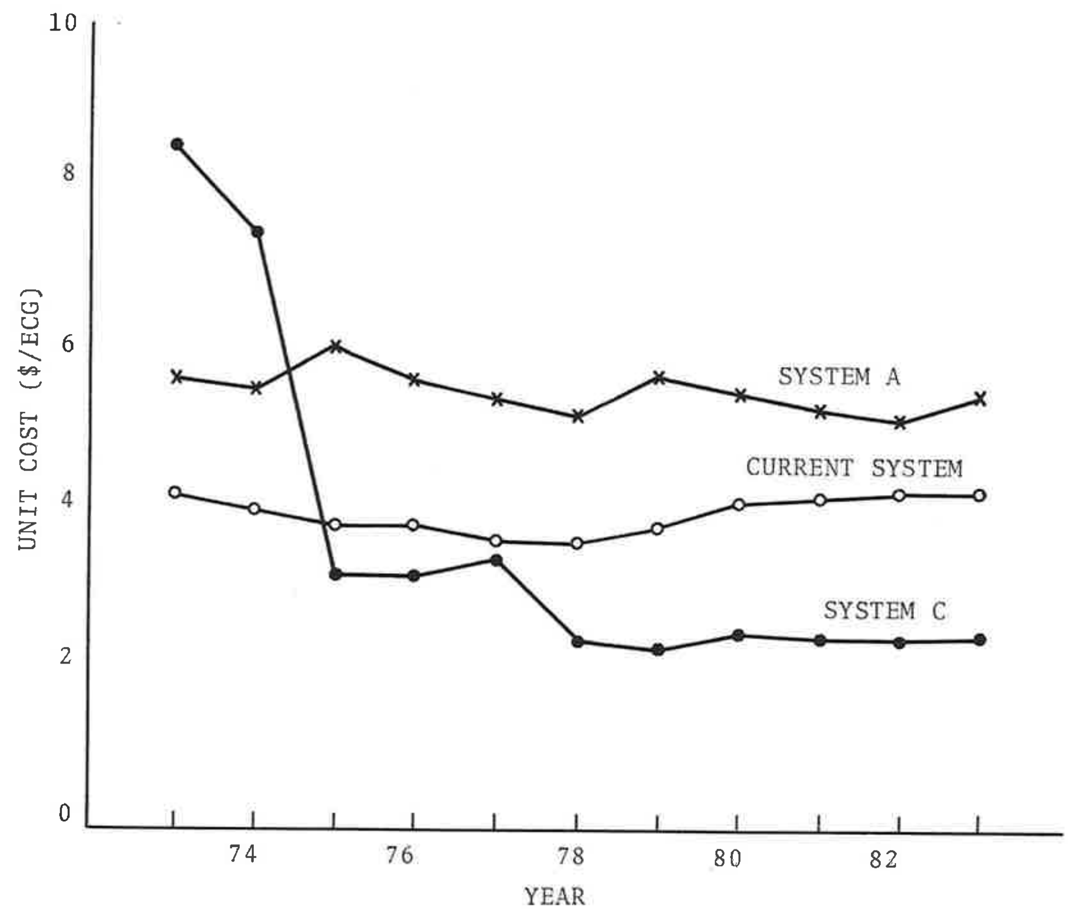


Figure 4-5. Cost Comparison

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APPENDIX

TRANSPORTATION SYSTEMS CENTER (TSC) OPTICAL SCANNER

A.1 OPTICAL SCANNING SYSTEM

To perform preliminary studies of the feasibility of optical scanning for the digitization of the ECG microfilms, a flying spot scanner was constructed at TSC. This scanner has a 2048x2048 spot resolution. In use, it can differentiate 64 gray levels. The scanner is connected to a Honeywell 516 computer with 32K 16-bit memory, which uses a high-storage-capacity disk-operating system. Accordingly, a complete image may be stored digitally where it can then be processed conveniently, using Fortran programming.

A.1.1 <u>Flying Spot-Scanner Design Details</u>

Before beginning this project, TSC had an Electronic Image-Systems display interfaced to the 516 computer. This device accepts X, Y, Z information (Z being light intensity) from the computer, and prints this as a point on Polaroid film, by illuminating with the light from a high-resolution cathode-ray tube (CRT). Originally, this device was used to display a digitally stored image in a form convenient for viewing.

If the Polaroid film is replaced with a transparency, and if a constant gray level is generated by the computer, the light from the CRT passing through the transparency is proportional to the optical density at the particular location where the beam falls. Therefore, if a detector is placed to receive the transmitted light, and the output of this detector is fed back into the computer, the image contained on the transparency can be digitized.

Four photomultiplier tubes are used as detectors. Their output is fed to a high-speed analog integrator which determines the total amount of light transmitted during the time the CRT beam is on. When the CRT completes its cycle, the integrator output is held constant, while a moderate-speed analog-to-digital converter digitizes the intensity integral. A simple interface

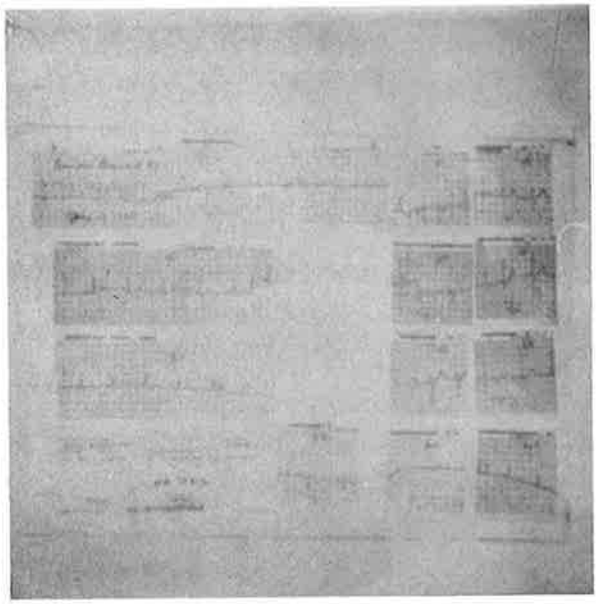

Figure A-3. Defocused ECG Image

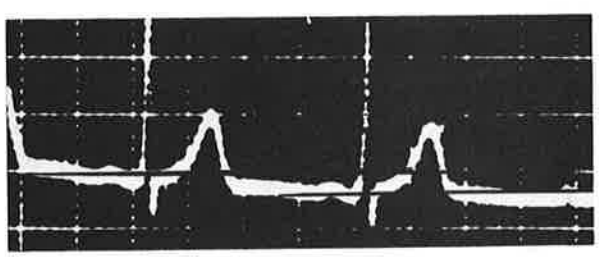

Figure A-4. Grid Line Detection

A.2.4.1 Grid-frequency detection - The grid-freqeuncy detection technique relies on the identification of the characteristic frequencies of the X and Y grids during scans made of the grid pattern alone. This characteristic spatial frequency is then used to remove information from the photograph, resulting in a processed image containing only the ECG trace.

A.2.4.2 Grid-pattern recognition - The grid-pattern recognition approach, uses a group of characteristic descriptors of both the data and the background noise (grid lines) which can be made to provide unique separation. One technique in this class involves taking the Fourier transform of the spatially distributed data and operating on it in frequency space. Although theoretically possible, this approach is impracticable because of the length of time and the large computational requirements associated with the process.

A.2.4.3 Optical Fourier processing - It is possible, however, to perform the required two-dimensional Fourier transform mentioned above using optical spatial-filtering techniques. During this process, the microfilm will be put in an optical preprocessor for removal of the grid lines before insertion in a scanner. The cost of this system would be alone equal to the cost of software development for the preceding two classes of techniques.