Cost of Managing Digital Diagnostic Images for a 614-Bed Hospital

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The cost of recording and archiving digital diagnostic imaging data is presented for a Radiology Department serving a 614 bed University-Hospital with a large outpatient population. Digital diagnostic imaging modalities include computed tomography, nuclear medicine, ultrasound, and digital radiography. The archiving media include multiformat video film recordings, magnetic tapes, and disc storage. The estimated cost per patient for the archiving of digital diagnostic imaging data is presented.

INTRODUCTION

RADIOLOGISTS HAVE ADDED digital diagnostic imaging systems to their armamentarium of diagnostic equipment. These digital imaging systems provide for the acquisition, display, manipulation, and archiving of diagnostic data. Digital images utilized for diagnosis are obtained from the following: (a) computed tomography (CT) scanners for both head and body; (b) nuclear medicine gamma cameras; (c) ultrasound scanners equipped with digital display capabilities; (d) digital radiography (DR) and digital fluoroscopy systems; and (e) other new imaging systems such as the whole body nuclear magnetic resonance (NMR) scanners. The archiving of these digital images has already become a major information management problem. As diagnostic imaging instrumentation continues to shift from the standard radiographic analog film recordings to those of digital acquisition systems, the problem of efficiently archiving digital diagnostic imaging data will grow. The purpose of this paper is: (1) to estimate the amount of digital diagnostic imaging data requiring

management; (2) to estimate the cost of managing digital diagnostic imaging data; and (3) to identify several technologies which over the next few years will influence the cost of the archiving problem.

THE AMOUNT OF DIGITAL DIAGNOSTIC IMAGING DATA

The examinations which generate digital diagnostic imaging data are shown in Table 1. Each imaging modality is identified by a row in Table 1. Using Table 1, it is estimated that somewhere between 254.8 Megabytes and 502.7 Megabytes of digital diagnostic imaging data will be generated and archived each working day. Archiving this amount of digital data is a significant problem. Two technologies are now used for efficiently managing this data. First, standard computer peripheral devices are used such as magnetic discs and magnetic tapes. Second, raster gray scale multiformat video film recorders are used to generate film recordings of the raster displayed digital images.

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Table 1. The Amount of Digital Diagnostic Imaging Data Generated by a Radiology Department Servicing a 614 Bed Hospital Population Group

Imaging Device	Number of Patients Per Day	Number of Images Per Patient	Record Size of Each Image	Number of Bytes Generated Per Working Day
Body CT Examinations	10 to 13	20 to 40	90,000 pixels; 2 Bytes per pixel; patient identification block of 1024 Bytes; 512 Bytes for each image	$36.1 \times 106 \text{ Bytes to } 93.9 \times 106 \text{ Bytes}$
Head CT Examinations	12 to 15	16 to 20	Same as Body CT Exam	$34.6 \times 106 \text{ Bytes to } 54.1 \times 106 \text{ Bytes}$
Nuclear Medicine Examinations (4 gamma Cameras)	28 to 42	7 to 10	128 x 128 pixel array; 2 Bytes per pixel; patient identification block of 1024 Bytes	$6.45 \times 106 \text{ Bytes to } 13.8 \times 106 \text{ Bytes}$
Ultrasound Examinations (3 Ultrasound Units)	15 to 20	30 to 42	512 x 512 pixel array; 1 Byte per pixel; patient identification block of 1024 Bytes	$117.9 \times 106 \text{ Bytes to } 220.2 \times 106 \text{ Bytes}$
Estimated Digital Radiography Examinations	10 to 15	12 to 16	512 x 512 pixel array; 2 Bytes per pixel; patient identification	$62.9 \times 106 \text{ Bytes to } 125.8 \times 106 \text{ Bytes}$

UTILIZATION OF DIGITAL DIAGNOSTIC IMAGING DATA

The demands for digital diagnostic imaging data are characterized by at least three successive time intervals as shown in Table 2.

The initial time interval is used for conducting the patient's examinations and generating the consulting report. This is a period of high intradepartmental activity. The Department's management strategy is stressed by multiple examinations and geographically separated imaging systems. A diagnostic imaging modality is ordered and a set of digital images is generated. These digital images are displayed on an interactive raster graphics display terminal. They are then properly reviewed and recorded on film by a multiformat video film recorder. The multiformat video film recordings of the digital images are then used by the radiologist in preparing the consultation report. These film recordings are subsequently placed in the patient's film jacket. If more than one diagnostic imaging modality is used, then the additional diagnostic information is integrated into the consultation report. The patient's film jacket provides an archiving method for storing and retrieving multiformat video film recordings of the raster displayed digital images. The digital data are also archived on computer magnetic tapes or discs. An average of 4 to 6 requests may be made during this time interval for the patient's film jacket. These requests may originate from intradepartment activities, from hospital inpatient areas, or from outpatient clinics,

The second time interval for demands upon the digital diagnostic imaging data occurs during the time the patient is in the hospital. This demand utilization time interval is characterized by variable, on-demand storage and retrieval. Access to the archived diagnostic digital images is required for consultation purposes, for patient treatment planning, and for teaching functions. Access to the patient's film jacket is sequential, allowing only one user at a time. An active case may receive an average of 10 requests during the first 10 days.

The third time interval is the long term archiving interval. Diagnostic images are required for scheduled outpatient clinics, for

Table 2. Demand Utilization Time Intervals for Digital Diagnostic Imaging Data

Time Interval	Characteristics
Initial Time Interval	Production of images from a single diagnostic modality; single modality diagnosis; integration of image information from more than one diagnostic modality
Patient Stay in Hospital	Variable on demand storage and retrieval
Long Term Archiving	Long term storage and retrieval

monitoring long term treatments, and for studies in disease progression or remission. An active case will receive 4 requests for the first two month period, 2 requests during the next ten months and 2 requests the following twelve months.

**THE COST OF ARCHIVING DIGITAL
DIAGNOSTIC IMAGING DATA
COST OF USING MULTIFORMAT
VIDEO FILM RECORDERS**

The estimated costs for generating and archiving multiformat video film recordings of digital diagnostic imaging data are provided in Table 3. The CT multiformat video film recorders are used for CT body, CT head, and digital radiography examinations. These recorders use 14 × 17 inch sheets of radiographic film. They are capable of recording 11 images plus an identification block on each sheet of film. The multiformat film recorders used for recording ultrasound and nuclear medicine examinations use 8 × 10 inch sheets of film. They record 16 images per sheet for nuclear medicine examinations and 6 images per sheet for ultrasound.

The cost per patient calculated for CT multiformat video film generation shown in Table 3 is based on the following costs: (a) \$30,000 for a CT multiformat video film recorder, prorated over 5 years plus 10% maintenance cost per year; (b) \$9,945 for a Kodak M7B film processor, prorated over 5 years plus 10% maintenance cost per year; (c) \$2.81 cost per sheet of 14 × 17 inch film; (d) \$0.15 chemical cost for processing each sheet of film; (e) 5 minutes of labor cost for film cassette loading and devel-

oping each sheet of film at \$3.50 per hour. This per patient cost does not include the use of conventional viewboxes. Nor does this per patient cost include the required radiologist's time for selecting the proper window and width level parameters required prior to exposing the multiformat video film recordings.

The cost per patient calculated for nuclear medicine and ultrasound multiformat video film generation shown in Table 3 is based on the following costs: (a) \$8,000 for each nuclear medicine or ultrasound multiformat video film recorder, prorated over 5 years plus 10% maintenance cost per year; (b) \$9,945 for a Kodak M7B film processor, prorated over 5 years plus 10% maintenance cost per year; (c) \$0.99 cost per sheet of 8 × 10 inch film; (d) \$0.08 chemical cost for processing each sheet of film; (e) 5 minutes of labor cost for film cassette loading and developing each sheet of film at \$3.50 per hour. This per patient cost does not include use of the standard viewing system nor the time required to properly adjust the display parameters prior to exposing film in the multiformat video film recorder.

The cost per patient calculated for digital radiography multiformat video film generation shown in Table 3 is similar to the calculations for CT body and head examinations.

The cost per patient calculated for video film archiving shown in Table 3 is based on the following labor costs for patient jacket archiving at \$4.25 per hour: (a) ten requests for film jackets for the first ten days, each requiring 5 minutes from a fast access film file; (b) 4 requests for film jackets for the following two months, each requiring 10 minutes for service; (c) 2 requests for the following ten months, each requiring 10 minutes for service; and (d) 2 requests for the remaining twelve months, each requiring 10 minutes for servicing.

The estimated cost for a 614 bed hospital for generating and archiving multiformat video film recordings for CT, nuclear medicine, ultrasound, and digital radiography will be between \$497,390 and \$697,700 per year. This cost is based upon 250 working days per year. Between 41,750 and 70,250 sheets of various size multiformat film will be generated and require storage space in the patient film jackets in the film file room.

Table 3. The Cost of Utilizing Multiformat Video Film Recordings for Archiving Digital Diagnostic Images

Imaging Device	Number of Film Sheets Recorded Per Patient	Cost of Video, Film Generation Per Patient	Cost of Video Film Archiving Per Patient for 2 Years
Body CT Examinations	2 to 3 sheets of 14 × 17 inch film	\$14.55 to 10.19	\$18.47
Head CT Examinations	2 sheets of 14 × 17 inch film	\$10.50 to 9.70	\$18.47
Nuclear Medicine Examinations (4 Gamma Cameras)	1 sheet of 8 × 10 inch film	\$2.95 to 4.11	\$18.47
Ultrasound Examinations (3 Ultrasound Units)	5 to 7 sheets of 8 × 10 inch film	\$12.25 to 8.85	\$18.47
Estimated Digital Radiography Examinations	2 sheets of 8 × 10 inch film	\$11.30 to 9.70	\$18.47

COST OF USING STANDARD COMPUTER PERIPHERAL DEVICES

The estimated costs for generating and archiving digital diagnostic imaging data on magnetic tape and magnetic discs are provided in Table 4. Each reel of magnetic tape is assumed to be 2400 feet long and read/write at 800 Bytes per inch. One reel of magnetic tape can store 21 Megabytes of digital data. The required amount of digital diagnostic imaging data to be archived on magnetic tape is provided in Table 1. It is assumed that the magnetic tapes will be removed from the tape drives at the end of each working day. The required number of tapes as calculated in Table A are taken to be the next higher integer value.

The cost per patient calculated for CT generation of magnetic tapes shown in Table 4 is based on the following costs: (a) \$14 cost per reel of 2400 feet of magnetic tape; (b) 15 minutes of labor cost, at \$3.50 per hour, to load each magnetic tape from the CT scanner; (c) 50 minutes of labor per day, at \$5.50 per hour, to transfer recorded magnetic tapes to the storage area; and (d) 20 minutes of labor per day to record tape archiving numbers and patient examination information in a notebook log. This cost per patient does not include a digital tape drive since the CT scanner system is already equipped with one.

The calculated cost per patient for generation of magnetic tapes for nuclear medicine examinations as shown in Table 4 is based on the following costs: (a) \$15,000 for a magnetic tape drive to archive diagnostic images, prorated over 5 years plus a 10% per year maintenance cost; (b) \$14 cost per reel of 2400 feet of mag-

netic tape; (c) \$5.50 per hour labor cost, 15 minutes of labor cost to load magnetic tape from nuclear medicine systems, 50 minutes of labor cost to transfer magnetic tape to storage area, and 20 minutes of labor to record the tape acquisition number and patient examination information in a notebook log.

The calculated cost per patient for generation of magnetic tapes for ultrasound examinations as shown in Table 4 is based on the following costs: (a) \$11,000 for the cost of two disc storage drives for temporarily acquiring the diagnostic images, prorated over 5 years plus a 10% per year maintenance cost; (b) \$15,000 cost of magnetic tape drive for archiving diagnostic images from the two disc storage devices, prorated over 5 years plus a 10% per year maintenance cost; (c) \$14 cost per reel of 2400 feet of magnetic tapes; (d) at \$5.50 per hour labor cost, 15 minutes of labor cost to load each magnetic tape from the two disc storage devices, 50 minutes of labor cost to transfer magnetic tapes to storage area, and 20 minutes per day of labor cost to record magnetic tape archiving numbers and patient examination information in a notebook log.

The calculated cost per patient for digital radiography generation of magnetic tapes is similar to that of CT body and head examinations. The estimated cost per patient for each retrieval from magnetic tape as shown in Table 4 is based on the following factors: (a) due to the extensive use of multiformat film recordings stored in the patient's film jacket, it is estimated that only 10% of patient examinations will have magnetic tapes retrieved; (b) one-quarter of the retrieved magnetic tapes will be copied at a cost of \$14 per reel of magnetic tape; (c) at \$5.50 per hour labor costs, 50 minutes to retrieve mag-

Table 4. The Cost of Utilizing Standard Computer Peripheral Storage Devices for Archiving Digital Diagnostic Imaging Data

Imaging Device	Number of Magnetic Tapes Required Per Day	Cost Per Patient for Generation of Magnetic Tapes	Cost Per Patient For Magnetic Tape Retrieval	Cost Per Patient for 5-day online Disc Storage
Body CT Examinations	2 reels to 5 reels	\$3.27 to 5.95	\$0.809	\$3.79 to 7.36
Head CT Examinations	2 reels to 3 reels	\$2.72 to 3.17	\$0.809	\$3.04 to 3.73
Nuclear Medicine Examinations	1 reel	\$3.13 to 2.09	\$0.809	\$0.25 to 0.27
Ultrasound Examinations	6 reels to 11 reels	\$8.22 to 9.89	\$0.809	\$7.98 to 11.10
Estimated Digital Radiography Examinations	3 reels to 6 reels	\$4.75 to 6.14	\$0.809	\$6.47 to 8.51

netic tape from storage area, 15 minutes to load magnetic tape into display system, and 50 minutes to return tape to storage area.

The estimated cost for a 614 bed hospital for generating and archiving magnetic tapes recorded at 800 Bytes per inch for CT, nuclear medicine, ultrasound, and digital radiography will cost between \$92,150 to \$159,115 per year. This cost may be reduced by recording at higher data densities and employing a two-to-one data compression algorithm.¹

It is important to consider the cost of providing on-line disc storage and retrieval of the digital diagnostic images. The estimated cost per patient for a 5-day on-line disc storage as shown in Table 4 is calculated on the basis of the following costs: (a) each disc storage device costs \$5,500 for 55 Megabytes of storage, prorated over 5 years plus a 10% per year maintenance cost; (b) each imaging modality is provided with enough disc storage devices to hold 5 working days of digital data storage; (c) 50 minutes per day to transfer image data onto disc storage devices, at \$5.50 per hour labor costs. After 5 working days of on-line storage, the diagnostic images are down-loaded onto magnetic tape for archiving.

The estimated cost for a 614 bed hospital for generating and archiving multiformat film recordings, magnetic tapes and a 5-day on-line disc storage for on-demand electronic viewing will cost between \$655,865 to \$965,095 per year. The number of magnetic tapes generated per year will be between 5,750 to 6,750 reels. The number of various size multiformat video recorded sheets of film will be between 41,750 to 70,250. This archiving strategy cost is partitioned into 74% for multiformat video film archiving, 14% for magnetic tape archiving, and 12% for a 5-day on-line disc storage system.

DIGITAL STORAGE DEVICES WHICH WILL INFLUENCE ARCHIVAL STRATEGIES

One of the technologies which could significantly alter archival strategies in the future is the combined use of a higher density tape drive and a data compression method. If the current 800 Bytes per inch (BPI) tape drives were to be replaced with a switchable 800 BPI/1600 BPI tape drive, then only one-half the number of required magnetic tapes would be needed. Further cost reduction for magnetic tape archiving is possible if a 3200 BPI tape drive is used. However, all previously recorded 800 BPI magnetic tapes would have to be written at the higher density.

Any technology or archival strategy which could reduce the number of multiformat video film recordings could have a significant impact upon the cost of archiving. One technology which might reduce the cost of video film recordings is the use of a dry silver paper video recorder.² Another technology which would reduce video film recordings is to use a laser film recorder^{3,4} for recording the full dynamic range of the digital diagnostic data. Such a device would enable the digital diagnostic data to be recorded on a small film strip and then retrieved with inexpensive readers placed throughout the hospital.

Cost reduction in the long-term archiving of digital diagnostic imaging data could be achieved with the use of an optical disc.⁵ The projected storage cost range for this device is about one microcent per bit or one-tenth the cost of magnetic tape.⁶

SUMMARY

The estimated amount of digital diagnostic imaging data requiring management for a Ra-

diology Department servicing a 614 bed hospital population is between 255 Megabytes and 500 Megabytes per working day. It is projected that this amount of data is increasing between 10% to 15% per year. Within a few years one-half of the diagnostic examinations will be generated with digital acquisition systems. It is estimated that the current archiving strategy of digital diagnostic imaging data costs between \$413,705 to \$625,148 per year. This management strategy is based on using multiformat films and magnetic tapes for CT data and only multiformat films for nuclear medicine and ultrasound examinations. This cost will increase as the use of digital radiography becomes widespread. The estimated cost for archiving all digital diagnostic imaging examinations on multiformat film, magnetic tape and a 5-day on-line disc storage system will cost between \$655,865 to \$965,093 per year for a 614 bed hospital. Between 3,750 to 6,760 magnetic tapes recorded at 800 BPI will be generated each year.

Between 41,750 to 70,250 sheets of various sizes multiformat video film recording will be generated and archived into patient film jackets.

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