Large Picture Archiving and Communication Systems of the World—Part 2

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A survey of 82 institutions worldwide was done in 1995 to identify large picture archiving and communication systems (PACS) in clinical operation. A continuing strong trend toward the creation and operation of large PACS was identified. In the 15 months since the first such survey the number of clinical large PACS went from 13 to 23, almost a doubling in that short interval. New systems were added in Asia, Europe, and North America. A strong move to primary interpretation from soft copy was identified, and filmless radiology has become a reality. Workstations for interpretation reside mainly within radiology, but one-third of reporting PACS have more than 20 workstations outside of radiology. Fiber distributed data interface networks were the most numerous, but a variety of networks was reported to be in use. Replies on various display times showed surprisingly good, albeit diverse, speeds. The planned archive length of many systems was 60 months, with usually more than 1 year of data on-line. The main large archive and off-line storage media for these systems were optical disks and magneto-optical disks. Compression was not used before interpretation in most cases, but many systems used 2.5:1 compression for on-line, interpreted cases and 10:1 compression for longer-term archiving. A move to digital imaging and communication in medicine interface usage was identified.

KEY WORDS: computers, radiology, picture archiving and communication systems (PACS), survey.

PART I of this two part series[1] reported the major findings of the 1995 worldwide survey of 82 institutions done to identify large-scale picture archiving and communication systems (PACS). The number of clinical large PACS went from 13 to 23 in a 15-month period.[2]

This second report from the same survey describes various technical features reported by the 61 institutions who responded to the survey. Some 23 institutions have large PACS by the survey criteria: daily clinical operation, three or more modalities on the PACS, terminals inside and outside of radiology, and a minimum of 20,000 examinations handled on the PACS annually.

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MATERIALS AND METHODS

A two-page survey form was sent by facsimile or mail to 82 institutions thought to have large PACS as of February 1, 1995. Survey questions covered a wide range of topics, as detailed in Part 1 of the report.[1]

Responses on several technical matters are reported here for the first time.

RESULTS

Institutional Bed Size

Table 1 shows the reported institutional bed sizes.

Workstation Distribution

Table 2 shows the range and average number of workstations reported inside of and outside of Radiology.

Network Information

The question about the network protocol was interpreted differently by some respondents. Responses included Transmission Control Protocol/Internet Protocol (TCP/IP), fiber distributed data interface (FDDI), PACS-net, and asynchronous transfer mode (ATM). TCP/IP seems to be the predominant protocol.

The responses to the question about network speed were 15 with 100 Mbits/sec (usually FDDI), 2 with 10 Mbits/sec Ethernet, 1 with 80 Mbits/sec Token Ring, 1 with 155 Mbits/sec ATM, and 4 without information.

Display Times

Image transmission times from a request at a workstation until the image is displayed on it were subdivided into (1) frame buffer memory to display, (2) local workstation disk to display, and (3) remote disk storage to display.

Within each of these categories the time to retrieve and display a 1,000 × 1,000 matrix × 8 bit image, a 1,000 × 1,000 matrix × 12-bit image and a 2,000 × 2,000 matrix × 12-bit image was

Table 1. No. of Beds at Large PACS Institutions

Facilities	No. of Beds
Asia	
Osaka University Hospital	1,116
Toshiba Hospital	310
Samsung Medical Center	650
Hokkaido University Hospital	875
Europe	
University Hospital of Geneva	1,600
University Hospital Graz	2,470
Viborg County Hospital	400
Conquest Hospital	400
Free University of Brussels, PRIMIS	700
Danube Hospital, SMZO	850
North America	
Baltimore VA Medical Center	280
Wright Patterson AFB Medical Center	301
The Credit Valley Hospital	360
Brooke Army Medical Center	450
University of Florida	570
Madigan Army Medical Center	600
UCLA Health Sciences Center	600
University of Virginia	620
Brigham & Women's Hospital	702
Hospital of the University of Pennsylvania	772
University of Pittsburgh	800
Houston VA Medical Center Hospital	850
University of California San Francisco	925

Abbreviations: VA, Veterans Administration; UCLA, University of California at Los Angeles; PRIMIS, Pluridisciplinary for Research in Diagnostic Imaging Systems; SMZO, Social medizinisches Zentrum Ost; AFB, Air Force Base.

asked. Because there were almost no differences in the 8- and 12-bit transfer times for the 1,000-class matrix images, they are shown together in Table 3.

Archive and Disk Capacity

Optical disks (ODs) in 15 installations and magneto-optical disks (MODs) in 5 installations are used as off-line storage media. The reported storage capacity of an OD varied between 0.6 and 10 Gbytes per disk with 10 different values given. The same is true with MODs, which range between 0.5 and 10 Gbyte/disk. OD jukeboxes have a capacity of between 76 and 2,400 Gbytes with an average of 786 Gbytes (6 of the 15 installations with OD jukeboxes have 1,000 or more Gbytes). In addition, four MOD jukeboxes with capacities of 20, 40, 60, and 1,000 Gbytes and two helical scan jukeboxes with 50 and 100 Gbytes are in use. Concerning magnetic disk storage, there are several larger ones with 35, 40, 70, and 200 Gbytes; the rest are between 1 and 18 Gbytes (with an average of 8.4 Gbytes).

Another question asked for the size of the magnetic disk storage on diagnostic workstations. The responses fall into three groups: 80 to 160 Mbytes (5 installations), 1,000 Mbytes (6 installations) and 2,000 to 6,000 Mbytes (10 installations). Disk space on review stations is more limited: 4 installations with 80 Mbytes, 6 with 200 to 700 Mbytes, 7 with 1,000 to 2,000 Mbytes and 1 with diskless review stations.

Table 2. Number of Workstations Reported

	In Radiology			Outside of Radiology		
	Range			Range		
	From	To	Mean	From	To	Mean
Interpetation	0	16	6	0	30	3
Review	0	12	3	0	93	16
Combined	3	17	9	—	—	—

Data Compression

The responses on the compression ratios employed before interpretation are shown in Table 4 for on-line and for long-term archiving.

Interfaces to Image Acquisition Devices

The data reported for DICOM and other digital interfaces is shown in Table 5. The reporting of analog interfaces was incomplete but included digital fluoroscopy, nuclear medicine, and ultrasound interfaces. Reporting of devices without interfaces is definitely incomplete, so it is not possible to give the distribution of all interfaced and noninterfaced devices.

Images per Study

The answers to this question are summarized in Table 6. They refer not only to large PACS, but to all 37 responding PACS installations. Three other modalities were also reported to be interfaced with a PACS: digital cardiology with 250 images per examination, mammography with 6 images per examination (analog interface to PACS) and a cineradiography system with a digital interface and an average of 200 seconds per patient.

DISCUSSION

Institutional Bed Size

The number of beds of the hospitals with large PACS varies between 280 and 2,500 with

Table 3. Reported Display Times (sec)

		1,000 × 1,000 Matrix Display				2,000 × 2,000 Matrix Display			
		Range		Adjusted		Range		Adjusted	
To Display From	N	From	To	Mean	Mean	From	To	Mean	Mean
Frame buffer	14	0.5	5	1.5	1.1	0.1	11	2.2	1.23
WS disk	14	0.1	10	3.2	—	1	10	4	—
Remote disk									
Group 1	6	2.8	5	—	—	2.8	25	—	—
Group 2	14	20-100	6,000	—	—	—	—	—	—

an average of 760. It is interesting to note the geographical distribution. In Europe the average is 1,075, in Asia 840 and in the United States 540. The mix of in-patient bed types included is not known, as no breakdown on chronic, acute, or other bed types was asked.

Workstation Distribution

About one-third of the hospitals have more than 20 workstations for review outside of Radiology. This supports an important trend that is strongly linked to economic savings by PACS—namely, that departments outside of Radiology need ready access to images and reports on electronic displays if faster communication and filmless operation are to be realized.

For both the interpretation and the review types of workstations outside of Radiology the distribution among the hospitals is skewed. Concerning workstations for interpretation 14 of the 23 large PACS have none at all outside of radiology, and only two hospitals (one in Japan, one in the United States with 16 and 30, respectively) account for 70% of the total.

With the trend toward primary interpretation from the PACS display (22 institutions) it is of high interest to know how many studies of the various types can be interpreted per workstation. Unfortunately, the data available provides no clear pattern to help with that question. Only three of the institutions reported 100% soft copy primary interpretation (with the exception of mammography). Of interest is that there is one large PACS that does no interpretation at all from soft copy.

Table 4. Data Compression Ratios

Compression Ratio	Before Interpretation	Other On-Line Use	Long-Term Archive
None (1:1)	12	8	6
2:1	6	6	—
2.1-2.7:1	—	2	8
3:1	—	1	3
5:1	—	—	1
8:1	—	1	—
10:1	1	1	7

Network Information

The sustained mean transfer rate under full-load question returned diverse results. The two Ethernets reported a mean transfer rate of 6 Mbits/sec; the 80 Mbits/sec Token Ring, a mean rate of 50 Mbits/sec; and the 155 Mbits/sec ATM, a mean rate of 1.5 Mbytes/sec (ca. 12 Mbits/sec). For FDDI (100 Mbits/sec) the reported mean transfer rates varied widely; 3 between 10 and 12.5 Mbits/sec, one with 33 Mbits/sec, 1 with 82 Mbits/sec and 1 with 100 Mbits/sec sustained mean rate were reported. (The latter value is probably the theoretical rather than an actual rate.) Incidentally, three institutions using the same commercial system answering this question reported different sustained mean rates, possibly an inadvertent error in measurement or reporting.

The answers to the network questions show a limitation of technical surveys. To get a high response rate, the questionnaire can be neither too detailed nor too technical. Conversely this can result in ambiguities that make data interpretation difficult if not impossible. In addition,

Table 5. Digital Interfaces

Modality	DICOM Interface	Other Digital Interface
CR	5	49
CT	25	26
DA	—	19
DF	—	15
MR	24	16
NM	3	30
US	17	30

Abbreviations: CR, computed radiology; DA, digital angiography; DF, digital fluorography; MR, magnetic resonance; NM, nuclear medicine; US, ultrasound.

Table 6. Images per Study

Modalities	No. of Respondents	Range from	Range to	Average	Median	Remarks
CR	23	1	15	2.73	2	Two outlies with 6 and 15, leaving them out (range: 1-32; average: 2.0)
CT	24	4	120	41	36.1	Taking only large PACS, the upper bound would be 60, average 33. There is one installation with only 4 images per CT. Without them, the lower bound would be 22. Nineteen installations within 22 and 40
DA	16	5	120	30.4	20	Fourteen installations between 10 and 60 (average: 25.8)
DF	11	10	60	19.5	14	One outlier with 60 (without it, range: 10-25; average: 15.4)
MR	20	9	600	104.2	77.5	Omit two outliers on the low end (9 and 12) and one at the upper end (600) (range: 35-120; average: 86.1)
NM	14	2	20	8.2	7.5	No outliers; relatively homogeneous distribution
US	21	4	40	18.9	16.5	No outliers

Abbreviations: CR, computed radiology; CT, computed tomography; DA, digital angiography; DF, digital fluorography; MR, magnetic resonance; NM, nuclear medicine; US, ultrasound.

as PACS have moved from research and development projects to commercial products, end users have become less interested in technical details.

At the time of the survey, FDDI was the leading network hardware and protocol supported by the main vendors (probably mostly as a backbone in connection with Ethernet and TCP/IP).

The reported mean transfer rates with full load are so diverse that evidently the definitions or interpretations or measuring methods were not comparable.

Display Times

For the times from frame buffer memory to display the three highest values reported may be due to an error as they have longer or equal display times than for local workstation disk to display. If these three values are omitted, the adjusted mean is 1.1 seconds for the display of a 1,000 × 1,000 image. The average for 2,000 × 2,000 images is 2.2 seconds (or 1.23 seconds if the upper outliers are omitted for the same reason).

Most of the display times from the frame buffer are between 1 and 2 seconds; sufficient for most purposes except for smooth scrolling. A few installations (6 out of 23) claim display times between 0.1 and 0.5 seconds. All the systems with 100% primary interpretation from workstations have short frame buffer to display times (between 0.1 to 1 second). Surprisingly, the differences between the display time from the frame buffer and from the local disk are relatively small. (It might also be that times below 1 second are difficult to measure, and that the 1 second display time frequently given is a rough guess.)

Nine installations reported display times of more than 2 seconds for 1,000 × 1,000 images from local disk. To allow for smooth reporting, this would require prefetching mechanisms from disk to the frame buffer for examinations with multiple slices.

The delay from remote disk storage (archive) to display is for the most part too long for direct requests from the workstation by a radiologist except for examinations with only a few images. Especially in the case of jukeboxes the image transport to the workstation must be organized as a background prefetch process.

The transfer times from remote disk storage to display fall into two groups as shown in Table 3. The first group probably uses remote magnetic disk, and the second one probably uses jukeboxes with optical or MOD disks. The single report of a time of 6,000 seconds might include fetching of off-line disks.

Archive and Disk Capacity

ODs and, to a lesser extent, MODs are presently the standard devices for long-term archiving with jukeboxes in the Tbyte range for these operational systems. The many different capacities for disks suggest a weak point; the technology is reliable but not yet stable. Enhanced recording densities and formats entering the market may mean that the disks of the image archives might need to be recopied, because the drives to read them will disappear even if the medium itself remains unchanged and readable. The problem also arises if one

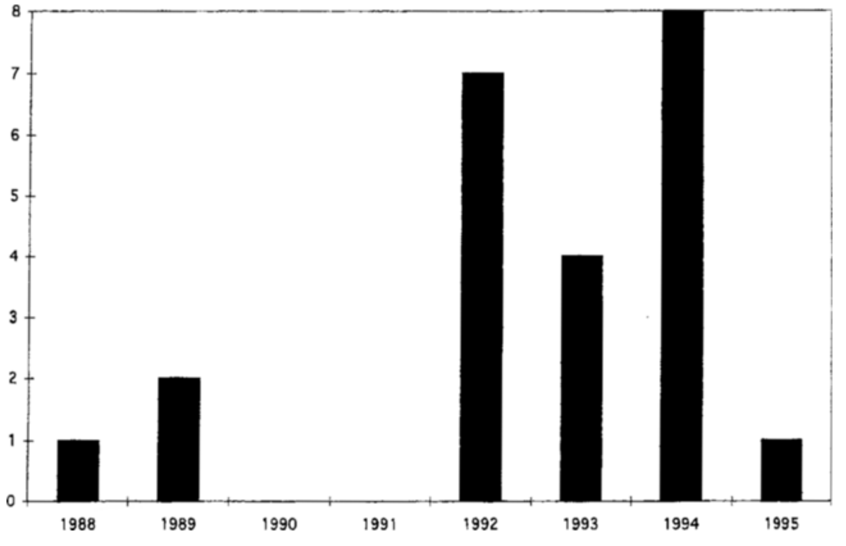

Fig 1. For each year, the number of the 23 large PACS that first began clinical operation of at least three modalities is shown. The 1995 data are from January only.

switches to the newer storage technologies that are available.

For diagnostic workstations, 1 Gbyte seems to be the minimum, going up to 6 Gbyte. The few installations in the 80 to 160 Mbyte range seem partly to work in an almost diskless manner in which images are transferred directly from remote storage to the random access memory.

Present Maximum Archive Length and Planned Archive Length

There were 26 responses to the months of on-line image archiving and 10 responses to the number of months for off-line archiving questions for individual modalities. The on-line archiving ranged from 1 to 40 months (average of 16 months). The off-line archiving ranged from none to 84 months imaging (average of 26.3 months). It is clear that the sites reporting have an average time of on-line archiving that is longer than 1 year, whereas the off-line archive average length is more than 2 years.

The response to the question regarding total months of on-line and off-line image archiving planned is most interesting. A total of 18 responses reported on-line archiving with a range of 12 to 240 months (average: 51.2 months). Many sites selected 60 months. Interestingly, no one commented on their planned off-line storage. One might speculate that the reporting sites have not considered the problem of off-shelf archiving for longer-term storage.

Data Compression

Data compression methods fall into the following two classes: lossless (also known as reversible compression, noiseless coding, redundancy reduction) and lossey (also known as irreversible, fidelity-reducing coding and entropy reduction). Image lossless coding compression ratios range up to about 3:1. The ratios reported appear in Table 4. Note the one site reporting use of a 10:1 compression ratio (lossey) before interpretation, a practice of interest and perhaps concern. Also note that five reported sites were apparently using lossey compression for on-line applications.

Many sites now operational use no compression (1:1) for not yet interpreted studies, 2.5:1 for on-line use (Joint Photographic Expert Group), and 10:1 for long-term archiving.

Interfaces to Image Acquisition Devices

The data reported for analog interfaces and for noninterfaced devices was not complete enough to be analyzed, but the most often reported analog interfaces were for digital fluoroscopy, nuclear medicine, and ultrasound. The digital interfaces reported were a mixture of digital imaging and communication medicine (DICOM) and other types; they are shown in Table 5. Unfortunately, the lack of adequate data for those devices without digital interfaces prevents computation of the percentage of digital interfaces in use.

The 23 Large operational PAC systems identified by this survey and their year of first clinical operation were reported in Part 1.[1] The histogram in Fig 1 shows how many began operation in each year. Only 9 of the 23 began in 1994 or 1995. The older systems would acquire the newer DICOM interfaces mainly as they replace acquisition devices. The number of the DICOM interfaces identified in 1995 is definitely higher than the number of American College of Radiology/National Electrical Manufacturers Association interfaces identified in 1993. The trend toward the use of DICOM is striking.

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Cost/Benefit Analysis of PACS: How Do Users Justify These Systems?

BROADCAST TAPES AVAILABLE FROM SCAR

On August 14, 1996, the Healthcare Informatics Telecom Network (HITN) broadcast as one in their series "Informatics: Washington Report" a program produced in collaboration with SCAR on Cost/Benefit Analysis of PACS. Participants were Michael Abiri, MD, Beth Israel Hospital, New York; Ethan Fener, Brigham and Women's Hospital, Boston; David Piraino, MD, Cleveland Clinic, Cleveland; Ken Spicer, MD, Medical University of South Carolina, Charleston; and Philip Drew, PhD, Concord Consulting Group, Concord, MA.

Tapes of this program are available from SCAR for $49.00 plus $5.00, shipping and handling. To order tapes, please contact the SCAR office, 1891 Preston White Drive, Reston, VA 22091; tel: 703-716-7548; fax: 703-648-9176.