Quality Assurance in Teleradiology and PACS:
Implications for System Design and Maintenance

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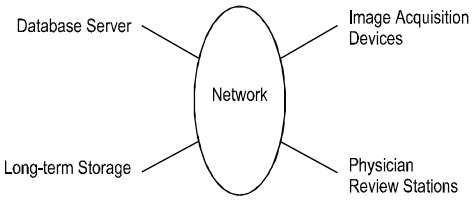
Key Elements of a PACS

- Image sources
  - Film Scanners
  - Video Frame Grabbers
  - Digital Imaging Modalities (CT,MR,CR,DR, etc.)
- Image display workstations
- Database management
- Image Storage

A Simple PACS



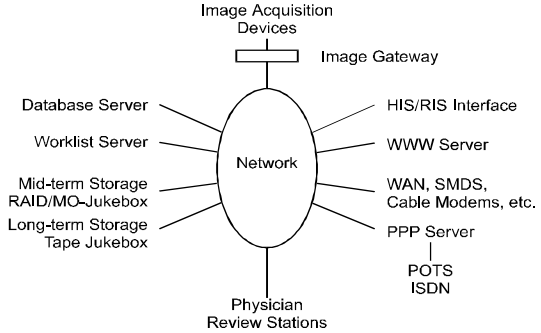
Requirements for Going Filmless

- An electronic archive for all image data for 7 years (20+ for mammography, 21+ years for pediatric patients)
- A method of electronic distribution of image data to referring physicians and surgeons
- A method for holding filmless conferences
- A method for printing films on demand for patients and referring physicians

Additional Elements for a Filmless Department

- Networked Film and Paper Printer(s)
- Long-Term Archive
- HIS/RIS Interface
  - Worklist Management
- Image Distribution Methods
  - WWW Server
  - WAN Support
  - PPP Support

A Full PACS Implementation



Considerations for PACS Design

- Scope of the project
  - Outpatient services / Teleradiology
  - Inpatient Mini-PACS (ICU, ER, MR & CT, etc.)
  - Full PACS
- Degree of film usage
  - Electronic capture only
  - Electronic capture and softcopy review
  - Electronic capture, review and archive
- Teaching, research, and conferences
- Netscape on all workstations

Considerations for PACS Design

- Image distribution for referring physicians and surgeons
  - Film
  - Dedicated workstations
  - PCs and WWW server
- Data volume estimates for storage and network design
  - New cases
  - Retrieval of comparison cases
  - Archival of image data
  - Print Volume

Volume Estimation

- Used to determine the number and type of hardware elements needed in a PACS
  - Workstations
    - Number for each configuration
    - Amount of RAM and local disk
  - Storage (mid and long term)
  - Server configuration
  - Printers
  - Network

Workstation Configuration

- You can not buy too much RAM
- Need to allow for operating system, new case and comparison case to simultaneously coexist in RAM
- Estimate case size based on 90th percentile size.
- Remember each type of study will have different statistics.
- Typically in-patient cases will be much larger than out-patient cases

Workstation Configuration

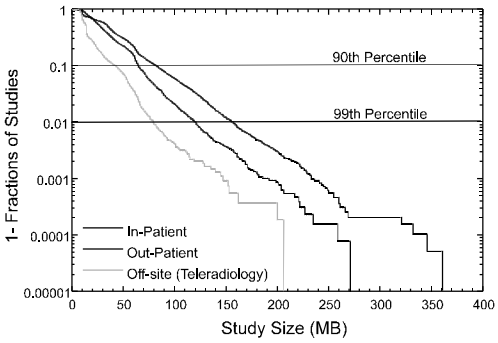
Procedure	Ave Size	90th %tile	Max Size	WS RAM
Body CT	48.7	76.5	250	280
Body MR	50.0	82.6	275	280
M-S MR	16.1	25.3	110	115
ENT CT	62.2	106.5	265	360
ENT MR	44.4	66.6	180	240
Neuro CT	30.5	84.1	275	295
Neuro MR	29.2	62.5	145	230

All sizes given in MB

Case Size by Source

Source	Average Size (MB)	Size 90th Percentile	# Series	# Images
Inpatient CT	44.5	105	3.4	85
Inpatient MR	36.6	65	6.0	180
Outpatient CT	50.5	85	3.8	95
Outpatient MR	30.6	65	5.7	160
Telerad. CT	39.0	65	3.4	75
Telerad. MR	13.8	21	5.7	95

Case Size Distribution



Factors Determining Number of Workstations Required

- The number of workstations required is equal to the number of film viewers which are removed.
- A random access film viewer can change cases faster than a PACS
- A PACS can load a case faster than a human can hang film. **BUT** film hanging is a fileroom task, while workstations are run by a radiologist
- Additional workstations must be allocated for research, teaching, and conferences

Accounting for Cases Read

- It is possible to get three different answers regarding the number of cases which are read
  - Signed Reports
    - Some reports describe multiple studies (e.g., combined spine reports)
  - Procedures Billed
    - Some procedures are billed as two studies, but are read as one (e.g. with and without contrast)
  - Cases recorded on PACS
    - The PACS records many extra cases (e.g., QC images, studies split due to patient problems, etc.)
- Corollary: Radiologists choose the largest number of the three to represent their work effort

One Year at Jefferson

	Dictated Reports	Billed Procedures	Cases on PACS
Body CT	9800	9800	7700
Body MR	4200	4200	4200
Neuro/ENT	13700	22800	20400
Total	27700	3680	32300

Short-Term Storage

- Short-term storage is resident upon the individual workstations
- The quantity is determined by the number of new studies that are to be read in two to five days
- Factor in the number of cases which will require previous studies (additional 30%)
- Allow at least 30% extra
- Buy workstations to which you can add you own disks

Medium-Term Storage

- Allow sufficient storage for all *inpatients* image data, including old exams which are retrieved from long-term storage for comparison
- Allow sufficient storage for all *outpatients* to cover the typical period from when a patient is scanned to when the referring physician or surgeon will review the images (typically 3-4 weeks)
- Rule of Thumb: Have equivalent to 8 weeks of new cases, where each week consists of 6 days.

Long-Term Storage

- Require an archive sufficient to storage all image data for 7 years
- Need to allow for 20 years or more for mammography, and up to 28 years for pediatric patients
- Need to project growth to account for increases in study size and case volume
- Buy storage which is expandable
- Storage should be fault tolerant

Short-Term Storage at Jefferson

- Currently we have 60 GB of short-term storage in NFS mounted disks
- We generate 6 GB of new data per day
- We extract from archive 2 GB per day
- 20 GB is used in research at any time
- Thus, we have (60-20)/(6+2) = 40/8 = 5 days online

Mid- and Long-Term Storage

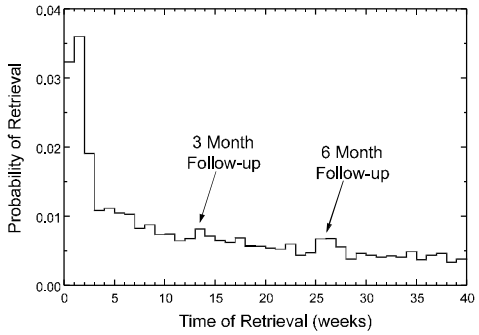
- We have ordered a 180 GB RAID for mid-term storage. This is expected to give 30 days online storage
- This will deduce retrievals from the jukebox significantly
- We have a 6 TB 4mm DAT (DDS-3) jukebox for long-term storage
- At current rates, this gives approximately 3 years of storage

Exams Retrieved from Archive

- Exams acquired between 4/1/97 and 12/31/97
- Exams retrieved between 4/1/97 and 8/1/98

Re-Reads	Percent	Number of Exams
0	77.740	18387
1	13.902	3288
2	4.913	1162
3	1.953	462
4	0.753	178
5	0.381	90
6	0.152	36
7	0.118	28
8	0.034	8
9	0.025	6
10	0.004	1
11	0.008	2
12	0.004	1
13	0.000	
14	0.004	1
	Total	23650

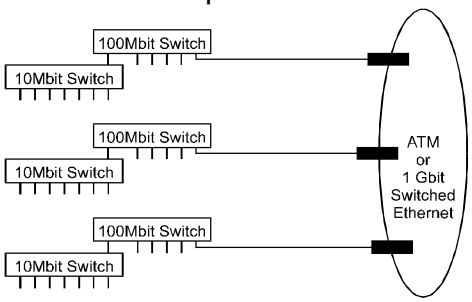
Retrieval Probability



Network Design

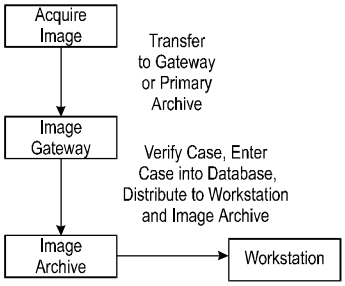
- The flow of data in a PACS must be designed to minimize network transfers and image data copying
- Networks should be hierarchical and switched so that they segment data traffic and optimally use the high internal bandwidth within switches.
- Multiple IP connections can be used for high data volume servers and network connections

Sample Network

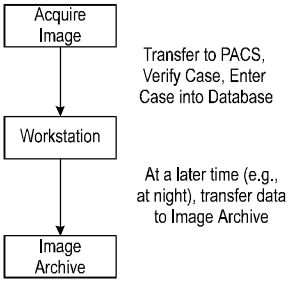


10 Mbit Switches are for scanners and printers
100 Mbit Switches are for workstations and servers

DICOM Workflow



Proprietary PACS Workflow



RIS/HIS Interface

- If you do not have an RIS/HIS interface, you must rely upon the technologists to correctly enter demographics on the image acquisition station
- Systems that do not have an RIS/HIS interface require intelligent human searches to overcome typing errors

"Smith, John" ≠ "Smith,John"
"Smith, John" ≠ "Smith, John A."
"Smith, John" ≠ "Smyth, John"
"Smith, John" ≠ "John Smith"

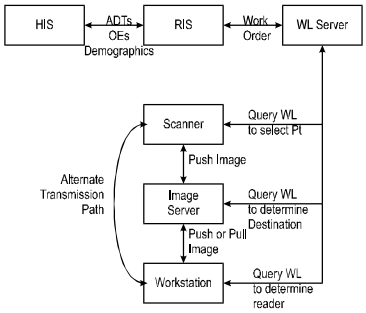
Reasons for a RIS/HIS Interface

- Verification of demographics information
  - Name
  - Age
  - Medical Record Number
- Corrections to demographics information (ADT records)
  - Name Changes
  - MR number history information

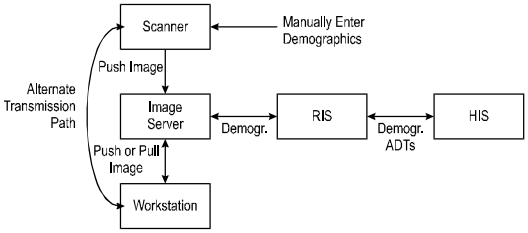
Reasons for a RIS/HIS Interface

- Admission and discharge information (ADT records)
  - Prefetch image data for inpatients
- Order entry records
  - Prefetch image data for inpatients and outpatients
- Report generation
  - Print key images on paper to augment report
  - Copy of report sent to PACS for use in future review
- Automated printing of cases
- Automated archiving of cases

Workflow using a Worklist Server



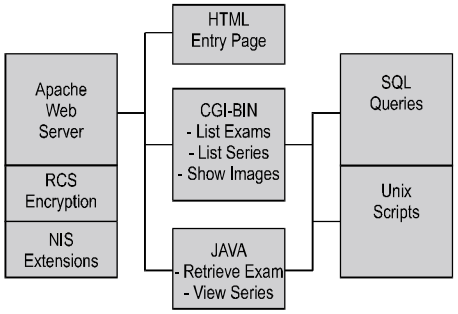
Workflow without Worklists



A WWW Server

- This is an inexpensive way to distribute images and report data to many users
- Minimal viewing hardware is required
  - 200+ MHz Pentium
  - 64-256 MB RAM
  - XVGA Monitor (1280 x 1024 x 8 bit or better)
  - Modem or network connection

The Jefferson WWW Server



Fault Tolerance

- Avoid single points of failure
- Have backup methods for performing each task
- Maintain a collection of commonly replaced parts such as hard disks, monitors, power supplies, and network equipment

Potential Single Points of Failure

- A dedicated database server is the most common point of failure.
- Most networks have no redundancy
- Power failures
- Non-error correcting disks
- Maintaining only copy of image data

Database Server Design

- Many sole source PACS have a proprietary database server which provides a distributed database for each workstation and the archive(s).
- The advantage of this method is that features such as key image selection, image annotation, etc. can be supported even though DICOM has not yet formalized such features.
- The disadvantage is that a single database server is a potential single point of failure.

Database Server Design

- Single point servers should either have a selected redundant server that can be *seamlessly* enabled, **OR**
- All hosts should maintain copies of the database, so that any host can become a server by proxy.
- Both are achieved with database journals
- **This requirement should be written into the purchase specification**

Ensure all Equipment have UPSs

- Small workstations can survive with a 1400 VA UPS
- Large workstations (e.g. those with greyscale monitors) require a 2200 VA UPS
- Servers, often require a 5000+ VA UPS
- Make sure all network equipment are also on UPSs

Ensure all Equipment have UPSs

- Connect all UPSs to workstation with monitoring software to allow automatic and orderly shutdown when batteries become depleted
- Monitor workstations and UPSs using SNMP

Keep at least 2 copies of every image data set

- At Jefferson, we maintain at least 2 copies of every case at all times.
- Cases are archived at the scanner for those devices which support an archival feature.
- A “primary tape” copy is generated when the study is entered into the PACS, and acts as a backup to the copy maintained on disk, or as a backup to the secondary tape.
- A “secondary tape” copy acts as the long-term storage, and is generated when a case is migrated from disk to tape.
- The primary and secondary tape sets are kept in separate buildings to prevent simultaneous destruction.

Use RAIDs

- RAIDs can be relatively inexpensive
- SCSI-to-SCSI RAIDS cost as little at $125 per GB (7/98)
- RAID level 1 uses disk mirroring
- RAID levels 3&5 use a checksum bit
- RAIDs are essential if you do not keep a second copy of incoming image data

Operational Procedure: Data Transfer Verification

- DICOM compliant storage class users and providers will eventually be able to use DICOM Verify to ensure that all data transferred satisfactorily
- Until that time, you must manually ensure that all data has been transferred.

Operational Procedure: Data Transfer Verification

- We have written a program which queries the database and displays information on the number of series and images that were stored. The technologist is responsible for checking each study that is sent
- An alternative is to have the image source retrieve the image data and compare it to the original
- Regardless, the PACS archive should keep a copy of all erroneous exams and image data for later evaluation

Operational Procedure: HIS/RIS Interface oversight

- Designate one person to oversee daily operation of this system
- This person is responsible for reviewing all changes to demographics which occur automatically
- This person is responsible for changing demographics on those cases which can't be determined automatically
- Not needed on order-entry worklist management systems

Operational Procedure: Worklist Management Supervision

- Replaces HIS/RIS oversight in worklist management scenarios
- This person is responsible for verifying that order entry records submitted after study completion are correctly matched to the study
- This person is responsible for correction of Jane and Joe Doe data when further data becomes available

Operational Procedure: Printing Films on Demand

- If you currently provide referring physicians and patients with copies of films, then you will need to develop a demand printing solution
- Patients will want "Original Films", and they will want them immediately
- Physicians often provide lists of images in advance

Operational Procedure: Printing Films on Demand

- Steps involved in printing a set of films
  - Locating the case on the PACS
  - Loading it from the archive (if not online currently)
  - Formatting the case for film or paper
    - 1 to 12 ups on paper, 12 to 20 ups on film
    - Whole case vs. selected images
    - Choice of window/level, multiformatting, etc.
  - Printing case and reports, generate folder
  - Sign out folder, track number of copies made.

Operational Procedure: Printing Films on Demand

- Fileroom personnel are currently involved in duplicating films and serving the needs of referring physicians and patients, but are incapable of printing films from scratch
- Radiological Technologists are capable of correctly selecting print formats, regions of interest, and windows/levels, but are not usually involved in the fileroom and are not readily available on demand.

Operating Procedure: Continuous System Monitoring

- The PACS is expected to operate 7x24
- PACS personnel should be available 7x24, using pagers and a rotating call coverage schedule
- Automated monitoring should be performed at all times, with pager notification of problems
- SNMP management or comparable programs should be considered if possible

Operating Procedure: Continuous System Monitoring

- Monitor the following at a minimum
  - Network connectivity exists?
  - Workstations, servers and scanners are alive?
  - There is enough free disk space on all systems?
    - Beware of root partition problems
    - Do not allow disks to become so full that you can not move studies or archive them.
  - Tape library operation, and queue status
  - Printer operation and printer queue status

Operating Procedure: Repair and Maintenance

- PACS are built with a variety of manufacturers equipment, and yet are expected in inter-operate
- One person should be responsible for calling service on all imaging equipment related to the PACS including the scanners.

Operating Procedure: Repair and Maintenance

- Every failure and error should be diagnosed internally first to aid in calling service and minimizing down time
- There should be a clear service call list for each piece (or type) of equipment.
- All repairs and failures should be logged to determine common sources of problems

Emergency Procedure: Reading cases during PACS failures

- First, you must identify the cause of the failure, and determine the time required to correct the problem
- Divide problems into three degrees of severity
  - up to 30 minutes
  - 30 minutes to 6 hours
  - more than 6 hours

Reading cases during PACS failures lasting up to 30 minutes

- Read emergency cases on scanner consoles or print films
- Given wet readings only
- Ensure that all unread cases are pushed from the scanners to the PACS when operation is returned to normal

Reading cases during PACS failures lasting 31 minutes to 6 hours

- Read all new cases on film, giving final interpretations
- Read emergency cases on scanner console if printing is operating slowly
- Ensure that all cases are pushed from the scanners to the PACS when operation is returned to normal

Reading cases during PACS failures lasting more than 6 hours

- Read all new cases on film, giving final interpretations
- Read emergency cases on scanner console if printing is operating slowly
- Print all old undictated cases on film, for interpretation by the radiologist
- Ensure that all cases are pushed from the scanners to the PACS when operation is returned to normal

Emergency Procedure: Failure of the WAN

- When sites on your WAN are disabled, then alternate communication methods are needed
- Typical T-1 installations have ISDN backup lines, both lines rarely fail together
- A router or hub failure will disable both T-1 and ISDN lines
- Couriers and printed films or tapes are the only recourse in the latter case

Requirements for PACS QA

- Include a PACS representative on your departmental QA team
- Include PACS QA criteria in your departmental QA program
- Have regular PACS QA meetings
- Have a QA audit of the PACS
- Have a QC program for the PACS requiring regular QC activities

QA Meetings

- Meetings need to be held weekly during installation and immediately afterwards
- Meetings can switch to monthly later
- There should be a fixed agenda or else the meetings turn into “gripefests”. Postpone gripes to the new business section on the agenda (last item)
- Include a summary of performance with tracking over time

QA Meetings

- The group should include:
  - Medical Physicists
  - PACS/RIS/HIS computer personnel
  - Attending Radiologists from each subspecialty
  - Department Administrator
  - Technical Admininstrator
  - Head of the Fileroom
  - Department Chairman, *ex officio*

QA Audit Items

- At a minimum the following should be tracked
- Stats regarding cases acquired
  - Number of cases, series, images, etc.
  - We have seen case size increase 20% in 1 year
- Stats on printing
  - cases printed, film usage, waiting time for prints
- Stats on archive
  - cases archived/retrieved, archive/retrieval time
- Stats on the database
  - establish benchmark queries which you run periodically to evaluate database speed as it grows in size

QA Audit Items

- Evaluate timeliness of service
- Perform regular audits (similar to repeat analyses)
- Evaluate the following
  - Cases wrongly identified
  - Images which are not displayed correctly
    - Window/Level
    - Orientation and Labeling
  - Cases which are incomplete
  - Cases which can not be retrieved from archive

PACS QC Program

- Perform paper printer and film printer sensitometry daily
- Evaluate paper and film print image quality weekly
- Evaluate monitor image quality weekly
- Cross-calibrate monitors and printers quarterly (including acquisition station monitors)

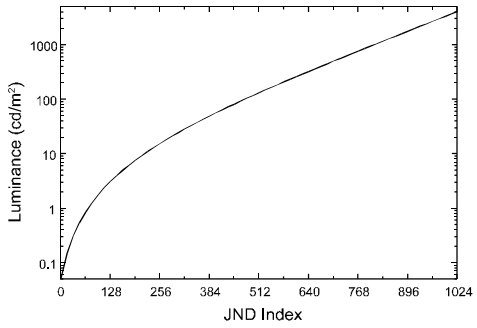
The Barten Model

- A model of the human visual response.
- Typically evaluated for contrast sensitivity target in a 2º by 2º square, with a modulation frequency of 4 cycles per degree
- The Standard Display Function (DICOM Supplement 28) is derived from the Barten model

Mapping to the SDF

- Monitors are measured in terms of luminance and map directly to JNDs using the Standard Display Function
- Hardcopy film transmissive optical density is mapped to Luminance using
- $L = L_a + L_o 10^{-D}$
- Hardcopy paper reflective optical density is mapped to luminance using
- $L = L_o 10^{-D}$

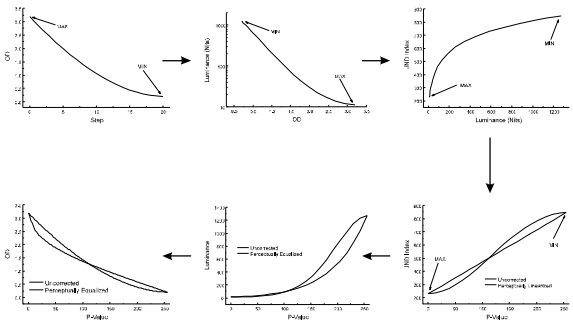
Standard Display Function



Perceptual Linearization

- Measure the maximum and minimum luminance (monitors) or calculate the luminance from measured optical densities (hardcopy)
- Determine the corresponding minimum and maximum JND index values
- Determine the number of JND values per p-value, for an N bit monitor (# p-values = $2^{N)}$
- Plot desired Luminance as a function of p-value
- Calibrate device to give desired luminance curve

Perceptual Linearization



Monitor Calibration

- You should be able to calibrate either the monitor or the display board
- Monitor calibrations
  - Brightness and Contrast
  - Color Balance and Convergence
  - Pin-Cushion and Barrel Distortion Correction
  - Window Size, Position, and Rotation
- Display card calibrations
  - Absolute mapping of pixel value to luminance

Medical vs. General Purpose Monitors

- General purpose monitors have a fixed gamma of 2.3. Corrections for visual response, and mappings to printers must be done in software. This reduces the number of bits that are achievable.
- Medical monitors have adjustments for gamma in hardware (after the D/A) and hence allow corrections without a reduction in the number of bits
- Some medical monitors have corrections for ambient lighting conditions

Procedure for Calibrating Greyscale Monitors

- Calibrate each monitor regularly
- Calibrate under the lighting conditions which prevail during regular viewing
- Adjust monitor contrast and brightness before calibration and thence never after
- Calibrate with the same background intensity always (about 20%, or a value comparable to the average intensity emitted from the monitor)
- Calibrate to match the standard display function

Evaluation of Image Quality

- Check monitor calibration photometrically
- Evaluation with test images
  - SMPTE test pattern
  - Linear greyscale ramps
  - Square and Circular test objects
  - Fine or coarse meshes
  - Focus tests (spots or crosses)

Hardcopy Evaluation - Film

- Sensitometry performed daily
- Test image (SMPTE) performed weekly
- Other test images performed as needed
  - Uniform fields of different intensity
  - Step Wedges
  - Vertical, Horizontal and Diagonal lines with different spacing and width.
  - Contrast-detail test

Hardcopy Evaluation - Paper

- Sensitometry performed daily
- Test image (SMPTE) performed weekly
- Other test images performed as needed
  - Uniform fields of different intensity
  - Step Wedges
  - Vertical, Horizontal and Diagonal lines with different spacing and width.
  - Contrast-detail test

Summary

- Design your PACS to be modular so that it is easy and inexpensive to enlarge
- Design redundancy at every possible stage
- Carefully consider what your workflow will be like after the PACS is installed by evaluating every current use of film, including timeliness and availability
- Do not assume that referring clinicians will embrace PACS

Summary

- Develop a policy and procedure manual and a QA process for the PACS when you start planning your PACS
- Have QC procedures and equipment in place when the PACS starts operation
- Do not begin operation until you have verified that image quality is adequate.
- Finally, have FUN!