Journal of Digital Imaging

Experience with Image Management Networks at Three Universities: Is the Cup Half-empty or Half-full?

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1.0 INTRODUCTION

THE DIGITAL IMAGING NETWORK (DIN) PROJECT is a federally funded demonstration and evaluation project which studies the usefulness of emerging management technologies for radiological images. The primary emphasis of the university-based efforts is in the clinical operation of the entire network. The project is interested in evaluating the concept rather than any particular product.

The project deals with a set of issues in the implementation of a total digital imaging network in various levels of patient care, including not only clinical and technical issues but operational and administrative matters as well. The program involving three universities can be summarized in a two dimensional matrix, Table 1.

For the SPIE invited session, each of the items in the matrix is discussed by a member of one of the project teams at the three universities.

This paper highlights the overall progress in the evaluation project, while more man 14 additional papers presented in this conference address specific topics. Readers are referred to the other papers for detailed information.

Table 1

	Clinical Perspective	Technical Perspective	Administrative and Operational Perspective
Baseline Study	x	x	x
Conventional Solutions	x		x
Digital Approaches	x	x	x
Future Requirements	x	x	x

2.0 PROBLEM DEFINITION

A good evaluation study requires a good baseline study. Significant amounts of effort were directed toward determining existing problems in radiology image management. The baseline study is useful in two ways: the definition of problems that digital technology should address and the evaluation of the effectiveness of digital solutions.

2.1 Clinical Perspective

The clinical issues of image management can be viewed either from the perspective of the "core" radiology service or from that of the referring physician.

The "core" functions of radiology are performing examinations, reviewing the resulting images, consulting, and generating and distrib-

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Online publication 30 April 2003
doi: 10.1007/s10278-002-6024-7

uting reports. Poor performance of any task connected with these functions will lead to poor service.

The hospital or referring physician must consider broader issues than those considered by the radiologist. Examples of such issues include the questions of what demands a physician makes on the radiologist and how such demands can be successfully addressed. Similarly, a physician may ask the radiologist if there is an imaging technique which can help in patient diagnosis. This dialogue defines the consultation phase—the two physicians talking is one of the most important interfaces between the radiology department and the rest of the hospital operations. After talking to the radiologist and deciding that a procedure needs to be done, the next step is to schedule the procedure, which involves the use of an HIS/RIS. This initiates the core radiology service (mentioned above), which starts when the radiologist performs the procedure. Next a diagnosis is made and reports are generated by a radiologist. The referring physician reviews the report and films and often speaks with the radiologist again, involving interaction both with people and the electronic systems.

From a clinical perspective, there are several potential problems in the film-based environment which result in poor service. First, a delay may occur in scheduling an examination. Once an examination has been completed, several factors may delay or adversely affect the quality of the report. These include both delays in accessing either current films or older images and missing previous studies. Since a single sheet of film cannot be in two places at once, the availability of films currently in use is also problematic. This is potentially more important when multimodality comparisons are required. Finally, the current workload on a radiologist may affect report generation time.

Delays in getting radiologic procedures and reports completed can result in delays in patient care, and, if the referring physicians become too frustrated by such delays, the radiologist's professional role may be affected. Improvements in radiology service can have a positive impact in patient care which in turn makes the radiology service that much more effective.

Non-problem

A number of problem areas have been identified in our study. There is however an important non-problem area that may become an issue in the digital environment. The image quality in current systems has been perfected over the past century and it is not a problem in current film-based systems. Furthermore the medical/legal issues are well-defined in this environment.

2.2 Operational Perspective

A number of problems exists in the operations of radiology service because the image media is film. A digital imaging network should be viewed as a device to solve significant film-based operational problems that impact radiology service.

Unavailable Films

During a baseline study at Georgetown University Hospital in 1987 we found that 9% of films were unavailable when requested. The reasons for this are that they may be in another department or signed out for multimodality correlation, used for educational and research activities, in transit, misfiled on shelves, misfiled in the wrong jacket, given away, or stolen. Some of these problems are virtually impossible to resolve (e.g., misfiling in the wrong jacket, given away) in a film-based service.

Misuse of Resources

Unavailable films cause a loss of productivity among radiologists, the clerical staff, the technical staff, and referring physicians and their staffs. Unavailable films also cause misuse of expendable supplies such as film and chemicals, and misuse of the equipment resources used in film duplication.

Report Generation

When a diagnosis requires a multimodality correlation study, reporting is often delayed due to difficulties in collecting related images from various imaging systems. This creates a delay between the completion of a procedure and reading.

Space

One solution to the problem of missing files is to duplicate film files, thereby increasing space requirements. Also, the report process is frequently hindered by the unavailability of films, so the match-up of reports and films is incomplete, forcing the duplication of files in many departments.

Cost

Conventional radiology department operating costs impacted by DINS are detailed in Table 2. These figures are based upon a 300 bed institution which does approximately 80,000 to 100,000 procedures per year.

Acquisition costs for equipment in a conventional department, including film handling equipment, the file room, and silver recovery equipment, is approximately $900,000.

3.0 CONVENTIONAL APPROACH

This section summarizes the conventional solutions in the absence of digital image management technologies. How does a radiology department manage the flow of film-based images and information and what is the impact of such approaches?

3.1 Clinical Perspective

RIS

How does a clinician currently deal with the problems of the conventional approach? A RIS is useful both for better film tracking and for unreported case identification. This can result in both improved report availability and a slight improvement in dictation turnaround time. But if the RIS and the HIS are not fully linked, restricted availability of information can result, since a user will have to deal with two systems. Centralized dictation service can improve both the speed of turnaround and availability but leads to the loss of some control over both reports and the establishment of priorities. The use of electronic mail through HIS/RIS is a helpful solution for some communication problems. There is a high threshold for communication because of difficulties with telephone and paging systems. A good electronic mail system lowers this threshold for communication between radiologists and referring physicians, resulting in easier physician-to-physician consultation.

Library

Centralizing the images by service or by imaging modality can cut search time and the probability of lost films. Conferences are useful in reducing demands for films, but are time and space consuming. Restricting access to film jackets requires cooperation and supervision but can also improve availability. In the absence of easily retrieved films, cases may be interpreted without appropriate prior or correlative studies. This may result both in the transmission of useless information and in frustration on the part of the referring physician and patient.

3.2 Operational Perspective

A number of operational improvements are possible in a film-based system.

File Room Operations

Additional personnel at $30k per year/person for technical support, $20k for clerical support, and increased overhead are incurred for adding personnel to the file room. However, there are means to correct or minimize file room problems other than additional personnel. Examples include alpha, numeric, or combination terminal digit or sequential filing schemes, and appropriate shelving systems, including movable aisles, pass-though shelving at an appropriate

Table 2

Archive Materials	$460k-720k
Labor	$1680k-2400k
Maintenance	$600k-1000k
Depreciation	$1000k-1500k
Space (opportunity)	$50k-100k
Total	$3790k-6720k

height, and optimized design, layout, and aisle size. HIS/RIS can be improved to track exams as well as jackets, and to produce listings of incomplete reports and billing. Film sign out can be enhanced to improve responsible party tracking, privilege suspension, and delinquent return follow-up. Finally, centralized file rooms and reading facilities could improve the efficiency of multimodality readings.

Dictation/Transcription

The film availability problem can be partially alleviated by improving report availability. If reports go out to the referring physicians quickly, they often are uninterested in seeing normal films, reducing the volume of film accessed. If reports do not go out, physicians must view films, normal or not. Nearly simultaneous access for transcription is now possible with telephone access to dictated material, off-site transcription, automated backup, and improved access to correlative results.

4.0 THE DIGITAL APPROACH

Over the past two years Georgetown University and the University of Washington have been implementing image management networks based on AT&T's CommView®. While the implementation is still underway, partial implementation has provided valuable experiences. The status of digital approaches to radiology image management is highlighted here.

4.1 Technical Issues

Georgetown Configuration

The Georgetown configuration consists of five groups: acquisition devices, the central database, display devices, a teleradiology link, and a research environment. Fiber optic cable at 40 Mbps is the primary communication medium for this network. Three acquisition modules link 2 CT, 1 MR, 3 Ultrasound, 2 film digitizers, and computed radiography (CR) to the database, which uses mirrored magnetic storage and an 89 platter optical jukebox archive. Display is via three 4-screen, one 2-screen, and four 1-screen enhanced graphic display workstations, located in neuroradiology, abdominal imaging, ultrasound, general radiology, the emergency room, a surgical intensive unit, nuclear medicine, and radiation medicine.

Teleradiology is accomplished via a T1 link to the Montgomery Imaging Center (MR and CT). The research environment includes SUN, PIXAR, PIXEL, and Konica devices (including the KDD, a film digitizer, and a printer).

University of Washington Configuration

The configuration at UW is similar to the one at GUH, being the same Philips-AT&T system, with a central Data Management System. DECRAD is the RIS with a DINS interface under development in an external UNIX system. A PCR, a MR, a CT, and a DSA are connected to the network. Displays consist of a 4-screen workstation in radiology and 1-screen throughout the hospital. The research machines include two SUNs and one UW imaging workstation. Teleradiology links to Sitka, Alaska (19.2k), the HarborView Medical Center (T-1 line), and the VA hospital are in place.

4.2 Clinical Perspective

Archive

The present magnetic archive has enough capacity for current work. Once CR becomes a routine imager it may fill the capacity quickly. Though the optical disk jukebox has ample capacity, full CR image loading will rapidly use up the magnetic portion of the archive. The CR and digitized film loading at trial or research rates does not pose this problem. The magnetic portion is mirrored which makes for high reliability, but the available space is halved. Why not mirror to an optical disk? Access times are better than those from the film file room, but the subjective perception of this time on the part of the radiologist may negate this improvement in speed.

Database

The database structure allows for smooth retrieval of single cases by name or identification number, but no relational search features are available. Image worklists can be generated, but the process is currently too slow to be used at reading time. Images cannot be lost, but if they have never been input, they cannot be retrieved. The system is technologist-dependent regarding the input of the images.

Network

Though the fiber optic links operate at fast rates, for CR images the transfer time in the absence of data compression very long. Without pre-fetching, the wait time is not clinically acceptable. Hardware allows a variety of high-speed links to the database/archive, but the number of such links allowed is, at present, too small. This limits the number of workstations or acquisition devices which can be connected.

Workstation Image Presentation

Performance is still deficient, too slow for digital radiography or for digital studies involving a significant number of changes. Multimodality image directories, and roam and zoom, through 2000×2000 images on a 1000×1000 screen at full resolution, are not yet available. We need the ability to compare two studies, pre-fetch, and synchronize two digital series. There is a high degree of clinician interest in the potential of the technology, which leads to the problem of assuring that expectations stay realistic.

Image Quality

Spatial resolution is borderline in some cases, especially for a small pneumothorax. Structured noise found in the results of some laser digitizers may make them unsuitable for primary services. Video frame grabbing works well but requires good quality assurance and technologist compliance. The limited gray scale of video frame-grabbed images is not a significant problem for ultrasound and neuroradiology MRI.

4.3 Operational Perspective

Although the system is operational, it operates in a reactive rather than an anticipatory mode. The network is not automated mainly because of the lack of a proper interface to imaging systems and the RIS. It is imperative to have an integrated RIS that functions as a master to the image management system. RIS integration will take several more months. Imaging system are connected through a video interface. More than image quality, the clumsiness of frame-by-frame data capture is a serious operational problem with the technologists. Other devices, such as a laser film digitizer is fine for smaller environments, but the operations are inadequate to meet the daily throughput requirements.

4.4 Economic Perspective

Economic analysis of image management may be the most difficult part of the project, for many of the important pieces of data are difficult to obtain. The primary benefit of the network is improved efficiency, which is difficult to quantify. The difficulties are compounded because the improved efficiency is based on many small improvements through the long chain of information and image management. Attempts are made to separate the analysis into two parts, solid and soft aspects.

Solid Aspects

The diagram in Table 3 details the expected changes in cost with changes in solutions.

Soft Aspects

Solid aspects of the model above are supply and archive costs, acquisition, and many costs

Table 3

	conventional	digital
1 Personnel	+++	–
2 Expendable Supplies	0	–
3 Equipment Maintenance	+	+++
4 Overhead		
Equipment Depreciation	+	+++
Plant Depreciation	+	++
5 Service Improvement		
Image Access	+	+++
Image Quality	0	0

("+" indicates increase, "0" no change, and "–" decrease).

in the conventional environment. Softer aspects are maintenance costs, productivity gains, quality improvements (such as image quality and access), and patient care (such as patient length of stay, care quality, timeliness of treatment). Depending on the optimism or pessimism of assumptions, we can project a 2-3 year wait for technology to be ripe for the acquisition of a full DINS and a 4-6 year payback being optimistic; a 3-5 year wait and 8-10 year payback being moderate; and a 5-7 year wait and 13-17 year payback being pessimistic.

5.0 FUTURE REQUIREMENTS

The evaluation projects at the universities have not been completed and it may be premature to predict the future. However, we have learned many important lessons as we approached the problem from the top down. Our initial impressions of future requirements are summarized below.

5.1 Clinical Perspective

What can be done to go beyond making the system merely clinically acceptable? These features would enhance the system beyond what is currently available in the conventional environment. This has the added benefit of improving the professional environment of DINS.

Area Networks

The current performance speed is too slow by a factor of 3-10 and better support is needed for the retrieval of old and new images, the coverage of clinics, batched image requests, further improvements in spatial resolution, HIS/RIS, and medical/legal issues. At the base is the radiologist's need to perceive and communicate abnormalities in a timely manner.

Workstation Improvement

Workstations must be intrinsically easy to use for radiologists and physicians. The person-to-person contact between physicians and radiologists must be maintained. Display parameters can be tailored to provide perceptually optimized displays for the individual reading. System operations should be configurable to the task and to the user; for example, pre-fetching cases or correlative studies should be based upon previous reading habits, updating this as experience accumulates.

Extending the Knowledge Base

We can expand the knowledge base by enhancing the teaching modes for systems, both for system training and radiology teaching, and integrating text with images. Examples of this are Georgetown's NLM-IAIMS project and the DRILL project of Ron Arenson of the University of Pennsylvania. We can enable expert system modes and links to off-site databases like MEDLINE, as well as wide-area network interfaces in order to facilitate radiologist-to-radiologist inter-institutional exchange of images and other information, and to support academic and clinical (expert consultation) use.

Other technical requirements for the DINS database are new and improved storage media, such as erasable optical disks, optical tape, and VLDS tape, improved image compression and decompression, distributed database management, and RIS integration.

5.2 Technical Perspective

Workstations

The technology needed will be here within a few years. Different levels of workstations, with varying numbers of image monitors and varying spatial/contrast resolutions and display/computing performance capabilities will be needed. These levels of performance will support improved interfaces and ergonomic considerations, RIS report handling ability, image analysis and processing, and 3-D visualization. As is evident from this conference, these are all important issues. New architectures, with parallel computing capability and chip-sized image computing processors, will be available in the next 5 years.

Image Networks

Salient issues regarding the image network are the transmission data rate, the communi-

Table 4

Ethernet on 68000 UNIX BSD 4.3	
10 Mbps	Raw media clock rate
6.7 Mbps	IEEE 802.3 Access layer
4.5 Mbps	IP layer
2.8 Mbps	TCP layer
1.2 Mbps	Applications

cation protocol overhead, the transmission medium, network topology, and interfaces to other systems and networks. Optically active systems will be more desirable. An example of how communication performance changes at different levels is given in Table 4.

A great deal of overhead is required. An obvious question is whether we should bypass the standard and achieve a higher rate. Examples of typical communications speeds are shown in Table 5.

Standards will play a large role in the future of DINS. In general, we need to improve the cost performance by a factor of 5 to make the DINS system clinically acceptable.

5.3 Financial Perspective: Financing

What do we do to prepare for the acquisition of a DINS system? Institutions must identify a representative to sell the technology inside and outside the department, as it may cost all of the available resources for 2 of 3 years. Plans for acquisition must include the cabling and environmental considerations in their institutional plans. Who will support DINS? Anyone whose work is improved (not just more sophisticated but with the same results). DINS can increase admissions and outpatient referrals, reduce hospital stay, reduce expendable supplies cost, improve revenue from satellite facilities, spur general hospital-wide productivity gains, and improve the recruitment and retention of radiologists and technologists.

Table 5

RS-23	<38.4 Kbps
RS-42	<10 Mbps
Ethernet	<10 Mbps
FDDI	<100 Mbps
HSC	<800 Mbps
DARPA proposal	>1 Gbps

Acceptance by third party payers for DINS service would do a great deal to advance the use of DINS. If reduced length of stay can be proven, this would go a long way towards third party payer support.

6.0 DISCUSSION

There are many interesting DINS related projects with emphases in specific areas such as image quality, image perception, interface, data compression, and hardware testing. In the case of this DINS project, the emphasis is on system integration and network operations. With each technical issue there are the added dimensions of network operations, which together eventually lead to the total digital department.

Another significant feature of the DIN project is comprehensiveness. An evaluation is carried out from the baseline study, in which administrative, operational, and technical issues are considered together in relation to meeting clinical needs.

The laboratory environment is very sheltered. In a patient care environment, a radiologist annually reads 50,000 images in 1,500 hours of film reading out of 2,200 working hours. On the average he can read 33 images an hour, devoting 30 seconds to each film. There is a tremendous pressure to get to the next case. The images cannot be left waiting. This production environment is something nonclinical colleagues have difficulty understanding. If the DINS system is not developed with a cognizance of this environment it will not be clinically acceptable.

The universities are researching technologies outside of the CommView® environment. CommView® is employed in handling clinical operations. Other devices are used to test advanced concepts regarding workstations, image quality, network performance simulations, and other areas. The CommView® network has been a good platform for our evaluation and it continues to improve.

7.0 CLOSING REMARKS

In the late 70's faculty at universities and Federal officials were concerned about fees in radiograph production. These have been replaced by computerized technology. This technology-led approach that preceded DINS technology assumed that the business of radiology could be made acceptable by identifying the functional areas in which the image production problems caused bottlenecks and removing these by applying technological solutions to each area. The efforts were predominantly independent, and they considered teleradiology, DINS, radiology information systems, and workstations as individual projects. About a year ago the universities and the Federal government found that they could take a more comprehensive approach to integrating the processes, and that network control would be required for a digital radiography environment of the future. Technology is now valued in terms of the business of radiology and the services provided rather than for the sake of the individual properties *per se*. Thus the problems as well as the potential benefits of the systems have just begun to emerge. We have solved some problems and are seeing new problems. More time, effort and ingenuity is required before an affordable total filmless radiology department becomes a reality—but the pieces are here now.

ACKNOWLEDGMENTS

Significant contributions to this project have been made by Ltc. Fred Goeringer (USAMRDC) and Dr. Barbara Kerlin (MITRE), as well as earlier leadership in DINS by Col. Tom Sweeny and Dr. Joseph Gitlin (FDA). The authors are grateful to Bruce Majors and Gabriel Plumlee for their expert technical assistance.

STATEMENT

This project is supported by the US Army Medical Research Acquisition activity of the USAMRDC contract number DAMA 17-86-C-6145. The views and opinions contained in this session are those of the participants and should not be construed as an official Army position, policy, or decision unless so designated by other documents.