UNDERSTANDING PACS:

*Picture Archiving and Communications Systems*

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Executive Summary

This handbook has been prepared to provide the reader with a basic understanding of Picture Archiving and Communications Systems (PACS) from its inception to the present day. Each chapter focuses on key issues that can be described with clarity. Chapter I: "The PACS Vision" addresses the history and development of the PACS concept, from initial revelations regarding digital images to what can be done today. Chapter II: "The PACS Attraction" addresses, from a clinical point of view, the advantages of the PACS concept and expected benefits to users. Chapter III: "Systems and Subsystems" illustrates the development of PACS from specific, well-defined requirements. Examples of installations of such subsystems and full systems are given. Chapter IV: "Components of PACS" discusses their availability, capabilities and limitations. The final chapter, Chapter V: "Considerations for Prospective Users" defines goals and objectives, discusses common problems and suggests steps for assisting users to define their requirements for PACS. The suggested readings are chosen for their contemporary applicability and their contribution to understanding the technology, applications and issues involved in PACS. Under each reference there is a paragraph discussing the relevance of the cited work. The glossary defines terms relevant to the clinical application and technology of picture archiving and communications systems. It includes terms that are useful to radiologists and other clinical personnel, to healthcare administrators, and to technical and scientific staff.
INTRODUCTION

When the future of diagnostic radiology or medical imaging is discussed by practitioners, scientists, administrators and entrepreneurs, many of them present a picture of radiologists and other physicians viewing images on multiple electronic display stations. These images will have been produced by a wide variety of modalities such as computed tomography (CT), magnetic resonance imaging (MRI), and conventional x-ray equipment, each of which conforms to an international standard and is linked to the display stations via a high speed network. In between the image generating equipment and the viewing stations are high density storage devices, computers, and interfaces to other information systems. The referring or attending physician is portrayed as having immediate access to patient's images and interpretive reports through an inexpensive personal computer that is connected to the imaging network.

In this scenario, the proponents assume that the necessary technology to support such practice exists, or will be available in the near term, that the product will be cost-effective regarding improved patient care, increased efficiency and replaceable costs, and that physicians, nurses, technologists and other health care providers will accept the changes required to implement the new systems.

It is suggested that each of the major components of picture archiving and communication systems (PACS) or digital imaging networks (DIN) be examined in terms of feasibility, economics and acceptance, in an effort to encourage a realistic perspective when considering the claims and expectations of the proponents of image management systems.

On the one hand, there have been dramatic changes introduced to diagnostic radiology by digital imaging that have been of great benefit to patient care; however, modalities such as CT and MRI require large expenditures for acquisition and maintenance, and they are associated with substantial data volume problems that have arisen where digital imaging modalities are in routine use. The concern with the management of the large volume of digital information has been central to the concept of PACS and the efforts to justify the systems in terms of cost-effectiveness and professional acceptance.

The impact of the development of computed tomography has been compared with that of the discovery of x rays by Roentgen in 1895. In her excellent article "The New Light," Nancy Knight presents a comprehensive summary of the reaction to Roentgen's discovery in the context of prevailing use and scientific advances of that era. She points out that because of the simplicity of x-ray apparatus, access to the new technology was soon available to all interested parties, amateur or professional. Since this is not true of modern imaging modalities, and today we are somewhat less sanguine about the future, we should make an effort to evaluate the costs and the benefits of image management systems as objectively as possible. The large amounts of digital data and information related to diagnostic imaging cannot be ignored. They must be managed in ways that will maximize patient care benefits and minimize related costs.

KEY ISSUES TO BE RESOLVED

When examining PACS or digital imaging networks, most workers in the field have found it useful to classify the components within four functional categories. H.K. Huang's textbook "Elements of Digital Radiology," uses this approach very effectively to describe the components of an electronic PACS. These include: 1) image acquisition, 2) storage and retrieval, 3) local and wide area transmission networks, and 4) display and interpretation. Each of these categories is comprised of hardware and software that may be considered individually as well as in terms of their interaction within and among the categories.

One issue associated with image acquisition is data compression; the issue being whether to use an algorithm that
produces relatively low compression ratios, but permits access to the original data, or a program that produces relatively high compression ratios that result in the loss of some of the data. The outcome affects both storage and retrieval functions as well as data transmission requirements. Another important issue within the acquisition category is the value of implementing the proposed ACR/NEMA digital image communication standards that will assure recognition of output from the various image generators, each of which produce unique format and content that would be indecipherable to other components of a PACS system without such a standard.

Within the category of storage and retrieval, several major issues arise when considering the inclusion of radiographic films that were produced by conventional x-ray examinations. Film digitization techniques, spatial and contrast resolution, storage media, and image access time, each pose important questions when the conversion from analogue to digital form is attempted. With regard to digital images generated by such modalities as CT and MRI, there are issues concerning the status of the images to be stored, i.e., pre and post processed (or both) and whether to store all of the images, or just those that in the judgement of the radiologist illustrate the interpretation.

Decisions regarding networks also require careful consideration if the system is to meet the stringent requirements of medical imaging. While there is no question about the need for “high speed” media to transmit medical images, the specific “throughput” capacity of a network often is an issue. Furthermore, the potential benefits of a separate, dedicated high speed network for images installed in parallel with a lower speed line for other data, must be carefully considered in terms of economic and technical capacity.

Perhaps the most important issue related to digital imaging from the practicing radiologist’s point of view, is the commitment to utilize electronic displays for primary diagnosis rather than film or other hard copy. While the adaptation to “softcopy” display for interpretation may be cost-effective, the primary user, i.e., the radiologist, must find it acceptable. Before this issue is resolved, much needs to be learned about the human/machine interface requirements and a generation of radiologists will have to be retrained. The utility of image processing techniques also is an important issue when considering electronic display and interpretation. If “softcopy” is to become routine in primary diagnosis, its value will depend on the positive contribution of image processing to the accuracy of the interpretation as well as the prompt availability of comparison and correlation images. A great deal of work remains to be done to demonstrate the value of these techniques to the diagnostic process.

Immediate access to electronic images by referring and attending physicians poses another issue for the medical imaging community. Should images be made available without the interpretive report or should they be withheld until the report is available? One solution to this problem is to produce the report immediately following the diagnostic procedure and include it with the data representing the images. Several technical developments offer this possibility, including speech recognition modules linked to personal computers. The integration of automated reporting functions at a diagnostic workstation with the display and image processing functions is an activity that deserves considerable attention by workers in the field.

**TODAY’S REALITY**

Digital imaging has made major contributions to patient care since its initial applications, and particularly since the wide acceptance of computed tomography in the 1970's. As the number and type of digital imaging equipment have proliferated, the benefits have been extended to more people and the relatively high costs have been justified by providers of health care and manufacturers of equipment to governmental agencies, health insurance companies and other financial supporters of health care systems. As of today, most of the benefits of digital imaging have been achieved through its technical characteristics to produce views of the human body that could not otherwise be attained except through more invasive procedures.
The high costs of digital imaging are not associated only with the installation and maintenance of the equipment, but also in the generation of enormous amounts of data. The concept of an image management system, or PACS, is based upon the extension of the benefits and the solution to what is perceived as a data management problem. The extension of benefits is expected to be achieved by applying recently developed computer technology to a system specifically designed for the clinical environment. Most workers in the field agree that the many components needed for an image management system exist, but a great deal of work needs to be done to demonstrate the technical feasibility of a complete system in a medical care setting.

The major unanswered questions are related primarily to the cost-effectiveness of such systems and professional acceptance of the components, particularly the image display workstation. With regard to the former, the real costs of an image management system include not only the hardware, software, and related maintenance, but substantial changes in staffing, training and relationships between the radiology department and referring physicians. Interfaces between the image management system and other existing information networks are essential to the successful implementation of PACS and must be given high priority if the system is to be viewed as something other than an additional resource for the radiology department. For the full potential of image management systems to be realized, the availability of both images and interpretive reports to the referring physicians must be achieved in a timely manner.

With regard to professional acceptance, while the diagnostic radiologist plays a key role, particularly with regard to the human/machine interactions at the image display workstation, the needs of technologists, administrators, and clerical personnel within the department must be considered. Of equal importance are the functions and responsibilities of clinical and administrative staff outside the department, who will view the system in terms of its contributions to patient care and its effects on the institution's financial status and marketing strategy. In teaching hospitals and university medical centers, the contributions of the image management system to training and research will also be critical to professional acceptance. Clearly, if successful implementation is to be achieved, all of the key personnel must be involved in the planning stage and in the decisions that determine the sequence of implementation.
Chapter II.

THE PACS ATTRACTION - Robert Allman, M.D., Ray Kilcoyne, M.D., and Roger Shannon, M.D.

INTRODUCTION

Imaging is an essential component of the health care delivery system. All medical specialties include radiologic imaging in the diagnostic work-up to some degree. The majority of diagnostic images are produced from film/screen combinations and are interpreted using film viewed on light boxes. The images are stored, transported and communicated from one physician to another on film. X-ray film has served physicians faced with diagnostic problems well for almost one hundred years. When this film-based system works, it works extremely well. However, over the years, problems in film-based systems have emerged which adversely affect the delivery of health care. Quality issues such as timeliness of reports, adequacy of images, accessibility of images to the radiologist and the referring physician, availability of comparison films for treatment planning or teaching conferences, transfer of films to other facilities, and availability for quality assurance, risk management and medical audit purposes need to be addressed.

Radiology information systems have helped define the management issues related to handling and distributing film-based images, but have not solved the problems. Although efforts have been made to improve the consistency and quality of images, technically poor studies, particularly from emergency room and portable devices, still abound. Despite sincere efforts to interpret images in a timely fashion, unreasonable delays may affect the clinical value of diagnostic examinations. Efforts to establish tight control over films fail for many reasons, and films are still lost, or more accurately are not available to individuals who require them at convenient times. The perceived and real deficiencies of the film-based system affect the quality of care and the professional stature of the radiology department. Film management affects: 1) patient satisfaction, 2) length of patient hospital stay, and 3) complications resulting from delay in accessibility of films or reports.

The financial implications of unreported films are self-evident, as is the impact on employee job satisfaction. Efforts by many institutions throughout the country to improve the performance of the film-based systems beyond their current level have been relatively ineffective. Films have inherent limitations for storage and transmission which may be overcome by modern electronic technology. "Re-engineering" is the process of examining the basic assumptions about a system and identifying new strategic and competitive advantages through the creative, effective, and innovative use of modern technology. How images are ordered, obtained, processed, interpreted, reported and used in the treatment of patients can be re-engineered by using new technology.

Although some individuals believe that digital technology is approaching the point when it will be practical to purchase a total PACS off-the-shelf, the consensus at the present time is that implementing a partial PACS made up of only those segments needed immediately is a safer approach. However, with the incremental approach one must maintain compatibility with future systems and subsystems. The clinical goal of a complete or a partial PACS is to improve the timeliness of the decision-support process by enhancing the order-entry/interpretation/results-reporting system. The specific objectives are the elimination of late reports, lost films and poor quality examinations, and improvement in image choices and communication between referring physicians and radiologists. More active consultation by radiologists will improve the relevance of the interpretation of images to the specific clinical questions and will aid in selecting the most appropriate work-up strategies and the proper sequencing of procedures. To do these things, radiologists may have to be more visible and readily available and may have to modify current practice.

THE MOVE TOWARDS DIGITAL IMAGING

If PACS is the problem solver, what specifically does it have to offer?

The expansion of high technology imaging over the past twenty years has greatly increased the quantity of medical images, a growing number of which are generated in digital format. Nevertheless, physicians are still using paper to request examinations and radiologists still interpret nearly all studies from film. Films are stored in bins in a file room, and reports are scattered in a variety of locations that defy counting. Efforts have been made to exploit the ability of computers to manipulate images and data and to interface imaging systems with radiology and hospital information systems. Recent developments make it possible to convert all images to electronic digital records regardless of their original form. It is, therefore, reasonable to consider managing an imaging service electronically.
In the transition from film to digital imaging, it is essential that radiologists be involved in all stages of a design and in the component selection process. Within the radiology department, various imaging modalities need to be integrated for an efficient operation, for example, linking CT, MR and computed radiography units to shared laser printers, storage devices and networks. By investing in equipment which improves productivity and decreases personnel overhead, one will not need large numbers of transporters to handle, distribute and store images in the digital department.

Although it is easy to be preoccupied by internal impact, one should also consider the effect of new technology on other departments. Improving patient care is always a first priority that brings specialty interests together. For example, the emergency room patient may need a radiologist to interpret images at any time of the day or night. A PACS teleradiology subsystem has the potential of making a radiologist available 24 hours a day, seven days a week. The radiologists may be available anywhere that is accessible to a network, and able to interpret images from any location linked to the network. This brings most hospital locations and the radiologist’s home into working relationships. The best practice demands that all images transmitted outside the radiology department be accompanied by a radiologist’s interpretation.

Digital imaging has the potential of insuring that portable and other images will always be of a high quality rather than hit or miss as is currently often the case. Digital networking insures that off-site locations will always have a radiologist available for interpretation. Other departments which will benefit by being connected to a PACS include plastic surgery, neurosurgery and oncology where staging, surgical planning and treatment evaluation will be enhanced by ready access to images from multiple modalities. Many other specialty areas will also be able to receive needed services.

The digital file room will be at the heart of any PACS. When selecting the hardware and designing the network, it is essential to provide accessibility of current and previous images to primary interpreters and to practitioners in other medical services. For primary radiologist interpretation, a high level of image resolution is needed. For demonstration to other departments, a lower level may be acceptable and data compression may be used to reduce considerably the time for image transmission and space required for image storage. A responsive mass storage device and an excellent database management system are critical.

Networking defines the distribution of images in and outside the radiology department to facilitate communication and consultation between locations, other radiologists and other physicians. Although a single network might accomplish this, it may be managerially and economically advantageous to consider multiple networks with different primary purposes. For instance, the networks within the radiology department must be tightly controlled by the radiology manager. Images obviously must be available for the radiologist at the appropriate workstation in order for the radiologist to dispatch his or her professional responsibility. The internal network is one of the medical devices essential to professional performance. On the other hand, images for review or consultation in other departments may be more appropriately managed and distributed by a hospital network manager. The hospital imaging network is part of the information service to the professional community at large. Although the two networks have much functionality in common, their role in professional performance is qualitatively different. These needs will vary from place to place.

Several other PACS components deserve mention. Computed Radiography (CR) or the direct digital acquisition of conventional radiographic images has the potential of markedly improving image quality, consistency, and accessibility. CT may be an initial PACS component or added later. Digital fluoroscopy may be an important acquisition in some departments. For those images which were acquired in a non-digital fashion, a film digitizer will be needed so that film images can be retrieved for comparison at the digital reading workstations. These digital workstations will be needed not only at many critical locations within the radiology department, but also at selected points in other departments throughout the hospital.

The challenge of information overload in medical imaging today can be met by implementing a PACS or a partial PACS. There will be both advantages and problems when switching to PACS. The problems may be solved only when technical solutions are accompanied by fundamental changes in the attitudes of physicians, managers and other personnel.
ADVANTAGES OF DIGITAL IMAGING

Digital imaging, particularly computed radiography, may offer consistent image quality at lower patient dose. The need for repeat examinations may be reduced because of increased image linearity and dynamic range. Several utilities are available for image processing and enhancements; something which radiologists have been striving to accomplish for years. Magnification/reduction, black-white reversal, edge enhancement and other types of image manipulation may improve visualization of tissue characteristics. Digital storage and transmission offer ready image availability. Images will be almost instantly available at display stations through a variety of strategies for accessing storage. Image replication without degradation means images transferred in radiology for interpretation may be released simultaneously for review by other physicians caring for the patient. Images may be networked to common storage devices and to shared printers, thus reducing the need for duplicating equipment at multiple locations. Images will no longer be lost!

["Of course it’s not lost,” Belgarath retorted. “I just haven’t pinpointed exactly where it is at the moment.” “Belgarath, that is what the word lost means.” (From Book 2 of the Malloreon KING OF THE MURGOS by David Eddings.)]

PROBLEMS WITH DIGITAL IMAGING

For a variety of reasons, image manufacturers in the past have avoided standardization not only with other vendors but within their own product line. It has been difficult or impossible to connect different imaging devices and display modules to each other through standard interfaces because of unusual connection requirements or non-standard signals. Obviously, interfaces are required for image networking and for integration of PACS with radiology and hospital information systems. Many professional organizations and equipment vendors are currently working on standard hardware and communications protocol characteristics for PACS. The ACR/NEMA standard presently represents the most promising approach to interconnectivity.

PACS will be a major capital investment that may not be directly reimbursable through additional fees for patient care services. On the other hand, the cost savings in terms of film, improved personnel efficiency, decreased length of patient stay and other difficult to quantify costs, have been studied, and PACS compares favorably with the present situation. It is difficult to measure the cost of behavior modification for the users of PACS. Undoubtedly there are time costs in learning a PACS. The cost of any complex transition is difficult to predict and harder to plan.

EXPECTED BENEFITS - IMPROVED PATIENT CARE

The expectations of digital imaging and communications are ambitious. They include: the elimination of film and chemical costs, the improvement in imaging diagnosis, remote consultation, more efficient use of personnel, improved communication and timeliness, coverage of multiple locations and availability of subspecialty consultation. Digital technology may allow radiologists to continue to retain their primacy as image interpreters and may discourage less trained physicians from rendering primary interpretations. It will reinforce the image of the radiologist as the imaging consultant and increase sensitivity to the needs of referring physicians. Greater control over the technology of obtaining and distributing radiologic information will require changes in attitude and behavior on the part of many radiologists. Real-time interpretation of images will have a greater effect on patient care than the current practice of batching examinations for interpretation. As compensation, there should be a reduction in the amount of time spent searching for misplaced/misfiled films and to insure the proper identification of each film. In the course of a busy film reading session, these quasi-administrative activities distract the radiologist from the principal concentration on diagnostic interpretation. The elimination of these factors may allow the radiologist to increase his/her workloads of interpretation without major increases in total effort.

Although clinical care aspects of PACS, particularly timeliness, accessibility of images, and improved quality are primary benefits to be obtained, there should be cost benefits identifiable as a result of faster reading and thus improved reporting and billing. Collection rates may be improved as a direct result of assuring that all images obtained in the department are actually interpreted and that all billings are in
fact reflections of images actually produced. PACS should improve the quality assurance process and lead to establishment of protocols for interdepartmental communication. Clinicians will routinely collaborate with radiologists to clarify the role of imaging in the decision support process, both in the positive sense of identifying significant finds, and in the negative sense of excluding significant findings.

QUALITY ASSURANCE AND RISK MANAGEMENT

Although quality assurance and risk management are not the principal reasons for implementing PACS, it will help in the attempt to assess radiologists' performance. The concept of evaluating performance is admirable. However, medicine in general and imaging in particular are still more art than science, and identifying the proper parameters for appropriate quality management has been difficult. PACS lends itself to adapting fundamental principles of industrial quality controls by eliminating variation in applying standards. High quality medical care consists of a scientific or technical component and an interpersonal component. One can focus on: 1) assessing or measuring performance; 2) determining whether performance conforms to standards; and 3) improving performance when standards are not met. This traditional concept of quality assurance can be facilitated through the collection of data from image management systems. In addition, PACS can promote a newer approach to quality in which statistical techniques are used to assist decision making concerning product quality and production processes. The order-entry/results-reporting cycle depends on many subsystems and personnel disciplines to support the timeliness of reports and the production of high quality images. If quality is defined as a continuous effort by all members of an organization to meet the needs and expectations of the patient, this common goal can be used to study the variations that occur between radiologists, technologists, file clerks, transcriptionists, and other individuals involved in this process.

By monitoring the timeliness of reports, equipment downtime, incident reports, examination repeat analysis, retrievability of radiographic records and production volume indicators, there can be active support from clinical and managerial leadership for Continuous Quality Improvement (CQI). Variation can be reduced and the processes may be studied as objects for improvement. Unnecessary variations may be eliminated through training of ancillary personnel in the rapid acquisition of technical skills be identification and reduction of procedural errors. This should improve turnaround time on diagnostic reports. Training can be directed at the acquisition and perfection of job-specific skills and at the principles and techniques of CQI. Employees can be shown how quality is defined and how to participate in its improvements. The ultimate result should be an improvement in the decision-support process and the elimination of lost films, late reports, and unbilled services so that radiology practice can be complete, accurate, timely and cost-effective, operating in the best interest of the patient.
Chapter III.

SYSTEMS AND SUBSYSTEMS - Robert Hindel, Ph.D.

INTRODUCTION

PACS can be arbitrarily large, but cannot be arbitrarily small. For instance, adding digital optical storage to a CT does not qualify as a PACS. However, directing images from two MRI's to a common workstation may qualify as a PACS or subsystem. NEMA, the National Electrical Manufacturers Association, considers an assembly of components to be a PACS if it includes:

- communication (digital or analog)
- digital data storage
- connection to image acquisition devices with analog or digital output
- analog or digital electronic display capable of serving more than one image acquisition device

A broader definition and one not restricted by a trade association’s policy would specify communication and integration capabilities by design. Even so, large image acquisition devices such as self sufficient and expensive CT and MRI systems, though supplying important image data, should not be defined as PACS in themselves.

Large PACS have been promoted and designed by several universities and commercially by some imaging companies. The general conclusion today is that these “pilot projects” have demonstrated the complexity of designing, installing and operating large PACS. In the meantime, smaller PACS deal successfully with well defined requirements.

TELERADIOLOGY

Teleradiology focuses on transmitting images from one location to another often using mature and affordable technologies. Such systems have been shown to be cost effective and meet the expectations of users. The chosen communication system is generally a commercial telephone service with a transmission rate from 9.6 kbaud up to 56 kbaud. Higher speeds are offered by T-1 lines (1.5 Mbits/s) and ku-band satellite transmission (512 kbits/s). The direction of the image traffic can be predominantly from a remote image acquisition site to a central department (scenario 2) or from a department to an expert’s home workstation (scenario 1). Alternately, the traffic can flow from a central department to ICU’s or ER’s (scenario 3). The central station may be a node on a larger network and may offer sophisticated services such as image processing and archiving. Scenario 6 illustrates this kind of a situation.

MODALITY CLUSTERS, PARTIAL AND FULL-SERVICE PACS

Modality clusters are partial PACS with communication between modalities, workstations and storage facilities. Teleradiology may or may not be included, depending on the distances involved. Imaging centers can start with such a partial PACS (scenario 4) and may upgrade later to broader service. Upgrading is best accomplished if a well established, mature communication link is used for modality integration. Other nodes can be added or transition to another network can be accomplished by means of a “gateway.” Scenario 6 uses two such gateways for transition into different environments.

Medium-sized PACS includes several modalities, central archiving, several types of workstations as well as a network as illustrated in scenario 5. A film digitizer is included for entering radiographic images in digital form.

Full-service PACS integrates image communication with RIS and/or HIS. Although it is generally accepted that PACS presupposes existence of a department management system in form of a RIS, the respective roles are not clearly defined. One PACS concept considers PACS to be a special service in the RIS environment supplying images on demand, while all text and control transmission would be handled by RIS services. Some implementations assign images to a special fast communication service. Others use fast networks for all types of communication as indicated in scenarios 2 and 6.
INTERFACING

Interfacing to image sources has been addressed by the ACR/NEMA Standard for new equipment. Although possible, retrofitting installed imaging equipment with an ACR/NEMA interface may be complex and expensive. Up to now there has been little enthusiasm on the side of modality manufacturers to permit access to digital image data or even to disclose the format on removable media. Increasing clinical interest in PACS has changed this attitude to some degree. Digitizing films and video signals may reduce the accuracy of information for primary diagnosis.

FILMLESS RADIOLOGY

"Filmless Radiology" is often cited as the objective of ambitious projects. Although storage phosphor technology is established as a valuable method of assuring high quality digital radiographic images, it does not by itself imply a filmless department. Since digital radiographic images of high quality contain up to 10 MBytes of image data and since radiographic procedures are very numerous, the resulting demands on storage, transmission, processing and display become very expensive. Compression, in particular "lossy" compression, would reduce this quantity and therefore the cost, but no reliable evidence exists that the change in image quality will not adversely affect the accuracy of the diagnosis for all radiographic tasks. Much of the complexity, frailty and cost of a PACS stems from demands of elaborate automation. Coupled with a demand that PACS be suitable for primary diagnosis, the resulting system becomes very complex and ceases to be cost justified if film replacement is the only consideration. The commercial developments of subsystems point in the direction of simpler PACS with well defined purposes using mature technology which is both affordable and reliable. Defining achievable goals for a PACS is probably the most difficult step in the planning process. Advanced technology, reliability and affordability are very difficult to achieve at the same time.

The following scenarios illustrate a progression from simple goals to ambitious projects.

Scenario 1
Teleradiology to the Home

A useful and efficient extension of a PACS is a remote workstation in the home of a radiologist.

Acknowledgement: Georgetown University Hospital.
Scenario 2
Satellite Transmission

Ku band satellite image transmission is used for this Telecommunication link between a large university PACS and a remote site.

Scenario 3
Expanded Teleradiology

Ethernet connecting two pediatric units with a teleradiology workstation.

Scenario 4
Modality Cluster

Modality Cluster combining two imaging centers and a radiology group clinic. Two 56kbps channels are used from the two sites. The images are stored on optical disks and films are produced on a hard copy unit.
Scenario 5
Medium Sized PACS at Medical Center

Full PACS handling MRI, CT and radiography via film digitizer. Images are stored on an optical jukebox and are displayed on two types of high-resolution workstations. Images are also dispatched to an intensive care unit and to the primary care department. A 10 Mb/s Token ring handles digital traffic.

ICU: Intensive Care Unit
JB: Jukebox
LFD: Laser Film Digitizer
WS: Workstation

Scenario 6
Full Service PACS

Large PACS including storage phosphor radiography, massive database, image optical archive, four tele-radiology channels and many display stations.

AM: Acquisition Module
CR: Computed Radiography
CW: Consultation Workstation
DIPS: Digital Image Processing Station
DW: Diagnostic Workstation
FO: Fiber Optics
GW: Gateway
LFD: Laser Film Digitizer
OJB: Optical Jukebox
RVS: Results Viewing Stations
INTRODUCTION

Components that can be used as building blocks towards an integrated PACS (Picture Archiving and Communications System) or Image Management and Communications (IMAC) system include image input devices, image display workstations, image transmission networks and devices, hardcopy output devices, storage devices, radiology information systems, and interfaces to both imaging equipment and hospital-wide information systems.

The various subsystems that make up image management systems today are defined by the way individual components are combined and “sized” to meet the particular applications. While systems that transmit images between hospitals, clinics, or physicians' homes might all be classified as “teleradiology,” due to the common feature of transmitting images from point to point, the differences in design can be dramatic. Image transmission can take from 7 seconds to over 7 minutes, depending on image resolution, compression ratios, and image transmission networks and protocols used. There is no single component that fits every application, just as there is no one vendor’s system that can meet every user’s needs. PACS designs are application-driven and the selection of components is defined by the user’s needs.

INPUT DEVICES

Images enter PACS from a host of sources, including direct image capture devices, image digitizers, and digital (or computed) radiography.

Image capture devices are needed to transfer images from the digital modalities (CT, MRI, NM, US) to the file server and/or transmit unit. There are two types of image capture devices used, analog frame grabbers and direct digital interfaces such as those using the ACR/NEMA Standard. Frame grabbers, which are popular in "off-the-shelf" teleradiology systems, are a means of capturing the image from the display signal of the imaging equipment without having to generate film. Direct digital interfaces allow capture and transmission of image data from the imaging equipment at full resolution and bit depth (grey scale). These data can then be manipulated as required allowing multiple window and level settings to be displayed and reducing the total number of images to be transmitted. Unlike frame-grabbed images, which have been limited by the process to eight bits, digital data sets may contain the full range of data produced by the imaging equipment. These data are then amenable to any required image processing and display (window width and level adjustments over the full range, for example).

The ACR/NEMA Standard is based upon the concept of a digital interface. Developed by the ACR/NEMA Standards Committee, it is nonproprietary, and allows for the transfer of images and associated data between imaging equipment either with or without an intermediate PACS network. The Standard is equipment-independent, and can be used with any PACS device which supports it.

Image digitizers are available in four forms: analog video cameras (coupled with analog to digital conversion boards), digital cameras, CCD (charge coupled device)-based scanners, and laser scanners. The last two are most commonly used in PACS systems. Analog video cameras are used in low cost, entry-level teleradiology systems. Most are manual systems with a maximum resolution of 1024 by 1024 by 8 bits (256 shades of grey). Analog cameras also require the use of an illumination source under the image (light box, etc.) and are commonly known as a “camera on a stick” for this reason. Digital cameras allow for a digital signal to be output directly from the camera and have a maximum resolution of 2048 by 2048 by 12 bits (4096 shades of grey). Digital cameras are infrequently used in PACS systems.

CCD scanners, otherwise known as flat-bed scanners, are gaining popularity as options to the more costly laser-based scanners that dominate the marketplace. They are generally used in high-end (1024) teleradiology systems and entry-level in-house film distribution systems and can resolve up to 4096 x 4096 by 12 bits. CCD scanners usually offer slightly lower performance characteristics than laser scanners, with an eight (8) bit (256 shade) grey scale output and narrow film density range. These systems
are usually semi-automatic or fully automatic in operation. Laser scanners are used by virtually all of the medical centers that transmit images from radiology departments to intensive care units. These devices “scan” the image with a fine laser beam that divides the image into nearly 20 million pixels (picture elements), providing a resolution of up to 4096 by 5120 pixels by 12 bits and full optical density (0 to 4.0).

Computed or digital radiography (CR) systems use stimulable phosphor plates with dedicated reader units as a substitute for the conventional film/screen combination employed with film-based radiology. The plate is exposed the same way as conventional film, with the resultant image on the plate “translated” by the reader, outputting a digital signal for softcopy viewing, storage, or transmission.

NETWORKS

There are two primary types of networks used in PACS — local area networks (or LAN’s) and wide-area networks (WAN’S). LAN’s are commonly used intra-hospital or intra-campus while WAN’s are used to transmit over longer distances. Each type of network has advantages and disadvantages. Factors to consider in choosing a network include image file size, data compression, storage capacity, network protocol, and the behavior of the network with increasing load.

Transmission speeds depend not only on the above mentioned factors, but on the protocol used with the particular network and efficiency with which that protocol runs. Image transmission speeds in LAN’S can range from under two seconds per uncompressed image of FDDI (Fiber Distributed Data Interface) backbones to over thirty seconds on a Token ring, depending on several factors. LAN communications protocols in common use in PACS today include TCP/IP (Transmission Control Protocol/Internet Protocol), and other proprietary protocols.

LAN’s are used extensively for in-house image distribution networks. These networks are designed around an “architecture” or topology of which there are three types: bus, ring, and star. Bus structures, which include Ethernet, string out the network access points along the length of the cable which is usually limited to under one mile. Workstations can access data any time the network is free. Ring structures are offered in two varieties, Token ring and Slotted ring, with the former considerably more prevalent in PACS designs. Token rings connect repeating devices at each station into a loop with information passing in one direction at a time. Token rings are available in several configurations with 4 and 16 Mb/second being the most common. Counter-rotating ring architectures are used in PACS as they are more resistant to failure than single Token rings. A new implementation of the Token ring architecture known as FDDI uses protocols that will allow images to be transmitted at speeds approaching the signaling (or rated) speed of the network, 100 Mb/sec. This would allow a 2K by 2K image to be transmitted across the network in near-real time. Star networks are used by some PACS vendors but suffer from dependence on the central hub which incapacitates the network if it fails. This differs from Token rings, which have no central hub.

Wide area networks, (WAN’s) allow for transmission between hospitals, imaging centers, and distant sites. WAN’s use either telephone lines or high speed transmission alternatives (multi-channel and/or high speed data lines, microwave, or satellite links) to transmit medical images. Most teleradiology systems use standard telephone lines that are capable of transmitting data at speeds of up to 38.4 Kb/sec. This allows for a 512 by 512 by 8 bit image with 6:1 compression to be transmitted in under 15 seconds.

Larger images (2048 by 2048 by 12 bits) like those transmitted between hospitals, require special transmission networks with exceptionally broad bandwidths. Microwave and satellite links can both transmit images in seconds due to their capacity. Shared multi-channel high speed data transmission services are also being offered for medical image transmission by several companies. Some charge the user only for the actual time spent on the high speed network.
SYSTEM AND FILE SERVERS

PACS use two types of servers — main system servers and distributed file servers. Usually an entry level PACS will utilize a single system server that contains the operating system software, network management software, and database management software. As the system expands, archive management software and information systems connectivity (HIS/RIS) can also be achieved through this unit. System servers are used as the hub of an in-house distribution network and ultimately as the central controller for a distributed PACS. Distributed file servers are used after the system reaches the point in time where a single system server can no longer effectively address all workstations without incurring network traffic problems. Distributed servers reduce system network traffic by acting as mini-system servers and routing images to the five to seven workstations they typically support.

Both system and files servers, like all PACS components, are sized depending on their application. Servers can be as simple as a single DOS-based personal computer unit or as advanced as single or multiple Sun or IBM-compatible workstations operating under Unix or RISC (Reduced Instruction Set Computing)-based processing systems. A well-designed server, whether system or file, will be able to handle multiple simultaneous commands as well as network management requirements without causing degradation of overall system performance.

COMPRESSION

One of the most controversial issues in PACS deals with image compression. This is used to reduce both image transmission time and storage requirements. Compression is achieved through a number of methods called algorithms and can be done in either hardware or software. Two forms of compression are offered: bit preserving (also called lossless or non-destructive compression) which reconstructs the image bit for bit like that of the original, and non-bit preserving (also called lossy or destructive compression) which does not provide an exact bit for bit replication of the original.

The controversy over compression arises because of the lack of controlled experiments to determine what level of data compression is usable before there is diagnostically significant degradation of the image. The problem is that the question of what amount of compression is acceptable is too general. Though very good experiments have shown that high levels of compression do not degrade diagnostic performance for certain tasks, the nature of such observer performance studies dictates that the set of tasks being evaluated is small. Overall, however, there is a growing body of evidence to support the use of destructive data compression, even for primary diagnosis in specific clinical situations.

Compression is very sensitive to noise. Most compression methods rely on the fact that pixel information in images tends to be correlated, that is, the value of one pixel can often be inferred from its neighbors. Noise, being a random phenomenon, is uncorrelated, and this reduces the predictability of one pixel value from another. The end result is that the noisy image is far more difficult to compress than a non-noisy one.

Compression is used almost exclusively in teleradiology systems and rarely used in hospital distribution networks. As compression and accompanying restoration add from five (5) to ten (10) seconds each per image, any transmission time savings over a LAN is often negated by the added time to compress and restore the individual images.

Compression, if used, varies in method and resulting ratio with different manufacturers. Most manufacturers offer lossless compression for many applications since algorithms which perform such compression are readily available. Before using lossy compression for diagnostic images, the user should experiment with images and survey the literature for research showing that the intended task is not adversely affected by compression.
IMAGE DISPLAY WORKSTATIONS

PACS utilize a variety of image display workstations. While an entry-level teleradiology system might use a video display monitor similar to black and white television, radiologists' workstations must display ultra-high resolution images with full grey scale to provide for a primary diagnosis. Image quality of softcopy displays compared to film can be done in an objective manner by measuring spatial and contrast resolution. A calculation based on a 14 x 17-inch film digitized at 2048 by 2560 pixels yields 2.5-3 line pairs per millimeter (lp/mm). Cathode ray tube displays exist which can equal this spatial resolution, at least as measured at the center of the tube face. Limiting the value of softcopy displays is their low luminance compared to film on a light box. The difference is typically an order of magnitude, with the film/light box being much brighter. Improving the value of workstation displays is the availability of the full digital data from the workstation which means that the full range of contrast resolution may be viewed on the CRT. The workstation also employs image processing techniques which can enhance the displayed image.

Virtually every PACS display workstation operates using either a mouse, trackball, keypad, or function key assignments. Available functions and patient database information are usually displayed on menus in a "windows-type" environment, with "point and select" operation performed through these devices.

Teleradiology systems generally use low to moderate cost display monitors combined with basic image processing software. These systems often include either a single 525 line (NTSC) monochrome or VGA (640 x 480) image display station and range in size from 9" to 15". Higher resolution 1024 line monitors are also used in some teleradiology applications, with screen sizes ranging up to 24".

Physicians' display workstations such as those found in hospital film distribution systems dictate use of multiple-screen displays, high local storage capacity and an easy user interface due to the large number of physicians who will be using the system. These systems generally display images at 1024 resolution or greater, with many systems capable of maintaining at least one full 2K by 2K by 12 bit image per screen in random access memory (RAM) so that a zoomed-in area (quadrant) can be displayed at full (2K) image resolution. Radiologists' workstations generally require at least two and often four image display monitors, high speed server connectivity, and ultra-fast local storage disks. Basic image processing software in display workstations includes at a minimum, window and level (brightness/contrast) adjustments, zoom (magnify a region of interest), roam (move over the image at magnified resolution), invert (black and white toggle), and flip and rotate image. Optional software varies with the vendor and may include on-screen annotation, animation, 3-D processing, measurements, and other advanced post-processing features.

STORAGE

Storage is the function for retaining images until called for viewing. While image storage was one of the driving forces behind the concept of PACS, (the "A" in PACS stands for archiving), delays in developing this technology and its high cost have hindered its widespread application. Storage is broken down into two distinct areas: short-term, which includes local (magnetic) storage, and long-term archive, which embraces optical and other storage media.

Local (or magnetic) storage, often referred to as the "hard disk" in the computer, retains digital image information on a magnetic disk for fast retrieval. Images stored in local storage are usually kept there for under a week because of the large image file sizes and the cost of high capacity magnetic drives. An image saved in local storage can often be accessed in under five seconds, and even quicker when high speed SCSI (Small Computer Systems Interface) drives are used. Local storage is used in both image display workstations and system servers.

Long term archives usually refer to WORM (write once, read many) optical disks. WORM disks come in multiple sizes and capacities of up to 10 GB each. WORM disks store data in a permanent, non-erasable, archive format. At present, WORM disks are best suited to storing data from the digital imaging modalities, e.g., CT, MRI, because of the high cost per megabyte of the storage.
media. About 30 images from a CT or 120 images from an MRI study require the same amount of storage as a single chest image digitized at 2048 by 2560 by 12 bits.

Newer technologies have also evolved that may be used to solve the storage problems. A recently developed technology known as magneto-optical (M/O) erasable optical drives allows for large file sizes to be kept and retrieved for a month or longer, then erased after they are no longer needed, much like a magnetic disk currently operates.

Magnetic tape archiving uses several media types and drives. The two major tape types are helical (similar to videocassettes) and linear (conventional reel-to-reel). Recently, optical tape has become available. It uses a technology similar to write-once optical disks, but on a flexible medium. These magnetic and optical tape archives offer a strong challenge to optical disks.

INTERFACES

One of the largest problems PACS technology has to overcome is the communications barriers between modalities, information systems, and other devices which communicate via proprietary methods. ACR/NEMA, Health Level 7 (HL-7), the IEEE (Institute of Electrical and Electronic Engineers), HISCC (Healthcare Information Standards Coordinating Committee), ASTM (American Society for Testing and Materials), and ANSI (American National Standards Institute), in the U.S.; CEN (Comite Europeen de Normalisation) in Europe; the Image Save and Carry (ISAC) Committee and others in Japan are attempting to address these and other communication problems by fostering communications and information transfer standards.

The ACR/NEMA Standards Committee has several working groups (WG) that are developing industry standards.

The most active of the ACR/NEMA working groups is WG VI which has maintained and refined the digital imaging and communications standard, often known as the "ACR/NEMA Standard". This standard addresses the transfer of image and associated demographic data between modalities from different vendors, two dissimilar modalities or, in the case of a PACS, between the modality(ies) and/or network server.

ACR/NEMA WG V has developed a magnetic tape standard that allows transfer of magnetically stored data from one modality vendor's unit to be able to be read on the magnetic tape drive unit of another modality vendor's unit.

ACR/NEMA WG VIII works primarily on HIS/RIS/PACS interface issues, and is currently involved with WG VI in developing the new network Standard.

ACR/NEMA WG IV has reviewed a data compression standard likely to be used in medical imaging. For each method of compression, the data elements and their ordering are sufficiently specified that, based on information from the standard, a decoder can be designed to properly reconstruct an image that has been compressed using an encoder which conforms to the standard.

Most recently, ANSI has formed a Standards Planning Panel for Healthcare Informatics. This panel includes representatives from interested U.S. Standards bodies (including those mentioned so far), and will coordinate activity within the U.S. It also provides liaison to European and other standards counterparts. These efforts are aimed at gaining international recognition of standards such as ACR/NEMA.

RADIOLOGY INFORMATION SYSTEMS

Radiology information systems (RIS) are dedicated information systems that allow the radiology department to operate more efficiently, and increase overall productivity. The systems generally consist of several "modules" that are sold either individually or as a complete package. The modules address specific areas—order entry, examination and appointment scheduling, film tracking
and management, inventory control, results reporting, charge capture, and management and statistical reporting. Available modules vary from vendor to vendor; however, there is a consistent functionality found in virtually every system.

RIS's, which provide an interface to the HIS for automated charge capture, offer the most benefits in terms of additional department revenue. Streamlined results reporting significantly reduces radiology report turnaround time, while scheduling modules make the most effective use of available resources. Management and statistical reporting allows objective management decisions to be made using unbiased data provided by the RIS

When considering a hospital-based PACS, it is necessary to view an RIS as a prerequisite or to make the functionality of RIS a part of the image management system.
INTRODUCTION

When looking for ways to improve imaging services to seek a competitive advantage, or exploring ways to improve the quality of healthcare while reducing costs, PACS may be the appropriate alternative. The first step in considering PACS technology is to examine the practice mission. In the process, changes needed for better performance will be identified. Every practice is unique and has goals unlike that of any other imaging practice. One of the ways to find out if the mission is being achieved is to assess what the referring physicians think of the service. To accomplish this, feedback from the referral sources should be obtained. This can be done by conducting periodic surveys, reviewing complaints, and checking overall performance. Monitoring a practice in this manner can provide the basis for assessing the need for PACS technology.

DEVELOPING GOALS AND OBJECTIVES

Following the definition of needs and requirements, issues will emerge which help define the long-term objectives and intermediate goals for achieving these objectives. For example, an objective may be to provide timely reporting to referring physicians while the near-term goal may be to reduce the report turnaround time from 36 hours to 24 hours. A later goal may be to reduce this time even further.

Goals should be specific. Performance checkpoints are needed to assess whether the goals are being reached and, if so, to establish new goals. These checkpoints can provide a basis for looking at alternative technologies and management methods. What are the requirements for reaching these goals and objectives? For example, what does the “reasonable” referring physician expect in terms of information in a report; does it include images; when is a report “complete”; what is a timely report; what consultation is needed; and, do these factors differ for different specialists?

This analysis will allow different alternatives to be considered. A workstation in every physician’s office would provide both images and reports on a demand basis, but it may be expensive. Who will pay the price? A simpler solution might be an improved word processing system with facsimile dispatching. Alternatively, digital voice dictation with physician call-in for reports might meet the requirement. Terminals tied into the RIS/HIS with access to reports may be an answer. On-call courier service can provide fast turnaround time in some practices.

Each of these solutions can be designed to meet some, if not all, of the performance requirements. The focus should be placed on the quality of performance and results rather than on technology. Technology is a tool to achieve the goals and objectives. Keeping technology in perspective as a tool to achieve a goal, rather than an end in itself, is a constant challenge. Technology will not, by itself, build referrals or result in a better managed department. It can, in fact, be counterproductive if misused. Clearly defined goals and objectives will be very helpful in clarifying each step of PACS implementation. These will also provide a way to sort through the many alternatives that exist and to find those best suited to meet unique requirements.

In earlier chapters, PACS implementations were described, including those done in small, incremental steps. Examples of “Mini-PACS” or PACS subsystems include: modality-specific devices, application specific communication links, teleradiology and networked hardcopy systems. Each of these applications satisfies goals to improve service, reduce labor and material costs, capture lost revenues, improve throughput and productivity, and enhance the quality of care. Longer range goals include installation of radiology information systems, interfaces and communication networks, and a central file server and archiving system with engineered interfaces to provide the foundation for future growth. These can be cost justified if they serve a well-defined need, improve performance over present methods, and are low-risk in terms of obsolescence and/or cost. The application cost can be lowered by building a foundation for future expansion and multi-use applications.

Priorities should be set for improved performance functions and to focus on fast changing technologies. Each imaging site has its own unique problems related to image access or management, personnel utilization or staffing, and communicating with
locations outside (and sometimes inside) the radiology department. A team approach should be adopted to address the issues of performance and the application of technology to improve service. This team should include radiologists and other imaging specialists, physicists, MIS personnel, administrators, referring physicians and where appropriate, outside consultants. Some needs are not likely to change very much, e.g., communication between MR reading stations. The technology, which is changing rapidly, is available at many different levels of performance and cost. Each vendor and associated equipment must be evaluated within the context of specific applications and measured against cost-performance requirements.

PLANNING FOR PACS IMPLEMENTATION

Planning is important because PACS is an integral part of the all digital medical record, which is where medical informatics is headed. Knowing what questions to ask and asking them, will contribute to preparedness for the future.

The vision of a fully integrated electronic imaging service should be defined to the extent possible. How will everything eventually work together? Elements of this vision likely will include an image management system, high-speed telecommunication networks, multi-modality archiving and display systems and appropriate interfaces. In the development of a master plan for the long-term vision, workflow patterns should be defined and analyzed to see how PACS technology can be applied most effectively, and indicate how application-specific solutions are compatible with future growth. This approach should minimize the risk of “dead-end” technology and obsolescence. The master plan can help avoid “penny-wise, pound-foolish” decisions which create future problems.

There are three major obstacles related to the acquisition and use of PACS technology:

• Status of technology — components are in varying states of development
• Cost Justification — data are lacking on how a capital-intensive PACS is cost justified.
• Behavior Modification — PACS will change how imaging services are run and how radiology is practiced.

Technology issues which include ACR/NEMA Standard implementation, open systems, high-speed communications and archiving strategies and software, will be resolved with time. Cost issues will be managed through technological cost-reduction, competitive processes among vendors, and the growing obsolescence and increasing cost of labor intensive existing systems. Behavior modification issues are the toughest challenge. Small steps taken today will facilitate acceptance of future changes related to implementing new technology.

COST ISSUES

What does it cost to move images now? How much time do physicians spend waiting for reports or looking for films? How much time do technologists spend processing and handling film? How much does film storage space cost now and what will it cost in five years? Cost models and internal accounting procedures can provide a basis for comparing the cost of PACS to present methods.

Some observations regarding costs considerations are:

• While it may seem obvious, it is still worth suggesting that priority should be given to those applications that will improve performance the most at the least cost.
• The sequence in which technology is applied may have a great effect on net cost.
• The average cost of handling film is approximately three times the cost of film. Most of the cost is the labor of physicians, technologists and clerical/accounting staff.
• If 75 percent of a practice operates well, concentrate on the 25 percent that doesn’t.
• The higher the number of procedures for which the technology is applied, the lower the cost per procedure.
• Long-term labor savings will accrue as the existing staff becomes more efficient in using PACS technology, requiring fewer additions to accommodate growth.
• Make some early decisions now. If the technology can be written off in a few years while performing useful functions and saving staff time, don’t spend $100,000 of time making a $100,000 buying decision.
• Moving images to physicians in the form of film or softcopy, is likely to be less expensive than moving physicians to images, even if additional film is used.
• Both physicians and hospitals benefit from labor saving technology, directly and indirectly.
• Some costs as well as some benefits which cannot be quantified at the outset may be realized.
• Cost issues should not be used as an excuse for inaction.

When considering spending money on new technology, raise the question, “Where can the money be spent to get a better return on the investment?” Technology is available today that is cost-competitive with present methods.

PROCUREMENT, ACCEPTANCE AND RISK MANAGEMENT

The acquisition of PACS will be determined by perceived needs, availability of proven technology, budgetary considerations, and ability to incorporate the technology in practice. For these reasons, it will likely take three to five years to fully implement the technology. A phased program for implementation is recommended with performance checkpoints at each step to assure effective implementation consistent with the ability to absorb and adapt to the technology. While the end point may be similar for most practices, the starting points may vary widely.

Because of the integration functions, both internal and external, PACS is different from other purchases made by an imaging practice. The system will affect the operation of the entire practice and constitute a long-term change in the way the imaging service is provided. That is why it is so important to define performance requirements initially, based on an assessment of needs.

Systems which need to work together may include components from many manufacturers. Written performance specifications should include well-defined interface and connectivity requirements between modalities and other information systems. System performance specifications, including image access speeds from short, intermediate, and long term storage; recall protocols; access speed to other information systems; service response and uptime guarantees; insurance against obsolescence; and upgrade policies should all be defined prior to acquisition.

A single manufacturer may not be willing to assume total responsibility for the system. If so, separate arrangements have to be made for total service, and for system and software support. The considerable up-front costs associated with custom software development need to be carefully documented. The ability of suppliers to provide long-term service and/or alternative service relationships should be considered. If a supplier does assume responsibility for system integration, emphasize the need for open architecture and obtain guarantees that will assure future flexibility. Demonstration of performance should be required for critical system elements. Components should be thoroughly tested prior to purchase and retested before acceptance to assure performance requirements are met.

Careful planning, a good team, clear-cut goals and objectives, performance criteria and compliance with stated requirements, will contribute to the successful implementation of PACS in practices looking to the future.
SUGGESTED READINGS - Philip Drew, Ph.D.

PACS SYSTEMS


*A thoughtful exposition of the forces that led to development of PACS systems and the problems that must be overcome before such systems can be a reality. Dr. Lodwick was one of the earliest proponents of digital image management and Mr. Taaffee at Massachusetts General Hospital is one of the leaders in designing and implementing such systems.*


*Many of the problems, both technical and operational, in realizing PACS systems are not apparent until actual implementation. For this reason the experience of those who have attempted implementation are particularly valuable. The group at UCLA has gained a great deal of practical experience through their initial implementations, which guides their ambitious plans for the first five years of the decade.*


*With at least 50 partial PACS systems in place, the Japanese have been active in development in their own country. As this article makes clear, activity there is effective, widespread and increasing. Differences in practice patterns between Japan and the United States make it difficult to transfer applications software, but hardware, operating systems and network software developed in Japan will play an important role in U.S. PACS.*


*Noting that PACS has been an unfulfilled vision for many years, the group at the Mallinckrodt Institute of Radiology laid out plans in 1989 for a "testbed" for PACS in which various system concepts could be implemented and evaluated. In their view, the system should embrace not only medical images but other pictures and data generated elsewhere at Washington University.*

TELERADIOLOGY


*An important lesson from PACS system implementations is that their existence changes the behavior of users of the systems -- radiologists, technologists, and referring physicians. Justification for PACS systems is often derived from considerations outside of the radiology department, as this paper demonstrates. The authors from the University of Pennsylvania provide quantitative measures, not just anecdotal information.*


*The University of Kansas supports remote military imaging facilities which transmit images for hundreds of miles over telephone networks to the University Hospital. There are a number of alternative means for such transmissions, including circuit switching, message switching and packet switching. This paper, by designers of the KU system, explores the issues and costs associated with various alternatives.*

In an earlier paper the group at the University of Kansas analyzed requirements for the teleradiology system eventually implemented to support remote military facilities. They reviewed the history of development of teleradiology, technical specifications and hardware requirements for systems.

DISPLAYS AND WORKSTATIONS


To assess the idea of interpretation with softcopy, a group at the University of Pittsburgh evaluated CT images displayed in several different modes on a CRT, concluding that diagnostic performance was just as good as with filmed images, thus allaying one concern with PACS. Although the result is restricted to a special case, it illustrates the hurdles that PACS implementations must cross. (A related editorial by Dennis Foley appears in the same issue).


The essential function of displays is to transfer image information to the mind of the radiologist for further processing, a process called interpretation. Thus, the task of the system designer is to match the display to the characteristics of the eye-brain system, about which technical knowledge is fragmentary and sparse. Drs. Pizer and Beard from the University of North Carolina masterfully review functional requirements and the ability of available displays to meet requirements.


The limitations of soft copy displays as replacements for film are a principal source of difficulty in PACS system design. In this carefully worked out discussion of the problems, the group from the University of Pennsylvania discusses hardware and software requirements in physical and operational terms, clearly defining needs and their own experience in conceiving a system to meet their needs.


The starting point in design of PACS was the alternator, whose characteristics they attempted to mimic with an array of monitors served by a large memory. The result was a system too expensive to justify in most settings. The cost of displays and associated hardware continues to fall, but experience illustrates the technical and economic difficulty of duplicating the alternator.

NETWORKS AND TRANSMISSION SYSTEMS


Like most other centers that have undertaken PACS installation, Georgetown University has taken a phased approach. Their initial installation was based on a system installed for CT and MR images in the neuroradiology department. This paper provides a frank discussion of the difficulties and problems encountered in putting such a system into operation.


Having been designed for data communications, most standard networks have not been entirely suitable for PACS. Nonetheless, PACS designers must depend on standard networks, whose capabilities steadily increase. The group at UCLA has systematically explored the abilities of several networks to meet their PACS needs.

"The three most difficult problems in making PACS a clinical reality are image archiving, very high-resolution display stations, and high-speed networking." With this introduction, the group at UCLA goes on to report their results addressing the third problem -- evaluating several networks.


Although now somewhat dated, this discussion of experience with an image management system based on Ethernet at the University of Kansas is still instructive. The discussion includes a careful explanation of technical terms, including a glossary.

**COMPUTED RADIOGRAPHY**


Computed radiography is important to PACS because it is the most likely avenue by which x-ray imaging will be brought into the digital realm. While CR images improve gray scale rendition in x-ray images, they generally lack the spatial resolution of film/screen images. Therefore, adoption of CR's problematical. The authors from the University of Arizona explore the issues in evaluating this important, new technology and provide some guidance to those considering adoption.


Since the digital manipulation available from computed radiography corrects errors in exposure, one of its principal applications has been portable x-ray examination, particularly for intensive care units, where the digital images can be transmitted electronically from the radiology department to the ICU. Dr. Ravin reviews experience with such a system at Duke University, noting benefits, pitfalls, and shortcomings -- information of value to anyone considering adoption of CR.


Although CR systems may do their image processing automatically, the authors from the University of Kansas conclude that some operator interaction at a workstation is desirable to optimize image parameters in the same manner that operator-guided windowing enhances CT and MR images.

**DIGITAL ARCHIVES**


It is now a commonplace that archiving all images in digital form taxes even the most capacious storage systems, a fact that furnishes one of the motivations to pursue partial implementations of PACS. Although storage technology has advanced since this article was written, it provides a good discussion of needs and the ability of storage systems to meet those needs.


Computer technology has provided a bewildering array of storage media for digital data. Among them are magnetic disks and tape, optical disks and tape, both erasable and not. Disks may be mounted singly or in jukeboxes. Dr. Hindel reviews the requirements of PACS systems.
and the suitability of different storage media for various applications.


Most designers of PACS recognize optical disks as a preferred storage medium for images. The early experience of the group at UCLA provides practical guidance about design of optical disk storage systems using a jukebox, their speed, reliability, and operability.

**COST EFFECTIVENESS**


Convincing economic analyses of PACS are few and far between. This analysis from the University of Washington is systematic and convincing. Its principal conclusion is that the savings from eliminating film are offset by the cost of maintenance of the electronic alternative. However, looking outside the radiology department, additional savings may theoretically be realized, although the savings do not necessarily go into the pockets of those who invest in PACS.


Rather than carrying out a cost-effectiveness analysis, this paper from the University of Iowa addresses the issues that face anyone seeking to justify PACS, noting not only issues of diagnostic accuracy and more timely diagnosis and intervention but also issues like promotion of hospital image and promotion of national R&D objectives.


Drs. Straub and Gur from the University of Pittsburgh begin by noting that most analyses of PACS find it hard to demonstrate that direct savings on film and technologist time justify the cost of PACS. Instead, they have focused on the importance of timely access to images for physicians directly involved in patient care. When queried, most physicians say that nonavailability of images can be a severe handicap for the timely practice of medicine, and PACS offers the promise of reducing this handicap.

**STANDARDS**


Clearly, one of the important impediments to development of PACS is the difficulty of connecting multiple devices that adhere to no common standard of digital communication. Believing that medical images have unique requirements not shared by other computer applications, the ACR and NEMA have joined forces to conceive and promulgate standards addressed to medical imaging systems. Their work has addressed communication interfaces, data compression, exchange media, validation, and interfaces among PACS, RIS, and HIS. The authors, who have led these efforts, reivew their goals and accomplishments.


Despite their importance, standards are mystifying to many who contemplate purchasing PACS systems. The first ACR-NEMA standard, concerning communication interfaces, was published in 1985. This article, by one of its developers, explains the standard.

Compression of images is one of the most controversial and misunderstood matters in PACS system design. Many designers believe it is essential, either on grounds of practicality or economy, but many radiologists, fearful that decompressed images differ from the originals, reject the technique. The authors from Eastman Kodak explore available techniques and their effect on medical images.
GLOSSARY OF CLINICAL AND TECHNICAL TERMS

ACR/NEMA Standard: A digital image communication standard developed by a joint committee of the American College of Radiology and the National Electrical Manufacturers Association.


Analog Image: An image produced by a continuously variable physical process (e.g., exposure of film).

Analog to Digital Converter (A/D): A device which converts analog data to a digital form.

Bandwidth: The difference, expressed in Hertz (Hz), between the two limiting frequencies of a band. The bandwidth is one factor in determining how much information a transmission medium (e.g., cable) can carry. See data transmission rate, throughput.

Baud: A variable unit of data transmission speed usually equal to one bit per second (bps).

Bit: Contraction of "binary digit", the smallest unit of data in a computer (usually 0 or 1).

Brightness: Perceived luminance.

Buffer: An area of storage that is reserved for use in performing an input/output operation, into which data are written or from which data are read.

Byte: A group of binary characters operated upon as a unit and usually shorter than a computer word. In most systems, a byte is a sequence of 8 adjacent bits.

CEN: A European standard-making body. The European Committee for Standardization.

Coaxial Cable: A cable consisting of one conductor, usually a small copper tube or wire, within and insulated from another conductor of larger diameter, usually copper tubing or copper braid.

Contrast: A measure of relative intensity difference in an image. High contrast implies mainly dark black and bright white content; medium contrast implies a wide distribution of intensities from black to white; low contrast implies a distribution of intensities consisting primarily shades of gray.

CRT: Cathode ray tube, e.g., a television picture tube used to display images.

Data Compression: A method of reducing required data storage capacity by storing data in encoded form. Various encoding methods are used to eliminate gaps, empty field, and redundancies to shorten the length of records.

Data transmission rate: The amount of data transmitted between nodes or over a medium in a time interval, expressed in bits per second (bps). The data transmission rate is one factor affecting the response time of the system.

Digital: Pertaining to the representation of data or physical quantities in the form or discrete steps rather than in a continuous stream.

Digital image: An image composed of discrete pixels each of which is characterized by a digitally represented luminance level. The screen size for a digital image might be 1024 by 1024 matrix of pixels x 8 bits (representing 256 luminance levels).

Digital to Analog Display Converter (D/A): An element of an image display system that serves to convert a binary quantity sample, or pixel, to an analog video voltage level for display.
Digitize: To obtain a digital representation of the magnitude of a physical quantity from an analog representation of that magnitude, e.g., to use a digitizer to scan a film (analog) image and create digital data representing that image.

Display: The presentation of data for viewing or the device used to present data. A video monitor is a typical display device.

DOS: Disk Operating System.

Ethernet: A communication protocol which runs on different types of cable at a data signaling rate of 10 million bits per second.

FDDI: Fiber Distributed Data Interface.

Fiber optic network: A type of computer network that uses pulses of light running through thin glass or plastic fibers, instead of electronic pulses travelling over copper wires.

Giga: A prefix meaning ten to the ninth power, one billion, as in Gbps (billion bits per second).

Gray level: The luminance value assigned to a pixel. A value may range from black, through grays, to white, e.g., an eight bit system accommodates 256 (2^8) levels.

Gray scale: The luminance available as valid gray levels for a given image processing system. The gray scale represents the discrete gray levels defined in a system. Also, a scale of brightness displayed and photographed with an image.

GUI (Graphic User Interface): A method of interacting with a computer system, typically using a mouse and a cursor, rather than a keyboard.

Hardcopy: A medium (e.g., film, paper) on which permanent analog representations of images or text are stored.

HIS: Hospital information system.

IEEE: Institute of Electrical and Electronic Engineers.

Image acquisition: The process of acquiring a digital image from either a digital or analog image modality.

Image archive: A computer subsystem for storing images, patient demographic information, and a database that will allow access to this information.

Interface: A shared boundary or a device to allow data to be passed across such a boundary. An interface might be a hardware component to link two devices or it might be a portion of storage or registers accessed by two or more computer programs. A data transmission interface is a shared boundary defined by common physical interconnection characteristics, signal characteristics, and functional characteristics of the interchange circuits. The standardization of there characteristics makes the interfaces possible.

ISDN: Integrated services digital network.

Jukebox: A storage device like a "Wurlitzer" record player which holds many optical disks and selects one to be read into the computer.

Kilobyte: 1,024 bytes.
Laser imager: A high quality image formatter, typically taking digital images as input and producing a sheet of film with 1 to 16 images on it.

Local area network (LAN): A data communications network designed to send and receive data from devices over intermediate distances.

Luminance: The incident luminous flux per unit area. Luminance is usually measured in candelas per square meter.

Magnetic disc: A flat circular plate with a surface layer on which data can be stored by magnetic recording. Disc storage provides random access to stored data.

Magnetic tape: A tape whose surface layer can be divided into discrete units each of which can be charged positively or negatively. Magnetic charge can be altered so that the information stored on the magnetic tape can be modified. Tape storage does not provide random access to stored data; it must be searched sequentially.

Megabyte: 1 million bytes, technically 1,024 times 1,024.

Modalities: Image generating equipment, such as CT, MR and conventional x-ray machines.

Modem: (Modulation/demodulation unit), a hardware unit which converts the binary signals of user equipment to audio analog signals for transmission on a communication circuit.

Network: A computer communication system which connects a variety of workstations with image modalities and an archive.

Open systems interconnection reference model (ISO/OSI): The International Standards Organization's Open Systems Interconnections reference model is the standard for local area network (LAN) architecture. The model consists of seven hierarchical layers: physical, data link, network, transport, session, presentation, and application. These layers address LAN design from the specification of the physical transmission medium to the capabilities of user interaction with LAN services.

Operating System: Software that controls the execution of computer programs and that may provide scheduling, debugging, input/output control, accounting, compilation, storage assignment, data management, and related services.

Optical (laser) disk: A storage disk using a laser to store and retrieve digital data. Optical disks provide significantly greater storage capacity than magnetic disks.

Pixel: The fundamental picture element of a digital image, e.g., display screens present a 1024 by 1024 pixel matrix. Each pixel can be thought of as a very small area of luminance. When a large number of them are placed adjacent to each other a picture is formed.

Primary diagnosis: The interpretation of medical images transmitted to a requesting physician to facilitate diagnosis and treatment.

Random access: The capability to obtain data from a storage device in such a way that the process depends only on the location of the data and not on a reference to data previously accessed. Disk storage provides random access memory; tape storage does not. Random access memory is necessary to support rapid system response times.

Resolution: The measurable physical characteristics of an image, commonly spoken of as spatial resolution for the geometric capability, and contrast resolution for the grayscale capability.
RIS: Radiology Information System.

Spatial resolution: Property of distinguishing two equal sized adjacent objects in the same place. Refers to the number of pixels in a specified area of a matrix.

T-1: A data transmission rate over a computer communication link, running at 1.544 megabits per second.


Teleradiology: The electronic transmission of radiologic images from a radiology site to a distant viewing station where interpretations are made.

Tera: A prefix meaning ten to the power twelve, one trillion, as in Tbytes (one trillion bytes).

Throughput: A measure of the amount of work performed over a given period of time. In discussion of communications networks, this term is used synonymously with data transmission rate, expressed in bits per second.

Unix: A computer operating system.

Window level: The middle value of the gray scale of the window width.

Window width: The range of the gray scale of the image appearing on a screen.

WORM: Write Once, Read Many: a form of optical disk in which the disk can be written only once (never erased) but read many times.