PACS Mini Refresher Course

Three Methods of Implementing a Picture Archiving and Communication System

H. K. Huang, DSc

A picture archiving and communication system (PACS) is a system integration of many components, including radiologic image acquisition devices, computers, communication networks, image display workstations, and database management systems. The author describes three general approaches to implementing a PACS. In the first approach, the department or institution acts as a systems integrator, designing and implementing the PACS. In the second approach, the PACS is planned on the basis of the department's operations and environment and then a manufacturer is contracted to design and build the system. The third approach is to purchase a turnkey system, with some modifications provided by the manufacturer for a specific clinical application. The author provides examples of each approach in the clinical environment and presents the disadvantages and advantages of each.

INTRODUCTION

A picture archiving and communication system (PACS) is an integration of many components related to radiologic practice. Depending on the application, a PACS can be a simple or a complex hospital-integrated system. For example, a PACS for an intensive care unit can be a simple system comprising a video camera for digitization of radiographs, a baseband video system to transmit the images, and a video monitor in the intensive care unit to receive and display images. On the other hand, the hospital-integrated PACS is comprehensive and requires careful planning and millions of dollars of investment.

During the past 10 years, many hospitals and manufacturers in the United States and abroad have researched and developed PACS of varying complexity. Some of these systems are in clinical trial and use. These systems can be loosely categorized

Abbreviations: FDDI = fiber distributed data interface, MDIS = Medical Diagnostic Imaging Support System, PACS = picture archiving and communication system, UCLA = University of California, Los Angeles

Index term: Picture archiving and communication system


1 From the Medical Imaging Division, Department of Radiological Sciences, School of Medicine, University of California Los Angeles, 405 Hilgard Ave, Los Angeles, CA 90024-1721. From the 1991 RSNA scientific assembly. Received September 23, 1991; accepted September 27. Supported in part by Public Health Service grant P01 CA 51198 from the National Cancer Institute, Department of Health and Human Services. Address reprint requests to the author.

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into two groups according to methods of implementation. The first category is the homegrown system, developed within the department or hospital because of clinical needs. The second category is market driven. Some manufacturers see some potential profit in developing a turnkey PACS, as either a new product or a component to enhance the sales of other product lines. In the late 1980s, the surgeon general of the U.S. military services initiated the Medical Diagnostic Imaging Support System (MDIS) concept. The MDIS adopted the military procurement procedures in acquiring PACS for military hospitals and clinics. This approach created a third category of implementing PACS. In this article, I discuss these three approaches and provide examples for each.

**METHODS OF PACS IMPLEMENTATION**

Most PACS implementation efforts are initiated by university hospitals and academic departments and by research laboratories of major imaging manufacturers. There are generally three methods of approach (1). In the first approach, systems integration, a multidisciplinary team with technical know-how is assembled by a radiology department. The team becomes a system integrator, selecting PACS components from various manufacturers. The team develops system interfaces and writes the PACS software according to the clinical requirements of the department. In the second approach, requirements specification and contracting, a team of experts, from both outside and inside the hospital, is assembled to write detailed specifications for the PACS for a certain clinical environment. A manufacturer is contracted to implement the system. In the third, or turnkey, approach, the manufacturer develops a turnkey PACS system and installs it in a department for clinical use.

These approaches each have advantages and disadvantages. One advantage of the first or systems integration approach is that the research team can continuously upgrade the system with state-of-the-art components and therefore the system will not become obsolete. The system so designed is tailored to the clinical environment and can be upgraded without depending on the schedule of the manufacturer. One disadvantage is that it requires a substantial commitment by the department to assemble a multidisciplinary team. In addition, the system developed will be one of a kind, and therefore service and maintenance will be difficult because it consists of components from different manufacturers.

The primary advantage of the second approach (requirements specification and contracting) is that the PACS specifications are tailored to a certain clinical environment, yet the responsibility for implementing the PACS is delegated to the manufacturer. The department acts as a purchase agent and does not have to be concerned with the installation. The disadvantages are that the specifications tend to be over ambitious because of the potential for experts, not familiar with the clinical environment, to underestimate the technical and operational difficulty. The designated manufacturer, who may lack experience with some components in a clinical environment, may tend to overestimate the performance of each component. As a result, the completed PACS may not meet the overall specifications. The cost of contracting the manufacturer to develop a specified PACS is also high due to the manufacturer's narrow profit margin in building only one system.

The advantage of the third or turnkey approach is that in a generalized production system, the cost tends to be lower. In this approach, the manufacturer needs a couple years to complete the production cycle. By the time a system is commercially available, some components may have already become
Advantages and Disadvantages of Three Methods of PACS Implementation

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<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>1: Systems integration</td>
<td>Built to specifications</td>
<td>Difficult to assemble a team</td>
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<td>State-of-the-art technology</td>
<td>One-of-a-kind system</td>
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<td>Continuously upgraded</td>
<td>Difficult to service and maintain</td>
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<td>Not dependent on a single manufacturer</td>
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<td>2: Requirements specification</td>
<td>Specifications written for a certain clinical</td>
<td>Specifications overambitious</td>
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<td>and contracting</td>
<td>environment</td>
<td>Technical and operational difficulty</td>
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<td>Implementation delegated to the manufacturer</td>
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<td>3: Turnkey</td>
<td>Lower cost</td>
<td>Manufacturer lacks clinical experience</td>
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<td>Easier maintenance</td>
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obsolete. Also, it is doubtful whether a generalized PACS can be used for every specialty in a department and be used for every radiology department. Most likely, these three approaches will gradually merge as additional clinical data regarding PACS become available. The Table summarizes the advantages and disadvantages of these three approaches.

Because of various operating conditions, the emphasis in PACS research and development is different in North America, Europe, and Japan. In the United States, PACS research is mostly supported by government agencies and manufacturers. In the European countries, it is supported through either a national or regional resource. European research teams tend to work with a single major manufacturer, and, since most PACS components are developed in the United States and Japan, they are not as readily available. European research teams emphasize PACS modeling and simulation, as well as investigation of the image processing component of PACS. In Japan, PACS research and development is a national project. The national resources are distributed to various manufacturers and university hospitals. A manufacturer integrates a PACS system and installs it in a hospital for clinical evaluation. The manufacturer's PACS specifications tend to be rigid and leave little room for the hospital research team to modify the technical specifications.

**METHOD 1: SYSTEMS INTEGRATION**

An example of the method 1 approach is the PACS research and development program at the University of California, Los Angeles (UCLA), which began in 1984. There are three phases: Phase 1, from 1984 to 1990, encompassed demonstration of the concept of PACS and the design of the PACS infrastructure. Phase 2, from 1990 to 1991, comprised clinical implementation of several PACS modules. Phase 3, from 1992 on, will include systems refinement, maintenance, and applications.

**Phase 1: Demonstration of Concept and Design of PACS Infrastructure**

To demonstrate the concept of PACS to physicians, in 1987 UCLA implemented two PACS modules, one in the pediatric radiology section (within the department) (2) and the other in the coronary care unit (3). The pediatric radiology section was selected because it operates independently and resembles a miniradiology department. It is an excellent model with which to study the implementation of a complete PACS within a radiology department. In this module, images are displayed on six 1,024-line monitors and on two 2,048-line monitors. The module is used for
daily conferences and case reviews. The coronary care unit was chosen for the second PACS module because a viewing station in this unit is convenient for clinicians who need to stay near their patients. It is a model of a PACS outside the radiology department. In this module, images are displayed on three 1,024-line monitors. Both modules are in clinical operation 24 hours a day, 7 days a week. The reaction from both radiologists and clinicians to using these two systems was very positive (2,3).

From 1988 to 1990, the UCLA team concentrated on the design of the PACS infrastructure. The critical components in the infrastructure are the communication system, cluster controllers, data base, fault tolerance design, and systems integration software. The details of these components have been described (4,5). This infrastructure supports a digital-based radiology operation.

The infrastructure was implemented from 1990 to 1991. There are 64 multimode and 48 single-mode fiber optic cables connecting the three buildings (Center for the Health Sciences, Medical Plaza, and Taper Building) housing the radiology department. There are two cluster controllers, one at the Center for the Health Sciences and one at the Medical Plaza. The infrastructure has been on-line since the beginning of 1991.

Communication System. — UCLA designed a three-tier fiber optic communication system with Ethernet, FDDI (fiber distributed data interface), and Ultranet (6,7). Ethernet is used to transmit images from acquisition devices to the acquisition computer. Since the acquisition device is slow in generating images, the transmission speed between these two nodes is not crucial. Images are reformatted at the acquisition computer and sent to the cluster controller by means of FDDI. Images are archived onto optical disks and distributed to the image display stations with the 1-Gbit/sec Ultranet. The three communication networks are coexistent in the infrastructure and serve as backups for each other.

Cluster Controllers. — There are multiple cluster controllers in the infrastructure. Each cluster controller is composed of an image server (model 4/490 SPARC, Sun Microsystems, Mountain View, Calif.) with 4-Gbyte magnetic disk storage, a 1-Tbyte optical disk library for archiving images, and a Sun 4/490 SPARC server running the data base (Sybase; Emeryville, Calif) for patient directory and text information. The architecture of each cluster controller is identical and can be used as the backup for the others. Cluster controllers are connected with the Ultranet. Images can be transmitted between cluster controllers at 4–8 Mbyte/sec.

Data Base. — An identical Sybase data base exists in each cluster controller. Current patient image information is updated continuously on the data base of every cluster controller.

Fault Tolerance Design. — In the infrastructure, every component has a backup. The data base exists in multiple copies, one in each cluster controller. Each cluster controller is located in a separate room to avoid potential disaster. The three communication networks back up each other, and all active fiber optic cables have a duplicate. Each cluster controller is powered by an uninterruptable power supply with up to 20 minutes of uninterruptible power.

Systems Integration Software. — The preceding four components are integrated as the PACS infrastructure by means of an elaborate system software. The system software was written in C programming language and runs under the UNIX operating system.

● Phase 2: Implementation of PACS Modules

Two tasks are required to implement PACS modules in a clinical environment. The first task is to connect image acquisition devices to the cluster controller through the infrastructure. The second is to design and implement display stations in the department and clinics. With respect to image acquisition, three computed tomographic (CT) and three magnetic resonance (MR) imagers with direct digital interface to acquisition computers and to two cluster controllers have been successfully connected to the infrastructure. Also, three computed radiography units and three film digitizers have been connected. The establishment of the infrastructure made these connections possible. Future connections of new image acquisition devices will be a routine engineering exercise.
Phase 3: Systems Refinement, Training, Maintenance, and Applications
Phase 3 comprises three stages. Stage 1 is the continuing development of display stations and their clinical implementation. Stage 2 consists of refining the system; upgrading the display station software; and establishing training, maintenance, and service. Stage 3 consists of researching PACS applications.

Stage 1: Display Stations and Clinical Implementation.—In this stage, five stations, each with two 2,048-line monitors, will be implemented in the pediatric radiology (two stations), neuroradiology, chest radiology, and bone radiology sections. Also, one printing station will be installed as a hard-copy device. The two new pediatric stations, one for inpatient and the other for outpatient use, will replace the current pediatric station. Additional 2,048-line monitors will be added as required. Additional 1,024-line monitors will also be implemented in hospital wards as needed. Figures 1 and 2 show the UCLA PACS infrastructure image acquisition and display stations.

Stage 2: Systems Refinement and Training, Maintenance, and Service.—During clinical implementation, procedures will be set up for training, systems maintenance, and service. Three groups of personnel must be trained. The first group is radiologists and clinicians. Training for this group is simple and should take no more than 15 minutes, since the display station is simple to use. The second group includes the PACS coordinator, technologists, and clerical personnel. This training is extensive and covers image quality assurance, updating the patient directory, and first-line troubleshooting. The third group is the PACS engineers. This training is most elaborate. It includes all operational aspects of the PACS. To date, two PACS coordinators and two engineers have completed this training and have been integrated into the PACS research and development team to gain experience.

Stage 3: PACS Applications.—The UCLA team believes that a PACS is not just a management tool; a PACS is a vehicle for future radiology practice and research. For this reason, three research areas in PACS applications are being planned. The first area is image quantification, which includes the conventional image measurement methods, image reformatting and registration, and derivation of parameters from images. The purpose of this research is to explore the potential of extracting information from digital images to facilitate radiologic diagnosis. The second area of research is interactive teaching. Traditional radiology teaching is passive in the sense that knowledge is transmitted by the teacher and the textbook to the learner. The PACS can be used as an interactive teaching tool for diagnostic radiology through the rich PACS data base. The third area of research is development of a digital imaging data base. Information science has taught us to derive knowledge from a data base. However, so far, the data base has been limited to text information, since no large radiologic (digital) image data base has ever existed. The PACS data base is the hidden treasure that awaits probing by the researchers. It is anticipated that this "knowledge base" will open a new horizon for radiologic research.

Method 2: Requirements Specification and Contracting
In this section, we give two examples of method 2. The first is the Hokkaido University Medical Information System Project in Japan. This PACS system is already in clinical operation and is continuously being upgraded. The second example is the MDIS for the Military Medicine Project, which is in the final stage of selecting a vendor.

Hokkaido University Medical Information System Project
The Hokkaido University PACS project (8) in Japan, under the direction of Goro Irie, MD, is probably one of the largest projects in medical information systems. It integrates PACS, hospital information systems, and medical records. There are three networks, one for each system. The project, started in 1989, adopts a top-down approach and is a whole-hospital information system, connected through a PACS loop. The system was planned by a team of experts from Hokkaido University, Fuji Medical Systems, and Nappion Electronic Corporation (NEC). The final system was designed and implemented by NEC. The department uses computed radiography exclusively, and all computed radiography units are connected to the network. Currently, there are twenty 1,024-line monitor display stations, each equipped with software provid-
Figure 1. UCLA PACS network at the Center for the Health Sciences and remote MR site. CHS = Center for the Health Sciences, GenUn = genitourinary radiology, PCR = Philips computed radiography, Peds = pediatric radiology, RIS = radiology information system.
Figure 2. UCLA PACS network at the Medical Plaza. *MP* = Medical Plaza, *Peds* = pediatric radiology.
ing a look-up table; rotation, inverse, zoom, and scroll capabilities; and subtraction, edge enhancement, and linear and angular measurement functions. The system handles 30% of the computed radiography images (300 per day) and 100% of the CT and MR images and digital subtraction angiograms (500 per day). Images are stored on magnetic disk for 1 week, and older images can be retrieved from the optical disk library in 40–60 seconds. The system is continuously upgraded by NEC. The target date for integrating the medical records with the PACS is in 1993. The medical records will include images from echography, endography, and microscopy, as well as charts from electroencephalography, electrocardiography, and electromyography. The number of terminals will be approximately 200.

- **MDIS for the Military Medicine Project**

  The purpose of the MDIS project in the United States (9) is to implement filmless medical imaging systems at several military medical treatment facilities over the next 4 years. The surgeon general of the military services created the MDIS project to exploit the results of extensive imaging research efforts over the past 10 years. These filmless MDIS systems will be acquired from industry through a contracting approach that (a) functionally describes subsystem and system performance for acceptable clinical operations, (b) validates proposed systems on the basis of performance evaluation, and (c) selects a system and awards a contract based on the best value to the U.S. government.

  The first four sites of the MDIS project will be Madigan Army Hospital, Fort Lewis, Tacoma, Washington; Brooke Army Medical Center, Fort Sam Houston, San Antonio, Texas; Wright-Patterson Air Force Base, Dayton, Ohio; and Luke Davis–Monthan Air Force Hospital, Phoenix, Arizona. The goals for the first four sites are as follows: In phase 1, 6 months after the contract is awarded, the basic MDIS for inpatients should be operational (40% digital). In phase 2, a graceful transition to MDIS, including the high-volume outpatient examinations, should be made (65% digital). Finally, in phase 3, the system is refined and expanded to include low-volume outpatient examinations (90% digital).

  The military first assembled a team of experts in 1989, and the team traveled around the country visiting different PACS research and development sites. They then wrote the technical specifications, including those pertaining to service, maintenance, and training, for the four sites. The military contracting office issued a request for proposals, inviting potential manufacturers to bid for the project. In the last quarter of 1990, the military selected two manufacturers as the two finalists. The qualifications of these two vendors were studied extensively, and the contract was awarded to a manufacturer in October 1991.

- **METHOD 3: TURNKEY APPROACH**

  In this approach, a turnkey system is purchased from a manufacturer, with some modifications made for a specific clinical application. An example is the COMMView system developed by AT&T and Philips (Shelton, Conn) and used by Georgetown University in Washington, DC (10), Bowman Gray School of Medicine at Wake Forest University in Winston-Salem, North Carolina (11), and the University of Washington in Seattle.

  In 1987, the Mitre Corporation selected the Georgetown University-The George Washington University Consortium and the University of Washington as the east coast and west coast sites to install a digital imaging network/PACS as a pilot study for the forthcoming MDIS (12). At the east coast site, COMMView was installed to test the concepts of digital archive and communication network and digital ultrasonography (US) display station. The standard COMMView was modified to include an optical disk library and a digital network. At the west coast site, computed radiography and digital display were investigated. A PCR-901 (Philips) was installed and interfaced to the COMMView display stations.

  The system installed at Bowman Gray School of Medicine was a departmental supported project. It was installed in modular components, first for US and neuroradiology. Eventually, the system will be expanded to encompass the entire department.
CONCLUSION
We have discussed three methods of implementing PACS. Each method has its advantages and disadvantages. It is most likely that these three methods will be merged during the next several years. The department or hospital implementing a PACS will follow these three approaches, retaining the best and discarding the irrelevant features based on its clinical requirements. While contemplating the implementation of a PACS, the issues of standardization, open architecture, reliability, and security must be considered.

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