Radiology Information Systems, Picture Archiving and Communication Systems, Teleradiology— Overview and Design Criteria

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Information technology (IT), long taken for granted in commercial settings, is now being utilized for health-care applications. Medical imaging has lagged comparatively due to the extremely vast data content of each frame; thus, the requirement for expensive high-end components. Further, IT in radiology has evolved from two distinctly separate camps—information systems, known as RIS (radiology information systems) and PACS (picture archiving and communications systems). Both RIS and PACS applications have migrated to the PC environment, enabling cost-effective implementation, but from two backgrounds: RIS from vendors using conventional information systems platforms and products, and PACS from radiographic film and modality vendors. The radiology department at Texas Tech University has assembled a seamlessly integrated, enterprise-wide RIS/PACS/teleradiology intranet. The design criteria include user-friendliness, flexibility to respond to changing needs, and open modular architecture to assure interoperability, cost-effectiveness, and future-proofing of investment. Since no single vendor could provide an integrated system meeting our specifications, we decided to assume the burden of constructing our own system. As the system integrator, we embrace open architecture, thus enabling the incorporation of industry-standard-compliant, COTS (commercially off the shelf) products as modules. Microsoft Windows NT operating system, Visual C++ programming language, TCP/IP (transmission control protocol/internet networking protocol), relational SQL (structured query language) database, ODBC (open database connectivity), HL-7 (health level seven) and DICOM (digital imaging and communications in medicine) interfaces are utilized. The usage of COTS components reduces the cost to very affordable levels. With this approach, any module in our system can be replaced when outmoded, without affecting other modules in our system, making it truly future-proof. Construction and evolution of our system (TECHRAD) is reviewed.

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WE HAVE WAY PASSED the “Industrial Age” and entered the “Information Age,” and as Nicholas Negroponte¹ pointed out in *Being*

Digital, bits instead of atoms are the essential ingredients on which our daily activities are based. Information technology promises to accomplish our daily tasks using information (bits), rather than actual physical objects (atoms).

Information is the “intelligence” extracted from raw data collected by organizations in daily transactions so that proper action can be taken. The evolution of information technology can be divided into three periods: (1) mainframe-dominance period of the 1960s, (2) rise of minicomputer and personal computer (PC) period in the 1970s and 1980s, and (3) networked super-PC period in the 1990s.² In the first period, the user depended on punch-card machines or dumb terminals to perform data entry. These data were sent to the centralized mainframes for batch processing. In the second period, minicomputers ushered in an era of interactive data entry and distributed data processing by shifting more and more computing power closer to the users. In the third period, super PCs were regarded as components of the ubiquitous network, which is now the lifeblood of business organizations.

Information technology has been playing an important role in business operations for some time. The goal of adopting information technology in the 1960s through 1980s was to improve the efficiency of clerical procedures through automation. Today’s goal is to provide vital information to employees instantly so as to respond to the business environment in general and customers’ requirements in specific in a timely fashion.

The application of information technology in health care has lagged behind other industrial sectors. Health care, with \$1 trillion annual cost, is the largest single market in the world. The health care industry wastes a staggering amount of money every year because of inefficient information systems—as much as \$270 billion per year.³ With relatively shrinking resources for health care and continuous demand for better care, we suggest that improvement in the quality of health care at reduced cost can be achieved through the implementation of information technology.

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THE CHALLENGE

The cost of health care has escalated at an alarming pace. The delivery of better health care at a reduced cost is the ultimate challenge faced by health care professionals.

MODERN INFORMATION TECHNOLOGY COMES TO THE RESCUE

Potential benefits and criteria of information technology for medical applications, specifically medical imaging are listed below.

Data Integrity

Only data satisfying predefined constraints are allowed to enter the database. There is a guarantee that no conflict exists among data stored in the database.

Data Availability (elimination of the missing film problem)

As soon as the image and the report for an examination are entered into the system, they are immediately available to the referring physician. Further, once stored, they will never be lost. This solves the film-loss problem once and for all. Further, multiple users can view any image simultaneously.

Fast Turn-Around

The radiologist no longer depends on clerical personnel to hang the films on the light-box before he can read a case. The radiologist has access to images as soon as an examination is finished. Further, speech-recognition-based dictation systems convert the voice dictation into text instantly, thereby achieving instant turn-around.

Trackability

Radiology information systems track every major event such as order entry, patient arrival, procedure execution, patient transfer, dictation, transcription, films checkout, patient discharge, and so on.

Complete Medical Record to Support Quality Health Care

Once the medical record is kept in an electronic form, it can be retrieved for review along vertical and horizontal directions. In the vertical direction, the physician is able to access diagnosis and treatment from previous visits. In the horizontal direction, the physician is able to access informa-

tion from various departments, such as laboratory test results, pathology findings, clinical data, radiology diagnosis, and so on.

System-Wide Protocol Enforcement

Institution-wide guidelines can be enforced by requiring the health-care personnel to log activity into the information system according to a standard protocol.⁴ For instance, a protocol can be set up so that the technologist has to enter the contrast material and quantity into the system before a procedure can be acknowledged. When the data are entered, they are checked and verified against a built-in protocol to make sure that guidelines are strictly complied.

Efficient Resource Scheduling

An information system can provide an up-to-the-minute snapshot of available resources such as openings in the work schedule, available radiologists to do interventional procedures and so on, so that resources can be used to the maximum.

ISSUES AND CONCERNS

The introduction of information technology into the daily health care operation also creates several issues and concerns. They are listed briefly below:

- (1) Physician acceptance
 - Intimidated by computer
 - Unfamiliar working environment
 - Softcopy reading
 - Query/retrieval by yourself rather than having technician hang films for you
 - Voice recognition instead of dictation/transcribing
 - Signing of reports electronically
- (2) Privacy⁵
 - A national-wide *Vitale* card recording personal demographic information, social security number, insurance data, insurer and type of entitlement has been in use in France. Its extension to cover complete medical record was barred by the Commission National pour l'Informatique les Libertes (CNIL) due to privacy considerations.
- (3) Confidentiality
 - Traditionally, doctors have maintained patient information confidentiality. As health care organizations handle the same information electronically for doctors, confidentiality must be maintained.

(4) Security⁶

Software lock/key protection is more vulnerable than physical locks.

It is easier to copy or modify electronic medical record than hard copy, and at the same time, it is harder to detect the occurrence of any illegal break-in. Better products to implement flexible encryption setting, log incoming/outgoing communication and auditing/reporting tools are needed.

(5) Reliability

Corporate networks suffered an average of 14 hours of downtime during the past 12 months according to a survey conducted by *Computer World* trade newspaper. The disaster of AT&T frame-relay outage in April 1998 should not be taken lightly.

CONSIDERATIONS FOR A SUCCESSFUL DEPLOYMENT OF INFORMATION TECHNOLOGY

Shall a custom system be built internally or a turnkey system purchased?

Who is responsible for the daily maintenance of the system?

Who is responsible for the future upgrade and growth of the system?

THE TEXAS TECH UNIVERSITY HEALTH SCIENCES CENTER APPROACH

In developing an integrated radiology information system/picture archiving and communication system (RIS/PACS) system, the Radiology Department of Texas Tech University Health Sciences Center (TTUHSC) has adopted the following approach.

User-Centered Perspective Rather Than Vendor-Centered Perspective

From the beginning, the Radiology Department of TTUHSC has determined to reserve the right to define the behavior model of the projected system. We wanted to define the functionality of the system first and then try to find or develop a product that meets this requirement. This is totally opposite to the idea of shopping for a commercially available system first and then try to adapt ourselves to such a system.

No vendor is capable of providing a generic system that serves our specific needs because we, like every institution, have unique, peculiar require-

ments. Every institution needs an information systems division to be the system integrator that combines subsystems from various vendors into a coherent working system. This is consistent with the approach of many large medical centers, businesses, and other institutions.

Ownership of the System

The evolution of managed care, as well as regulatory changes with time and technological advances, provides an enormous challenge to information systems in medical centers. Therefore, evolution and growth of the system to meet continuous change should be anticipated and addressed from the outset.

The risk of locking into a particular vendor is that you cannot take full advantage of the latest technology that best serves you. Normally, a vendor requires the user to submit a change proposal for evaluation. This process takes time and is expensive. Even worse, the decision of whether to implement the proposal is based on the vendor's perspective instead of the user's interest. The institution needs to have the final say of when and how the system should evolve with time, rather than let the vendors make decisions for us.

Assumption of ownership means the institution will be the ultimate responsible party to keep the system up and running. This imposes a great burden.

Open Modular Architecture

As the system integrator, we embrace open architecture, thus enabling the incorporation of commercial, off-the-shelf (COTS) products as modules. This approach is predicated upon the existence of industry standards, either de jure, authorized by standard-setting body or de facto due to wide acceptance. The following standards are noted: Communication—TCP/IP; RIS interface—HL7; PACS Interface—DICOM; database—relational database using SQL query language, ODBC; programming language—C++, Visual Basic.

Mass-Produced COTS Components

To reduce costs, mass-produced COTS components are used as much as possible. Major benefits arising from this strategy include the following:

- Development time is saved. No reinventing the wheel.
- The cost is low due to mass production.

- The product is debugged quickly and enhanced regularly due to the large installed base.

The list of mass-produced COTS components includes Intel (Santa Clara, CA) X86-based PCs, Microsoft (Redmond, WA) Windows NT operating system, Advanced DICOM toolkit by Merge Technology (Milwaukee, WI), Image Processing toolkit from DOME Imaging System, Inc (Waltham, MA), and so on.

INTEGRATED RIS/PACS/TELERADIOLOGY SYSTEM BY TTUHSC

From the inception, we realized that a seamlessly integrated RIS/PACS/teleradiology system is the only good solution to run a film-less radiology department. By reviewing the responses from various vendors to our RFP, we found that no single vendor could satisfy our criteria listed below:

- A single integrated system rather than a collection of fragmental, isolated subsystems.
- Flexibility for future growth.

It was found that vendors come from two distinct camps: RIS-oriented and PACS-oriented. RIS-oriented vendors tend to be well-established companies, having field-proven products well-suited to handle text data, but weak in handling images. Also, they carry a burden to be backward-compatible with previous-generation products introduced many years ago. PACS-oriented vendors tend to be start-up companies that jump to the PACS wagon with the latest technology. However, they soon realized that PACS cannot be operated without the support of RIS and tried hard to catch up. As a result, no product is a well-thought-out product from its inception.

Another concern is that no product provides a generic framework to which future applications can be attached as add-on modules.

Microsoft Windows NT provides a good framework upon which to build client/server architecture. Its wide support of various multimedia devices makes it easy to handle contents-rich data at the client side. Furthermore, Microsoft back-office suite provides comprehensive server functionalities ranging from database management, system management, and messaging service. Its support of industry-standard TCP/IP protocol make it easy to create a networked computing environment. Abundant third-party software written for Windows NT provides ready-to-use software as a module or useful toolkits

that makes the development of application software much easier. Consequently, we decided to build our own integrated RIS/PACS/teleradiology system based on the Windows NT framework.

After the framework was laid out, the actual implementation was done in stages.

Stage 1: Proof of Concept

We started with the simplest model—point-to-point, peer-to-peer teleradiology, by use of rapid application development (RAD) tools. The scenario is that a technician at the remote hospital scans films into digital images via a Lumisys laser scanner and stores the images in compressed form along with demographic data on the remote disk. A computer located at the TTUHSC polls the remote disk to detect the existence of newly acquired digital images and pulls them over a telecommunication link. Once pulled over, the examination is registered onto the central database, and the associated images are decompressed and ready for reading.

This system was finished quickly by using Visual Basic programming language and has been in service for more than 3 years. The remote site is so simple to use that it requires only minimal training.

Stage 2: Extension to Multipoint Client/Server Teleradiology Network

Three things were added to the system at this stage;

- (1) Integrated Services Digital Network (ISDN) telecommunication was used to serve multiple remote sites (in this case, the radiologists' residence) from the same central hub.
- (2) Remote procedure call (RPC) was initiated by the remote site (client) to request image and report retrieval on demand from the central site (server).
- (3) More efficient programming language (in this case, Visual C++) were used to replace the Visual Basic language to gain performance.

Microsoft Access was used as the database management engine at this stage due to its ease of use.

Stage 3: Extension to Mini-PACS/Teleradiology

Several things were added to the system at this stage:

- (1) Images were acquired directly in digital form through DICOM interfaces rather than

through film scanning. Currently, computed radiography, computed tomography, magnetic resonance, and angiography are captured this way. Ultrasound and nuclear medicine will be added in the near future.

- (2) Microsoft SQL server was used to replace Microsoft Access to handle the high volume of transactions in the daily operations.
- (3) Reading stations and review stations were added to the emergency center, and four ICUs, two in the Radiology Department, to support real-time reading/review functions.

These stations were equipped with sophisticated front-end software to support image manipulation and image display functions required by radiologists. The software is continuously enhanced.

- (4) Extension from a private on-call network into an Internet-empowered network.
- (5) System management tools were used to centrally manage the system security policy, software deployment, and traffic monitoring.
- (6) Current procedural terminology (CPT) and International Classification of Diseases, Ninth

UNIVERSITY MEDICAL CENTER
Department of Radiology

Patient Name : XXXXXX, XXX
Date of Exam : 07/20/98
Hour of Exam : 07:45AM
Att. Physician: DEEB MD,SAMMY
Rad Ord. Phy. :
Admit Date : 07/13/98
Task# : 08851150-1
Precert# : AVY2F9000
Referring Phy.: LONG,THOMAS NIELSEN

Age : 60 Y-M
MRN : 52-52-66
Films: 2
Tech : AT
Room : 464_A
Audit: 501121
Loc : 4W
Gen# : 08849682-1

CLINICAL INFO: NONE AVAILABLE.
CPT code: 71020
ICD code: 466.1

REPORT:

PA AND LATERAL CHEST:

Basilar atelectasis and small pleural effusions persist bilaterally. The NG tube extends into the stomach. Compared to the previous days films there is no significant interval change.

OPINION: NO SIGNIFICANT CHANGE.

GLENN H. ROBERSON, M.D.
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Fig 1. Sample diagnosis report.

Revision (ICD-9) coding software were added so as to automate the charge-capture (by the radiologists) as soon as the report is done.

Stage 4: Integrated RIS/PACS/Teleradiology

We currently have a fully integrated system. Work in progress includes:

- (1) Replacement of the obsolete, existing RIS by a more powerful one to provide up-to-the-minute vital information such as admission, discharge, and transfer (ADT) so that report print-out can be routed correctly.
- (2) Application of voice-recognition technology to generate the radiology reports without the requirement for transcription personnel to achieve fastest turn-around.⁷ A sample report containing text, as well as images with annotation, is shown in Fig 1.
- (3) Addition of a long-term archive juke box.
- (4) Extension of such a radiology-centric database into an institution-wide medical record database.

- (5) Enhancement of security and reliability to make a robust, high-availability system

In summary, we started with an open architecture framework upon which we built a complex system. This framework allowed us to start small and gradually add more functionality without abandoning our previous investments. Existing modules can be replaced by new modules of similar functionality, but better implementation, with little impact on the rest of the system. For example, a less powerful Access database engine is replaced by a more powerful SQL server database engine relatively easily due to two factors: (1) The compliance to industry-standard SQL language by both products leaves the application software virtually unchanged, and (2) the industry-standard ODBC makes the switch-over totally transparent to application software.

In view of continuous changes in the health-care industry, as well as in technology, to future-proof your system and investment is important. We have used this philosophy to implement an integrated RIS/PACS/teleradiology system.

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