Coping With PACS Downtime in Digital Radiology

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As radiology departments become increasingly reliant on picture archiving and communication systems, they become more vulnerable to computer downtime that can paralyze a smoothly running department. The experiences and strategies developed during various types of picture archiving and communication system (PACS) downtime in a large radiology department that has completely converted to soft copy interpretation in all modalities except mammography are presented. Because these failures can be minimized but not eliminated, careful planning is necessary to minimize their impact.

KEY WORDS: PACS, failure, hospital information system, server.

BY THEIR NATURE, widely distributed picture archiving and communication systems (PACS), computerized hospital information systems (HIS), and radiology information systems (RIS) alter the interaction of clinicians, radiologists, technologists, and administrators. The heart of this alteration is widespread image availability and rapid access to preliminary and formal reports. When PACS systems fail, the benefits of rapid image and report accessibility, reliable archiving, and quicker image interpretation[1] are erased. The disadvantages of reliance on a soft copy information system are highlighted. During PACS failures, alternative methods of temporary archiving, image production, image interpretation, and report dissemination must be implemented rapidly and efficiently. In departments such as ours that have heavy reliance on PACS, this transformation to a nondigital or partially digital environment represents a marked and difficult shift in workflow and the usual methods of doing business. The resulting algorithms to deal with this downtime are a compromise between competing factors of technologists and radiologist time and expertise, demands of the clinician, rapid report and information dissemination, cost, medical legal issues, and adequate patient care.

PACS downtime is an uncommon but possibly catastrophic event that tests the resiliency of the radiology department, the foresight of department administrators, and preparedness of radiology department personnel. As radiology departments move to a complete digital environment, dependence on this technology becomes more complete. The inevitable system crash, or even planned outages, can bring a smoothly running department to its knees, create chaos and trepidation among clinicians and referring services, and demoralize and frustrate radiology department personnel. This report outlines the experiences of a large radiology department when presented with failures of its PACS. We present our empirical solutions to the immediate workflow problems generated by these failures. These solutions may benefit other institutions when they are presented with similar problems.

BACKGROUND

Brooke Army Medical Center has completely converted to soft copy reading in all areas except mammography. This system uses high-resolution monitors within the radiology department and an extensive network of PACS and HIS terminals for clinician use on wards, emergency room, operating rooms, intensive care, and clinics. This configuration is not limited to only filmless image generation and interpretation but approaches the model of "real-time radiology" as proposed by Thrall.[2] He described an integrated computerized system of study request, digital imaging, report generation, and widespread and instantaneous image and report availability.

The HIS and PACS systems are physically independent in both their computers and their associated networks. The architecture for the PACS system is a spoke and hub configuration (Fig 1) along optical fiber connections to all viewing stations. The core of the PACS system consists of 2 PACS servers, and 3 optical disc jukeboxes (1 terabyte each) with their respective controllers. The PACS server performs the database functions, short-term images image storage and retrieval, RIS

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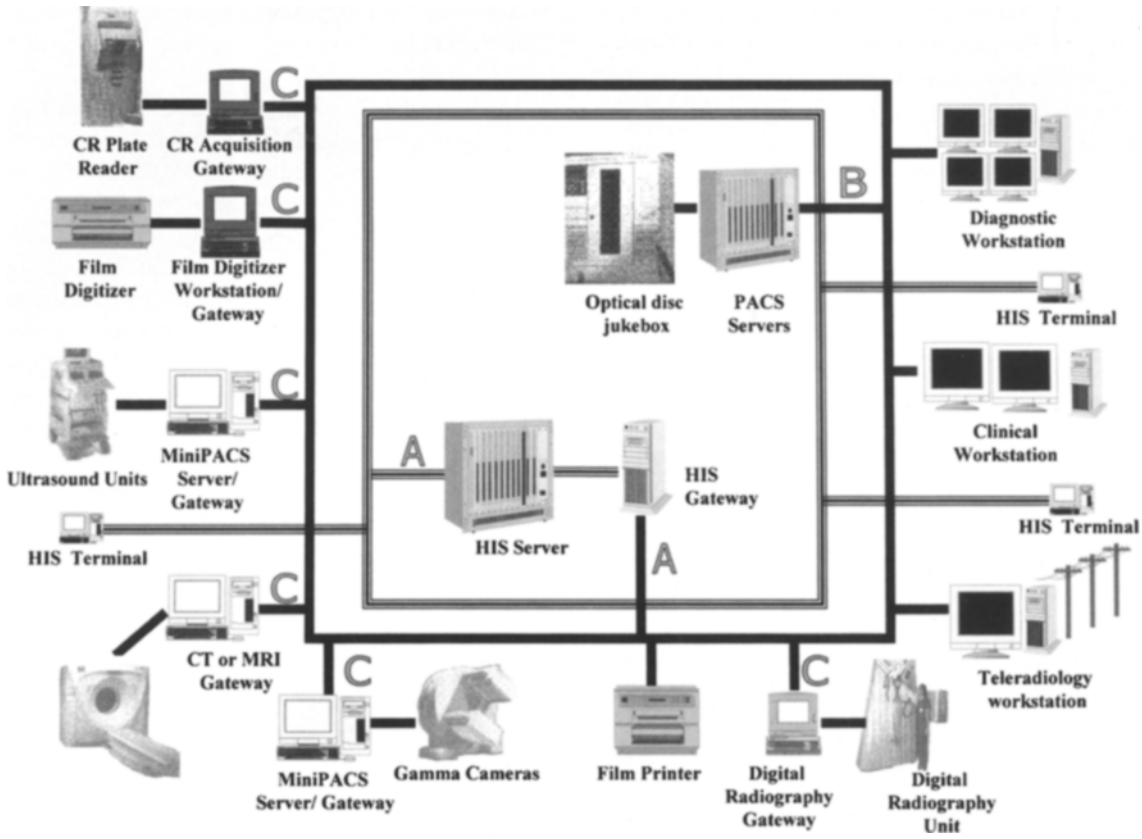

Fig 1. Schematic diagram of PACS/HIS Architecture, Brooke Army Medical Center. HIS and PACS networks are independent and connected through a gateway computer. Important sites of potential failure: (A) Failure of gateway or miniPACS server between individual imaging modality and the PACS server. (B) Failure of the PACS server. (C) Failure of the HIS/PACS gateway or the HIS server.

functions for the PACS, and interface functions to RIS module of the HIS. It also is the central input point for all imaging modalities and the film digitizer and is the output source of image files for all viewing stations and laser film printers. Transfer of all recently acquired images to long-term storage on optical jukeboxes is made from the PACS server after 2 to 5 days (Table 1).[3,4]

All plain films are acquired either through computed radiography (8 computed radiograph [CR] readers located both in the hospital and off site), or directly through a digital radiography (DR) system. Each of these CR or DR units requires a gateway computer to translate vendor-specific image formats into DICOM3 format used by the image server. All other modalities are interfaced using DICOM3 compatible gateways with either individual service miniPACS (10 cameras in nuclear

Table 1. Current Major PACS Components

Equipment Function	Model	Vendor	Software	Installation
PACS Server	Sparc 20	Sun Microsystems, Palo Alto, CA	Solaris 5.4 GE Advantage v7.11.1	1994
PACS Server	UltraSparc 30	Sun Microsystems, Palo Alto, CA	High speed 5.6 GE Advantage v7.11.1	1999
HIS to PACS Gateway	Dell 2200	Dell, Round Rock, TX	Mitra Broker	1998

NOTE. Data from Brooke Army Medical Center. Although a large scale PACS has been in place at BAMC since 1993, software, hardware, and major imaging devices have undergone extensive change and revision in almost all areas.

medicine, 6 units in ultrasound, and 5 fluoroscopy units) or the individual image acquisition consoles of each piece of equipment (3 spiral computed tomography [CT] scanners, 2 1.5 Tesla magnetic resonance [MR] units).

Five laser film imagers, largely a legacy from pre-PACS installation, are used mainly for hard copy output when the patient is sent to another institution and in very limited circumstances in the operating room and for teaching uses. However, they assume an important role when some types of PACS failure occur. The laser film imagers can be reconnected directly to the CR and DR units during some types of PACS failure.

Images are sent from the PACS server to high-resolution radiology department viewing stations, where formal readings are rendered, and short preliminary reports are typed by the radiologist and attached to the images on the PACS system. They also are immediately available to medium-resolution clinician terminals where both images and the preliminary report can be viewed when either is available. Images can be entered into the PACS system independent of the HIS, but formal reports can not be generated unless they are first created and exist in the HIS database. Merging of PACS images and HIS study request is performed by radiology technologists through a rapid, transparent, and fault tolerant interface. The preliminary radiologist typed report is not available on the HIS.

The HIS was developed independently of the PACS as a Department of Defense–wide system. In addition to a myriad of information management functions including pathology, laboratory and clinic administration, it contains a nongraphical RIS module that performs the functions of scheduling, patient demographics management, and radiology report generation. The PACS system is independent of the HIS system and only limited demographic, study tracking, and image report data are allowed through the HIS or PACS gateway. HIS terminals are ubiquitous; they are found in all clinician offices, reception areas, radiology imaging areas, and radiology reading rooms. All study requests, except for those from outside the institution, are generated electronically by clinicians at their HIS terminals. Radiology study reports are typed into the HIS by transcriptionists and are available in both preliminary and final verification form to the clinicians within 4 to 48 hours. Importantly, the final and preliminary reports are automatically transferred from the HIS to the PACS system and replace the brief typed radiologist report when they are available.

HIS and PACS integration has eliminated hard copy reading lists and readout books, because the short impressions typed on the PACS are widely available. Digital communication in medicine (DICOM) work lists generated by the PACS are extremely efficient in managing the reading list workload. A result of this PACS architecture is that all online imaging studies are available instantly for viewing at all radiology and clinical workstations, making the image interpretation process and clinician viewing of a study independent of a specific location.

TYPES OF PACS DOWNTIME AND TEMPORARY SOLUTIONS

HIS and HIS to PACS Gateway Failure

Unexpected failures occur approximately 5 times a year and last 1 to 2 hours. No major workflow modifications are necessary. If the HIS fails or is brought down for scheduled maintenance or software upgrade, then the traditional paper-based system of study ordering is temporarily reinstituted. The process of merging PACS and HIS studies performed during the downtime must be monitored carefully, because it easy to neglect to enter studies into the HIS once they have already been performed. A major impetus for performing merging in our institution is the transcription process, which is brought to a halt when the HIS fails, because study demographics are assigned and stored by the HIS (Fig 1A).

PACS Server Downtime

PACS server downtime precludes access to radiology images on both radiology and clinician viewing stations and requires major restructuring of department workflow (Fig 1B). This downtime has several causes. Within the last 3 years, the most damaging failure was caused by an unexpected crippling software failure, which rendered the PACS server inoperable for 3 days. Less severe unplanned failures lasting 15 minutes to 3 hours have occurred approximately 2 to 3 times a year. There have been 3 planned major software upgrades requiring 8 to 24 hours system downtime in the last 3 years. Finally, the servers are brought down for approximately 1 to 2 hours late at night once a week for database backup.

During these failures, the HIS is still functional, so soft copy study orders are still accomplished. As soon as this type of failure is recognized or anticipated, a plain film reading center is activated. This involves the following actions.

1. Emergency services, orthopedic, intensive care services, and clinics are notified immediately of the nature of the failure, informed of the duration of the expected downtime, and requested to schedule only urgent studies. The reason for this request is that the transition to film-based reading is very labor intensive and will cause at least 1 hour to be lost before smooth film-based reading processes are accomplished. Our experience has been that clinicians are understanding and cooperative if informed immediately of changes in study availability.

2. If the PACS is brought offline for a planned reason, such as software upgrade, the last intensive care unit film is printed routinely so future comparison can be made. Requests for similar printings from other clinicians are taken for patients in whom comparison films may be needed during the expected downtime.

3. CR and DR images are stored on magneto-optical (MO) discs for reloading on the PACS when it becomes operational.

4. The laser film printers are disconnected from the network and reattached to the CR or DR units in stand-alone mode.

5. Intensive care unit, emergency room, and orthopedic films are printed in duplicate and 1 copy given to the referring clinician by placing it in a spot easily accessible to the service. A second copy is used by the radiologists in generating the official report. Although this policy may seem wasteful of film, it was instituted for several reasons. Film loss rates in our hands and at other institutions has historically been 20% to 38%.[5] We feel it is inappropriate to allow this to occur during an already trying time of system failure. Especially in the intensive care unit setting, nonavailability of previous studies can be disastrous. If the system is down for only a short time, film costs are minimal when compared with the benefits of close film control, rapid interpretation, and availability to clinicians.

6. Individual services (except those in which plain films are read) are placed in a stand-alone mode in which image interpretation is performed from the vendor-specific consoles or independent mini-PACS. This increases communications burden on the department. In our experience, a 50% increase in telephonic and physical traffic to individual services is expected, with concomitant disruption in efficiency of all radiology personnel.

7. During PACS downtime after hours, the laser printers in MRI and CT are disconnected from the PACS network and reconnected to the CT and MRI consoles. Studies then are printed in single copy and placed in the plain film reading center. Because the PACS common interface for reading CT and MRI are no longer available, efficient interpretation is difficult for the lone on-call radiologist who frequently is not proficient in use of the non-PACS display software. This is not necessary during the duty day when staffing is optimal and vendor specific display software at imaging consoles can be used for study interpretation by the individual services. They generally have not been trained in the use of these vendor-specific display interfaces. In our institution, nuclear medicine and ultrasound mini-PACS workstations continue to be used for soft copy reading, because these systems are used for day-to-day readout, and radiologists have experience in their use.

8. Additional radiology technologists are called in. Conversion to a film-based reading system requires a significant overhead cost in terms of film processor maintenance, additional time to develop films, film manipulation, and in creating a film and interpretation center where none had existed before. Ultimately, when the PACS server becomes functional additional personnel also will be needed to insure studies performed during equipment failure are transferred adequately to the PACS system.

9. A plain film reading center is created. A major shift in workflow to a traditional reading room style is necessary and requires the following components: (1) large-volume high-speed alternator near a PACS viewing station so that side-by-side comparisons with prior studies can be made, (2) HIS terminal, (3) hot light, (4) telephone, (5) transcription device. (6) Also required are film storage bins for temporary archiving films that have been read and removed from the alternator. At our institution, the films are stored in order of removal from the alternator and the list of patients kept for quick referral. Although alternate systems have been tried, such as alphabetical filing, these have been found to be more time consuming, and equipment downtime has been short enough so that more elaborate systems have not been needed. (7) Sepa-

rate alternator is needed for intensive care unit films and separate storage bins. Because comparison films are extremely important in this setting, all films remain on the board until patient transfer. This is especially important if the CR or DR gateway is expected to be down more than 6 hours. (8) Radiologists read the plain films, type impressions into the PACS terminal, and dictate the examination into the transcription system. Because only the image transfer capability to PACs is inoperative and all other HIS or PACS functions are operational, impact on hospital functioning is minimal.

Although many of the actions and necessary equipment outlined above and below may seem obvious, only careful preplanning and positioning of equipment will assure that appropriate actions take place during the chaotic period after failure. Our experience has been that unused hard copy reading equipment quickly disappears once soft copy reading is embraced, and necessary backup communication and viewing equipment frequently is not available in a user-friendly environment once hard copy reading is abandoned.

When the PACS system becomes operational, studies that have been stored locally on miniPACS or on MO discs (in the case of CR or DR units) must be transferred to the PACS system. This process must be monitored closely because 100% transfer efficiency is not always accomplished because of procedural errors in computer entry during the hectic failure period.

Gateway Failure Between Imaging Modality or Service and PACS or MiniPACS Failure

With the exception of CR or DR failures, these failures usually have little impact on global system and mainly are an inconvenience to the individual service. Fortunately, miniPACS computers and the gateways between major imaging devices rarely fail, with failure rates generally less than once a year for each gateway and less than twice a year for the miniPACS computer. Because more than 1 simultaneous gateway failure is highly unlikely and has never happened in our system, a clue to PACS server failure is the inability of multiple services to communicate with the PACS. With the exception of plain film radiology, all services have the capability of operating in a digital stand-alone mode either within their own mini-PACS or individual imaging consoles. There is a 2- to 7-day local image storage capability, and so services (except for plain film radiology) can function with little modification in workflow without contact with the PACS for an extended period. Clinicians usually accept temporary loss of access to these images on their own local PACS terminals, and simply revert to pre-PACS modes of physically traveling to the individual service if they need to view a study. Because the HIS and PACS are not affected, electronic study ordering, transcription, and the practice of typing preliminary reports on the PACS (albeit within a "dummy" study without images) continue uninterrupted. When the mini-PACS/CR/DR gateway becomes functional, it is essential that a technologist reviews the transfer of studies from the failure period to insure all mini-PACS studies are merged with the corresponding study on the PACS (Fig 1C).

CR reader and CR gateway failures have little effect at our institution because of the ability of our 8 CR readers to absorb remaining workload among them if one goes down.

DISCUSSION

Migration from a film-based to filmless department can have enormous advantages in terms of markedly improved study accountability, widespread and rapid image and report availability, rapid image retrieval and image comparison, and flexibility of workspace configuration. Certain failures of the PACS may require varying degrees of temporary reinstatement of a film environment. The degree and exact mechanics of this conversion are obviously dependent on the system configuration, the length of the expected failure, legacy equipment available, and level of training on back-up systems. After 7 years of experience with large scale PACS, the following principles can be offered for dealing with PACS failures:

1. Once a well-functioning PACS and HIS are in place, there is considerable resistance to even a temporary return to film-based reading by radiologists, technologists, and clinicians. Every effort to preserve a digital imaging environment should be made. Although 100% reading of softcopy images is highly desirable, achieving this goal at all times may result in unacceptable expense of additional backup equipment and service contracts. Especially when legacy equipment is available and failures sufficiently infrequent, temporary return to hardcopy interpretation may be a palatable and cost-effective alternative.

2. The longer the interval since film has been routinely used, the less institutional memory is able to recall the steps necessary to perform film based reading. For technologists, detailed instructions on film screen techniques and careful written instructions in setting up a film imaging center are necessary.

3. Accurate diagnosis of the underlying problem and rapid response by maintenance personnel is crucial. Around the clock in-house availability of technical personnel obviously is desirable, but may be financially impractical. Because of the lack of technical expertise, crashes during nonduty hours have the greatest potential for disaster because both misdiagnosis of the problem and inability to recognize the seriousness of some types of failure are more likely to occur. The result is sometimes painfully extended periods of system downtime. This problem is best solved by education of radiologists and technologists in basic system architecture and before-the-fact instruction on failure procedures. Detailed instruction manuals with up-to-date telephone numbers and well-defined procedures are imperative, because even well-trained personnel can rapidly loose sight of critical goals in the chaotic and hectic times of system failure. Written instructions on the types of failure warranting emergent calls to maintenance personnel, along with the authority to make these calls, also will prevent sometimes expensive maintenance calls in situations that can be dealt with less expensively during duty hours.

4. The critical nature of certain failures must be recognized and maintenance contracts written to reflect the need for rapid response in these situations. Expert consultation should be available readily to key personnel, such as the chief technologist and radiologist on duty during nonduty hours.

5. Planning during equipment acquisition for the inevitable long-term (greater than 12 hours) PACS failure should include adequate local memory storage for at least 2 days worth of patient data, a backup system of transfer, or both. Special attention to the transparency, speed and ease of use of the backup system, and careful consideration of failure situations is crucial. In many instances additional software or equipment may need to be purchased to assure a smooth transition in failure situations. An example at our institution of these situations is the need for MO disc drives and additional printer drivers for the CR readers.

6. Uninterruptable power supplies for critical components are mandatory. Claims from engineering personnel touting the reliability of facility electrical power should be regarded with skepticism. As a minimum, gateway servers, miniPACS servers, and the PACS and HIS systems should have uninterruptable power supplies.

7. Additional help should be brought in during severe PACS failures. Expecting the skeleton crews working during off duty hours to perform adequately at the inevitable markedly increased workloads (25% to 50% above normal)[6] during these times increases the chance for significant error and clinician dissatisfaction with the radiology product.

8. Expertise and supplies to support temporary film-based reading must be maintained. Because many film-based supplies have a short shelf life, only limited quantities can be expected to be on hand in the event of severe failures. Logistic support must be planned and available during these emergencies. Dark rooms and at least some vestiges of the traditional reading room must be maintained.

Many of our policies are institution specific and stem from the relative independence of the HIS and RIS module of our PACS. For example, the ability to enter preliminary reports into our PACS system is an important feature at our institution because of the widespread availability of PACS terminals within the hospital. Institutions with limited PACS availability to clinicians (or lack of a similar capability on their HIS) will need to modify their system of preliminary report dissemination. Similarly, institutions at which the HIS and PACS are more closely integrated, possibly running on the same platform with integrated software, will require even closer attention to failure algorithms, because hardware failure is likely to affect both systems.

Another institution-specific issue is our availability of adequate emergency filming capabilities in the form of laser film imagers and adequate CR and DR assets. Departments without adequate film printing assets may need to adopt alternate techniques. At one extreme, these techniques may use more extensive use of film screen and wet processor capabilities. An alternative approach is to attempt to avoid hard copy interpretation entirely by purchase of backup gateways, workstations, power supplies, and extensive training in backup

soft copy interpretation on the various vendor specific workstations for each modality. This latter approach was considered and rejected at our institution because of prohibitive cost, availability of legacy laser imagers, unwieldy logistics of reconnection, and inadequate timely access for clinicians to the soft copy images.

Individual service preference of soft copy interpretation also dictates procedures during PACS failure. In our institution, ultrasound interpretation is performed on ultrasound miniPACS because color is not available on the PACS system. Similarly, nuclear medicine studies are interpreted on an independent miniPACS for the same reason and because of the lack of cine loop review on the PACS system. In these services, PACS capabilities determine the extent of PACS use during routine image interpretation. As expected, PACS failures affect these services to a lesser extent. Institutions with different levels of PACS sophistication and the resulting greater or lesser reliance on PACS may find that they are affected in significantly different ways by PACS failure.

Many of the processes outlined above during PACS failure should have applicability at other institutions with heavy reliance on digital imaging and PACS. Our relatively independent HIS and PACS architecture, and the spoke and wheel configuration of our PACS present problems that may apply less with the newer distributed archiving architecture. Nevertheless, the above outlined general types of failure can and will occur with disconcerting frequency regardless of architecture. Careful planning can minimize the effects these failures on the hospital and the radiology department.

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