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Review ■

Costs and Benefits of Picture Archiving and Communication Systems

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Abstract A picture archiving and communication system (PACS) is an electronic and ideally filmless information system for acquiring, sorting, transporting, storing, and electronically displaying medical images. PACS have developed rapidly and are in operation in a number of hospitals. Before widespread adoption of PACSs can occur, however, their cost-effectiveness must be proven. This article introduces the basic components of a PACS. The current PACS cost-analysis literature is reviewed. Some authors conclude that the PACS would pay for itself, while others find the PACS much more expensive. Explanations for these differences are explored. Almost all of these studies focus on direct costs and ignore indirect costs and benefits. The literature characterizing the indirect costs of PACSs is reviewed. The authors conclude that there is a need for uniform, well-defined criteria for the calculation of the costs and savings of PACSs.

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In this environment of skyrocketing health care costs, the acquisition of new technology is under intense scrutiny. Until a few years ago, medical decision makers could pass on the costs of new technologies without much difficulty. Today, hospitals face diagnosis-related groups (DRGs) and other reimbursement schemes that force more careful analyses of new purchases. As Hilsenrath et al. state:

Profitability is increasingly used as a criterion for investment in health care owing to economic pressures that limit the scope for cross-subsidization. Profits will erode if capital expenditures do not ultimately reduce costs, or alternatively, lead to an equivalent or greater increase in revenues. [1991]²³

Radiology's reliance on expensive technology makes it an obvious target of budget-conscious administrators and politicians.

A picture archiving and communication system (PACS) is an electronic and ideally filmless information system for acquiring, sorting, transporting, storing, and electronically displaying medical images.¹³ Proponents stress its benefits, including the elimination of expensive silver-based film, improved access to new and old films for all physicians, reduction in the physical storage requirement of bulky films, and lower personnel costs. Although the technologic requirements once seemed daunting, the PACS has developed rapidly over the last ten years and is in operation in a number of hospitals. Before widespread adoption of PACSs can occur, however, they must be proven to be cost-effective.

In this report, the basic components of a PACS are introduced. A review of the current PACS cost-analysis literature includes evidence of the impact a PACS might have on existing hospital practice.

Image Acquisition

The use of digital images is analogous to but distinctly different from conventional film-based techniques. First, the image must be acquired. Three basic methods can be used to acquire the image. The first

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is computerized radiography (CR), computed tomography (CT), and magnetic resonance (MR) stand-alone imaging systems (and other devices creating digital images) connected to image-capture computers, and the second is digitization of film. In CR, the machine produces the image on a phosphor cassette (similar to a standard film cassette). Then, a special machine—the CR image reader—constructs a digital image from the plate. With CT and MR scanners, the method used to interface between the scanner and the data-capture computer depends on the sophistication of the scanner. Older scanners (e.g., GE 9800 CT scanner, General Electric Medical Systems, Milwaukee, WI) require a special device to transfer imaging data to the image-capture computer. Newer scanners have a host computer that can be directly connected to the image-capture computer. The third basic method uses a film digitizer to convert standard radiographs into a form that can be interpreted by the image-capture computer.

The image-capture computer is responsible for three tasks: 1) decoding the received image data; 2) converting the images into a standard format, when necessary, and 3) transferring the images to the data management host computer.

Data Management Subsystem

The data management computer is the core of the PACS and is functionally equivalent to the administration office in a film-based system. It has four major functions: 1) acquiring images from the capture computer; 2) archiving images; 3) distributing images to the display workstation; and 4) processing image-retrieval requests.

An automated optical disk library (ADL) is used as a long-term image archival and retrieval device.³³ To make possible the accession of several years' worth of films, enormous amounts of data must be stored on the ADL. For example, one double-spaced page of text consists of approximately 300 words. Assuming that there were five characters per word, this would be approximately 1,500 bytes per page. By comparison, one standard chest x-ray consists of four megabytes or nearly 2,700 pages of text, and one CT scan consists of 20 megabytes or approximately 13,500 pages of text. Researchers have estimated that a functional PACS must be able to have on-line access to a minimum of two years' worth of CT and magnetic resonance imaging (MRI) scans. To meet that criterion, a 500-bed hospital would require 1.3 terabytes (one terabyte = 10^9 bytes) of archival memory storage.³⁹ An ADL serves these tremendous data-storage needs in the most cost-effective manner.

Display Subsystem

From the clinician's perspective, the critical component of the PACS is the display workstation. Several articles review the performance specifications of the optimal workstation [1990¹²; 1991²⁴]. The design of medical workstations is primarily oriented toward the rapid display of images. Additionally, the capabilities of workstations are continually expanding in an effort to assist the viewer with features such as zoom and quantitative analysis of images. There are three categories of PACS workstations: high-resolution ($2,000 \times 2,500$ pixels), medium-resolution ($1,000 \times 1,600$ pixels), and low-resolution (512×512 pixels).

Typically, spatial resolution in the display is a function of the number of pixels. However, the *acquisition* resolution of the desired image is a function of digitizing and readout parameters, both of which may influence the *overall* display resolution. For example, medium-resolution workstations are most appropriate to display CT and MRI images because those modalities acquire series of smaller images. A high-resolution monitor might render CT and MRI images too "block-like" or too small.

For conventional x-rays, the requirements differ according to the intended use. High-resolution viewing stations are used to replace the conventional view box for original interpretation because they provide sufficient resolution to match the diagnostic quality of conventional films. Medium-resolution workstations are adequate for remote viewing in areas such as intensive care units, operating rooms, and conference rooms. The use of low-resolution stations is reserved for some teleradiology applications.

Hilsenrath et al. summarize recent evidence regarding PACS spatial resolution (number of pixels available to form the image) requirements for adult chest examinations. The detection of abnormalities involving fine detail, such as pneumothorax and interstitial lung disease (chronic obstructive pulmonary disease and emphysema), is more difficult with digital images based on the $1,000 \times 1,600$ -pixel and $2,000 \times 2,500$ -pixel formats. Studies have found no difference between standard x-rays and digitized images of pulmonary nodules that do not involve fine detail even at medium resolution [1991²³].

Perhaps even more important than spatial resolution is contrast resolution—the ability to distinguish between the object of interest and the surrounding tissue. This is a function of the viewer's ability to detect differences in the intensities of individual pixels relative to adjacent pixels. For example, 10 bits would mean that each pixel would have a range of gray-

Figure 1 One possible scheme for a picture archiving and communication system (PACS) network that has been used by the Department of Radiology of the University of California at San Francisco. ATM = asynchronous transfer mode; CT = computed tomography; MR = magnetic resonance; CR = computerized radiography; NM = nuclear medicine; US = ultrasound; HIS = hospital information systems; RIS = radiology information systems; MAC = Macintosh Computers, Inc.; LRI = Laboratory for Radiological Informatics; DB = database. (Courtesy of H. K. Huang, University of California at San Francisco.)

scale values from 0 (absolute black) to 2^{10} (maximum intensity). Contrast-resolution limits may be more important than the spatial limits for chest radiography and abdominal imaging.³⁸ Current consensus is that 12 bits is acceptable for CT, MRI, and CR for all types of tissues. Ultrasound images require only 8 bits.³⁹ The literature suggests that current monitor technology may be adequate for urography and myelography but inadequate for mammography and skeletal radiology. A high-resolution monitor is acceptable for a general PACS [1991²³]. Workstation design is an active area of research among PACS investigators and includes such topics as the ideal number of monitors for a viewing station and the appropriate level of darkness for the viewing room.

Network

Underlying the PACS is the digital communication network for transmission of images and image-related data. The structure of the network is another area of intense research and affects interfaces with large-scale radiology information systems (RIS), hospital information systems (HIS), and outside physicians.²² The structure of the network has a funda-

mental impact on speed of the local workstations to display new and archived images. A recent article reviewed different network strategies [1991²⁹]. Figure 1 shows one possible scheme for a PACS network.

No estimate of the total number of PACSs currently in use is available in the literature. Nevertheless, the dream of an operational PACS is a reality in several locations. The following groups have all published papers regarding their experiences with PACSs: the University of Pennsylvania [1989⁷; 1991²⁸], the University of California at Los Angeles [1991²⁷], Georgetown University [1991²⁵], the University of Washington [1990¹⁷], Hokkaido University in Japan [1991²⁶], the University of Trieste in Italy [1992³²], and Utrecht University Hospital in the Netherlands [1989⁶]. Studies describing the use of PACSs in a critical care unit and intensive care unit, and a neuroradiology unit have also been published [1988²⁻⁴; 1992³³]. While these studies continue to push the boundaries of state-of-the-art technology, they also provide valuable data regarding clinical acceptability and image-delivery performance as well as the reliability and maintenance requirements of the system. The most recent study demonstrated that under regular operating conditions, the PACS outperformed the current film-

Table 1 ■

Review of the Direct Cost-Analysis Literature for the Picture Archiving and Communication System (PACS)

Author/Site	Methods	Results	Comments
Andriessen et al. ⁶ / Utrecht	Model includes equipment, installation, operation, storage, and personnel costs. It also includes estimates of shorter stay as a result of increased efficiency.	Investment costs of the PACS are substantially higher than those of the present system (86% of the PACS' costs are due to the equipment). Higher investment costs will not be compensated for by savings in materials, floor space needs, and personnel. Preliminary results suggest that compensation is achieved if the PACS decreases hospital stay by one-third of a day.	Utrecht had the highest costs of PACS equipment (six times higher than average U.S. costs), thus limiting the application of their results for U.S. hospitals.
Parrish et al. ^{10,13} / University of North Carolina	Compared film-based system with two high-speed networks and two low-speed networks for five different sizes of hospitals with 15,000 to 125,000 procedures per year. Considered personnel costs. Assumed that the PACS costs will decrease by 50% every five years. (Fixed performance.)	A high-speed network PACS is less costly than low-speed networks for all scenarios. A high-speed network PACS will be less costly than film for hospitals with more than 60,000 procedures in 1995 and hospitals with more than 15,000 procedures in the year 2000. A low-speed network PACS should cost less than film for 60,000 and 30,000 procedures in hospitals in 1995 and 2000, respectively.	Their assumption that PACS costs will decrease by 50% every five years seems overly optimistic, even if performance remains fixed.
Benson et al. ⁸ / Georgetown University	Georgetown University developed its own Cost-Analysis Model for Digital Imaging Networks (CADMIN). Essentially, it is a life cycle cost analysis that follows all the expenses and revenues associated with the operation of its prototype Digital Imaging Network. (DIN). It uses historical financial information to predict the impact of DIN technology on the future financial position of the department.	No published data available currently.	A brief description of a model that has not yet produced cost estimates.
Vanden Brink et al. ^{1,9} / TMG	Used Technology Marketing Group (TMG) model. (Sponsored by major manufacturers of diagnostic imaging equipment.) Phase I inputs include variables related to operation of radiology department based on survey. Phase II reflects labor time savings due to the PACS, installation, service, depreciation, etc. Allows for gradual implementation of the PACS.	Model was used to compute the costs of manual PACSs for 14 imaging centers in 1988. Results were compared with a cost profile of an average U.S. 400+ bed hospital derived from a previous TMG tracking study. Comparison showed that the model accurately predicted costs in these 14 imaging centers. Total predicted cost per average PACS examination was \$21.49. Annual costs were found to have a linear relationship to the number of examinations and the number of beds in the hospital. Annual cost of a manual PACS at a 500-bed hospital is \$2 million. According to this model, the PACS will pay for itself in five years and will produce savings of more than \$0.6 million per year in subsequent years.	This study was performed outside a university setting. The results of the linear regression were unexpected: PACS costs per examination should drop as the number of studies increases.

Saarinen et al. ^{11/} University of Washington	Multilayered spreadsheet model. Includes costs for equipment, storage, supplies, and labor. Also includes variables for installation and training costs. Includes sensitivity analysis with pessimistic, mean, and optimistic estimates for such things as inflation rate, filmless use rate, and maintenance costs.	Acquisition cost of digital radiography is \$7.5 million. Average annual cost savings of filmless system over conventional system is \$840,000. They calculate that a PACS could potentially generate approximately \$1,000,000 after ten years and a positive cash flow after nine years. Film cost savings attributed to the PACS can be largely offset by the PACS' equipment maintenance cost. Cost-effectiveness varies with intangible benefits such as referring physician and support staff productivity gains.	This is one of the best models. It includes almost all of the relevant costs including the costs of acquisition, operation, and training. The authors clearly state their assumptions and summarize the results of their sensitivity analysis. One additional interesting contribution the authors make to the literature is an "impact ranking" of their major model assumptions.
Seshadri et al. ^{5/} University of Pennsylvania	Models three scenarios: 1) presently existing film system, 2) digitizing film for use with the PACS, and 3) direct capture of image without producing film. Includes costs associated with equipment, maintenance, supplies, space, and personnel.	Cost of a film system is \$2,528,001 per year. Cost of a film digitizing system is \$2,342,005 per year. Cost of a completely digital system is \$1,828,542 per year. The film system is the least capital-intensive in terms of equipment and maintenance but is very expensive in terms of space, overhead, supplies, and personnel.	This study clearly lays out the direct costs associated with the PACS in three tables. The simplicity makes the study readily comparable with others. A few variables are missing, however, including acquisition costs for the first year, training costs, and commercial costs such as the cost of insurance, profit margin, and marketing expenses. All of those typically will increase system costs by 50% to 100%.
Van Gennip et al. ^{35,36} and Van Poppel et al. ^{20/} Netherlands	CAPACITY (Cost and Critical Analysis of Picture Archiving and Communication Indicating its True Yield) software package. Allows inputs for variables such as film, optical disks, workstations, and manpower. Calculates the costs in the year of introduction for the conventional system and the PACS within a radiology department. A series of annual cost calculations predict the break-even moment. User-supplied data (from various hypothetical and real departments of radiology) are checked for plausibility against expert heuristic rules.	Overview of data from 15 cases collected with CAPACITY software suggests that both hospital-wide and partial PACS implementations do not pay back yet. Only nuclear medicine PACS may be introduced as cost-neutral in the near future. When the cost of hardware components is allowed to drop 5% to 25% per year, some hospital-wide systems will become less expensive than film in the future with breakeven between 1998 and 2021. Experience with CAPACITY demonstrated major differences among the case hospitals in terms of PACS configurations and their costs. Most of the variation among film-based systems results from diverging estimates of non-medical personnel costs ($r^2 = 0.86$). Most of the cost variation among the PACS stems from different estimates of the costs of the workstations ($r^2 = 0.97$) and the network ($r^2 = 0.95$).	CAPACITY cost-modeling software facilitates the collection of cost-analysis data by radiology departments. In the future, it could serve as one mechanism for standardizing cost-analysis studies.
Warburton et al. ^{31/} Victoria General Hospital	Projected annual costs (including capital replacement) for a fully digital department based on experience with a prototype.	Compared with conventional diagnostic imaging, digital imaging raises overall annual costs by nearly \$0.7 million (Canadian currency), or 11.6%. Sensitivity analysis indicates that all reasonable changes in the underlying assumption still result in higher costs for digital imaging.	One of the most credible studies: sound methodology, clear tables, reasonable assumptions.

based system in terms of time needed to acquire an image. A neuroradiology PACS module consisting of a scanner, a data management and archive computer, and a display workstation was available 92% of the time, with the display workstation available more than 99% of the time. The overall user acceptance of the system was 3.4 on a four-point ranking scale [1992³³]. As a prototype, the PACS has proved to be fully functional at this time. A 1992 study found that several hospital-wide PACS implementations either were operating or were in the planning phase at Baltimore VA Medical Center, Madigan Army Medical Center, UCLA, Hokkaido University Hospital (Sapporo, Japan), SMZO Hospital (Vienna, Austria), Hammersmith Hospital (London, England), and other institutions.³⁵

Costs of PACSs

As researchers solve the PACS' technical difficulties, the main obstacle to its large-scale introduction will be cost. For a hospital administrator to commit large sums to purchase and install a PACS in the near future, he or she needs proof of the PACS' cost-effectiveness now. Cost analyses* measure expenses in dollars and help identify whether and under what conditions the PACS will reduce expenses. Specifically, there are two types of costs analyses—direct and indirect. Direct cost analyses measure expenditures immediately involved in operating a PACS: scanners, computers, film, space, and personnel. Indirect costs include those variables altered by a PACS, such as the ease with which both radiologists and referring physicians obtain and view films. Cost-effectiveness analyses focus on how the new technology affects clinical outcomes such as diagnostic accuracy, timeliness of diagnosis, and length of stay.²³ Warburton puts it this way: "cost-benefit analysis requires all costs and effects to be valued in money, while cost-effectiveness and its variants (cost-utility, cost-minimization) leave health effects in their natural units (years of life, hours of time saved, etc.) [1992³⁷]. True cost-effectiveness studies are much harder to design than cost-analysis studies. The researchers involved in the development of PACSs are aware that the burden of proof is on them. To that end, researchers have generally relied on cost-analysis models to characterize the costs of PACSs. In the next section, published direct cost analyses of PACSs are reviewed. Subsequently, both indirect cost analyses and cost-effectiveness studies of PACSs are discussed.

*Cost analysis and cost-benefit analysis are used interchangeably in this report.

Direct Cost Analysis

Twelve studies that discuss eight model systems—some real, some hypothetical—are reviewed. The major assumptions and conclusions of these studies are summarized in Table 1.

Clearly, these recent cost-analysis studies disagree about the costs and benefits of PACSs. Some conclude that the PACS would pay for itself, while others find the PACS much more expensive. Van Gennip et al. reviewed five studies, including some of those summarized here, to assess why their outcomes diverged (Fig. 2). They found that the reported annual costs of hospital-wide PACSs varied between two and four million dollars. Two of the studies found that PACSs cost 65–88% of what film-based systems cost. Two other studies determined that PACSs were 1.8 to 2.7 times more expensive than film systems. Estimates of total costs of the film-based system also differed among researchers. These differences could not be explained by variations in the sizes of the hospitals, or by the numbers of examinations performed.

Differences between the studies can partly be explained by the fact that the costs of space, material, and personnel varied. For example, the costs of one square foot of archive space ranged from \$10 to \$140 per year. The purchase prices, maintenance costs, and amortization costs for similar types of equipment also differed. In general, film-based equipment costs twice as much in the Netherlands as it does in the United States. PACS equipment costs in the Netherlands exceeded those in the United States by a factor of six. Of course, the researchers may have incorporated different kinds of equipment in their models. In terms of personnel, most studies agree that PACSs require specially trained operators. For the film-based systems, however, not every study accounted for the time spent by medical personnel on film management.

Often, there is not even a constant ratio between the number of examinations and the use of equipment, material, space, or personnel. In Pennsylvania, 4.2 square feet of film is used per examination, whereas in the Utrecht University Hospital only 3.3 square feet is used. Van Gennip et al. hypothesize that these results may stem from differences in the definitions of an "examination" or from variation in patient case mix. Interestingly, they analyzed the components that are not taken into account by every study (e.g., silver recovery costs). They found that, except for medical personnel costs, these other components make up only a very small portion of the total costs.

Overall, the University of Pennsylvania's study was the most optimistic. Comparatively, that department used the most film and had the highest cost for archive space, two areas where PACSs save money. The University of Utrecht produced the least optimistic study. It had high equipment costs and did not predict savings on personnel since that hospital does not currently need many people to operate its film department. Van Gennip et al. conclude that the differences among these studies demonstrate clearly the need for uniform, well-defined criteria for the calculation of the costs and savings accruing to PACSs [1990¹⁹].

Indirect Costs and Benefits of PACSs

As Straub and Gur point out:

The implementation of PACS has largely been stalled by lack of a clear demonstration of the cost-effectiveness of such systems when compared with conventional film archiving and communications systems. Traditional cost analysis has compared the cost of implementing PACS with direct, or actual costs of the typical film-based archival system (file room). Thus, the results of cost-effectiveness studies that assess the impact of PACS on the radiology department are somewhat controversial and demonstrate marginal impact at best. Although mentioned in a cursory way, what has largely been ignored is the substantial indirect or "hidden" costs of the health care system that may result from inefficiencies inherent in traditional film archival systems. [1990¹⁸]

These indirect costs include the costs of increased lengths of patients' hospital stays, duplication of examinations, and decreased efficiency of physician practices. Decreased efficiency potentially results from lack of timely access to diagnostic images or reports. A whole literature is emerging that attempts to describe and quantitate PACSs' organizational impact and the associated indirect costs and benefits.

Two widely cited reports from the University of Pennsylvania demonstrate the effect of a digital imaging network (DIN) on physician behavior. For one year, this innovative study alternated eight-week periods during which chest radiographs were digitized and made available to intensive care unit physicians. The results showed statistically significant reductions in the times taken to perform some clinical actions when images were available on the digital display console. For example, the time to begin drug therapy decreased from a mean of 4.7 hours when standard films were viewed to a mean of 3.3 hours when digital images were viewed.² Interestingly, the use of digital images led to changes in the times at which physicians reviewed images, and consultations be-

Figure 2 Top, Estimates of the total costs of the film-based system, specified for the costs of equipment, material, space, and personnel, as determined by five previous picture archiving and communication system (PACS) cost-analysis studies. Middle, Estimations of the total costs of the PACS, specified for equipment, material, space, and personnel, as determined by four previous PACS cost-analysis studies. Bottom, The costs per examination of the PACS minus the costs of the film-based system, specified for the costs of equipment, material, space, and personnel, as determined by four previous PACS cost-analysis studies. Reprinted with permission from Van Gennip EMSJ, Ottes FP, Van Poppel BM, Andriessen JHTH. Why do cost-benefit studies of PACS disagree? SPIE Medical Imaging IV: PACS System Design and Evaluation. 1990;1234:894-904.

tween medical intensive care unit staff and radiologists decreased. During the control period, consultations with radiologists, whether by telephone, by written report, or in person, occurred for 95% of the films. When physicians viewed digital images, they used the transmitted reports to review the radiologists' interpretations for 50% of the images, and otherwise consulted radiologists another 10% of the time. That means that intensive care unit physicians viewed nearly 40% of the digital images *before* radiologists' interpretations were available.^{4,28} These studies suggest that, at least for intensive care patients, PACSs will affect both patient management and radiology department work flows.

Investigators also examined potential time savings among radiologists and file-room staffs [1990¹⁶]. Warburton reviewed this literature. In one study, self-reported film-handling times suggested that 4.4 full-time-equivalent (FTE) staff would be required to operate a PACS. Overall, the PACS would reduce radiology department staff (including employees of the film library, but excluding radiologists) by 18.5 FTEs (26%). This could lower overall staff costs by 22%. Another study from the same hospital used data from time-and-motion studies to estimate film processing, transport, and checking times. This method underestimates total film-handling times because it counts film handling in a room during a procedure as part of the procedure. Nevertheless, this study estimated that film-specific activities account for 10% of radiology department FTE staffing.³⁷ A study by Saarinen et al. at the University of Washington used a combination of time-and-motion measurements, activity sampling, and interviews to estimate film-handling times. The study showed that the PACS could eliminate slightly more than half of the tasks in the file room. Furthermore, radiologists could save 10% of the time they spend reading films by no longer having to search for films. Radiology technologists could also save as much as 10% of their time with the PACS due to a reduction in film-processing time for digital modalities. Saarinen et al. emphasize that this estimate is subject to significant patient mix aberration and measurement error.¹⁶ Models created by a Dutch group should provide additional data about personnel savings in the future [1992³⁴].

Several studies focused on the effects of PACSs beyond the radiology department, such as the effect on the lengths of patients' stays. Although rigorous data are lacking, several surveys describe physicians' beliefs that PACSs will lessen delays related to imaging and will shorten patient stays. Back in 1985 and 1986, unpublished data from a proprietary study by the Technology Marketing Group showed that radiolo-

gists and hospital administrators believed digital imaging with PACSs would shorten the average length of stay by 13% and 6%, respectively.¹ Straub and Gur published a survey of the medical staff at the University of Pittsburgh's teaching hospital concerning the impact of imaging delays. Respondents indicated that delayed access to films or reports frequently (14%) or occasionally (60%) resulted in duplicate examinations and frequently (15%) or occasionally (45%) lengthened patients' hospital stays. Overall, the physicians estimated that radiology-related delays added 5–30% to their practice costs (mean 16%). Although the University of Pittsburgh study did not directly measure the costs of prolonged lengths of stay, it did test hypothetical "impact factors" of 1%, 3%, and 5%. The authors used these calculations to generate estimates of the efficiency cost (outside radiology) of conventional film management. They concluded that these "indirect costs" might be 1.5 to 7 times higher than direct film library costs [1990¹⁸].

Other evidence rejects the hypothesis that digital imaging will reduce hospital stays sufficiently to produce net savings. Warburton conducted a survey of admitting physicians about the effects of imaging procedures on the care and lengths of stay of hospital inpatients. In 112 continuous randomly selected cases, she found no inpatient examination that lengthened a stay in a way likely to be averted by digital imaging (95% confidence interval 0–2%). On the other hand, Greater Victoria Hospital Society statistics, unrelated to the digital imaging project, showed that 1% of inpatients admitted through the emergency department had their stays lengthened at some point by delays in medical imaging [1991³⁰]. The magnitude and cause of the observed delays were not recorded. Based on these results, it is unclear what effect conversion to digital radiology will have on length of patient stay and hospital costs.

The acceptance of PACSs by referring clinicians may be critical to the overall utility of PACSs and may be a major factor in a hospital's decision to purchase a PACS. A hospital-wide survey of referring physicians at the University of Washington by Saarinen et al. addressed the clinical determinants of a PACS' acceptance. Saarinen et al. found that the factors that caused referring physicians to support the PACS included 1) elimination of lost, misplaced, and checked-out films and 2) elimination of trips to and from the file room. The major shortcomings of the technology were 1) system reliability and 2) reduced diagnostic capability.¹⁷ Another study by Saarinen et al. combined questionnaire data and trip-distribution data to forecast the average time referring physicians spend traveling to and from the radiology department file

room. The two methodologies generally agreed and showed that the time involved approached approximately two weeks per year per referring physician. If this lost time can be recovered through PACSs and translated into increased patient visits, it may be worth \$3 to \$8 million annually in additional billable revenue.¹⁵

Conclusion

In his speech to the First International Workshop on Technology Assessment of PACS, B. L. Crowe stated that "PACS is at present going through a crisis with a number of large systems either being stalled or having difficulty with funding and a number of major PACS manufacturers reappraising the marketing and support of PACS" [1992³¹]. An article published by a representative of Philips Medical Systems, one of the major manufacturers of PACSs, echoed Crowe's sentiments. From an industry perspective, "the medical market is not large enough to justify substantial new development of PACSs" [1990¹⁴]. Crowe rejects the concept of the "technologic imperative." The existence of a new technology does not automatically mean it will be adopted. He outlines key elements that will lead to its widespread dissemination and acceptance.

- The technology must meet a deeply felt need of a large group of potential users.
- The technology must be capable of performing a function better than existing technology.
- The technology must be available at the same cost as existing systems or products or must cost less.³¹

Technology assessment is explicitly designed to address these questions. For Crowe and others like him, the answers so far do not clearly favor PACSs. For example, he mentions how PACSs have been criticized for their limited ability to display and manipulate multiple images in reasonable time. In this tenuous environment, accurate assessment of PACSs' benefits as well as their costs holds the key. Many of these benefits are listed in Table 2.

This report and others point out the lack of standardization among cost-benefit studies and the "need for uniform, well-defined criteria for the calculation of the costs and savings of PACS."¹⁹ Furthermore, many of the current cost estimates are based on custom systems that were designed locally or that were serving as alpha sites for manufacturers. This precludes a meaningful evaluation of the real costs of such systems. Initially, the original costs of com-

Table 2 ■

Summary of the Benefits of the Picture Archiving and Communication System (PACS)

Category 1—benefit to the diagnostician

- Improved access to current patient records
- Improved access to patient history records
- File integrity and speed of retrieval
- Better diagnosis

Category 2—benefits to the referring physician

- Better patient management/earlier intervention
- Better patient outcome
- Reduced length of stay
- Reduced legal costs due to maladministration claims based on loss of films, lack of patient history, etc.

Category 3—benefits to the patient

- Reduced radiation exposure from x-ray equipment
- Shorter examination times
- Reduced radiation exposure as a result of less need for re-takes of images
- Reduced patient inconvenience in attending hospitals for examinations and reexaminations
- Reduced chance of adverse reaction to contrast agents

Category 4—benefits to the hospital

- Better communication with physicians
- Better hospital administration
- Better training of radiology and other students through access to on-line image files and to digital teaching files
- Greater staff retention due to improved morale

*Reproduced with permission from Crowe BL. Overview of some methodological problems in assessment of PACS. *Int J Biomed Comput.* 1992;30:181-6.

mercial systems may be more expensive, though over time these costs should decline.

Crowe adds that:

Far too much attention has been paid to the itemization of costs of PACS systems without sufficient attention being paid to the discrimination of benefits Until benefits of PACS systems can be clearly quantified in a standardised and acceptable manner, then I believe that the radiology profession will continue to remain unconvinced of the advantages of digital radiology systems. [1992³¹]

It is not only radiologists who need to be convinced of PACSs' utility and cost-effectiveness, but also referring physicians, hospital administrators, and politicians. To implement PACSs on a large scale, advocates must work creatively and vigorously to assess PACSs even as they strive to advance the technology.

To facilitate these efforts in this evolving field, we make the following recommendations:

- A panel of experts should establish precisely defined criteria for what constitutes the most important elements of a PACS cost analysis. These criteria should include specific definitions of costs

as well as benefits. It remains to be determined whether these criteria should include direct costs, indirect costs, or a combination of both. Through this consensus, researchers can develop reproducible and comparable cost-benefit studies. In other words, this will allow comparison of "apples to apples." Cost evaluation software such as Cost and Critical Analysis of Picture Archiving and Communication Indicating its True Yield (CAPACITY) and the newer PACER⁴⁰ may provide a foundation on which an expert panel could build.

- Any methodologic discussion should take into account the modular nature of current PACS development. Most PACSs begin in only a few departments or in a single ward rather than hospital-wide. Some of the infrastructure changes necessary to accommodate these "mini-PACSs" may provide future benefits as PACSs expand throughout institutions. At this time, though, the cost of a PACS should be considered largely additive to the cost of running a film-based system until entire sections or divisions of radiology departments become filmless.
- Consideration of professional costs needs to be included, along with consideration of hardware and software costs. For example, a PACS may allow fewer neuroradiologists to serve a community's needs. Alternatively, it may allow existing radiologists to review a greater total number of films.

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