DIGITAL RADIOGRAPHY SYSTEMS

A DISCUSSION PAPER

BY THE

NATIONAL HEALTH TECHNOLOGY ADVISORY PANEL

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AUSTRALIAN INSTITUTE OF HEALTH

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Any comments or information relevant to the subject matter of this report would be welcome.
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THE NATIONAL HEALTH TECHNOLOGY ADVISORY PANEL

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DIGITAL RADIOGRAPHY SYSTEMS

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DIGITAL RADIOGRAPHY SYSTEMS

EXECUTIVE SUMMARY

- Digital radiography systems are a rapidly developing technology for the management, storage and transmission of digital images.

- The term digital radiography covers a wide range of systems from simple transmission units to major hospital data management systems, with capital costs of the order of $0.2M to $9.0M.

- Digital radiography systems have the potential to provide benefits to radiologists, hospitals and patients through the ability to enhance images, improvements to security and cost of storage, better management of images and better access to patient records.

- At the present state of development, there are problems with system costs, technical maturity and acceptability to radiologists and other users.

- The use of digital radiography systems in Australia may already be justified in certain applications. However, each introduction of a system would need to be carefully assessed with regard to costs and benefits, and detailed discussions held with all interested parties.

- The cost and performance of systems put in place should be evaluated to provide information for other potential users.

- Developments in digital radiography are occurring rapidly and should be kept under review. There could be opportunities for local industry in developing system components and software.

- There would be value in ongoing consultation involving health authorities, the Australian Hospitals Association, the Royal Australasian College of Radiologists, and other professional bodies on the development of a suitable strategy for introduction of digital radiography systems into the Australian health care system.

INTRODUCTION

Considerable research and development activity is taking place in other countries on the information technology of digital radiography (also known as computed radiology). While much of this technology had its origins some years ago in areas such as the defence industry, its application to health care is comparatively recent and is still evolving rapidly. Digital radiography provides the potential for hospitals and associated installations to deal with data from diagnostic imaging in a more cost effective fashion than is possible with the traditional methods. The term encompasses a range of systems, from quite basic data links between single centres, to complex data management networks for total diagnostic image handling within hospitals.

The NHTAP decided to consider this area of health technology because it is developing rapidly, is complex and has major cost and quality implications for hospitals.

This paper examines various issues associated with digital radiography systems and is intended to provide a basis for further discussion in this area. Specifically it addresses the possible benefits of digital radiography systems and the problems that might prevent their successful introduction.

Digital radiography involves the replacement of X-ray film or other analog data records by digital images, produced by a computer and displayed on a cathode ray screen (CRT). The subsequent transmission and storage of these digital images is achieved using Picture Archiving and Communications Systems (PACS). These systems have come into operation following recent developments in optical disc technology and in high speed data transmission. Some PACS systems have been developed to provide services to remote localities and these are of interest to Australia. Aspects of digital radiography are already well developed, for example in computed tomography (CT) scans, where digital images are displayed on CRTs and stored on magnetic tape. The following discussion covers some of the wider issues involved in the conversion of diagnostic images to digital format for routine use in hospitals.

The collection, storage, and retrieval of information has a cost. Developments in electronic data processing have resulted in this cost being highly visible in terms of expensive capital equipment. Information handling has undergone a fundamental change as it has evolved from a labour intensive to a capital intensive activity. The cost of handling data by electronic methods may be no dearer than by the manual systems replaced. However, what is certain is that the change to electronic data processing involves the acquisition of new equipment and the recruitment of staff with new skills. These tasks present managers with new problems. Australian hospital administrators may soon be asked to make decisions relating to complex data processing systems involving the transmission and storage of diagnostic images.

From the experience of the past twenty years, it is a reasonable assumption that the introduction of a new data processing system will be a difficult and often frustrating task, given the well-known gap between promise and performance. Difficulties are likely to be highlighted in a hospital environment where information is often required urgently in the management of patients and where administrative systems may already be under considerable pressure. What then are the anticipated benefits of the introduction of digital radiography systems into hospitals? More particularly, do the benefits justify the capital, operating and indirect costs required to implement the new systems?

BENEFITS OF DIGITAL RADIOGRAPHY SYSTEMS

The benefits of using digital radiography systems may be seen as:

- ability to manipulate image data
- better security of images
- better management of images
- improved access to patient records
- reduced space requirements for storage of records.

Data Manipulation

A major benefit of digital radiography is that, unlike conventional film images, digital data can be electronically manipulated by radiology staff to enable image enhancement, transmission to a number of locations, or storage and retrieval. The capacity to manipulate digital data can provide the radiologist with greater diagnostic information and more flexibility in the use and interpretation of the images.

Use of digital radiography provides the possibility of recalling a number of images from different diagnostic equipment and comparing images obtained at different times. Such use could, for example, provide rapid availability of images from MRI, CT and ultrasound examinations, and a comparison of current diagnostic information with images of the patient obtained during previous examinations.

These advantages to the radiologist can lead to benefits for the patient through greater accuracy of diagnosis, the need for fewer examinations and consequently reduced exposure to ionising radiation, and a more accurate history. The benefits to the hospital are through better administration of image files, reduced response time to requests, absence of lost images (as the data are held permanently in archive on optical disc) and the possibility of fewer support staff to service the diagnostic function (including retrieval of old imaging data).

Security of Storage

Hospital systems place great emphasis on the secure storage of patient records, often over long periods of time. Existing systems have developed over many years in response to perceived administrative, legal, and patient servicing requirements. Whether current filing systems, which are often seen as cumbersome and inefficient, should continue is a matter for separate discussion. However, the availability of digital radiography presents an opportunity for the permanent storage of images on optical disc or magnetic tape in a secure archive. Once the image is stored on optical disc it need never leave the central repository, unlike the film which travels around the hospital. Requests for the image are serviced by either the digital transmission of the image (to the ward, clinic or office) or by the production of a copy on film, which is then physically transported to the required destination.

Management of Images

Allied with the benefits of security of storage of images is the possibility of the management of images in accordance with the needs of radiologists, clinicians and patients. Images which are required immediately while the patient is in hospital can be stored on-line on magnetic disc media. Once the patient leaves the hospital, the images can be stored on optical disc for twelve months or more, depending on the patient's condition. After a nominated time, the image can be archived for long-term storage purposes to meet legal requirements and stored off-site in a record-keeping warehouse.

A major benefit is the flexible management of images rather than the current systems based on inflexible rules for the storage of film. In terms of film storage it is recognised that patients have differing requirements. A surgery patient may only visit the hospital for three days with no follow-up, whereas some paediatric patients may require treatment and follow-up over a period of 20-30 years. Present image management systems lack the flexibility of treating patient records on an individual basis. Digital radiography presents a unique opportunity for medical record administrators to introduce improved management of patient records.

Access to Patient Records

Although all patients have unique identifiers at present, such as Medicare numbers, typically little use is made of this information in hospital systems. In effect, each visit to each hospital is seen as a separate episode, generating a separate set of records. Although there may be good reasons for this approach - for example, the patient may be presenting with a different problem - on balance it would be preferable for the patient's complete medical history to be available for review prior to treatment or diagnosis. It may not always be possible to rely on the patient for this information as the patient may not know the precise details of previous treatments.

The storage of digital radiography images in a shared network allows other medical institutions (with appropriate security clearance) access to patient history. For example, in the Newcastle area, there are a number of hospitals which the patient could visit. Under an inter-hospital digital image management system, it would be possible for a clinician to request the patient's history from another hospital and to view the images. Also, an image transmission system to link the Prince of Wales and Prince Henry's Hospitals, Sydney has been considered (see Appendix). These hospitals share patients but are some ten kilometres apart.

Patients will benefit from better record administration if it results in more appropriate treatment, a reduction in the number of repeat examinations, and less waiting time. These factors have direct economic consequences both to the hospital in terms of reduced costs and to the patient in terms of improved diagnosis and less waiting time.

Ancillary Benefits

Storage of film in hospitals is demanding of space, both in terms of facilities for holding reports and provision of access to staff to retrieve them. Use of PACS to handle image storage results in savings in space which may be significant in many hospitals. There may also be considerable potential savings to hospitals through use of digital radiography in terms of cost of silver recovery from films.

PROBLEMS WITH DIGITAL RADIOGRAPHY SYSTEMS

The fact that digital radiography systems have not been introduced in hospitals, despite apparent benefits, indicates that there are problems with the systems that have not yet been solved. Such problems are related to their cost, technical maturity, timing of introduction, and also to the views of system users (radiology staff and referring clinicians).

Cost of Digital Radiography Systems

Establishment of a digital radiography system is capital intensive. In an environment of scarce resources, the justification of a large capital budget may be seen as a problem. Although, as noted in the introduction, the cost of the digital radiography system may be no more than the existing system when all costs and benefits are considered, capital outlays of the the order of $2-9M (1) over a period of ten years require detailed examination and justification.

The level of capital cost to a hospital will vary considerably, depending on the complexity of the digital radiography system which is to be installed. A basic data transmission link between two hospitals, for sending images to a central viewing station might cost about $170,000 (Appendix). The model configuration of a digital radiography system for the new teaching hospital at Newcastle would be associated with estimated costs of the order of $2.4M. Higher capital costs would be required in larger installations which used additional viewing stations and stored more diagnostic information.

Capital expenditure priorities must be based on the perceived benefits of digital radiography systems as compared with other initiatives and ongoing expenditure on existing facilities. To place the costs of digital radiography systems in perspective, government and private organisations regularly budget for capital expenditure on electronic data processing systems. In a sense, hospitals are only now being faced with the decisions that financial institutions, airlines, and government instrumentalities have had to take over the previous ten years as regards investment in computer systems.

The cost problem is perceptual as well as financial, given that in other areas of activity hospitals expend large capital sums on complex projects. However, cost-benefit studies will be necessary to justify each proposed system and, to date, few hospitals have been prepared to undertake such detailed evaluations. A further point is that hospitals may be reluctant to take on board the costs of organisational restructuring and training associated with the introduction of a digital radiography system, particularly when other areas of expenditure are seen as having higher priority.

Technical Maturity of Digital Radiography Systems

Assessment of the technical maturity of digital radiography systems presents a substantial challenge. Obviously such assessment should involve radiologists, other medical staff, systems analysts, communications engineers and administrators. This in itself presents a fertile field for disagreement amongst experts in different areas. In addition, objective assessment may be hindered by suppliers of equipment, some of whom have tended in the past to announce the availability of products before they are ready for the market-place. A further confounding factor is the tendency of researchers and administrators to report success rather than failure when describing the implementation of digital radiography systems. Published accounts will in general not reflect current experience, due to delays in journal publication. Up-to-date experience is difficult to obtain and to assess in a thorough manner.

Assessment of digital radiography systems may be divided into the following areas:

- Screen resolution
- Speed and capacity of retrieval
- Image compression techniques
- Storage capacity

A technically mature system must be able to satisfy system design goals in each of these areas.

. Screen Resolution

Many radiologists are not yet satisfied that viewing images on a CRT is clinically equivalent to viewing films. A viewing console with a matrix of 1024 x 1024 pixels (1000 line screen) costs of the order of $25,000. Viewing consoles are available at 2048 x 2048 pixels but are considerably more expensive both in capital and data transmission costs.

Although an increasing number of images (currently some 10-15% average) are digitally generated on CT, MRI, and DSA systems, (usually at the 512 x 512 pixel level) a hospital would be unlikely to make a decision to acquire a digital radiography system unless the medical staff were satisfied with the image resolution of films on the CRT viewing screen. Film resolution is usually specified at the order of 2.5 line pairs per millimetre and radiologists are likely to seek similar standards when viewing digital images on CRT screens.

. Speed and Capacity of Retrieval

Radiologists are used to viewing several images simultaneously. A digital radiology system must be able to meet this requirement, and the results of a number of investigations may be required for viewing. This implies the need for high speed data transmission and a multi-screen viewing console.

Typically, a 4-screen viewing console costs of the order of $275,000 and a number of consoles might be required in a radiology reporting centre. A possible compromise between speed and cost is a two-screen viewing console and this approach is being tried by General Electric at the Milwaukee Regional Medical Centre (2).

The numbers of multi-screen diagnostic review stations and single-screen physician review stations will vary with each particular hospital situation. There will be a need to balance cost considerations with the level of service required by radiologists and other medical staff.

A related problem in retrieval is the ability of the image transmission network to manage the data transfer load in a reasonable time. Mankovich describes a system at the Department of Radiological Services at the University of California, Los Angeles where a digital image network in the paediatric radiology section is being introduced. The system, using an optical disc, has a response time of 1.3 minutes for a single 2048 x 2048 x 8 bit digital radiography image of the chest. Slow response time is improved by pre-programming the system to retrieve images from optical disc in advance and store them on the magnetic disc for viewing when required. The authors suggest that recent developments in optical disc technology could reduce retrieval time by 70% (3).

A recent leading article in the journal Health Technology noted that "the time required to constantly transfer millions or even billions of bytes of data to and from the storage device can produce "electronic traffic jams", especially in systems handling more than one or two imaging devices" (4). It also noted, however, that fibreoptic based electronics has the potential to increase transfer rates substantially.

The area of data transfer and image retrieval appears to present problems and can best be described as developmental; it must be considered on a system by system basis. Adequate levels of data transfer may well be achievable for reasonably simple networks. At the present state of development, data transfer and retrieval performance in large systems is an area of difficulty, placing heavy demands on computing power and network design. Substantial research and development effort is being made in this area by all major manufacturers of digital radiography systems.

The developing nature of the area has been highlighted in an overview by Figley and Margulis of recent developments (5). In this, it was noted that Prof. Baum of the University of Pennsylvania was introducing a new digital radiography system. The authors commented that his experience would be awaited with interest, particularly documentation of the system's cost-effectiveness. On balance, existing problems with speed of retrieval are seen as a significant limiting factor in the acceptability of digital radiography systems.

. Image Compression Techniques

One of the solutions to the problem of speed of retrieval is image compression, whereby the data in an x-ray image are compressed depending on the amount of redundant data. For example, an original CT image involving 500,000 bytes of storage might be reduced to 25,000 bytes at a compression ratio of 20:1 by only recording the non-redundant pieces of information. Each image is scanned and reduced appropriately by use of a proprietary algorithm. Compression can take the form of destructive or non-destructive compression (6), and depends on the approach adopted by each particular supplier. The effect of destructive compression is that the original image could not be recreated, if required, and this approach may not be acceptable to radiologists.

In general, adoption of compression techniques lead to a situation where a hospital tends to be committed to one digital radiography supplier. Further, there are as yet no uniform standards for compression of data, which may present problems in the transfer of images from one system to another. However it is possible to understand the attraction of image compression when it is considered that a digital radiography system may require the transmission of 1.19 million bits of data each second (7).

While it may be desirable in terms of image quality not to perform image compression until the patient's diagnosis and treatment is completed and the images are ready for permanent filing, the fact is that the retrieval advantages of compression are of most benefit when the patient is under active treatment and the images are in frequent use. The question which only radiologists can answer is whether the resolution of the transmitted image is reduced to the point where its diagnostic value is impaired. There are few reported studies of the effects of data compression on image quality and diagnostic accuracy. In one study by Gitlin, the clinical findings, based on interpretations of original images, were determined to be 6 to 10 percent more accurate than those made using compressed images at a compression rate of 20:1 (8). Such results are not likely to convince radiologists that they should change from use of film to digital radiography systems using compression techniques.

In diagnostic radiology there is a constant level of anxiety as to the accuracy of a radiological diagnosis. A possible additional error factor of up to 10% is not acceptable to radiologists, all other things being equal. Any compression system could be required to be as accurate as existing systems, rather than less accurate, before it could be considered for adoption.

On the other hand, major research and development is being undertaken in this area, and there is the prospect that performance will improve. Even with existing systems, a number of hospitals in the USA are already using digital radiography in routine diagnostic imaging. Further work will be needed to demonstrate the accuracy of evolving systems as compared with film.

If there are substantial doubts in Australia about the acceptability of data compression, then data transmission requirements could be even greater than generally assumed in the overseas literature, as current systems tend to use some form of compression.

An ECRI Technology Assessment recommended that imaging departments should provide for installation of fibreoptic or coaxial cable connecting all imaging rooms to allow for very high speed data transmission (9). This approach has been adopted in Newcastle in the design of the new teaching hospital at a cost of approximately $1M.

In summary, image compression presents major problems, but appears to be working satisfactorily in a number of hospitals in the USA. However compression of data may limit portability of an image, as only users who possess specific hardware and software can reconstruct the image.

The ECRI report noted (p.91) that "A universal technique for data compression and reconstruction is not likely to be agreed upon in the near future, if ever." (9) It would appear that the selection of a compression technique would be one of the major decisions facing systems analysts and radiologists in the implementation of a digital radiography system.

. **Storage Capacity**

The problem of data compression is directly related to the problem of data storage. Cox (University of Kansas Medical Centre), in relation to a 540 bed hospital system, noted that current requirements for storage were 1 gigabyte per day (1 billion bytes) where only 25% of examinations were managed digitally. A requirement of 47 gigabytes per day was estimated for 100% digital imaging. A need for long term image archiving of the order of 37,000 gigabytes was envisaged (10). What is certain is that large amounts of magnetic and optical disc storage will be required for a digital radiography system. A multiple disc storage device (juke-box) capable of providing storage and retrieval for up to 64 discs, costs of the order of $400,000 with each disc costing $800. Currently each disc holds 1 gigabyte per side. The number of images that can be recorded per disc depends on the type of images and the compression ratio used.

Multiple juke-boxes can be supplied so that the capacity for optical storage is large, a 1000 gigabyte system being possible at a cost of approximately $2 million. Assuming that a CT image takes 500,000 bytes of storage, then 2000 images can be stored per gigabyte or 2 million images per system. This represents an initial cost of approximately $1 per image stored which would reduce as the cost of the original equipment was amortised. When considering storage equipment acquisition costs, plus the cost of automated handling and transmission to access the required images, a compression ratio of 50% could reduce storage and retrieval costs by approximately $1M.

It is possible that the desire to minimise storage costs may tend to offset radiologists' concern about the quality of images. Efficient storage procedures are essential to ensure that only necessary images are stored on-line, given that a 500 bed hospital may need immediate access to 20,000 images with up to 5 million images in archive. Although the costs of these storage requirements would appear prohibitive at an initial cost of $1 per image, technological developments in optical discs have already occurred which increase the capacity of discs by a factor of three (6 gigabytes per disc). The use of compression at 20:1 would reduce storage costs from $1 to the order of 5c per image.

Hindel, reviewing developments in the USA, noted that "Well publicised projections place the cost of storing 1 Mbyte of data at $0.05. This is considerably cheaper than storage of the equivalent amount of diagnostically significant information on film. Several large imaging departments are investigating the use of optical storage principally to reduce operating costs" (11).

In summary, with the cost in Australia of storing a digital image ranging from 5c to $1 depending on the approach taken to compression and the density of storage on optical disc, there may be cause for concern about the economic viability of storing up to 5 million images. However, optical disc storage is an area of rapid technological development. The model system referred to in the Appendix estimated a cost of $656,000 for optical storage of 5 million images, using 20:1 compression of data, at an initial cost of approximately 13c per image.

Clearly a major concern of systems analysts and administrators will be the selection of a storage system and the formulation of retention policy for digital images. There will be a need for caution in this area if digital radiology systems are to be cost-effective. Hospitals may need to consider how long images should be stored, given frequency of retrieval of archival material and any legal requirements. At George Washington University Medical School it has been found that only 4% of films over 1 year old are recalled from storage (Allman, personal communication).

Timing of Introduction of Systems

Apart from the problems of cost and technical maturity of digital radiography systems, there remains the problem of timing their introduction. This may best be posed by the question "Are Australian hospitals ready to undertake the expense and effort necessary to introduce digital radiography systems?". In other words, is this major activity seen as a sufficiently high priority in view of other priorities and the existing pressures that hospitals face in terms of budgets. From discussions with radiologists and hospital administrators, it would appear that at present digital radiography systems are commonly seen as desirable, but not essential. The experience with the introduction of computer systems in industry and government is that it is necessary to have the full support of managers and users for them to be introduced successfully. Otherwise the system will either not work, due to lack of financial or personnel resources, or will not be used by the professionals for whom it was designed.

Despite the existing reservations of radiologists and hospital administrators, it should be remembered that similar reservations were expressed previously in other areas of computer applications such as banking, insurance, airlines and government departments. Over the past 10-15 years computer systems have matured sufficiently to be attractive to these sectors and have become widely accepted. The timing of introduction of a system is influenced by the maturity of the technology, manufacturer support, cost-benefit and willingness by managers and professionals to be innovative. In some areas, hospitals have fallen behind other organisations in the adoption of computer techniques. It may be the case that hospital administrators will have to take initiatives to advance to the level of computer implementation in other organisations.

An important factor in the timing question is the amount of effort being invested by major companies in the development of computerised hospital administration systems and digital radiography systems. Firms such as Kodak, IBM, General Electric, Philips, Siemens, 3M, Fuji, Sony, Toshiba and Hitachi are undertaking major development programs aimed primarily at the American market. A recent conference of the International Society for Optical Engineering was devoted entirely to image data management and display for medical imaging (12). In addition, there are a number of joint ventures being undertaken between major firms and the US Government, and research is being conducted by manufacturers and university hospital medical centres. The level of investment, as demonstrated by exhibitors at the 1987 Assembly of the Radiological Society of North America, was of such an order of magnitude as to convince some US analysts that digital imaging systems would be in general use in US hospitals by the mid 1990's. Although such projections are usually viewed with some reservation, it must be recognised that there are strong pressures to bring hospital administrative systems into the computer area. A more conservative estimate is that major digital radiography systems will not be in widespread use in the US before the end of the century.

Despite much coordinating effort in USA between suppliers, users and government, no system-wide standard for digital radiography has yet evolved. The lack of standards is a matter of concern to Australian radiologists, who have justifiable concerns about obsolescence and incompatible equipment. The standards proposed by the American College of Radiology and the National Electrical Manufacturers Association (13) are only just beginning to be implemented and much of the presently available equipment does not meet this standard.

The introduction of working digital radiography systems in the USA has started and will be watched with interest by financial analysts in terms of effect on the profitability of equipment suppliers. At this stage, no major supplier is prepared to forego the opportunities presented by providing digital radiography systems to hospitals. The success or otherwise of digital radiography systems in the USA will have a strong influence on the attitude of Australian radiologists and hospital administrators to this technology.

Views of System Users

The views of users of digital radiography systems, particularly radiologists, are obviously a major factor determining the acceptance of digital radiography systems. An exposition of the likely costs and benefits of the systems is seen as an essential step in providing an understanding of the technology to potential future users. Appropriate consultation will be required between professional bodies, the Royal Australasian College of Radiologists, hospital administrators, health authorities and relevant manufacturing organisations. It is clear that there would need to be involvement with radiologists and other medical staff working in public hospitals, as this group would be likely initial users of digital radiography systems. Co-operation with this group would require an understanding of their preferences and of how digital radiography systems might enable them to provide a better service to patients.

Some of the possible concerns of Australian radiologists are exemplified by reactions to a paper by McFee (14), reporting on the interpretation by two radiologists of chest and abdominal films of neonates, initially from transmitted images and subsequently from the film radiographs. The comparison showed 0.5% clinically significant discrepancies, and 6.7% minor discrepancies in the transmitted images. While such results might appear satisfactory to a systems analyst, many radiologists would consider this level of interpretation error (major discrepancies in 7 out of 1400 cases) as unacceptable.

The films in the study reported by McFee were digitised to a matrix size of 1024 x 1024 x 8 bits (256 shades of gray) and read back on display monitors with 1000 line, 15 inch, video screens. An Australian radiologist (Sorby, personal communication) is of the opinion that digital image reporting might only be acceptable using 2048 x 2048 x 12 bit monitors and that there is no evidence that even that approach would lead to improved diagnosis or patient management. Such a view has serious implications for systems design, as a 1024 image takes 8 mbytes whereas a 2048 images takes 48 mbytes. In other words, a digital radiography system would require 6 times the information capacity of currently used technology to meet some requirements for image quality.

The requirements of radiologists regarding acceptable levels of accuracy and viewing resolution could potentially be so demanding as to make a digital radiology system almost impossible to justify in cost-benefit terms. Obviously these matters would require careful discussion and analysis to see if these criteria were required in all circumstances or whether there may be some situations where other requirements might be applicable. The fact that magnetic resonance images are currently acceptable at 512 x 512 x 8 bits may provide room for discussion, although it is recognised that the majority (80%) of radiologists' work relates to reading x-ray films which contain a great amount of detail.

While the views of radiologists and other medical staff on current technical performance are an important factor, a number of other matters need to be considered in reaching a position on the place of digital radiography systems in the health care systems. At least in some situations, currently perceived deficiencies in image quality may be offset by benefits through use of the systems. For example, reduced image quality would need to be balanced against gains to patient care through the elimination of lost or delayed films. There may be very substantial benefits through transmission of images over considerable distances, providing the capability of prompt consultation. As discussed previously, there will be advantages to the radiologist through the ability to manipulate digital data to enhance the image characteristics.

A recent paper by Arenson (15) concluded that the availability of a medical image management system for chest images in the medical intensive care unit led to significant reductions in the time taken for physicians to initiate action, such as altering drug therapy, for patients.

Various strategies to minimise performance shortcomings might be considered. One approach could be a "partial" digital radiography system, with images being available to the radiologist on film, prior to being stored in a PACS. Again, film reading could be reserved for selected types of critical radiological examinations.

Consideration would also need to be given to the extent to which diagnoses in various types of cases will be influenced by individual images, compared with other diagnostic results and clinical examination.

While there are various technical difficulties with digital radiography, this area of technology is developing rapidly and it is possible that many shortcomings will be eliminated in future systems. It is also significant that a number of major hospitals in the USA and elsewhere are already using digital radiography in routine patient management, implying that on balance performance is seen as acceptable, even at the present stage of technical development.

Obviously there are a number of professional sensitivities which will require in-depth discussion between radiologists, physicians and systems analysts to establish if specifications for digital radiography systems can be agreed upon which meet realistic requirements, are technically feasible and economically viable. The results of further studies on the comparative clinical impact of film and digitised images will be an important input to such discussions.

CONCLUSIONS

While digital radiography is an expensive, rapidly developing technology, with some significant technical limitations, a number of activities in this field are currently being undertaken in Australia and are summarised in the Appendix. Clearly there is a need for continued detailed evaluation of overseas developments to ensure that any Australian projects are carried out in full awareness of most recent data.

Because of the nature of the technology, digital radiography systems involve expenditure on capital equipment and this is an area where there are already significant demands for resources. Even at this stage, use of digital radiography systems would seem justified in Australia in some applications. Each project would merit detailed planning, assessment of costs and benefits, consultation with all user groups and up to date information on applications of the technology.

It would be highly desirable for the cost and performance of all digital radiography systems put into use in this country to be evaluated and reported for the benefit of other users of the technology. An option which might be explored is the establishment of pilot projects in selected institutions to gain experience and obtain detailed data on costs and effectiveness of digital radiography systems under Australian conditions. Given the continuing developments in various areas of digital radiography technology, there could be opportunities for Australian industry in the design and production of system components and software.

It is suggested that there would be value in ongoing consultation involving health authorities, the Australian Hospitals Association, the Royal Australian College of Radiologists and other professional bodies on the development of a suitable strategy for introduction of digital radiography systems into the Australian health care system.

APPENDIX

SUMMARY OF DIGITAL RADIOGRAPHY ACTIVITIES IN AUSTRALIA

NSW SOUTH WALES

New Teaching Hospital Newcastle	A proposal has been developed for the implementation of a digital radiography system at the hospital which is scheduled to commence operation in 1991. Broad-band communication cabling of the hospital has been completed.
Prince of Wales/ Prince Henry Hospitals	. A proposal has been developed for transmission of outpatient images between the two hospitals. . Transmission of nuclear medicine images at Prince of Wales hospital has been implemented.
Royal Children's Hospital	A proposal has been developed for the establishment of a digital radiography system in the paediatric area of the hospital.
Royal North Shore Hospital	Development of a computerised radiology reporting and management system is proceeding.

VICTORIA

Royal Melbourne Hospital	Development of a system to transmit MRI images for remote viewing.
Queen Victoria Hospital, Monash Medical Centre	Implementation of a public hospital Management Information System which can be linked to a digital radiology system.

QUEENSLAND

Royal Brisbane Hospital	. Feasibility study of digital radiography system to store and retrieve medical images. . Teleradiology project to provide health services to remote areas of Queensland using QNET and satellite transmission.
Princess Alexandra Hospital	Development of a system to transmit MRI images for remote viewing.

SOUTH AUSTRALIA

Royal Adelaide Hospital	Investigation of TV system to transmit MRI and CT images to Flinders Medical Centre.
Flinders Medical Centre	Investigation of costs and benefits of storage of medical images in digital form.

WESTERN AUSTRALIA

Sir Charles Gairdner Hospital/Royal Perth Hospital	Investigation of use of optical disc and fibre optics link for transmission of MRI images from SCG Hospital to Royal Perth.

TASMANIA

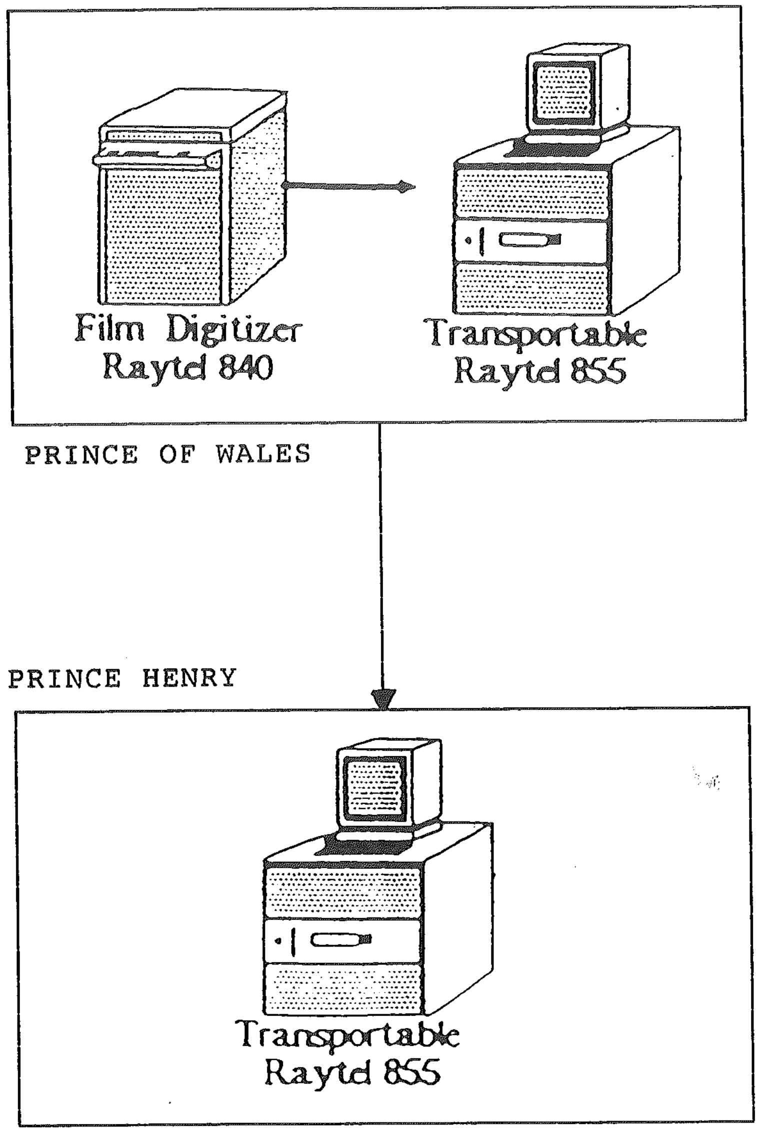
Development of inter-hospital management information system.

IMAGE TRANSMISSION SYSTEM
PRINCE OF WALES/PRINCE HENRY HOSPITALS

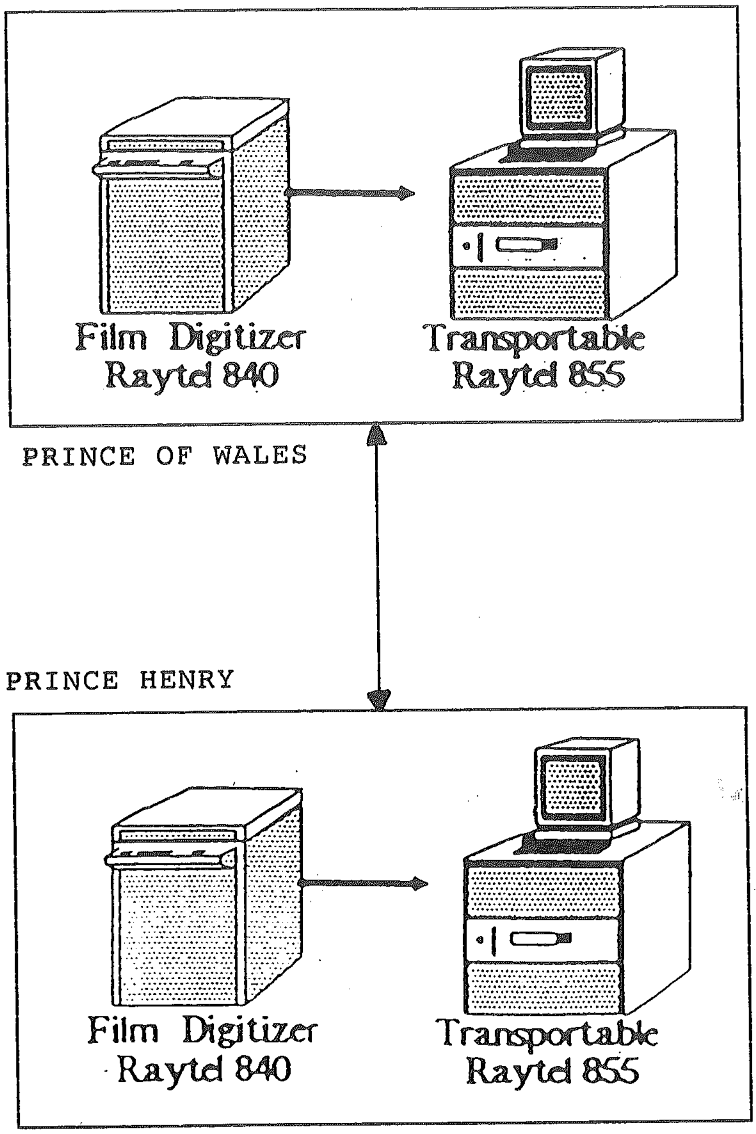
	COST
OPTION 1 Patient films are digitized at Prince of Wales and transmitted a distance of 10Kms to Prince Henry to a central viewing station.	$170,000
OPTION 2 Patient films are digitized at either hospital for transmission to a central viewing station at either hospital.	$220,000
OPTION 3 Patient films are digitized at either hospital. After transmission to a central point, they are then digitally transmitted to the hospital ward. There would be a central viewing station and three remote viewing stations at each hospital.	$370,000

Source: System proposed by Tower Medical Imaging Pty Ltd.

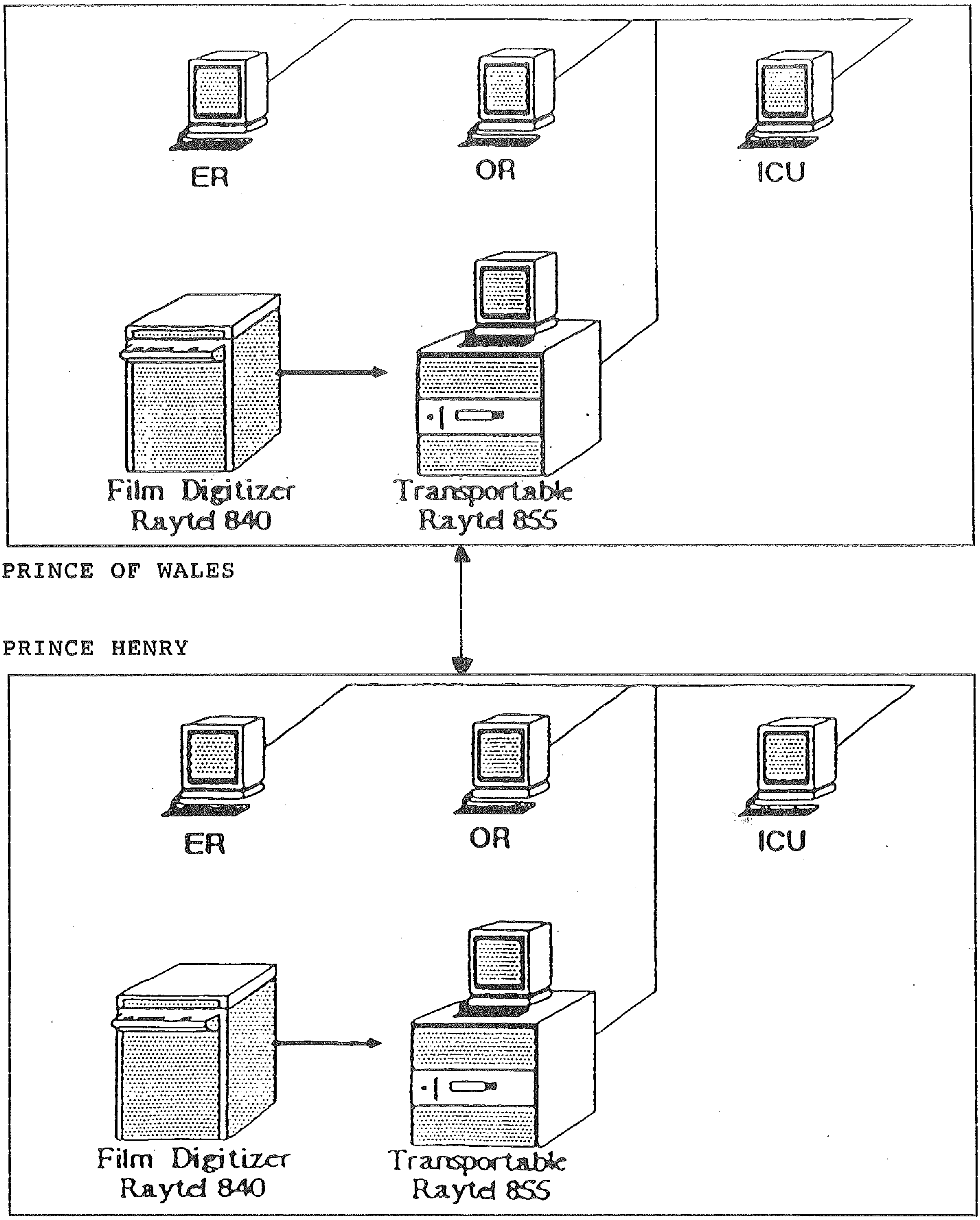
OPTION 1


Film Digitizer
Raytel 840
Transportable
Raytel 855
PRINCE OF WALES
PRINCE HENRY
Transportable
Raytel 855

OPTION 2


Film Digitizer
Raytel 840
Transportable
Raytel 855
PRINCE OF WALES
PRINCE HENRY
Film Digitizer
Raytel 840
Transportable
Raytel 855

OPTION 3


ER
OR
ICU
Film Digitizer
Raytd 840
Transportable
Raytd 855
PRINCE OF WALES
PRINCE HENRY
ER
OR
ICU
Film Digitizer
Raytd 840
Transportable
Raytd 855

MODEL DIGITAL RADIOGRAPHY SYSTEM FOR NEW TEACHING HOSPITAL, NEWCASTLE

ESTIMATED FILM USAGE

Type of Service	Number per Year	Number of Films per year	Ten Year Archive
Chest X-Rays	18,000	31,500+	
Ultrasound	1,000	3,000+	
CT Scans	4,000	10,000+	
Angiographs *	2,000	30,000+	
Barium Studies	1,000	5,000+	
Contrast Studies	1,000	5,000+	
Skeletal	18,000	72,000+	
Abdominal	1,000	2,000+	
Facial	500	1,400+	
Skull	500	1,600+	
Total	47,000	162,000+	1,620,000(est)

* Includes angiography, venography, and interventional procedures.

In the first instance, the model is designed to work on film while the patient is in hospital. Upon discharge, the film is converted to a digital image (by the Laser digitizer) and stored on optical disc. Should film be required at a later date, a hard copy can be produced on the 3M Laser Imager.

It is proposed that no films be stored in the hospital and, to that end, no provision had been made for an x-ray film storage room. The building has been wired with a broad-band co-axial cable in anticipation of the implementation of a digital radiography system.

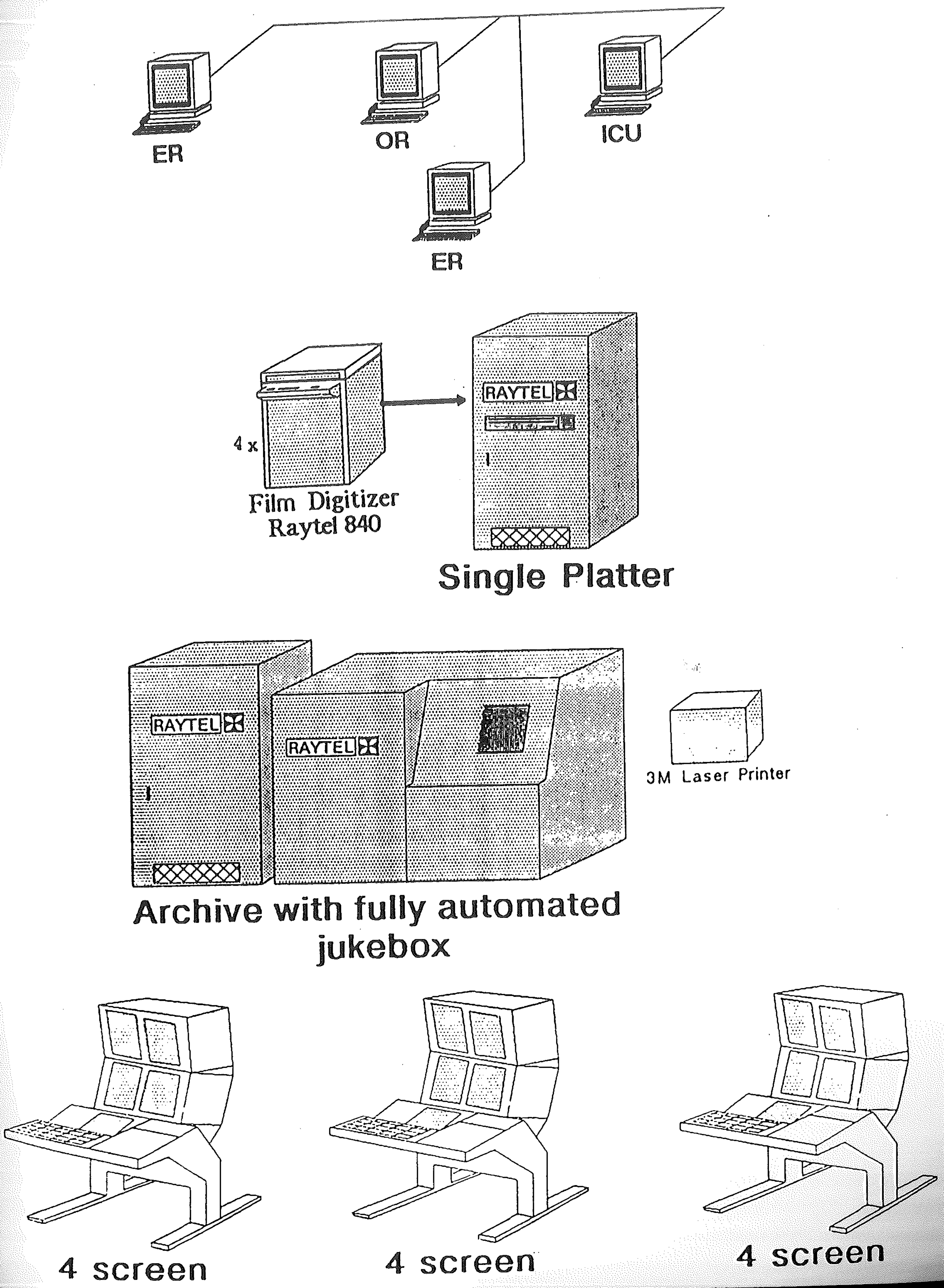
Source: Dr I Uebel, New Teaching Hospital, Newcastle.

ESTIMATED COST OF MODEL CONFIGURATION FOR DIGITAL RADIOGRAPHY SYSTEM NEW TEACHING HOSPITAL, NEWCASTLE

Description of Components	Cost	Total
1 x Optical Disc Archive 64 disc drive, each disc 2 Gigabyte (Juke-box)	$393,000	$393,000
1 x Single Disc Drive (Manual interchange of discs)	$183,000	$183,000
Optical Discs (100 x $800)	$80,000	$80,000
4 x Laser Digitizer	$120,000	$480,000
1 x 3M Laser Imager (produces hard copy film of digitized image)	$100,000	$100,000
3 x Four-screen Viewing Consoles	$276,000	$828,000
4 X Remote Single Screen Viewing Console	$25,000	$100,000
1 x Network to support system for data transmission (MAP 802.4)	$60,000	$60,000
4 x Remote Modality Interface to each system e.g. MR, CT, DSA, Angio	$34,000	$136,000
Estimated System cost		$2,360,000

Source: System proposed by Tower Medical Imaging Pty Ltd.

MODEL DIGITAL RADIOGRAPHY SYSTEM
FOR NEW TEACHING HOSPITAL, NEWCASTLE



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