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ESTIMATING THE IMPACT OF A DIFFUSE TECHNOLOGY ON THE RUNNING COSTS OF A HOSPITAL

A Case Study of a Picture Archiving and Communication System

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Abstract

Objectives: This paper considers the methodological problems that arise in conducting cost analyses in economic evaluations where only observational (rather than experimental) data are available and where the technology being evaluated is diffuse, such that the unit of analysis has to be the institution rather than the patient.
Methods: A case study is reported that concerns the application of computer technology in radiology: picture archiving and communication systems (PACS). A range of different approaches were used to estimate changes in running costs, including time series analyses of routine data and direct observation of resource use.
Results: The analysis illustrates some of the difficulties involved in costing the introduction of a diffuse technology. Nevertheless, it provides a firm indication that, overall, the introduction of PACS was found to be associated with a significant increase in hospital costs, suggesting that the initial expectations of financial savings were unduly optimistic.
Conclusions: The research demonstrates that, using multiple methods, it is possible to estimate cost changes within a single hospital. In addition, the paper discusses the nature of the uncertainties in such analyses and possible ways of representing such uncertainty in terms of confidence intervals.

Keywords: Cost analysis, Diffuse technology, PACS

As the role for economic evaluations becomes more widely accepted, considerable emphasis has been placed on improving the quality of economic studies and in defining methodologic standards for them. Recently, a number of papers have focused on cost analyses, suggesting that many published studies have been naïve, with the result that potentially misleading conclusions about the relative costs of alternative technologies have often been reported.

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Reviews have pointed to the need for more detailed statistical awareness (1) and led to more detailed analytical guidance, including recommendations for bootstrapping (2;3). However, the focus of such discussions has been almost exclusively on the analysis of cost data in the context of randomized clinical trials, where the technology being evaluated is discrete and patient-specific. Another important focus of work has been on handling censored patient cost data (9;12). Costing problems have thus been seen to stem mainly from the skewed distributions and/or censored observations of randomized sampled stochastic data sets.

However, there are many evaluative situations in which the problems are very different. In particular, there are situations where the research design cannot reasonably be a randomized trial and has simply to be observational, and where the technology is diffuse (rather than discrete) and the unit of analysis for costing has to be the institution rather than the patient. In this paper we use the definition of diffuse technology as one that comprises several distinct elements that exert different costs and effects, often across several different services and patient groups, and where it is important to understand the overall effects on the institution employing the technology (11). Computer-based information networks, used for a variety of different types of information, are common examples of such technologies in health care. Typically, such technologies have high capital costs, and, as more attention is paid to the need for research evidence of the value of such technologies, more economic evaluations will have to face the joint issues of learning as much as possible from observational data and dealing with the whole institution effects of diffuse technologies.

Picture archiving and communication systems (PACS) are a specific example of such a technology. PACS offers the promise of a solution to the problems associated with storing, retrieving, and reporting diagnostic information. Hospital-wide implementations aim to produce a completely filmless and operationally more efficient hospital, in which the acquisition, storage, distribution, reporting, and viewing of images is in a digital computerized form using a hospital-wide network of viewing stations. The magnitude of the efficiency improvements brought about by the implementation of such systems is not currently clear; some early evaluations of hypothetical PACS networks predicted either cost neutrality or cost savings associated with PACS (10;16), whereas later studies indicated that PACS would be associated with significantly increased costs (15;17). Hence, any evaluation of PACS would need to be able to reflect that potentially this diffuse technology could have an effect on all patients referred for a radiological examination at the hospital and not simply on discrete, relatively homogeneous patient groups.

One of the largest and most technically successful hospital-wide PACS installations is that implemented at Hammersmith Hospital. The U.K. Department of Health funded the capital costs of the system, with the condition that an independent health services evaluation be undertaken. The overall research methodology adopted in that evaluation and the summary results are described in detail elsewhere (6), and data on several aspects of the benefits of PACS have been reported separately (7;18;20;22;23;24). The research principally involved an observational design, whereby before and after comparisons and time series analyses were undertaken at the experimental hospital site. This research design was as robust as could be employed, given that a randomized controlled trial would require allocation at the hospital level (5). This paper explains the multimethod approach used to estimate the changes in running cost that resulted from the introduction of the technology, presents the results, and discusses the substantive and methodologic issues they raise.

METHODS AND DATA SOURCES

The empirical assessment of the cost impact of PACS was undertaken from a hospital perspective. However, there is no reason to believe that the results would have been different had

Table 1. Data Sources for the Assessment of PACS on Running Costs

Cost component	Data provided by hospital finance department	Data obtained from radiology budget statements	Data collected by direct observation
Total radiology costs	×	√	×
Radiology staff			
Radiologists	×	×	√
Radiographers	×	×	√
Darkroom technicians	×	√	×
File room clerks/porters	×	√	×
Healthcare assistants	×	√	×
Consumables			
Films/chemicals	×	√	×
Utilities	√	×	×
Maintenance	√	×	×
Other staff			
Computer staff	√	×	×
Medical physicists	√	×	×
Other clinical staff	×	×	√
Length of stay	×	×	√

a broader health service perspective been adopted. Where PACS implementations involve teleradiology links, a broader perspective is required.

The effect on hospital running costs was explored using three types of data:

1. Specific PACS costs provided by the hospital finance department;
2. Radiology department budget statements; and
3. Direct observation of resource use both within and outside radiology.

Table 1 indicates which of the three types of data was used for each element of cost.

Data Provided by Finance Department

A number of key PACS cost parameters were identified that were incontrovertibly related to the introduction of PACS, and where the only robust estimate of the PACS-related cost/saving was that provided directly from the hospital finance department. These parameters were PACS-specific maintenance costs, costs associated with dedicated PACS computer staff and medical physics staff, and additional PACS-related "electricity costs." It was only possible to obtain point estimates for these parameters with no observed variation, so it was not possible to indicate the statistical uncertainty in the estimates using conventional means.

Data from Radiology Budget Statements

The impact of PACS on the running costs of the radiology service was investigated using data provided by routine financial systems. The time series of monthly budget estimates of total radiology running costs were examined to identify a shift at around the time where PACS-based operation began. However, this approach was not expected to provide a definitive result since total expenditure was known to vary considerably from month to month, making difficult the identification of any signal caused by PACS. Thus, the principal focus for this element of the cost analysis was on individual expenditure items within radiology on which PACS was expected to have a marked effect:

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- Expenditure on films and chemicals;
- Expenditure on clerical staff;
- Expenditure on darkroom technicians; and
- Expenditure on healthcare assistants.

These data were drawn from the routine departmental monthly budget statements for the financial years 1991–92 to 1996–97 to identify significant shifts at the time PACS was introduced. There were two major PACS-related changes at Hammersmith: a) the first (Change 1) in September 1995 saw the radiology department move to operating with PACS (e.g., all radiology reporting became PACS-based, but hard-copy laser-printed images were produced for users outside radiology); and b) the second (Change 2) in March 1996 saw the whole hospital using PACS, and the production of hard-copy images for internal purposes ceased. Change 1 defined the before and after PACS periods for expenditure on darkroom technicians and healthcare assistants, since these resources were principally concerned with the production and transfer of film images within the department. Change 2 defined the relevant periods for expenditure on films and chemicals and expenditure on clerical staff, since marked changes in the use of such resources would require that film production had largely ceased.

All analyses used data adjusted to 1996–97 prices. Initially, all time series were inspected visually, and if the PACS shift was obvious and unequivocal, then the PACS-generated change in cost was simply estimated from the raw data. Where this was not possible, formal time series analysis methods were used: auto-regressive integrated moving average (ARIMA) models were specified for each cost item, where this was possible (14). Such models explain variation in the dependent variable (i.e., costs) using past (or lagged) values of the dependent and a stochastic error term. Therefore, any time trends relating, for example, to department or hospital activity levels or imaging examination complexity are incorporated within the model structure.

Uncertainty in the cost estimates derived using these data was indicated by 95% confidence intervals, determined using the standard deviations around the regression coefficients in the time series models, where they were specified. For the one series where a model was not specified (darkroom technicians), the confidence interval reflected the variability in the pre-PACS data series.

Data Collection by Direct Observation

For certain activities within radiology where PACS-related savings were strongly hypothesized, there were no readily available data from which the effect of PACS could be reliably estimated. For such factors, monthly budget statement data were thought unlikely to be sensitive enough to pick up PACS-induced cost changes in the short to medium term. Thus, additional direct data collection exercises were conducted where the focus was on key resource use parameters within radiology thought most likely to be affected by PACS:

- Time taken by radiologists to produce reports (8);
- Time taken in preparation for regular joint meetings between clinical groups and radiologists (21); and
- Time taken by radiographers to undertake examinations.

For each of these parameters, data were collected on a broadly representative sample, allowing extrapolation of the results to the work of the whole department. Thus, the PACS-related cost implications for the whole radiology department, associated with each parameter, were estimated for a 12-month period.

The PACS-related cost implications for referring departments were also assessed using direct data collection on selected key resource parameters. One of the key savings predicted by the hospital's original financial model of PACS was in clinician staff time. The improved availability of medical images with PACS was expected to free up both junior and senior clinician time from image and report-searching activities. In referring departments, data were collected on the following resource parameters:

- Clinician time devoted to image-related activities;
- Length of outpatient consultations; and
- Length of inpatient stays (19).

In assessing the extent to which such changes in length of stay were seen at Hammersmith, the evaluation adopted the approach of focusing on two specific patient groups—total hip replacement and total knee replacement—rather than using data on all inpatients. This was done because data on length of stay for all hospital admissions are influenced by a wide range of factors, and it was not expected that the "signal" associated with the introduction of PACS would be identified through this "noise." Data on length of stay were analyzed using ordinary least-squares regression analyses (19).

For the data collection exercises outside radiology, the focus was on clinical areas where PACS was predicted to have a large effect. Thus, extrapolation of the sampled data to the whole hospital was not straightforward. While the findings from a single department are unlikely to be highly representative of all other departments, such data do allow an upper estimate of the resource savings/costs to the hospital to be estimated. This approach to extrapolation of observed resource use data outside radiology was adopted here.

Given that these cost estimates were derived using sampled resource use data, indicators of variation in the cost data could be calculated. Thus, 95% confidence intervals around the mean cost estimate were determined, reflecting the variation seen in the underlying resource parameter.

RESULTS

A summary of the results of the cost analyses is provided in Table 2.

Data Provided by Finance Department

The annual maintenance contract for the PACS installation at Hammersmith was £456,000 per annum (4.8% of the contract price). The additional costs associated with dedicated PACS computer and medical physics staff were £63,000 per annum, and the additional electricity costs directly attributable to PACS were £45,500 per annum.

Data from Radiology Budget Statements

The time series of total monthly expenditure by radiology from April 1991 to March 1997 is presented in Figure 1. Data on the monthly expenditure for selected components within the radiology budget are presented in Figures 2 to 6. All data are presented in 1996–97 prices.

The time series for total monthly departmental expenditure (Figure 1) shows no clear pattern on visual inspection, and there is no clear shift in total cost evident at the points when PACS came into operation either within the department or throughout the hospital. No ARIMA model could be identified for this series and no PACS-induced change could be measured. Thus, the main focus of time series analysis here was on the individual items of expenditure where PACS was, *a priori*, expected to have the largest effect.

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Table 2. Assessment of PACS on Running Costs: Summary Results (Annual Costs)

Cost component	PACS-induced changes in running costs (£'000s)	95% confidence intervals (£'000s)
Radiology staff		
Radiologist	−36	−64 to −8
Radiographer	+41	+16 to +66
Darkroom technician	−27	−26.5 to −27.5
Clerical	−15	−36 to +6
Healthcare assistant	−19	−28 to −10
Consumables		
Films/chemicals	−188	−244 to −132
Utilities	+45.5	N/A
Maintenance	+456	N/A
Other staff		
Computer/medical physics	+63	N/A
Other clinical staff	−235	
Length of stay	0	N/A
Total	+85.5	N/A

The time series for monthly expenditure on film and chemicals (Figure 2) reveals that some observations have negative values. This reflects a situation of lower than expected expenditure on the item over a number of months followed by an "accounts correction" in order to bring the financial position back to balance. The largest negative value is for the month of March 1996 when the hospital first began completely filmless operation. The visual inspection of the data suggests a lower expenditure on such costs following the introduction of PACS. The dependent variable in the time series model was monthly expenditure on film and chemicals in real terms differenced once. (Data were differenced to obtain a dependent variable that was stationary.) The estimated time series model had a significant negative coefficient for the PACS dummy variable, indicating a PACS-associated reduction in expenditure on film and chemicals of over £15,000 per month.

The time series for monthly expenditure on clerical staff (Figure 3) shows no clear pattern on visual inspection, and there is no clear shift in such costs when PACS came into operation. The estimated time series model shows a coefficient on the PACS dummy variable that was not significantly different from zero. Thus, the model indicates no significant change

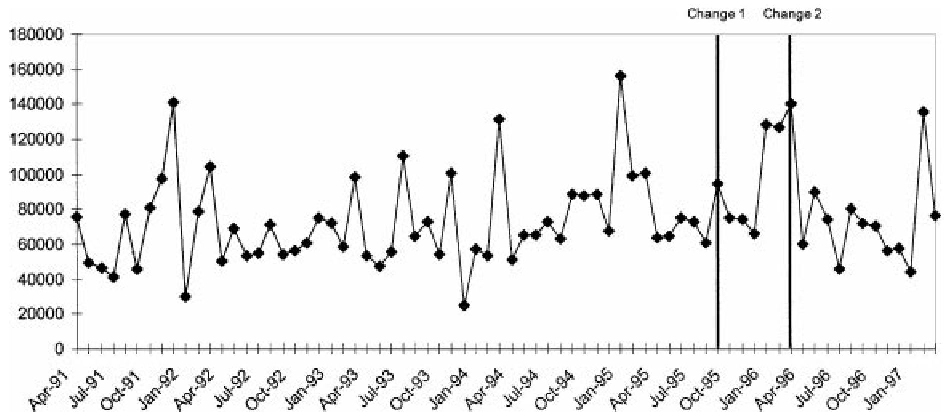

Figure 1. Total monthly expenditure by radiology. From Bryan et al. (6).

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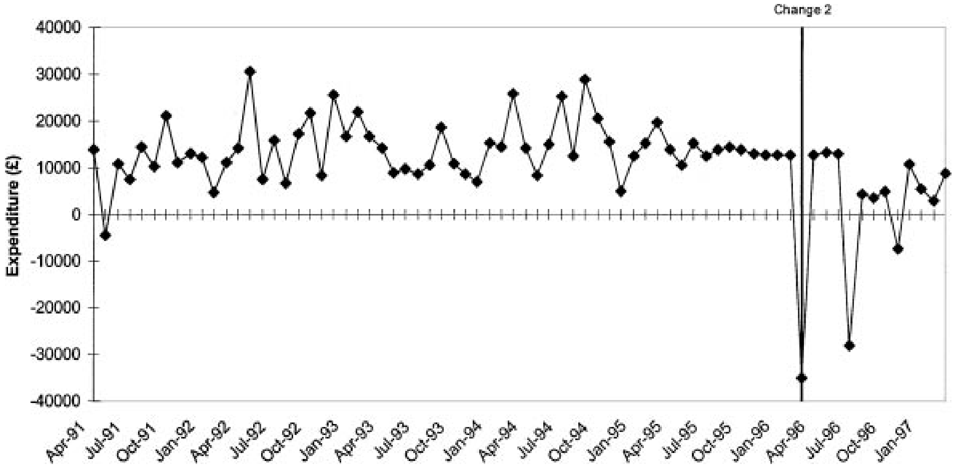

Figure 2. Monthly expenditure on film and chemicals.

in expenditure on clerical staff following the introduction of PACS. This probably reflects the fact that any such savings will take time to be realized because there is continuing use of the existing film archive.

The time series for monthly expenditure on darkroom technicians (Figure 4) shows a very clear shift in such costs in advance of the introduction of PACS. The very clear nature of the shift in costs makes time series modeling unnecessary. Prior to the preparation for PACS, two whole-time equivalent darkroom technicians were employed in radiology at an average monthly expenditure of over £2,200. In anticipation of the abolition of the darkrooms, these two posts were ended with their work temporarily absorbed by other radiology staff. Thus, this sum represents the PACS-related savings associated with the reduced need for darkroom technicians.

The time series for monthly expenditure on healthcare assistants (Figure 5) shows no clear pattern on visual inspection, and there is no very clear shift in such costs evident at the point when PACS was being used routinely within the department. However, the estimated time series model had a significant and negative coefficient for the PACS dummy variable,

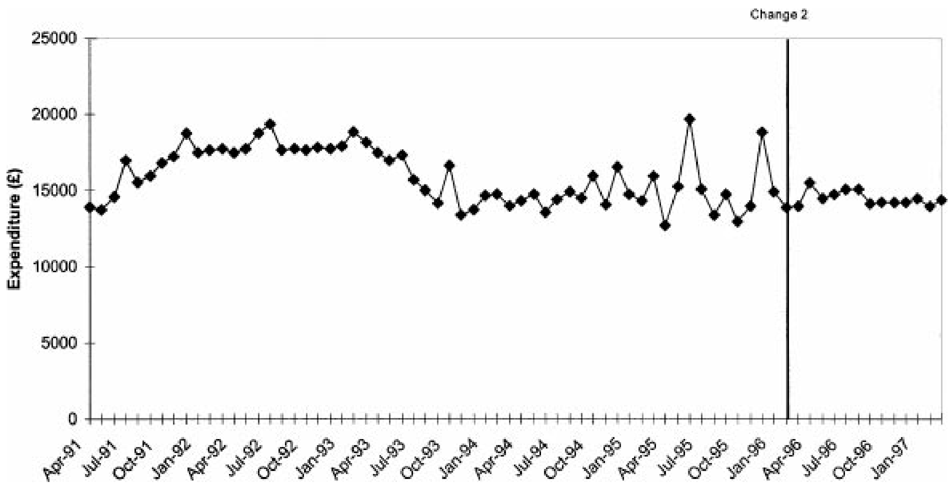

Figure 3. Monthly expenditure on clerical staff.

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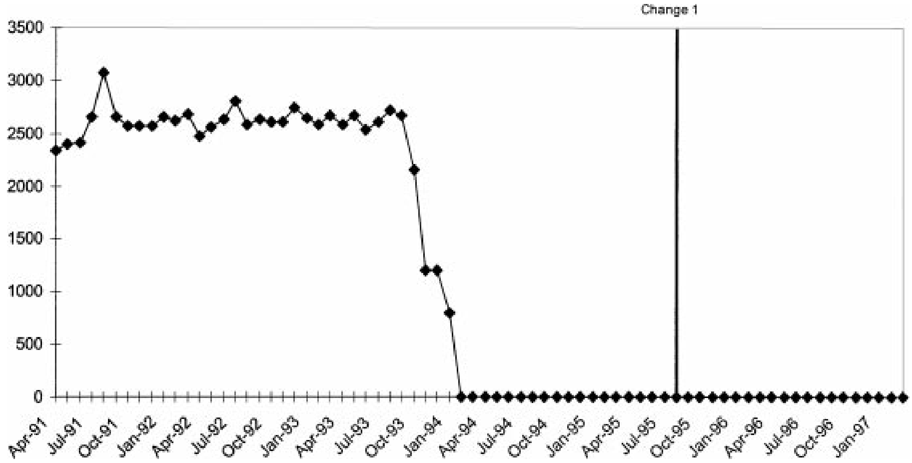

Figure 4. Monthly expenditure on darkroom technicians.

indicating that PACS was associated with a reduction in expenditure on healthcare assistants of just over £1,600 per month.

Data Collection by Direct Observation

No statistically significant PACS-related change in the time taken by radiologists to produce radiological reports was observed (8). Data relating to preparation for joint meetings between radiologists and referring clinicians revealed an annual saving of £36,000. The survey of radiographer time inputs to radiographic examinations showed a significant increase in examination time using PACS by approximately 2 minutes per examination. If all radiology examinations were lengthened by 2 minutes, then the additional annual cost of radiographer staff time would be approximately £41,000.

In terms of clinician staff time, data from the diary exercise in respiratory medicine found that junior clinicians devoted, on average, 95 minutes per week to image and report searching tasks when film was in use. This time was reduced to 11 minutes per week with the introduction of PACS ($p < .01$). No change was identified for senior clinical staff. These results represent an annual savings in junior clinician time costs in respiratory medicine of

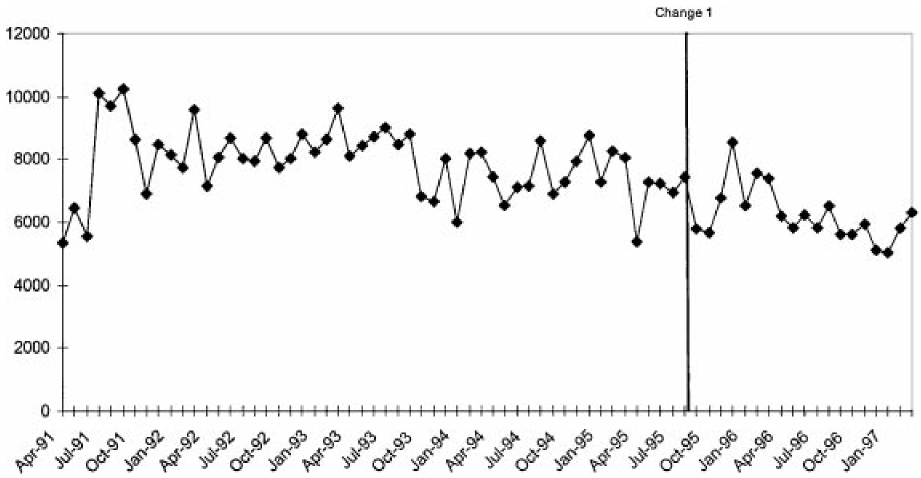

Figure 5. Monthly expenditure on healthcare assistants.

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just over £9,000. On the assumption that the results can be applied more broadly to other clinical departments, the total PACS-related savings to the hospital in junior clinician time would be approximately £195,000.

The data collection in fracture clinics found that PACS was associated with a small but significant reduction in consultation time: mean consultation time fell from 4.3 minutes to 3.7 minutes ($p < .01$). Extrapolating these results to all fracture clinic consultants reveals that PACS could save over 22 hours of surgeon time per year, a savings to the hospital of less than £1,000. However, there would obviously be significant cost implications if this time saving were replicated in all outpatient clinics throughout the hospital: a savings of approximately £40,000 per annum. However, the study conducted in fracture clinics found no significant difference in the number of patients seen per clinic session, which suggests that the reduction in consultation time was too small to have a noticeable impact on clinician productivity.

The data on length of hospital stay revealed no PACS-induced change for hip replacement patients. The result for knee replacement patients, however, was dramatic: the regression analyses attributed a 25% reduction in length of stay to PACS. This attribution is implausible, and there is no explicable mechanism by which PACS might bring about a reduction of this magnitude. Moreover, data from other aspects of the broad evaluation (for example, the survey of referring clinicians) do not support this result. Unfortunately, PACS-related data collection for this substudy ended prematurely in September 1996 (after only 9 months of PACS-based operation) with the move of most orthopedic work to another site. We conclude that there is no convincing evidence of a PACS-induced change in the length of inpatient stay and, hence, estimate no change in costs from this factor (19).

DISCUSSION AND POLICY IMPLICATIONS

Diffuse technologies, including most information technologies, are typically associated with a large capital outlay, and so it is imperative that rigorous evaluation is undertaken on the early implementation sites so that future investment decisions can be better informed. Given this, it is necessary that robust evaluation methods are developed that allow data from early sites to be appropriately analyzed and interpreted. The case study reported in this paper reveals the success in using a multiple methods approach to analyzing the costs of a diffuse technology implemented at a pioneering site. While caution must be exercised in generalizing to other applications the results found here from one site, the evaluation provides an analystical framework for others to use when considering the introduction and subsequent impact of such a technology.

In substantive terms the results reported here suggest that PACS has almost certainly added to hospital costs, and the optimistic expectations that overall costs might be significantly reduced now seem implausible. To place the cost estimates reported in this paper into context, the total budgeted expenditure for Hammersmith Hospital for the year 1996–97 was £99 million. The total level of activity in terms of finished consultant episodes (FCEs) for the same financial year was 27,753. The total increase in costs brought about by the implementation of PACS at Hammersmith, as estimated in this evaluation, has increased the cost per FCE by approximately 1.8%.

The analysis identified a number of important net additions to overall costs and some key areas where revenue savings have been realized (Figure 6). As with many cost changes estimated in economic evaluations, they represent a combination of changes that would have a direct budgetary impact and others that are likely to be absorbed in the system. As predicted by Hammersmith at the outset, the three key additional revenue costs associated with PACS concern the maintenance of the PACS technology, dedicated onsite maintenance staff, and costs associated with utilities (10). As expected, the principal revenue savings

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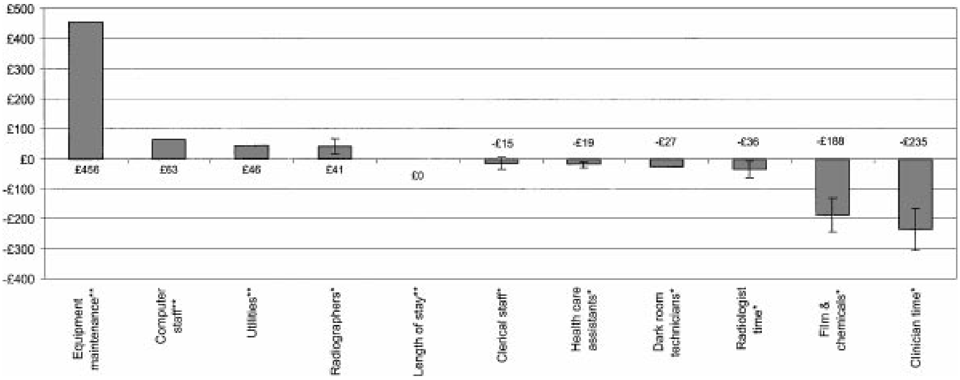

Figure 6. PACS-induced change in running costs per annum (£'000s, 1996 prices). *95% confidence interval reported. **No confidence intervals reported: values are point estimates with no observed variation.

generated by PACS was in terms of reduced expenditure on film and chemicals. These have had a clear and direct impact on budgets, and the savings identified were in line with the predictions made by the hospital.

The staff-related revenue savings in radiology that were identified in the study were much lower than predicted. Important additional "savings" linked to the introduction of PACS that were identified in this research concerned the use of clinician time. However, it is unlikely that either of these savings will have direct revenue consequences for the hospital. Thus, the notional costs linked to clinician time in this analysis are merely a reflection of the value associated with the additional clinical activities that can be undertaken with the time released when PACS is in operation.

The aspect of running costs, on which this analysis provides the least satisfactory evidence, is probably the issue of the cost implications of any change in length of stay. The original submission from Hammersmith, justifying the proposed investment in PACS, included a substantial cost saving resulting from an expected reduction in average length of inpatient stay due to PACS. They estimated a 1% fall in length of stay on average across all specialties, based on the assumptions that approximately 10% of the acute beds were occupied by patients for whom the most significant investigations are radiological and that, due to the rapid availability of the images with PACS, a reduction of 10% in length of stay in these beds could be achieved. Against a background of almost unanimous skepticism that any reduction in length of stay would occur, the empirical study undertaken focused on two relatively small and homogeneous groups of patients who were seen as the most likely groups to benefit, the argument being that for these orthopedic patients earlier availability of images could speed mobilization and hence readiness for discharge. The results showed no significant change associated with PACS for hip replacement patients and an implausibly large change for knee replacement patients. This aspect of the study was severely compromised by the move of this activity to another site soon after the installation of PACS, and the perverse findings almost certainly reflect other changes in management and patient selection occurring at the same time as PACS.

In methodologic terms the results demonstrate the need to use multiple methods to assess different aspects of running costs. They also indicate the nature of the uncertainties involved and possible ways of representing the degree of uncertainty in terms of confidence intervals. For some costs, there is properly a single point estimate, with no associated stochastic sampling error. The issue for these is not uncertainty about the accuracy of the estimate but questions about their generalizability or relevance to other contexts. In the absence of estimates from other sources, we can see no empirical basis for dealing with this other than through sensitivity analysis with essentially arbitrary alternative point estimates.

For the cost components where we have analyzed time series data, we have represented the uncertainty in terms of the confidence intervals around the change coefficients. While this is conceptually straightforward, these values are specific to the regression model and equation specification and might have varied if other data had been available to introduce into the explanatory model.

For PACS-related cost changes outside radiology, our estimates are based on nonrandom samples of the hospital activity that might be affected, for example, data from respiratory medicine on clinician time devoted to radiology-related activities. Random sampling of such activities would be logistically difficult, in that it would potentially involve all (or any) department or group of patients. Moreover, given the problems involved in a study making comparisons over time where there are likely to be other concurrent changes, our examples were purposively chosen to study the context in which it was thought most likely that a change would occur and be observable. These were situations where we thought the signal-to-noise ratio would be highest. The difficulty is then in grossing up to the whole hospital cost changes, and our figures probably represent upper estimates. However, our confidence intervals represent the uncertainty surrounding the estimates obtained from the particular area of activity we chose to observe.

Indeed, given that this analysis is based on data from a single institution, considerable caution is required before generalizing to other settings. The issue of generalizability of study results is a generic issue, discussed at length elsewhere (4;13), but one that is particularly problematic when considering evaluations of pioneering early technology implementations. Therefore, rather than seeing the outcomes observed at Hammersmith as inevitable elsewhere, they provide hypotheses for testing in future evaluations or, less formally, issues that other sites should think carefully about and assess for themselves whether they seem plausible outcomes in their different hospital context. While in principle it would be nice to have much stronger evidence from multicenter studies of such technologies on which to base subsequent investment decisions, in practice we need to make the best use of any available information, even if it is from a single site.

Although we believe that the analysis reported here represents a substantial advance on any previous cost analyses of diffuse technologies, we recognize that by comparison with much of the recent discussion of uncertainty around costs, some aspects may appear relatively crude and open to possible bias. But such analyses represent an important part of the reality of economic evaluation, and one where there is likely to be greater future interest. In the United Kingdom, the development of a health service research and development program specifically addressing issues of service organization and delivery will repeatedly encounter similar costing issues.

Further improvements on these methods require that economists begin to take an active interest in them. In the first instance, we need to see wider recognition of the importance of these issues, with more thorough reporting and presentation of such costing studies. Then, from comparative study, work is needed to begin to develop a professional consensus as to how best to undertake and report results. Improvements to the art of such studies may well yield much bigger returns in terms of improving the quality of the evidential basis for decision making than further small refinements to the already much more exact science of handling uncertainty associated with stochastic patient-specific resource use data from randomized trials.

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