Technology and the Future of Medical Equipment Maintenance

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Abstract

Maintenance of medical equipment has been changing rapidly in the past few years. It is changing more rapidly in developed countries, but changes are also occurring in developing countries. Some of the changes may permit improved maintenance on the higher technology equipment in developing countries, since they do not require on-site expertise.

Technology has had an increasing impact on the development of medical equipment with the increased use of microprocessors and computers. With miniaturization from space technology and electronic chip design, powerful microprocessors and computers have been built into medical equipment.

The improvement in manufacturing technology has increased the quality of parts and therefore the medical equipment. This has resulted in increased mean time between failures and reduced maintenance needs. This has made equipment more reliable in remote areas and developing countries.

The built-in computers and advances in software design have brought about self-diagnostics in medical equipment. The technicians now have a strong tool to be used in maintenance. One problem in this area is getting access to the self-diagnostics. Some manufacturers will not readily provide this access to the owner of the equipment.

Advances in telecommunications in conjunction with self-diagnostics make available remote diagnosis and repair. Since components can no longer be repaired, a remote repair technician can instruct an operator or an on-site repairman on board replacement. In case of software problems, the remote repair technician may perform the repairs over the telephone. It is possible for the equipment to be monitored remotely by modem without interfering with the operation of the equipment.

These changes in technology require the training of biomedical engineering technicians (BMETs) to change. They must have training in computers and telecommunications. Some of this training can be done with telecommunications and computers.

Introduction

The maintenance of medical equipment has obviously been carried out since the existence of the first medical equipment, which may have been only the sharpening of a flint knife or a bone drill. In the modern sense of maintenance of medical equipment, it dates to more recent times. Apparently the first medical maintenance shop set up in the United States was in July of 1922 by the US Army. The first training of biomedical equipment technicians in the US was initiated by the Army during World War II. Even during World War II, there was not an extensive amount of medical equipment, nor was it very sophisticated.

Single phase x-ray equipment, standard analytical laboratory equipment and simple operating room equipment was all that existed. Physicians used primarily what they could put in their black bag. The development of the new medical equipment did not progress very rapidly, nor were there rapid changes in technology in other fields prior to World War II.

After World War II, technology increased with the transfer of the war developments to the private sector. New technology development was expedited after 1957 with the advent of the Russian satellite. This began the technology development race between the USSR and the United States in the space program. These developments drove advances in technology in many fields, including medical equipment. In 1968 at the American Society of Quality Control Meeting in Boston, there was a symposium with physicians and engineers discussing the design and maintenance of medical equipment. From that meeting, there became a greater dialogue between engineering personnel and healthcare delivery personnel.

Shortly after that, training programs for biomedical equipment technicians were developed and hospitals began hiring staff specifically to maintain medical equipment. During this time approximately 70% of the repairs were mechanical in nature, but the curricula were designed to teach the technicians electronics, since that was where technology was leading the development of medical equipment.

At this time, the author was told by one of his engineers that we would see the time when we would have the era of throwaway electronics. He said it would no longer be possible, in many cases, to repair electronics and in other cases, not cost-effective to make the repairs. In the last 25 years we have rapidly approached that situation with medical equipment and other electronic devices. At the same time, technology has developed so rapidly that equipment becomes technically obsolete before it wears out.

WHAT MEDICAL INSTRUMENTATION MUST BE DESIGNED FOR

(From the 1968 Quality Society Biomedical Instrumentation Program - Boston)

1. High reliability is required since lives may depend on the equipment functioning properly.
2. All equipment, regardless of manufacture, must be compatible.
3. Even millivolt shocks from the equipment can be lethal in the hospital.
4. The customer will not be interested in the equipment, only whether it performs its function.
5. The customer will have no patience with the equipment.
6. Untrained operators will use the equipment.
7. Equipment must be designed to show the presence of malfunction.
8. Manuals will be lost.
9. The equipment will receive no maintenance.
10. The hospital is a hostile environment containing explosive and corrosive materials, which subject the equipment to severe electrical and mechanical shocks.
11. Damaging fluids will be spilled on the equipment.

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The Annual General Meeting

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Baroness Robson of Kiddington

Baroness Robson, who died on 9th February, kindly invited the ladies attending the 1990 Congress in London to have tea with her on the terrace at the House of Lords. Many of the ladies who went there were impressed with the occasion and in particular with the way Lady Robson took the trouble to move around to talk to as many of the ladies as possible.

Lady Robson was chairman of Queen Charlotte's Hospital and the Chelsea Hospital for 14 years and chairman of South West Thames Regional Health Authority for 8 years.

The following example with an electrical washing machine illustrates this:
Maintained life expectancy = 8 years[1]
Unmaintained life expectancy = 5 years
Re-investment costs approx US$4000 (simple model, approx. 10kg capacity)

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unmaintained life expectancy = 5 years

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$$\text{Savings US\$} = \frac{4000 \times 3}{5} = 2400 \text{ US\$} \quad \text{Maintenance cost ceiling} = \frac{2400}{8} = 30$$

$$\text{Cost ceiling in \%} = \frac{300 \times 100}{4000} = 7.5\% \text{ of the replacement cost per year}$$

In other words, the hospital (secretary) should not spend more than 7.5% of the value of that washing machine per year, if it wants to remain 'in the black'. This should not be too difficult. The maintenance expenditure for such a washing machine should not be higher than 3% (overall costs including personnel). Our immediate objective is to develop a basic list of cost ceilings for the standard equipment of health facilities up to district hospital level as a control instrument. It must be left to the health administrations and maintenance units in the countries to extend, modify, and develop more precise figures.

It should be noted that relatively high maintenance expenditures shortly after installation and when approaching the end of useful life may occur ('bath-tub effect': expression derived from the graphic presentation of this phenomenon).

[1]Preliminary life expectancy data from Delphi survey.

Outlook

During recent years we have investigated the cost-effectiveness of maintenance services in three countries, mainly by using the comparative cost-effectiveness method. We considered all costs recorded on working hours, material and transport. The results of some hospitals are surprisingly encouraging. In El Salvador one hospital could increase its cost-effectiveness (billable income) between 1994 and 1995 by 177% (derived from[27]). In Senegal one hospital achieved a 65% increase, another one as much as 446% (1993-94) (derived from[28]). In three Jordanian hospitals within two years (1994-95) a cost benefit ratio (maintenance input: savings) of 1:4.4-5.4 could be achieved by almost completely (95%) abandoning outsourcing and introducing in-house maintenance services. The introduction of a preventive strategy led to an increase of 130% in cost-effectiveness. At the same time the availability of operational equipment shot up from 50% to 90%[29].

As impressive as these figures are, the studies revealed also the weaknesses in some hospitals. In El Salvador two of the three hospitals investigated achieved 55-77% less billable income for the maintenance unit due to poor supervision and by lowering preventive activities. In Senegal a maintenance unit in one of the three hospitals surveyed increased its losses (billable deficit) in maintenance expenditures by 46%, above all because of extremely poor productivity and the insignificance of the interventions.

The life expectancy related cost-effectiveness method has not yet been employed and tested in the field. This paper will hopefully stimulate more action in this respect. If this is the case, it can be expected that physical asset management will become more accepted by decision-makers and health workers. But acceptance alone will not provide the necessary resources for maintenance and other areas of technology management. Many developing economies will not be in a position to afford substantial spending on the development of national maintenance systems for public healthcare services.

In 26 developing economies in Asia and Africa more than 25% of health expenditure is contributed by donors. In eight countries external aid exceeds 50%[23]. I therefore call upon the donor community to show more commitment to promoting rational physical asset management (PAM) for those countries. This should be done in two ways:

1. assisting countries in the development of adequate PAM systems;
2. contributing to recurrent expenditures for maintenance.

Contributing to recurrent budgets is a controversial issue. On the one hand, ethical considerations and the presumed interest of the donor organisations in keeping up the function of their contributions would favour such an idea. On the other hand, if one follows a more cynical line of reasoning, at least some donors have more interest in promoting their home industry by maximising, for example, the output of medical equipment to developing economies. In addition, one may fear that budget aid may kill national initiatives for developing self-contained financing systems. I, however, believe that the 'pro' arguments are more convincing in view of the serious situation of the majority of the patients. One important condition must be that contributions to maintenance are distributed via a suitable national body through the regular budgetary channels to avoid parallel structures. Such a body could be created as a foundation with a suitable legal status, and would be controlled by the donors involved and the national stakeholders in public health services ('basket funding'). A foundation of this kind could in the long term evolve into a professional society and/or a spare part procurement agency.

However, a financing system may be constructed, without a carefully designed and adequately funded PAM system, health systems will render only low-quality and expensive services. An essential precondition for overcoming this obstacle consists of applying suitable tools to measure performance and effectiveness. Investing in tools such as PAD and life expectancy related cost-effectiveness may contribute to this objective.

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Working towards better building services engineering management by degrees

Petra Godwin, Brunel University, Uxbridge, Middlesex, UK

Let's assume that, if you're reading this, you are already a manager. As you well know, managers are not born – nor are they made (well, not from easy-to-assemble kits). Managers evolve over time: from the bedrock of their formative education, picking up knowledge and skills on the job, attending courses, training in their specialisms and in general management, experiencing life, expanding their minds, rising to personal challenges. It never stops.

The professional institutions recognise this. They call it continuing professional development. The UK government recognises it. They call it life-long learning. Employers (some) acknowledge it call it 'impending staff development policy'. Other employers call it a load of...but these are the dinosaurs of commerce and industry.

Managing cultural change

In recent years sustainability has been a big issue for many people engaged in the business of managing building services engineering and facilities. For many, the focus has been setting up and running environmental impact systems (controlling emissions; being seen to be 'green'). Engineers have designed and installed 'efficiency' into every physical system until they're blue in the face! They realise increasingly that a little social engineering – through cultural change – is called for, not only to benefit the sustainability of the planet's ecology, but also, to benefit the sustainability of business itself – keeping it out of the red! Against this backdrop, Brunel University has developed its new MSc course in Building Services Engineering Management.

Why study for an MSc?

This MSc course presents an opportunity and a challenge. It is an opportunity to expand or update knowledge in both building services engineering and management. It also gives those engineers who have been involved in management for some time the possibility to reflect on life, relate theory to experience and affirm understanding. It's an intellectual challenge to take on board some new ideas, formulate discussions and arguments for examination. It may be studied as part of a strategic career plan; or as evidence of Continuing Professional Development, with the added benefit of a recognised academic qualification on successful completion from a university with an enviable reputation in engineering.

The new course, an evolution from the highly successful MSc course in Building Services Engineering, has been designed with the needs of engineers in mind. Students are likely to be either established in, or moving into, roles where they are required to manage a building services engineering function. This might be in the operation and maintenance of buildings; in installation contracting; in the design process; or in sales into the industry.

Brunel University has been educating building services engineers at MSc level since 1976. The new MSc in Building Services Engineering Management and the MSc in Building Services Engineering are available by distance learning, so students can study in their own time, at their own pace, either in their workplace or at home. In addition, the Building Services Engineering course is offered for full-time study at the university's West London campus in Uxbridge. As the university has examination centres around the world, students do not need to travel far to attend end of year exams.

For a brochure and application form, please contact: The Postgraduate Administrator, MSc BSE/BSEM, Department of Mechanical Engineering, Brunel University, Uxbridge, Middlesex UB8 3PH, Tel: 01895 203269. Fax: 01895 203266. E-mail: msc-building-services@brunel.ac.uk may achieve a limited cost reduction only by making the maintenance system more efficient. In my view there is no reason to believe that rational maintenance cannot produce accountable benefits, too.

Comparative cost-effectiveness of maintenance: one classical approach to assessing cost-effectiveness is to compare costs incurred by in-house services with the hypothetical costs which exclusive involvement of private service providers would cause[19,7]. The productivity and overheads of the in-house service must be taken into account. The method is relatively easy to apply, provided that a good record system is in place (as in all the other methods presented). The disadvantage is that it does not give direct clues about the question of whether to support a maintenance system or to prefer a replacement strategy.

Interest-related cost-effectiveness: another, rather theoretical approach relates to the fact that idle equipment (=waiting for repair) represents a non-productive investment. By recording the time idle and the investment value of equipment, losses can be calculated using the current average interest rate of money invested at a bank. This approach gives a more direct picture of, for example, the actual losses experienced by neglecting maintenance. For the working level in health facilities, this kind of abstract analysis is of little help.

In view of the apparent weaknesses of those methods, a more problem-oriented formula is proposed, ie, *Life expectancy related cost-effectiveness*: a general effect of maintaining and repairing physical assets is, trivially enough, the prolongation of their useful life. Increased life expectancy can significantly reduce replacement expenditures[14,15] - and in the end, life-cycle costs[17,18]. Simplified, this would mean comparing the accomplishable (=efficiently maintained) life expectancy of a physical asset with its life expectancy under poor maintenance conditions. But how can such life expenditure under the circumstances in developing economies be determined? Sufficient and reliable data are not available because of the lack of relevant records. The only alternative would be to carry out surveys. To avoid long-term investigations, we have surveyed 16 essential physical assets with the help of a Delphi study. Questionnaires have been designed and sent to around 20 experts on physical assets management in developing economies. The procedure is to inform the participants (who do not know each other) of the results and to ask them to review their estimations until consensus is achieved. The figures extracted in this manner are, due to the method, proxies. But using approximate data, instead of statistically validated data which require long-term investigations and considerable resources, is a good alternative.

The savings (S) during the lifetime of an item achievable by rational maintenance can be calculated as follows:

$$S = \frac{\text{re-investment costs} \times \text{difference between maintained and unmaintained life expectancy}}{\text{unmaintained life expectancy}}$$

The expenditures for maintenance must not exceed these savings. Otherwise one must consider either replacement instead of maintenance, or reducing maintenance cost. The expenditure ceiling for each physical asset can be calculated as below

$$= \quad \text{annual maintenance cost ceiling} = \frac{S}{\text{maintained life expectancy}}$$

ments, at least as long as funds are available. In developing economies, permanent monitoring of performance and cost efficiency is needed to encourage health administrations to provide maintenance funds. But let us not forget that wherever funds are managed, personal interests are not far away. This attitude evidently favours acquiring new equipment instead of maintaining the equipment at hand. And it is always nice to get the latest models!

In order to avoid an excessive and unnecessary influx of new equipment, administrators and health workers need to understand the merits of systematic and preventive maintenance services. This can only be achieved if the quality of such services becomes measurable.

Principles

Quality assurance may be described as a cycle consisting of a code of practice (work standards) which receives feedback from a monitoring and evaluation (M&E) system backed by an information system. M&E systems use indicators, ie criteria which measure the progress and success in terms of quality and quantity. M&E in maintaining health equipment is traditionally restricted to looking into the correct application of maintenance procedures and some more or less superficial cost aspects (process indicators). Safety checks of equipment, if performed, can also be regarded as a quality indicator. The latter is more an impact indicator, as eg average down-times of equipment. Conclusive cost indicators are virtually non-existent or not applied, but would be highly desirable.

Process Indicators

Process indicators measure how maintenance work is done, using accepted standards. Important standards refer to:

- number and composition of the workforce;
- productivity;
- compliance with standardised intervention times;
- ratio of corrective and preventive works;
- correct application of forms and standardised maintenance procedures;
- availability of tools and spare parts.

Details on indicators related to those standards can be found in a number of general publications (for example [3,4,5,6,16,23]). A few publications refer to the specific circumstances in health services[7,8,9].

Process indicators are proxy indicators in relation to the result of maintenance activities (impact). They cannot measure effects directly. They only describe the way activities are being carried out. But in a (common) situation, where the development process is too young to provide visible results, these proxies give a good idea about progress.

Impact Indicators

Impact refers to an effect which can unmistakably be related to the intervention employed. For example, the number of injection pumps in working condition may be influenced not only by maintenance interventions, but also by the fact that they are rarely used at the health facility observed. Consequently, impact indicators should either address clear cause-effect relationships or be accompanied by observations about the working environment, thus allowing for correct interpretations of the findings. Even this will be difficult to assess with indicators such as 'average period of hospitalisation per patient per year' or 'number of visits of out-patients necessary for successful treatment'. Too many other factors inside and outside the health facility influence these criteria, though undoubtedly a significant effect can be attributed to maintenance. But it is hard to quantify without excessive effort and resources. Good indicators are:

- (average) down-time per year (change in staff must be monitored);
- operating time per year (changes in patient attendance and changes in staff must be monitored);
- satisfaction of the health workers (clients) with maintenance performance using eg response times[25] (only applicable if clients have a good understanding of the resources and objectives of their maintenance service).

The first two indicators can only be assessed in a satisfactory way if the health facility has a well developed maintenance information system. Without detailed and reliable records over more than a year, the results would be questionable. Too often such records are not available. This is why alternatives which need minimal time and resources must be sought, for example an approach that is commonly called 'quick appraisal'. Sometimes this method ('quick and dirty') is viewed with suspicion, because health workers tend to think that a more comprehensive and detailed approach is preferable. In principle this is true, but tight financial and time budgets force us to look for compromises. We therefore suggest using a quick appraisal method based on standardised quantitative and qualitative questionnaires and checklists: 'Physical Assets Management in Health Services in Developing Economies', in short, PAD[10,11]. In this way, also, conditions can be captured which cannot be described statistically but have to be recorded in comparable and cost-effective fashion. PAD is composed of different modules which can be combined or used separately, as the situation demands, in a quick and efficient way.

Among other matters, one part of PAD deals with the maintenance (management) structure at central level ('what does central level do about maintenance?'):

- central maintenance department;
- training;
- private service providers, agents.

Another part focuses on the maintenance services at district level using the relevant WHO guidelines ('how does my maintenance department work?')[12]:

- staff;
- workshop facilities;
- budget;
- spare parts;
- procedures and administration.

Last but not least, the state of physical infrastructure and assets is described ('what does my health facility look like?'):

- buildings, sections, rooms;
- utilities, plants;
- equipment;
- hygiene, waste disposal.

The principle underlying most questionnaires or checklists consists of using a simple valuation with ratings 'good', 'fair' and 'poor'. These ratings are defined in two ways. First of all, the following is the general meaning:

'poor' physical facilities do not allow the operations required by sound health management. Health services are seriously impaired; the building conditions endanger patients and users.

'fair' technical problems limit the range of health services. The health facility cannot operate as expected, but some essential services can be provided.

'good' the building conditions of the health facility allow all services to be rendered as planned.

Secondly, each form which records a specific part or feature of the physical assets (eg 'hygiene') is accompanied by an evaluation key, which defines in detail each criterion.

The limitations of the PAD method are linked to its punctual nature. Though the difference between an initial situation and a later one (minimum 6 months) can be assessed with satisfactory precision and reproducibility, the change process itself can hardly be judged. This applies especially to the crucial factor of analysing the cost-effectiveness of maintenance services. Without reliable and specific records about spending on maintenance and repair (cost centre accounting!) in relation to the operationality and safety of the physical assets maintained, sound economic evaluations are not possible.

Cost Indicators

The basic question is, what kind of benefit one can expect when investing in maintenance. Predominantly qualitative expectations are connected to an improved quality of healthcare and safer treatments, and even to reducing morbidity and mortality. Many people argue that the monetary aspect is therefore not that important and that one

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The Technical and Financial Impact of Systematic Maintenance and Repair Services within Health Systems of Developing Countries

Hans Halbwachs, Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) Gmbh

The General Situation

Everyone who knows the technological conditions under which health workers in developing economies are forced to deliver healthcare services will agree on the need to improve the management of physical assets. Buildings are dilapidated, power and water supply hardly work, and most equipment and vehicles do not function.

Examples from Malawi and Nepal illustrate the situation. In five Nepalese rural health facilities, approximately 67% of building components or utilities were rated 'poor' in 1994 (meaning totally inadequate)[1]. 76% of the equipment found in 14 health facilities in Malawi was in working condition, which sounds encouraging. But looking into the age of the few items (only 33 per health facility on average), the picture changes. 72% had almost reached anticipated life expectancy or were already obsolete[2]. This phenomenon is caused by something one may dub 'Darwin's Principle': the survival of the (few) fittest.

These circumstances contribute to poor health service quality and the frustration of health workers, and lead in the end to disgruntled clients. In the past it was mostly the ever-ready donor who stepped in and provided replacement of physical assets. In recent years the donor community has become increasingly hesitant and has begun instead to ask the partner to take care of the maintenance of physical assets... and leaves him alone with this problem. Most developing countries are not in a position to deal with this situation without external technical and financial assistance.

Funds for Maintenance and Repair

As a rule of thumb, approximately 1-2% of the investment cost is needed annually to maintain health buildings. For utilities the figure is around 3% and for equipment, between 4% and 6%[20]. These figures seem to apply in industrialised countries as well[21]. On average 4% of the total investment value of a health facility is required per year. In reality, in the public health services of most developing economies, expenditures range between 0 and 1%. Another rough indicator is the share of the annual recurrent budget for maintenance. 10-20% appear to be acceptable depending on the size and level of a health facility in a developing economy; but for most countries the figure is below 5%. For industrialised countries the figure is much lower, due to high personnel costs[22].

It is unlikely that the governments of many developing economies will be able to bear the required amount on their own, in the foreseeable future. Even if portions of the generated income of autonomous health facilities can be added (in Kenya for example 25%), the financial need for carrying out maintenance services with acceptable efficiency will not be met[23]. Some donors provide maintenance contracts for a couple of years, but are still unable to offer more sustainable solutions.

In view of the meagre resources, one should set priorities in maintenance and repair. It appears from empirical observations that Pareto's Principle can be applied to maintenance costs: only 30% of the total funds desirable for maintenance would suffice to cover 70% of the problems.

This is because the majority of maintenance and repair jobs are of a trivial nature, as long as a preventive strategy using in-house services is used. It could be shown in a case study in a German hospital that by establishing an in-house service and introducing a preventive maintenance programme for suction pumps, life-cycle costs could be reduced by about 80%[24]. The effect of abandoning a preventive strategy can be dramatic: within 2 years the accountable (billable) income of a governmental service centre in Central America dropped by 103%[26], due to the increased need to carry out costly repairs. The drop of 103% meant that in the end the health administration had to subsidise the health facilities serviced!

Motivation of Administrations

As mentioned previously, public health bureaucracy in the past could more or less rely on donors when replacements were thought necessary. Though these expectations are no longer met, most administrators still have little motivation to allocate substantial funds. On the one side, this can be explained by the acquisition of a bad habit. On the other side, even a well-meaning hospital secretary may argue that maintenance swallows valuable cash, which he needs for more important goods such as drugs. The perception of industrial managers about the value of maintenance is similar[13].

This attitude is understandable, since he may never have come across any documented information on cost efficiency or even on the monetary benefit of rational maintenance systems. This applies equally to the public health systems of industrialised countries. But hardly anyone there would seriously contest the idea of spending money for keeping up the value of the invest-