Maintenance and the Life Expectancy of Healthcare Equipment in Developing Economies

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Abstract

Measuring the economic viability of systematically maintaining physical assets (buildings, utilities, medical equipment) in healthcare is important in emerging economies with limited resources. This paper puts forward a way to estimate the benefit by comparing the input for maintenance with the savings achieved by extending the useful life of physical assets. For this purpose, life expectancies have been studied under conditions with and without systematic maintenance based on a planned and preventative approach for a selection of utilities and medical equipment. The result shows that the average prolongation of useful life for healthcare equipment in emerging economies is about two-fold. Specific figures on the life expectancy of 16 different items are presented. Finally, recommendations are given on how to employ the method locally.

Background and Objective

Developing suitable maintenance services as part of a comprehensive approach towards Physical Assets Management (PAM) in developing economies is as much a question of technology and know-how transfer, as it implies conceptual, managerial and even policy related dimensions. Such systems should be based on certain criteria:

- compatibility with other management systems, e.g. district health management
- adaptation of PAM and maintenance systems to the specific local needs (decentralisation)
- involvement of all relevant partners in health (public and private health services, service providers, foreign cooperating partners and NGOs)
- economic viability

This paper focuses on the latter aspect, keeping in mind that fact that the support needed from health planners and other decision makers can often be mobilised by presenting economic arguments.

Literature on the economic implications of a rational maintenance approach is scarce. It is pointed at comparing costs of different maintenance strategies (Miethe 1993: Kosten-Nutzen-Bestimmungen für krankenhaustechnische Dienste) or is confined to considerations in industrialised countries that merely describe ways of minimising costs. Cost-benefit investigations in the pure sense are not part of managing maintenance systems. Consequently, practical methods to analyse the economic gain are not readily available. One way to look at this is to derive the economic characteristics by comparing useful lives (or life expectancies) of items of equipment and utilities.

As compelling as this method may seem, it is difficult to find the life expectancy data required. Some literature (Brandrup-Luckanow *et al* 1994) contains estimates, but without explanation, of how such figures have been determined and in which scenarios they can be used. Other is focused on circumstances in industrialised countries (AHA 1998) or on a single group of equipment (Takouo 1996). Even manufacturers rarely provide figures on useful life. Depreciation figures cannot be used, because they are based not only on the useful physical criteria but also on considerations such as tax regulations. Hard data from maintenance service records in developing countries are hardly available.

Methods

A simple way to determine the benefit is based on the positive effect of maintenance on the useful life of utilities and equipment (Riha *et al* 1998). Extending the life of assets (expressed as the Prolongation Factor) means that replacement occurs less frequently and thus leads to savings in capital costs. These savings can then be compared with the expenses for maintaining the assets. The formula:

$$\text{Annual Savings [\% of capital value]} = \frac{100 * 1\text{-}1/\text{Prolongation Factor}}{\text{Life Expectancy without Maintenance [yrs]}}$$

$$\text{Prolongation Factor} = \text{Life Expectancy with Maintenance} / \text{Life Expectancy without Maintenance}$$

In view of the difficult data situation it was decided to use Delphi planning as a semi-quantitative method which would give at least a plausible trend for a selected number of items.

The method included the following steps:

For the Delphi survey a group of experts of initially 23 members from 16 different country backgrounds (see 4. Acknowledgments) were selected. Of these, 20 are hospital or biomedical engineers, one a public health physician with experience in health facility management, two physicists working in the field for more than 20 years and 10 years respectively and one health economist. The members did not know each other during the process, thus avoiding opinion leadership.

This was followed by the formulation of a questionnaire. The core issue was to estimate the useful life of an item operated in two different scenarios: under systematic, planned preventative maintenance and under conditions where no maintenance or only emergency repairs are carried-out. Due to the experience that in developing countries often equipment of inferior quality (products of poor design, construction and/or made of poor materials) is used, responders were asked to estimate the life expectancies of 16 items of poor and good quality. The items were characterised by brief connotations (see results by item in tables at the end of the paper). The questionnaire was distributed together with an explanatory letter to all members, describing the background of the study and the method. There was room on the questionnaire for comments or for qualifying the estimates. Responders were specifically asked not to give figures where they were uncertain.

The results were collected, evaluated and distributed together with amended questionnaires to all members asking them to revise their judgment if they felt it necessary. This procedure was repeated twice, resulting in three questioning rounds.

The data was collected between July 1997 and August 1998. The basic statistical analysis (mean, mode, max, min) was performed using Microsoft Excel mathematical functions and presented by plots generated by the same software. Outliers were determined according to tests of the American Society for Testing Materials (American National Standard 1994).

The prolongation factors were calculated as the mean of matching pairs of each individual estimate (useful life without and with maintenance). A calculation based on the life expectancy means would distort the result.

Results

The Delphi survey has come up with estimates given by experts from various countries. Therefore the figures represent orders of magnitude that can be well used for first trend calculations.

Air Conditioner (window type)

The difference in performance between poor and good quality is striking. The maintenance economics of this equipment is very positive, looking at the high prolongation factors.

Generator (diesel)

The relatively broad range of the life expectancy of poorly-maintained low-quality diesel generators suggests that this category is sensitive to the geographical or/and technical environment.

Generator (petrol)

The ranges for the useful life of petrol generators are rather broad in general, indicating the fundamental sensitivity of such equipment in general. Petrol generators should be avoided.

Pick Up

As one can expect with duty cars, poor quality does not pay off even under adequate maintenance conditions, whereby 'poor quality' probably refers to pick-ups which are designed more or less for urban use.

Refrigerator (electrical)

The broad lifetime ranges, the mostly low prolongation factors and the rather scattered responses confirm that compressor refrigerators do not operate well under extreme working conditions.

Refrigerator (kerosene)

Judging by the high prolongation factors and life expectancies kerosene-driven (or gas-driven, one may safely assume) refrigerators of good quality fare significantly better than the corresponding compressor type. This is actually no surprise, considering the technology involved, although users tend to complain about the amount of work required for smooth operation.

Steriliser (vertical)

The widely scattered responses for poorly-maintained vertical sterilisers again suggest sensitivity towards difficult working conditions.

Steriliser (horizontal)

Horizontal sterilisers are clearly less sturdy than vertical ones, most probably because of the sensitive gasket systems and door mechanisms. As a logical consequence horizontal sterilisers benefit more from systematic maintenance, as the higher prolongation factor proves.

Washing machine (electrical)

As to be expected, cheap (poor quality) washing machines are an extremely costly investment.

Anaesthetic Machine (Boyles)

Again we have a wide scatter of opinions, suggesting the expected general sensitivity and the variations in design of anaesthetic machines. Maintenance benefit is fairly good in general and very good with sophisticated models at difficult locations.

Centrifuge

Lab centrifuges appear to have less problems with heavy working conditions. The high prolongation factor for poor-quality samples may be due to the motor design (with brushes or brushless?).

Hot Air Oven

Also here the responses vary greatly, probably due to the variable working environments encountered.

Microscope

The widely scattered responses are somewhat puzzling. One explanation may lie in the high variation of lighting unit designs. High prolongation factors for microscopes of good quality point to a good return on the maintenance required.

Sphygmomanometer (aneroid)

The barometer type of blood pressure machines seems to greatly benefit from maintenance, as the prolongation factors suggest. The machines are clearly more prone to become damaged under difficult working conditions than the mercury type, as the heterogenous responses show.

Sphygmomanometer (mercury)

Surprisingly, mercury blood pressure machines survive only slightly longer than the aneroid ones. The reason may be connected to the market value of mercury.

Suction Pump (electrical)

Contrary to the standard rule that poor quality does not allow for meaningful maintenance, at the first glance it seems that cheap suction pumps do not fit this concept. But a look at the achievable lifetimes indicates that better quality pays off in the end.

General Interpretation

The figures confirm and surpass the general notion among hospital maintenance experts that adequate maintenance increases the useful life of health technology at least by a factor of 1.5 (prolongation factor).

The largest maintenance benefit can be achieved with medical equipment, though on average there is not much difference between utilities and equipment. For trend calculations, a prolongation factor of 1.9 (mode of means) can be assumed for both categories.

Discussion

The Delphi method had to be applied using conventional mail corres-pondence. This caused serious delays, in particular with experts resident in emerging countries. As a consequence the process had to be restricted to three questioning sequences. The statistical computation of the remaining data must be regarded as a compromise. A full Delphi survey ending up with all responders agreeing on each value would probably have been more reliable.

Though the last round comprised only 16 responders, the study sufficiently proves that the method leads to plausible results: the data collected on good and poor quality are consistent with empirical and anecdotal experience. Prolongation factors may often be higher for poor quality items, but remain unimportant in view of their low life expectancy, as one would anticipate. There are opinions that the prolongation factor for buildings may be similar (Schwabe 1999: personal communications).

For more precise estimates the Delphi method can be employed locally within the framework of a workshop:

- invite as many resource persons as possible
- pose the questions using pinboards and cards (metaplan technique)
- let the experts answer anonymously, on cards
- arrange cards in groups as a histogram
- interpret result (avoid discussions) and repeat process until all members are of the same opinion.

With figures obtained in such a way, probability is high that cost-benefit estimates would be reasonably accurate, and could become accepted by management as a standard method of monitoring the economic performance of maintenance services. The method may also be linked with productivity (Fennigkoh 1987), schedule maintenance (AHA 1988) and (to a lesser extent) repair time standards for monitoring purposes e.g. the performance of contractors.

Acknowledgments

I am grateful to the participants in the Delphi Survey, namely:
Boyssons, Paul (Niger)
Clauss, Jurgen (Germany)
Dietrich, Emil (Germany)
Dunkel, Volkmar (Germany)
Green, William (Kenya)
Horneber, Dieter (Philippines/Malawi)
Huys, Jan (Netherlands)
Jager, Peter (Panama/Cabo Verde)
Karaschinski, Klaus-Dieter (Germany/Kenya)

Khandpur, R.S. (India)
Kwankam, Yunkap (Cameroon)
Litschauer, Hans (Kenya)
Mangenot, Laurent (Senegal/ Cote d'Ivoire)
Miethe, Bernhard (Germany)
Mkwizu, Y. (Tansania)
Mwalilimo, P. (Malawi)
Ndambiri, Jackson (Kenya)
Nevill, Andrew (Malawi/UK)
Porter, David (UK)
Remmelzwaal (Mozambique)
Riha, Josef (Côte d'Ivoire)
Staack, Udo (Jordan)
Vogt, Pierre (Switzerland).

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Consolidated Data

The following tables show the consolidated data for each item investigated. Some people may prefer to use the mode instead of the mean, because the mode better reflects the prevailing opinion of the experts involved in the study. The minimum and maximum figures are helpful to get an idea of the range, and make it easier to determine more specific figures for specific locations and situations.

Abbreviations used:
WM = Well Maintained
PM = Poorly Maintained
GQ = Good Quality
PQ = Poor Quality

Figures for life expectancy are given in years.

	UTILITIES		MEDICAL EQUIPMENT	
	Prolongation Factor		Prolongation Factor	
	Good Quality	Poor Quality	Good Quality	Poor Quality
MEAN	1.9	1.9	1.9	2.2
MIN	1.6	1.6	1.3	1.5
MAX	2.2	2.5	2.9	3.1

AIR CONDITIONER (window type)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	11.0	5.0	1.8	6.0	3.0	1.9
MODE	10.0	5.0	2.0	6.0	3.0	1.7
MIN	10.0	5.0	1.4	5.0	3.0	1.5
MAX	12.0	6.0	2.0	7.0	3.0	2.5

GENERATOR (diesel)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	19.5	10.5	2.0	10.0	4.5	2.2
MODE	20.0	10.0	2.0	10.0	5.0	2.0
MIN	18.0	10.0	1.8	9.0	3.0	1.8
MAX	20.0	12.0	2.0	10.0	6.0	3.3

GENERATOR (petrol)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	15.0	10.0	2.0	7.0	4.0	2.6
MODE	20.0	15.0	2.0	5.0	4.0	3.0
MIN	10.0	6.0	1.9	5.0	2.0	2.0
MAX	20.0	15.0	2.0	10.0	5.0	3.0

PICK UP

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	9.5	5.5	2.0	5.0	3.5	1.7
MODE	10.0	5.0	2.0	5.0	4.0	2.0
MIN	7.0	4.0	1.7	3.0	2.0	1.3
MAX	12.0	8.0	2.7	6.0	4.0	2.5

REFRIGERATOR (electrical)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	11.5	6.0	1.6	7.0	4.5	1.5
MODE	10.0	6.0	1.5	8.0	4.0	1.2
MIN	10.0	5.0	1.3	5.0	3.0	1.2
MAX	15.0	8.0	2.0	8.0	5.0	2.0

REFRIGERATOR (kerosene)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	14.0	8.0	2.2	6.5	4.0	2.0
MODE	15.0	10.0	1.9	8.0	4.0	2.5
MIN	10.0	5.0	1.8	4.0	4.0	1.3
MAX	17.0	10.0	3.0	8.0	4.0	2.5

STERILISER (vertical)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	15.0	8.0	1.5	9.5	5.0	1.5
MODE	15.0	8.0	1.3	8.0	6.0	1.3
MIN	14.0	8.0	1.3	5.0	3.0	1.3
MAX	15.0	8.0	1.9	12.0	6.0	2.0

STERILISER (horizontal)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	12.0	7.0	2.1	6.0	4.0	1.8
MODE	12.0	6.0	2.4	5.0	4.0	2.0
MIN	10.0	6.0	1.5	5.0	3.0	1.4
MAX	14.0	10.0	2.4	8.0	5.0	2.5

WASHING MACHINE (electrical)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	9.0	6.0	1.7	5.0	3.5	1.7
MODE	8.0	6.0	1.6	5.0	4.0	1.5
MIN	8.0	6.0	1.6	5.0	2.0	1.5
MAX	11.0	6.0	2.0	5.0	4.0	2.0

ANAESTHETIC MACHINE (Boyles)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	12.5	7.5	1.7	8.0	4.0	1.9
MODE	10.0	6.0	1.5	10.0	5.0	2.5
MIN	10.0	5.0	1.4	5.0	2.0	1.2
MAX	15.0	10.0	2.4	10.0	5.0	2.5

CENTRIFUGE

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	11.5	8.0	1.5	8.0	3.5	2.0
MODE	12.0	8.0	1.5	8.0	4.0	2.0
MIN	10.0	6.0	1.3	7.0	3.0	2.0
MAX	12.0	9.0	1.7	8.0	4.0	2.3

HOT AIR OVEN

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	13.0	9.0	1.5	7.5	4.0	1.9
MODE	15.0	10.0	1.5	8.0	4.0	1.8
MIN	10.0	6.0	1.2	5.0	2.0	1.2
MAX	15.0	10.0	1.7	8.0	6.0	2.7

MICROSCOPE

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	17.0	8.5	2.4	7.5	4.0	1.9
MODE	20.0	8.0	2.3	8.0	4.0	2.0
MIN	10.0	6.0	1.3	5.0	3.0	1.5
MAX	20.0	10.0	4.0	10.0	6.0	2.0

SPHYGMOMANOMETER (aneroid)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	7.5	3.5	2.2	4.0	1.5	2.6
MODE	10.0	4.0	1.6	5.0	1.0	1.5
MIN	5.0	2.0	1.2	2.0	1.0	1.3
MAX	10.0	5.0	5.0	5.0	3.0	5.0

SPHYGMOMANOMETER (mercury)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	8.5	4.0	2.2	4.0	2.0	2.1
MODE	8.0	4.0	2.0	4.0	2.0	2.0
MIN	8.0	3.0	1.6	3.0	1.0	1.5
MAX	10.0	5.0	2.7	5.0	2.0	3.0

SUCTION PUMP (electrical)

	GOOD QUALITY			POOR QUALITY		
	Life Expectancy		Prolongation Factor	Life Expectancy		Prolongation Factor
	well maintained	poorly maintained		well maintained	poorly maintained	
MEAN	10.5	6.0	1.8	6.0	2.0	2.8
MODE	10.0	5.0	1.7	6.0	2.0	2.5
MIN	10.0	5.0	1.4	5.0	1.0	1.7
MAX	15.0	8.0	2.5	7.0	3.0	5.0