REFLECTIONS ON THE ECONOMY OF MAINTENANCE

GTZ & Ministry of Health, Abidjan - February 1998
J.Riha, L.Mangenot, H.Halbwachs, G.Attémené

INTRODUCTION

The concern regarding adequate budgetary allocations for maintenance of physical assets in the health sector of developing countries remains a major preoccupation in the international discussion and particularly amongst the donor community. This question arises whenever arguments are presented in favour of maintenance interventions. Recently an interesting approach has been initiated by Hans Halbwachs [1], suggesting to define an annual **MAINTENANCE COST CEILING** based on 'life-expectancy related cost-effectiveness', that is by relating maintenance cost to the expected increase in lifetime. We would like to propose some further reflections based on that concept in order to provide convenient quantitative guidelines for engineers, administrators and decision makers on the cost implication of maintenance approaches, as part of the continuing discussion on **PHYSICAL ASSETS MANAGEMENT.**

In order to arrive at a generally applicable conclusion of our arguments a certain degree of abstraction will be necessary. However we shall include at every step a practical example to demonstrate that this presentation is not just an academic exercise but that it offers some useful tools for planning and monitoring.

IMPROVEMENT OF LIFE EXPECTANCY DUE TO MAINTENANCE

Depending on type and quality of equipment or building, rate and condition of use, the life expectancy of any physical asset is limited, that means it has to be replaced regularly at certain intervals if we wish to provide a continuous service. It is plausible that efficient maintenance should increase this useful life = the life expectancy.

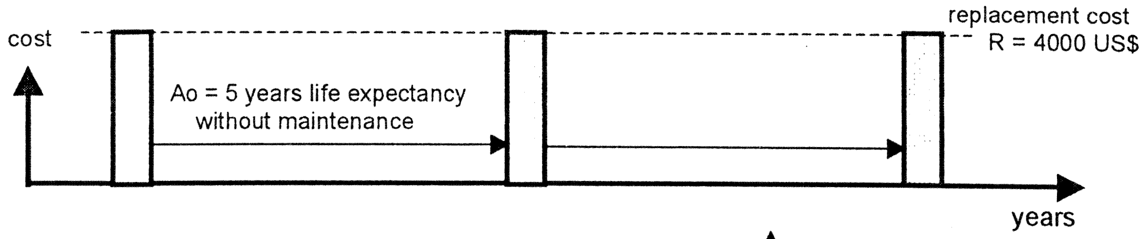
As a guide through this discussion we would like to present the example of a medium sized washing machine used in a difficult environment, and assume the following hypothetical characteristics:

(1) **replacement cost & life expectancy** — washing machine **as our example:**

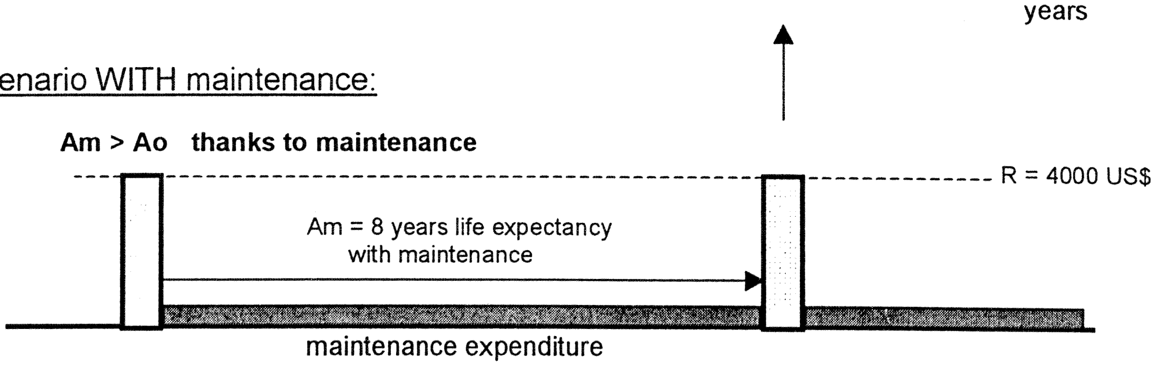
R = replacement cost of equipment
Ao = years of life expectancy without maintenance
Am = years of life expectancy with maintenance

R = 4000 US$
Ao = 5 years
Am = 8 years

scenario WITHOUT maintenance:



scenario WITH maintenance:



We found it convenient for further calculations to express this increase in life expectancy as an improvement factor relative to the scenario without maintenance.

(2) **X = improvement factor of life expectancy**

$$X = \frac{Am}{Ao} = \frac{\text{life expectancy with maintenance}}{\text{life expectancy without maintenance}} \geq 1$$

our example:

$$X = \frac{8 \text{ years}}{5 \text{ years}} = 1.6$$

SAVINGS ON ANNUAL REPLACEMENT COST DUE TO MAINTENANCE

The cost of replacing the equipment at the end of its useful life can be expressed as annual contributions to the replacement over the lifetime. This is the amount one would need to raise every year to pay for the eventual replacement. For the purpose of our discussion this is the same as the annually diminishing value of the equipment, called depreciation or amortisation by managers and accountants.

(3) **Do = annual replacement cost without maintenance**

$$Do = \frac{R}{Ao} = \frac{\text{replacement cost}}{\text{life expectancy without maintenance}}$$

our example:

$$Do = \frac{4000}{5 \text{ yrs}} = 800\$/yr$$

(4) **Dm = annual replacement cost with maintenance**

$$Dm = \frac{R}{Am} = \frac{\text{replacement cost}}{\text{life expectancy with maintenance}} = \frac{R}{Ao * X} = \frac{Do}{X}$$

our example:

$$Dm = \frac{4000}{8 \text{ yrs}} = 500\$/yr$$

Since the maintenance intervention results in an increased lifetime the annual replacement cost with maintenance is smaller than without maintenance **Dm < Do**. The difference **Do - Dm** defines an annual saving in replacement cost:

(5) **SA = saving per year due to maintenance**

$$SA = Do - Dm = Do - \frac{Do}{X} = Do * \left(1 - \frac{1}{X}\right)$$

our example:

$$SA = 800\,\$ - 500\,\$ / yr = 300\,\$ / year$$

THE ANNUAL MAINTENANCE COST CEILING Mmax

Of course maintenance comes at a cost, but we can now estimate at what level this can be justified : Ref.[1] - The annual maintenance cost should not exceed the achievable saving on replacement cost per year due to maintenance, otherwise maintenance efforts would be uneconomical and absurd.

That means the saving on replacement cost per year (formula 5) defines already the **annual maintenance cost ceiling.** In our example an expenditure of up to 300 $ per year for maintenance of that machine can be justified while aiming at an increase in life time from 5 to 8 years.

(6) **Mmax = annual maintenance cost ceiling**

$$Mmax = SA = Do - Dm = Do * \left(1 - \frac{1}{X}\right)$$

our example:

$$Mmax = SA = 300\,\$ / year$$

For purposes of planning and for comparisons we found it more useful to define this annual maintenance cost ceiling **as a percentage of the replacement cost**, that means as a function independent of the asset value. Ref.[2]

(7) **MR%max = annual maintenance cost ceiling as percentage of the replacement cost:**

$$MR\%max = \frac{100 * Mmax}{R} = \frac{100 * Do}{R} * \left(1 - \frac{1}{X}\right) =$$

$$MR\%max = \frac{100}{Ao} * \left(1 - \frac{1}{X}\right) \quad \text{as \% of R}$$

our example:

$$MR\%max = \frac{100}{5} * \left(1 - \frac{1}{1.6}\right) =$$

$$MR\%max = 20 * 0.375 = 7.5\%$$

$$Mmax = 4000 * 7.5\% = 300\$/yr$$

$$MR\%max = \frac{100}{Ao} * \left(1 - \frac{1}{X}\right) \quad \text{as \% of R}$$

The benefit of the abstract representation of **MR%max in formula 7** should be noted, namely that the annual maintenance cost ceiling is represented as a function of two independent variables:

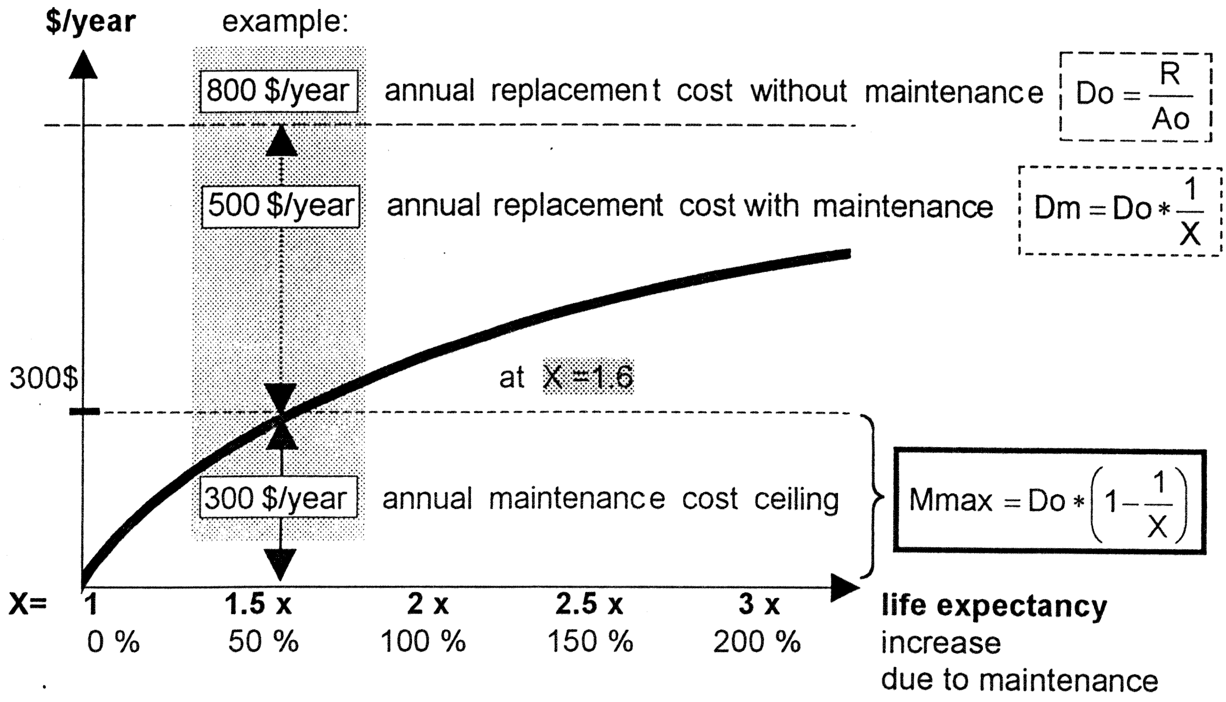
Ao **years of life expectancy without maintenance**,
= an equipment parameter, which depends on type and quality of the asset, rate and condition of use

X **improvement factor of life expectancy thanks to maintenance**,
= an intervention parameter, which is an expression of the effectiveness of our maintenance efforts

The separation between **equipment parameter** and **intervention parameter** makes this formula for the annual maintenance cost ceiling particularly useful for planning purposes, for example by combining assets in groups of similar characteristics.

Furthermore the mathematical functions involved are relatively simple and are easily calculated. The graphical representation as well as a tabulation of these formulas follows to further demonstrate the relationships between the different variables and to show at what level maintenance can be economically justified.

THE GRAPHICAL REPRESENTATION of Mmax



ANNUAL MAINTENANCE COST CEILING

Ministry of Health, Abidjan
February 1998

Project PMS DEMM / gtz

R = replacement cost = investment
Ao = life expectancy without maintenance
Am = life expectancy with maintenance
X= Am / Ao >1 = **improvement factor of life expectancy** thanks to maintenance
Do = R / Ao = annual replacement cost without maintenance
Dm = R / Am = Do / X = annual replacement cost with maintenance
Mmax = Do - Dm = Do * (1 – 1 / X) = **annual maintenance cost ceiling**
MR%max = 100 * (1 - 1 / X) / Ao = **Mmax as percentage of the replacement cost R**

Table for factors 1 / X et (1 - 1 / X)

X =	1,00	1,25	1,50	1,75	2,00	2,25	2,50	2,75	3,00	
% impr	0	25	50	75	100	125	150	175	200	%
1 / X =	1	0,80	0,67	0,57	0,50	0,44	0,40	0,36	0,33	
1 - 1 / X =	0	0,20	0,33	0,43	0,50	0,56	0,60	0,64	0,67	

Table MR%max = annual maintenance cost ceiling as % of replacement cost R

improvement factor of life expectancy thanks to maintenance →

years of life expectancy without maintenance ↓

X =	1,00	1,25	1,50	1,75	2,00	2,25	2,50	2,75	3,00	
Ao = 1	0,0	20,0	33,3	42,9	50,0	55,6	60,0	63,6	66,7	%
2	0,0	10,0	16,7	21,4	25,0	27,8	30,0	31,8	33,3	%
3	0,0	6,7	11,1	14,3	16,7	18,5	20,0	21,2	22,2	%
4	0,0	5,0	8,3	10,7	12,5	13,9	15,0	15,9	16,7	%
5	0,0	4,0	6,7	8,6	10,0	11,1	12,0	12,7	13,3	%
6	0,0	3,3	5,6	7,1	8,3	9,3	10,0	10,6	11,1	%
7	0,0	2,9	4,8	6,1	7,1	7,9	8,6	9,1	9,5	%
8	0,0	2,5	4,2	5,4	6,3	6,9	7,5	8,0	8,3	%
9	0,0	2,2	3,7	4,8	5,6	6,2	6,7	7,1	7,4	%
10	0,0	2,0	3,3	4,3	5,0	5,6	6,0	6,4	6,7	%
11	0,0	1,8	3,0	3,9	4,5	5,1	5,5	5,8	6,1	%
12	0,0	1,7	2,8	3,6	4,2	4,6	5,0	5,3	5,6	%
13	0,0	1,5	2,6	3,3	3,8	4,3	4,6	4,9	5,1	%
14	0,0	1,4	2,4	3,1	3,6	4,0	4,3	4,5	4,8	%
15	0,0	1,3	2,2	2,9	3,3	3,7	4,0	4,2	4,4	%
16	0,0	1,3	2,1	2,7	3,1	3,5	3,8	4,0	4,2	%
17	0,0	1,2	2,0	2,5	2,9	3,3	3,5	3,7	3,9	%
18	0,0	1,1	1,9	2,4	2,8	3,1	3,3	3,5	3,7	%
19	0,0	1,1	1,8	2,3	2,6	2,9	3,2	3,3	3,5	%
20	0,0	1,0	1,7	2,1	2,5	2,8	3,0	3,2	3,3	%
21	0,0	1,0	1,6	2,0	2,4	2,6	2,9	3,0	3,2	%
22	0,0	0,9	1,5	1,9	2,3	2,5	2,7	2,9	3,0	%
23	0,0	0,9	1,4	1,9	2,2	2,4	2,6	2,8	2,9	%
24	0,0	0,8	1,4	1,8	2,1	2,3	2,5	2,7	2,8	%
25	0,0	0,8	1,3	1,7	2,0	2,2	2,4	2,5	2,7	%
26	0,0	0,8	1,3	1,6	1,9	2,1	2,3	2,4	2,6	%
27	0,0	0,7	1,2	1,6	1,9	2,1	2,2	2,4	2,5	%
28	0,0	0,7	1,2	1,5	1,8	2,0	2,1	2,3	2,4	%
29	0,0	0,7	1,1	1,5	1,7	1,9	2,1	2,2	2,3	%
30	0,0	0,7	1,1	1,4	1,7	1,9	2,0	2,1	2,2	%
31	0,0	0,6	1,1	1,4	1,6	1,8	1,9	2,1	2,2	%
32	0,0	0,6	1,0	1,3	1,6	1,7	1,9	2,0	2,1	%
33	0,0	0,6	1,0	1,3	1,5	1,7	1,8	1,9	2,0	%
34	0,0	0,6	1,0	1,3	1,5	1,6	1,8	1,9	2,0	%
35	0,0	0,6	1,0	1,2	1,4	1,6	1,7	1,8	1,9	%

NOTES ON USING THE MAINTENANCE COST CEILING Mmax & MR%max

A number of important assumptions and observations should be noted to clarify the concept of the annual maintenance cost ceiling and to show it's potential application:

General assumptions

A. Spending money on maintenance up to **Mmax** does NOT automatically guarantee the increased equipment lifetime aimed for.

B. Success will rather depend on the efficiency of the maintenance management system and on the competence, motivation and organisation of the staff involved.

C. A maintenance system also depends to a considerable extend on the general health management system. Inefficient maintenance operations can be due to sloppy hospital management and not necessarily due to lack of technical competence.

D. It must be understood that the concept of systematic and preventive maintenance not only includes operations of purely technological nature but also activities, which address the competence of users, of administrators and of management in general.

Observations to note

1. **Mmax does not take into account interest rate and inflation**, which would make the whole discussion far more complex. The simplification appears justified in order to demonstrate trends and relationships rather than define exact figures.

2. **Mmax = maintenance for availability,** strictly to keep the equipment in functional order, which does NOT include any operating expenditure, because Mmax was defined through the annual replacement cost.

3. **Mmax defines a limit of average annual maintenance spending** when aiming at a specific extension of lifetime, but it is NOT a time function of annual spending limits as the equipment ages.

4. **Mmax defines the economically justifiable limit** – we should aim at average annual maintenance expenditure well below this limit to give maintenance some economic advantage . The level actually to be applied is a question of policy.

5. **When defining maintenance expenditure** we must take into account the cost of the entire maintenance system and it's operation, for personnel, tools, transport, parts, infrastructure, technical & user & management training, administration, contracts, etc.

6. We have to **monitor maintenance activities,** equipment inventory & performance in order to utilise the above concepts in a sensible manner, hence there is need to keep records and to analyse them regularly.

7. **The rate of use** influences equipment performance and must be taken into account when estimating lifetime, i.e. high rate of use means shorter **Ao**. In this way the rate of use will also influence the annual replacement cost and Mmax.

8. **Maintenance expenditure varies** in reality during the life of most equipment (f.e. more for training at the beginning, more for costly wear later on). **Mmax** is meant to provide a global estimate of average expenditure.

ADVANTAGES AND POSSIBLE APPLICATIONS OF THE CONCEPT Mmax

The concept of **Mmax** when seen in the context of the above observations can serve to provide guidelines for the management of maintenance, for estate management, for maintenance policy, etc. with the aim to improve the state of the health infrastructure to the benefit of the patients:

I. The definition of **Mmax** provides a frame for decision making, by showing that maintenance must be effected within a certain cost ceiling and that this limit can be estimated by use of a plausible economic argument to justify investment in a rational maintenance system (refer to the diagram on investments of the MoH in the Côte d'Ivoire 1994-97 used to justify maintenance expenditure).

II. The method allows a direct economic analysis of the effects of a maintenance system on single items or on groups of physical assets.

III. The method focuses on the effects of maintenance by largely excluding other factors such as operating costs (for example: reagents, energy consumption)

IV. The method reminds us that maintenance is only one part of a cyclic process of asset management (ref.[3] FAKT)

V. We can include the costs and the effects of non technical activities such as user training or management training as part of the rational maintenance intervention

VI. The approach using **Mmax** offers the potential to describe the efficiency of a maintenance system in a quantitative way. One might f.e. develop additional indicators to describe and monitor maintenance interventions relative to the economic limit, by taking into account actual equipment availability.

The concept of **Mmax** is not a formula to satisfy all tastes and demands but it should be seen as a relatively simple tool which can be used to advantage on all levels of the health system. The tabulation given should assist the application of this idea to obtain rough estimates.

ANNUAL MAINTENANCE COST CEILING APPLIED TO INVESTMENTS

Estimates for MR%max assuming the following parameters:

	buildings	equipment	
Ao =	**20**	**5**	**years**
Am =	30	10	years
X =	**1,5**	**2**	**x**
Increase in % =	50	100	% above Ao
MR%max =	**1,7**	**10,0**	**% of investment per year**
Proposed level of maintenance	**1,0**	**5,0**	**% of investment per year**

Investments of the Ministry of Health Côte d'Ivoire 1994 – 97

source: DEMM S/DEM 1998

Côte d'Ivoire	**buildings**	**equipment**	**total**
15 Million inhabitants			
Primary	9,1	8,9	18,0
Secondary	11,5	9,7	21,2
Tertiary	29,8	25,4	55,2
	50,4	**44,0**	**94,4 million US$**
Mmax .	**0,86**	**4,40**	**5,25 million US$/year**
Proposed level of maintenance	**0,50**	**2,20**	**2,70 million US$/year** only for investments 94-97

Region West	**buildings**	**equipment**	**total**
1,5 Million inhabitants			
Primary	0,9	1,1	2,0
Secondary	2,2	1,7	3,9
Tertiary	1,0	1,0	2,0
	4,0	**3,8**	**7,8 million US$**
Mmax .	**0,07**	**0,38**	**0,45 million US$/year**
Proposed level of maintenance	**0,04**	**0,19**	**0,23 million US$/year** only for investments 94-97

NOTE: all investments in buildings have been grouped together irrespective of rehabilitation or new construction

NOTE: all equipment has been treated in the same manner

EQUIPMENT POLICY BEYOND ECONOMY

A. Replacement Policy - No Maintenance
- replacement on breakdown
- planned replacement

B. Maintenance Policy
- repair on breakdown
- planned preventive maintenance

There are circumstances when maintenance or rehabilitation does not seem to pay and a general replacement policy is advocated. Typical examples are cheap one-way consumables. But such policy is also practised in capital-intensive businesses, such as car-hire operations in an affluent environment, when cars are replaced annually or after very limited mileage.

A replacement approach appears justified and economically sound under conditions such as: easy availability of capital, non-bureaucratic management, good rate of return from use, good second-hand market etc.

For most circumstances in the public domain and especially in the health sector these conditions do not apply. One should also look beyond a myopic search for THE most economical solution, especially in developing environments: it is after all an important aspect of development to address such questions as

- transfer of skills and of know-how
- development of confidence
- development of national capacities
- reduction of wastage of natural resources
- reduction of dependency on imports
- reduction of dependency on donations and on loans

These are all arguments in favour of maintenance. Therefore planned preventive maintenance should be practised as alternative to the haphazard replacement or repair approach so frequently found in developing countries – and it should be done in an economical manner. After all we should strife to provide the best possible service with the limited means available. In this sense we do hope that our presentation can give further impact to rational asset management approaches by showing that

MAINTENANCE can be made ACCOUNTABLE and ECONOMICAL

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THE AUTHORS

Josef Riha, Dipl.Ing. DIC CEng EurIng FIHEEM
GTZ Chief Technical Adviser
Ministry of Health / DEMM
01 BP 7172 Abidjan 1 Côte d'Ivoire
Email riha@africaonline.co.ci

IN COLLABORATION WITH:

Laurent Mangenot, D.U.T.
GTZ Technical Adviser
Ministry of Health / DEMM
01 BP 7172 Abidjan 1 Côte d'Ivoire
Email mangenot@africaonline.co.ci

Hans Halbwachs, Dipl.Ing. IEng MIHEEM
Chief Technical Adviser
Deutsche Gesellschaft für Technische Zusammenarbeit GmbH - GTZ
Division for Health, Population and Nutrition
P.O.Box 5180 D-65760 Eschborn Germany
Email hans.halbwachs@gtz.de

Godiskine Attémené, Ing.Gen. M.Ing.Biomedical
Assistant Director for Maintenance
Ministry of Health / DEMM
04 BP 1845 Abidjan 4 Côte d'Ivoire
Email riha@africaonline.co.ci

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