WHO/EOS/94.57
ORIGINAL: ENGLISH
DISTR.: LIMITED

World Health Organization

Tools for the Assessment of Operation and Maintenance Status of Water Supplies

Draft Report

Operation and Maintenance Working Group

Water Supply and Sanitation Collaborative Council

Tools for the Assessment of Operation and Maintenance Status of Water Supplies

Draft Report

Prepared for the World Health Organization by

Andrew Cotton
Liliane Pintelon
Jan Janssens
Ludo Gelders

June 1994

ACKNOWLEDGEMENTS

The authors would like to thank the World Health Organization for sponsoring the preparation of this report which is one of the activities developed by the Working Group on Operations and Maintenance of the Water Supply and Sanitation Collaborative Council. The valuable assistance of Richard Franceys of WEDC is also acknowledged.

Dr. Andrew Cotton
WEDC
Loughborough University of Technology
Leicestershire
UK

Dr. Liliane Pintelon
Industrial Studies
Catholic University Leuven
Belgium

Ir. Jan Janssens
IWSA/TECHWARE
Brussels
Belgium

Prof. Ludo Gelders
Industrial Studies
Catholic University Leuven
Belgium

CONTENTS

EXECUTIVE SUMMARY

The objective of this study is to review the literature on the performance measurement of operations and maintenance for urban and rural water supplies and to draw up a proposed list of performance indicators to assist in the assessment of the status of operations and maintenance (O&M). This should provide a useful tool for O&M managers.

The wider objective of this study is to contribute to improved sector performance and better levels, standards and coverage of service at lower costs. Furthermore, this should contribute to the long term sustainability of the service.

A framework is proposed which comprises firstly an *audit* of the O&M function using checklists for assessment and secondly an outline *performance reporting tool*. The audit procedure enables periodic 'snapshots' of the O&M function to be taken in order to make rapid assessments for strategic purposes. The performance reporting tool is meant to be used on a regular basis by the O&M management for close follow-up of the O&M function and its activities. The framework is applicable to both urban and rural water supplies.

Within this overall framework, a number of performance indicators for the O&M of urban and rural water supplies are defined and their application discussed. There needs to be a performance target associated with each performance indicator; no attempt is made to prescribe target values, as this has to be undertaken locally. The recommended procedure is to assess the status, or performance, of O&M by comparing each performance indicator with its respective target. This assessment should lead O&M managers to act in order firstly to rectify shortcomings in existing performance and secondly to improve future performance.

A conscious attempt has been made to suggest only those performance indicators which are of primary relevance to O&M and which can be assessed without too much difficulty.

In urban water supply the management of O&M is normally centralised and controlled by public sector agencies which cover the abstraction, treatment, transmission and distribution of water. Performance indicators are suggested for the following areas of activity in O&M of urban water supply.

- Service
- Equipment
- Financial
- Personnel
- Materials
- Work order control

In rural water supply, the models for O&M management range from highly centralised ones which are entirely within the public sector, to community managed schemes owned, operated and maintained by a local community-based organisation (VLOM-based systems). In between these extremes there is a continuous spectrum of models involving the community, the various tiers of government, and the private

sector. Performance indicators are grouped into the same categories as described above for urban water supply.

Further work still needs to be carried out in order to achieve the aims of this project. This report represents only the first of three stages. Stage 2 involves testing the O&M assessment procedure in a limited number of case study areas, the results of which will be used to provide feedback for the continued implementation of the project. It is hoped to be able to be able to analyse performance indicators from urban water utilities in Mauritania and Senegal. Stage 3 comprises the final evaluation of the O&M assessment procedure through its application at regional level. The results obtained will be reviewed by the Operations and Maintenance Working Group who will recommend further action in a number of countries.

On completion of the project, it is anticipated that the following benefits will be identifiable: the provision of a manual and general guidelines for O&M assessment of value to sector professionals; the availability of annotated checklists and parameters for O&M performance evaluation; increasing awareness amongst sector professionals of the importance of the O&M function and tangible improvements brought about during the implementation of the stages of this project.

TERMS OF REFERENCE

1. The proposal for this activity has been developed by the Working Group on Operations and Maintenance of the Collaborative Council for Water Supply and Sanitation. Further background notes are given in Annex 1.

2. The project will address both urban and rural water supplies.

3. A desk study will be carried out to develop a general framework and indicator parameters for the assessment of operations and maintenance status of water supplies in lesser and least developing countries. This will be achieved through a review of currently available literature, including available case study material, on performance categories, indicators and targets which relate to the operations and maintenance status of urban and rural water supplies.

4. One of the outputs from the final report will be a proposed list of performance indicators which will form the basis of a usable tool.

5. Recommendations will be made for further work regarding:

- the testing of the operation and maintenance assessment procedures using studies;
- the subsequent application of these procedures and their evaluation.

6. The report will be structured as follows.

- Introduction, background and TOR
- Philosophy/draft framework for urban and rural supplies
- Proposed performance indicators for urban and rural supplies
- Recommendations for future work
- References

INTRODUCTION

Objectives

The objectives of this study are to review the literature on the performance measurement of operations and maintenance for urban and rural water supplies and to draw up a proposed list of performance indicators to assist in the assessment of the status of operations and maintenance. This should provide a useful tool for O&M managers.

The wider objective of this study is to contribute to improved sector performance and better levels, standards and coverage of service at lower costs. Furthermore, this should contribute to the long term sustainability of the service.

Definitions

This section presents definitions of the most important terms and concepts with respect to operation and maintenance. A further classification of terms can be found in the glossary at the end of this publication.

"Operation and Maintenance" is used as a general concept covering all kinds of activities carried out by technical departments in water supply utilities and by communities in order to sustain its public services and to maintain its existing capital assets.

The term "Operation" refers to the procedures and activities involved in the actual delivery of services to the public , for example, abstraction, treatment, pumping, transmission and distribution of drinking water.

"Maintenance" refers to activities aimed at keeping existing capital assets in serviceable condition, for example, repair of water distribution pipes, pumps, public taps etc.

Operations and Maintenance Performance

The crucial role of good operations and maintenance (O&M) practices in both urban and rural water supply has been recognised for many years. If water supplies are to be operated and maintained satisfactorily, it is essential to have an effective O&M management system. In order to be effective, O&M managers (whether they be public utilities or community-based organisations) need to be able to measure the status of the O&M functions.

The objective of this paper is to develop simple tools to assist in the assessment of the status of O&M locally at either the utility or project level. It is not intended that these tools be used only by external evaluators; by setting out a framework as well as suggesting suitable performance indicators, it is the intention that further tools be developed for use by local planners and managers on the ground, which are tailored to the local situation.

Performance indicators are tools of great potential value to all managers. Equipped with information provided through performance measurement, management can formulate policy and implement action that is relevant to the problems revealed, or avoid action that is irrelevant and/or inappropriate, and which might have been adopted in the absence of this information. Performance indicators are normally applied in three main fields: problem diagnosis, performance monitoring and future planning.

The approach adopted is to define performance indicators having quantitative or qualitative values which cover the field of O&M activity. Associated with each performance indicator is a performance target; the status, or 'performance', of O&M is then assessed by comparing each performance indicator with its respective target. This assessment procedure is not an end in itself. The global objective is to improve the performance of O&M; therefore, having assessed the status of O&M, action must be taken by O&M managers firstly to rectify shortcomings in existing performance and secondly to improve future performance. This enables performance comparisons to be made:

- between different time periods for a programme or organisation;

- between different programmes or organisations.

The application of performance indicators to the water supply function is by no means new. However, most of the literature reviewed pertained to the overall evaluation of projects and programmes rather than specifically focusing on the status of O&M. This means that whilst lists of performance indicators already exist, it is important to review their relevance specifically to the O&M function.

Whilst such an approach has the apparent advantage of simplicity, the characterisation of performance in this way is obviously dependent on the number of indicators used and the quality of the data upon which they are assessed. Difficulties can arise when interpreting performance indicators; for example, it may be difficult to determine exactly which are the decisive factors in a particular situation, and the information gathered may not offer any real guidelines for improvement.

In an attempt to address these difficult problems, a framework is proposed which comprises firstly an *audit* of the O&M function using checklists for assessment and secondly an outline *performance reporting tool*. The audit procedure enables periodic 'snapshots' of the O&M function to be taken in order to make rapid assessments for strategic purposes. The performance reporting tool is meant to be used on a regular basis by the O&M management for close follow-up of the O&M function and its activities. There is no attempt to devise a diagnostic procedure for fault detection, as it is beyond the scope of this project; guidelines for this have been proposed by UNCHS (1989).

The framework is intended to encompass both urban and rural water supplies. At first sight, its application might appear to be biased towards large urban water utilities. However, the philosophy underlying the approach is to improve the effectiveness and efficiency of the management of O&M; this is equally as valid for small community supplies as it is for large urban networks. Whilst the details (such as relevant performance indicators) may differ, the principles remain the same.

It is apparent that public utilities (into which category the vast majority of water supply agencies still fall) have lagged far behind manufacturing industry in maintenance management. This can be attributed in part to the fact that maintenance problems which result in loss of production of manufactured goods have more immediately quantifiable effects on sales and profits. There may be lessons to be learned by the water sector from industry; this review therefore encompasses literature relating to industrial maintenance management in addition to the water sector. Many performance indicators came to light during the course of the literature review. However, in line with the objective of this study, an attempt has been made to select only those indicators which are of primary importance and can be measured without too much difficulty.

No attempt is made to prescribe arbitrary performance targets as this must be done within the local context. The setting of appropriate targets is by no means straightforward; the following key issues can be identified (adapted from Koch, 1991):

- involvement of customer/community representatives in the target setting process;
- time and support required to complete this process;
- relationship of local standards to regional or national standards;
- standards of management;
- engendering a 'cultural environment' which gives priority to O&M management.

A FRAMEWORK FOR OPERATIONS AND MAINTENANCE PERFORMANCE MEASUREMENT

In this chapter a framework for O&M performance measurement is proposed, comprising an audit of the O&M function and a performance reporting tool. The framework is applicable to both urban and rural water supplies.

The Purpose of Auditing

The audit is a systematic procedure to objectively obtain and evaluate evidence about the O&M organisation and practice of any given organisation. Auditing, although not commonplace, is growing in popularity as the results provide a valuable tool for understanding the way O&M works.

Audits may be carried out for several reasons:

- whenever scrutiny of O&M is required.

- prior to making organisational or policy changes.

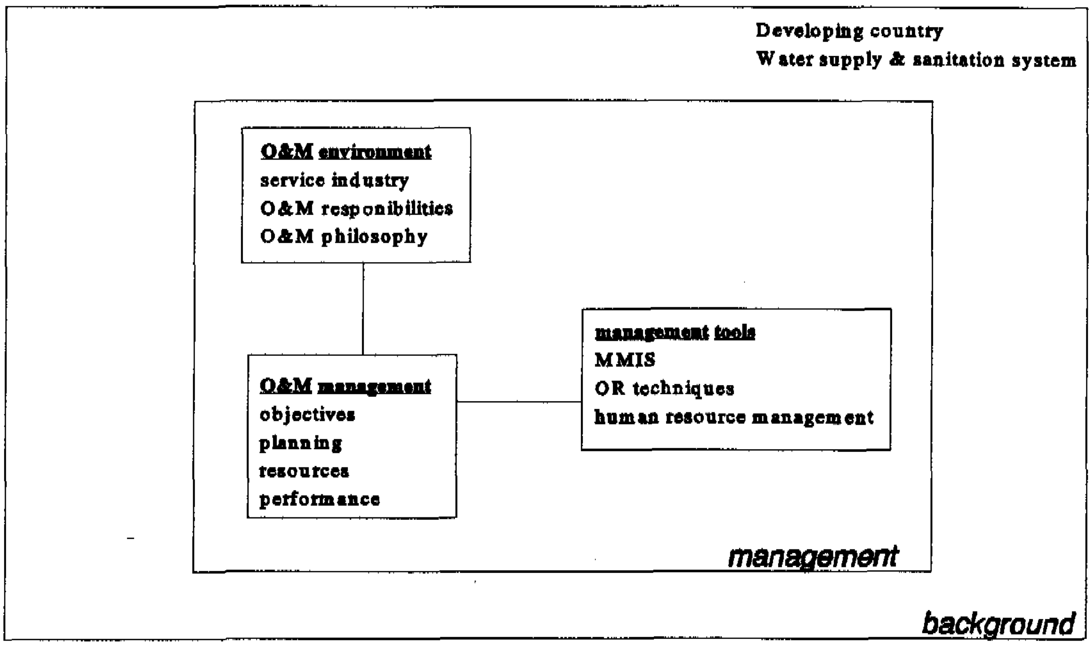
- when independent opinion is needed in addition to internal views.

- for comparative purposes; or to establish performance targets for new facilities.

Audits are normally carried out using checklist and questionnaire responses, based on individual interviews (a sample checklist can be found in Annex 2). The main disadvantage of this method is the danger of being too narrow in focus. This can be avoided by working with well structured checklists supported and cross referenced by a framework. Ideally, this framework should contain all relevant O&M elements, the relationships between those elements, and the links between the O&M function and other business functions. The framework should present an independent view of the O&M functions, objectives, organisation and practices, against which checklist questions and answers can be evaluated.

Box 1 illustrates this type of framework. Two parts can be distinguished: 'background' consists of general information on the developing country and the WS&S, while 'management' focuses on O&M organisation and practices. There are three sub-sections to the management part of the framework: the O&M environment which determines the scope for the O&M manager, the O&M management function and the management tools available to the manager (A discussion of these elements will follow in the section on audit procedure).

Box 1 Overview of framework



Prior to beginning an audit, careful planning of the contents and structure of checklists is essential. A suitable choice of open or closed questions has to be made; the emphasis of questions may need to change according to the interviewee; and if figures are not available, decisions about estimations will be required.

The value of auditing is important at three levels: for consultants it provides basic information about the O&M function, and a context against which more detailed information from performance indicators can be interpreted. For staff members working within O&M it helps to make the O&M function transparent, removing 'company blindness' from work, and for international comparisons, this information helps develop guidelines for O&M practices and planning for future investments in WS&S plants.

A Structured Audit Procedure

The checklist should begin with a section on 'background information' (see Marcelis (1979) & (1984) and Kelly (1991)), which provides general information and an overview of maintenance management within the organisation. This is proceeded by sections dealing with the differing elements of the maintenance management system. These sections are discussed in greater detail below.

Background information

This information provides a broad context to the WS&S system and prepares the interviewers for the type of answers to follow. Background information needs to be gathered prior to beginning the interviews and includes details on:

Developing country

The O&M practices within an organisation may be affected by the development status of the nation in question. The types of issues that need to be addressed include:

- Technology needs and availability of appropriate technology. These differ between countries because of variations in economic development, politics, infrastructure, raw materials and climate (see Chiteris (1982), Alaerts et al (1977)).

- Political agendas and international contacts, i.e. donor/host relationships, organised technology transfer programmes (see Nakajima (1982)).

Water supply and sanitation systems

Details of the WS&S system are required before considering O&M organisation and practice. Issues include:

- age of the WS&S system (if new, running-in failures may be expected; if old, rehabilitation may be urgent)

- capacity utilisation and efficiency (low utilisation may indicate design over-capacity or system malfunction)

- long-term capacity strategy (the ability of the current design to cope with the rapidly growing urban population (Pickford (1977))

- standardisation issues (especially important if the system is not installed by local firms)

O&M organisation and practices

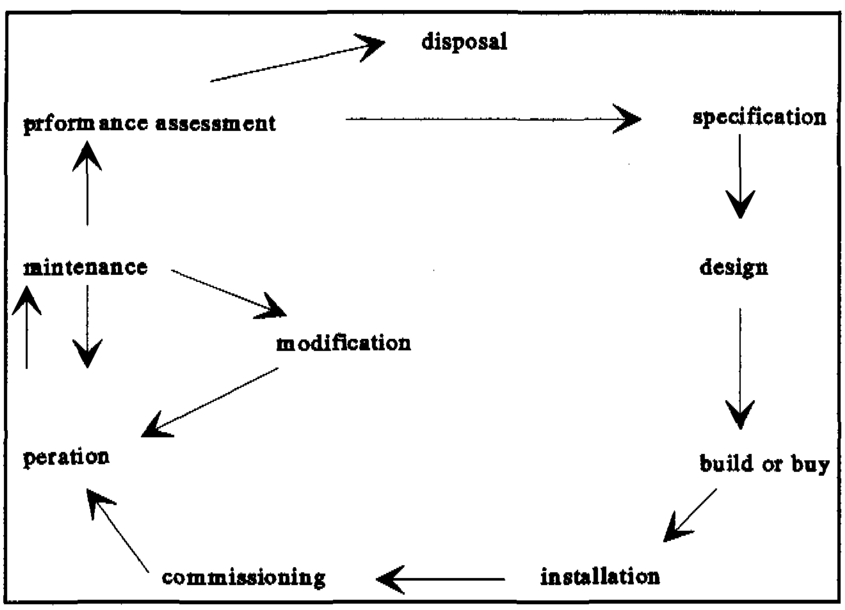
Service industry: WS&S is normally a function of a public utility based within the 'service industry', and as such, performance evaluation is much more difficult to quantify than in manufacturing industry. With the latter, breakdowns leading to production loss and lost sales opportunities can be relatively easily quantified. With WS&S systems, breakdowns leading to reduced quality and/or quantity in supplied water and subsequent health and environmental problems are difficult to quantify in monetary terms or with accurate statistics. This complicates the O&M management function, since it is difficult to objectively choose between policies advocating, for example, more investment in O&M or ensuring there are fewer or shorter breakdowns.

Responsibilities: It is important to have a clear understanding of all O&M responsibilities, including the way O&M is organised and how it relates to the overall management of the WS&S system. For example, O&M may form either a substantial or minor part of WS&S management. If the former is the case, O&M will have considerable decision-making power over elements such as purchasing spare parts and hiring personnel; if the latter, decision-making power will be limited. This difference in power needs to be taken into account when evaluating O&M organisation and practices.

Philosophy: An understanding of the O&M environment depends on the attitude management staff adopt with the function. If, for example, O&M is seen as an area of major concern for management, it may be easier to invest in maintenance resources, or to adopt and implement maintenance philosophies such as RCM (reliability centred maintenance), or TPM (total productive maintenance).

One concept which offers a view on maintenance engineering that is a combination of management, financial engineering and other practices applied to physical assets is life cycle costing, or terotechnology (see Box 2). The global approach advocated by this concept ensures that all cost components (investment and operating costs) and all O&M related aspects are considered.

Box 2 Life Cycle Costing



O&M Management

Objectives: From a management viewpoint, objectives need to be as clear as possible, since they will form the basis for determining O&M policy and for supporting O&M decisions. Moreover, setting realistic targets motivates staff to achieve and maintain them. Although a statement of clear objectives may seem an obvious requirement, in practice they are often lacking from the O&M function.

Objectives tend to be general, such as 'O&M should keep the plant running'; whereas ideally they need to be explicitly stated, such as 'O&M budget is $X, downtime should not exceed Y hours; personnel utilisation should be at least Z%'.

Planning: O&M and maintenance decisions concerning equipment fall into three categories of planning: long term (strategic), medium term (tactical) and short term (operational).

- *Strategic planning* is concerned with the provision of resources to ensure a continuous, satisfactory performance of the plant. This will include decisions concerning construction of new WS&S systems, capacity enlargement projects and major rehabilitation projects. These decisions should take into account the following: life cycle costs, economic factors (i.e. available budget, ability to charge consumers for water supplied, economic and physical growth in the area served), technology and technical aspects (appropriateness of the technology used, modular design, local construction firms), support aspects (provision of spare parts, training programmes) etc. Too often many of these elements are overlooked.

- *Tactical planning* is designed to ensure effective and efficient plant operation, by adopting the right O&M policy. With maintenance, for example, this means finding the right mix of preventative and corrective maintenance interventions.

- *Operational planning* occurs once aggregate allocation of resources has been made. Daily operational planning assumes that a rational work order and job documentation system exists. It should be noted that not every employee hour should be scheduled in advance in order to achieve sound operational planning; a certain amount of capacity may be reserved for emergency tasks.

Resources: Sound resource management is crucial for effective O&M management. The types of resources to consider are personnel, repair shop, materials and information & documentation. For WS&S plants in developing countries, it is advisable to rely on own, or at least local, resources. In practical terms this means training personnel instead of being dependent on outside (mostly foreign) consultants, engineers and workers, or stocking the right number of parts, since poor infrastructure may delay the replacement of spare parts.

Personnel management involves hiring and training the right people, ensuring a broad mix of skills throughout the organisation and motivating staff to perform competently. If the objective of O&M is to provide the safe, reliable and efficient operation of production plants, the following skills are required from O&M personnel to achieve this goal:

- operational skills that allow systems and equipment to function within their designed capabilities.

- deviation-detection skills that help identify and analyse those factors, areas and operational characteristics that may lead to potential or actual failure.

- repair skills that enable the restoration of systems and equipment to their original operating condition.

- documentation skills that enable the recording of the entire event.

A repair shop is a useful resource for O&M. Equipped with powered machine tools, welding equipment and electrical test equipment, the repair shop can correct and/or manufacture spares as and when required.

The MRO (Maintenance, Repair and Operating Supplies) store of the WS&S system will normally carry a variety of spare parts and consumable goods. The main management issue involves guaranteeing availability of these parts by identifying the right trade off between stocking (the number of parts in stock) and stock-outs (how to ensure a reasonable level of service) for spares.

Used correctly, information and documentation can be an asset to O&M management. Data in the form of technical information on equipment parts, interchangeability of spares, sequences of (dis)assembly and equipment failure history can help to transform the management process. Increasingly, computerised maintenance information systems are being used in this sphere. Similarly, administrative procedures can aid O&M functions by maintaining efficient and effective maintenance activities through well structured systems.

Performance reporting: [redacted]

The choice of appropriate performance indicators and the development of a sound performance reporting system are important elements to O&M, which are discussed in greater detail later in this chapter.

Management tools

There are a variety of management tools available that can be used to support the decision-making process for the O&M function.

Mann (1983) reports that investment in data processing equipment for O&M may yield benefits. Further studies report that the use of a computerised information system can help achieve better labour productivity, equipment availability, control of the MRO store (through more accurate, timely information and cross referencing), availability of technical data, maintenance history information and easier performance reporting.

Human resource management concepts (see Pulat & Alexander (1991) and De Groote (1986)) may be adopted and adapted to training and the motivation of personnel.

Design review methods may be used for checking the maintainability and reliability of WS&S plants, depending on the specific characteristics and logistics in developing countries.

Operational research techniques (see Pintelon (1992), Bornstein & Rosenhead (1990)) may be useful in ensuring the optimum use of resources. Although some may be inappropriate for WS&S in developing countries, models such as repair-limit (for the replacement of old equipment), or those for determining the optimum spare part inventory can be effectively employed. Computer simulations can be of value in testing alternative scenarios and predicting the outcome of using different maintenance policies.

Performance reporting tool

Performance reporting

Performance reporting is an indispensable part of all management functions. Typically, the performance reporting tool is used on a regular basis by O&M management in order to keep a close check on all O&M functions and activities. Monthly, or bi-monthly reports aid management by evaluating performance for the previous period and anticipating problems that may subsequently arise.

Until recently, performance reporting for O&M had been relatively neglected in practice, reflecting both the low profile of this function and the difficulty of quantifying performance in this area. The output of O&M has proven difficult to evaluate because:

- maintenance is a service function, and as such, the merits and shortcomings of the rendered service are not immediately apparent. This makes it difficult to justify the use of resources and level of expenditure on assuring proper plant performance.

- the evaluation of O&M performance depends on the perspective applied: accountants may perceive O&M in terms of costs, while engineers will focus on performance in terms of reliability, availability, and maintainability of equipment.

- it is difficult to distinguish between operations and maintenance functions. For example, more extensive maintenance may be required because of operator faults, or simply because more plant activity was required.

A conceptual approach to performance reporting: literature review

The O&M manager must address a wide range of management jobs within the department: planning, purchasing, personnel, quality control, inventories, technical problems and budgets. To assist the manager in the task of evaluating performance within these sections, a review of conceptual approaches to management is detailed below.

within these sections, a review of conceptual approaches to management is detailed below.

Box 3 gives an overview and brief evaluation of the methods used for maintenance evaluation drawn from both literature and practice.

Box 3 Overview of performance tools

Type of PI system	Advantages	Disadvantages
Indicators		
Overall PI (Box 4)	*Popular (compact)*	*Too strong aggregation*
PI collection (Box 5)	*More complete*	*Not always conclusive*
Structured PI list (Box 6)	*Standardised*	*Not yet for control purposes*
Benchmarks		
Checklists (Box 7)	*Quick insight*	*Rough and rigid*
Surveys (Box 8)	*Acceptable if available*	*To be used with caution*
Graphical reports		
Pie, line & bar chart (Box 9)	*Popular*	*Misuse*
Perf. potential graphs (Box 10)	*Actual vs target*	*Often subjective*
Radar graphs	*Clear insight*	*Limited number of PIs*
Elaborated methods		
Hibi (Box 12)	*Global*	*Rigid and complex*
Luck (Box 13)	*Fairly global*	*Complex*
MMT (Box 14)	*Handy management tool*	*Careful implementation required*

Box 4 Example for overall performance indicator

The following overall PI represents the relative merits, on a year-to-year basis, of the maintenance function within an organisation (a detailed discussion of this PI may be found in Jardine (1970)):

$$E = \frac{k}{xC + yL + zW}$$

where:

- C = total maintenance cost expressed as a percentage of the replacement value of the plant and equipment
- L = lost time due to maintenance expressed as a percentage of the scheduled production hours
- W = waste of materials due to poor maintenance expressed as a percentage of the total output at the appropriate stage of the process
- x = total cost of maintenance in base year
- y = total cost of lost time due to poor maintenance in base year
- z = total cost of waste produced due to poor maintenance in the base year
- k = a constant such that the efficiency index equals 100 in the base year

Box 5 Example for MRO (maintenance, repair and operating supplies) store

- items in inventory
- items removed from inventory
- items added to inventory
- inventory value
- average value of inventory
- number of movements
- value issued
- number of stockouts
- turnover

Box 6 Example for maintenance efforts, effects and effectiveness

- **maintenance effort:**
- department operation
- manpower
- work order
- economy
- service assessment
- service operation
- maintenance intensity
- service cost

- **maintenance effects:**
- plant condition
- breakdown severity (MTTR)
- breakdown frequency (MTBF)
- plant performance
- machine utilisation
- output quality

- **overall effectiveness:**
- progress in cost reduction index
- degree of maintenance intensity index

- **overall economy service index**

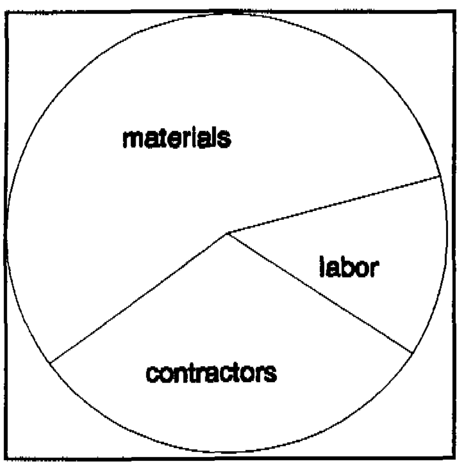
Box 7 Example for materials management

indicator	value	norm	note
rotation ($/month)	.....	3-4	exclusive critical items
% no-demand	.....	3-5	not available when needed
% dead items	.....	1-3	no demand for 2 years

Box 8 Maintenance cost as % of total production costs

Sector	%
pharmaceutical	2
metal working	1-3
textiles	3-5
paper	8-10
chemical	10-15
mining	15-25

Box 9 Example for maintenance budget



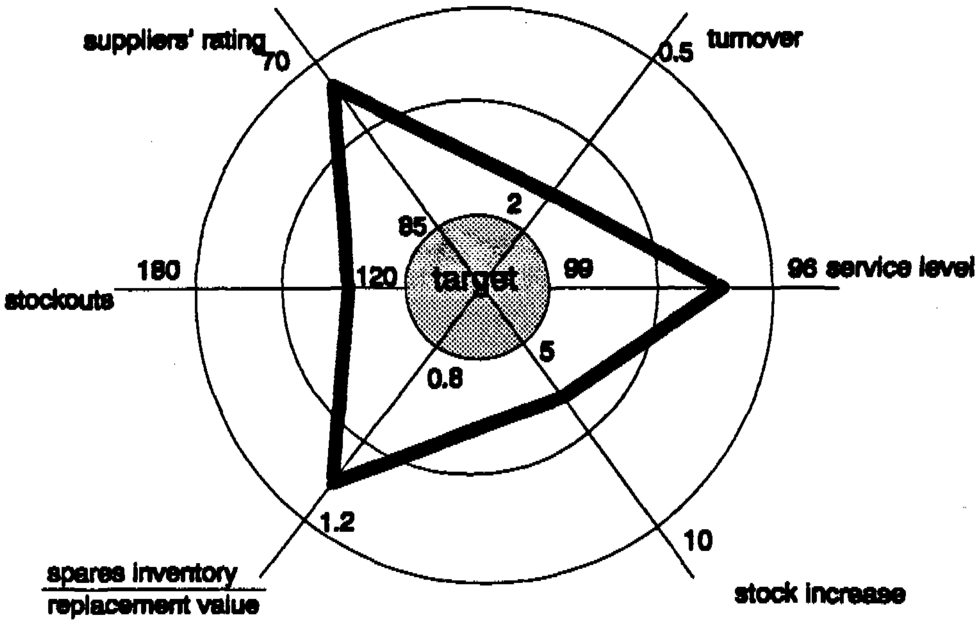
Box 10 Example of perf. potential graph

master score		overtime (%)		effectivity (%)	budget variance (%)
poor	0	10	0	0	+/- 10
	1				
	2	9	1	20	+/- 8
	3				
	4	8	2	40	+/- 6
	5				
	6	7	3	60	+/- 4
	7				
	8	6	4	80	+/- 2
	9				
Excellent	10		5	100	+/- 0

Note:

- overtime % = hours worked in overtime/total number of hours worked * 100
- effectivity = % of jobs done RFT (Right the first time), i.e. jobs executed properly so that no new intervention is required (say within 3 days) after the first one
- budget variance = (budget - costs)/budget * 100

Box 11 Example of radar graph



The above graph represents six PI's for an MRO store. For each PI another axis is drawn. Peformance improves from the outer circle inwards. The target values for the PI's may be found on the inner circle. The thick line indicates the current performance. The distance between the target circle and the thick line thus represents the difference between the desired and the actual performance.

The indicators are defined as follows:

- suppliers' rating = number of orders without mistakes received/total number of orders received
- stockouts = number of times an item requested by O&M was not readily available from the MRO store
- spares inventory/replacement value = classical measure often used in manufacturing industries
- service level = number of requests from O&M fulfilled immediately and accurately/total number of requests
- turnover = annual usage/inventory value: it gives an indication of the time an item spends on average in stock: the higher the turnover, the faster the item moves, ie the less time it spends in stock
- stock increase = new items added to the stock/number of items already in stock; this can be kept low through disposal of obsolete items and standardisation of new equipment

Box 12 Example of elaborated method (after Hibi)

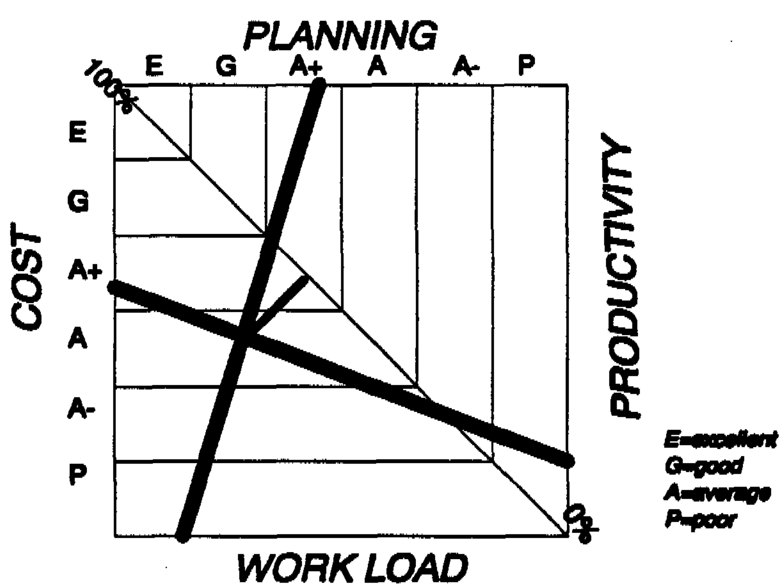
integrated efficiency scale =(total repair cost + total amount of production losses, yield ratio, supplies, energy, quality, etc resulting from shutdown by failure or malfunction)

----

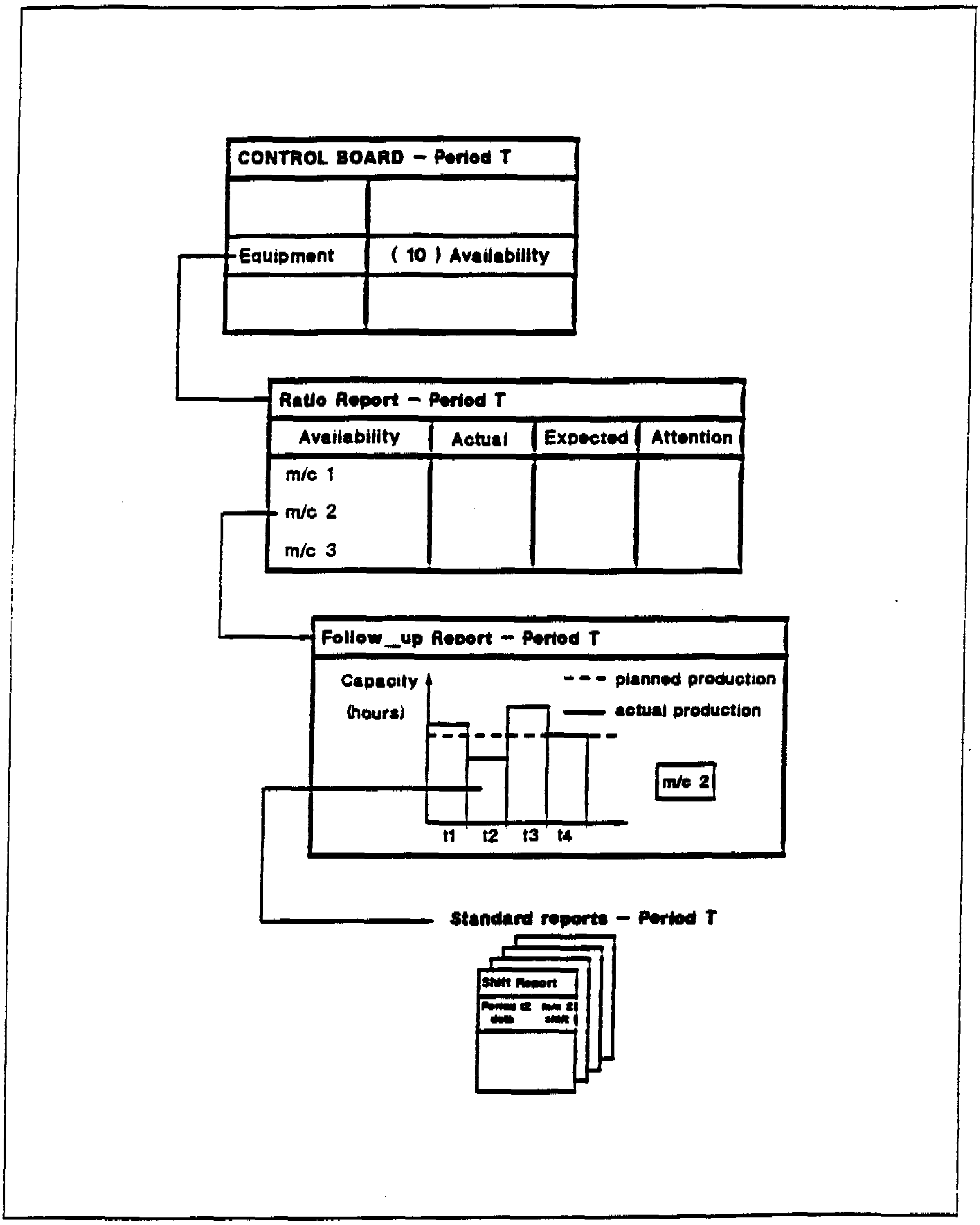
total value of control scale

Box 13 Example of elaborated method (after Luck)

The graph represented below is modelled after Luck (Jardine (1970)). Four aspects contributing to the global performance are chosen and measured along the four sides of a square. A suitable scale on the side of the square is then chosen by the decision-maker for each index such that the graduations on the opposite sides of the square result in a (not necessarily linear) progression through six subjective ranking values from P (poor), through A+, A, A- (average), G (good) to E (excellent). The actual performance for each of the aspects is indicated on the sides of the squares and opposite sides are connected. The intersection of these lines gives the overall performance. By projecting the intersection point perpendicularly onto the diagonal a numerical value for the global performance is found.



Box 14 Example of elaborated method (maintenance management tool)



Performance reporting tool: an example

In order to make the performance evaluation process as productive as possible, one could think of organising chosen performance indicators (PI's) through a control board linked to a network of detailed reports. An example of such a maintenance management tool (MMT) used in some Belgian firms can be found in Pintelon (1992) and is illustrated in Box 14.

The small but carefully chosen number of PI's on the bi-monthly generated control board gives a clear picture of the different aspects of O&M performance and their inter-relationships. By comparing actual values for these PI's over a given period with predetermined target values, it is possible to identify potential problem areas. The causes of these problems can then be tracked by investigating the detailed reports in question.

For example, one of the indicators on the control board may relate to the % of overtime worked. Assume that the % of overtime for a period was 25%, a figure much higher than the target of 5% or less. If this occurs continuously, then reference could be made to various reports - a trend report, a pie chart showing the % of time maintenance workers spent on their different duties, or a stacked bar chart showing the number of hours and overtime hours spent on each of the areas. More details to help identify the problem could be found in the shift reports or top-ten-job-list for the job area in question.

Guidelines for the use of detailed reports

- *Self-supporting*. Detailed reports (DR's) should contain all the necessary information required to read and understand its contents. Cross referencing to additional information from other reports should be avoided.

- *Function*. A DR should also contain information about its location and function in the DR network. This permits more efficient searching within the network.

- *Uniformity*. DR's should be as uniform as possible in order to facilitate consultation.

- *Selection*. Avoid generating numerous 'just-in-case' DR's that are infrequently used. The user should be able to generate additional reports if necessary.

- *Statistical relevance*. Statistics that are used need to be relevant and easily aggregated and disaggregated.

- *Duplication*. Avoid duplication in order to maintain a clear and transparent DR network. A small degree of duplication cannot be avoided and can sometimes be of interest.

- *Graphs*. The choice of graphical representation needs to be made carefully.

Guidelines for the selection of performance indicators

- *Purpose.* PI's should be matched to the objectives of O&M and their role in achieving those objectives needs to be clear.

- *Visibility.* Each PI should be relevant and transparent in order to provide insight.

- *Definition.* Defining a performance indicator is a time consuming process in which PI's are suggested, critically analysed and redefined until a consensus is reached on their value. All persons involved in the use, analysis and targeting of O&M should contribute to this process.

- *Control power.* PI's should be used to report on the performance of O&M which is under the control of the user, i.e. on the process that he or she, either alone or collectively, can influence. Informative PI's can be interesting, but for effective management, control PI's are needed.

- *Computation.* The method of computation and data collection must be carefully defined for each PI. The method must allow for validation of input data (how data can be retrieved, interpreted), and clear definition of data collection points.

- *Consistency.* PI's must remain consistent over time, and in the face of other variations in, for example, exchange rates, inflation or interest rates.

- *Comparability.* Careful consideration must be given to comparison of PI's between divisions or companies because of differentials in circumstances and/or targets.

- *Aggregation.* The use of a single PI to evaluate overall efficiency should be avoided, since the ratios used in aggregation may obscure valuable information. It is recommended that a relatively small number of ratios be chosen for each topic, such as capital, manpower, material, equipment and service.

- *Data integrity.* The integrity of data and timeliness are essential elements for PI's. Since PI's aggregate large quantities of information, it is crucial that they are reliable, with cross-checks being built in where possible.

PERFORMANCE INDICATORS FOR THE OPERATION AND MAINTENANCE OF URBAN WATER SUPPLIES

Introduction

Frequent disruption to water supply and poor water quality can be a serious threat to human health, safety and socio-economic development in urban areas. In addition, the incidence of unaccounted-for-water that arises from leakages, differing types of water supply systems, illegal connections to distribution pipes or failures in the accounting system may have a considerable impact in terms of water shortages or costs of developing a new water supply. Thus, the importance of effective O&M to the overall WS&S system should not be underestimated.

Effective O&M must be co-ordinated with government departments that have responsibility for activities that may lead to the contamination of ground or surface water supplies, especially through landfills, sewerage systems or hazardous waste disposal.

The introduction of performance indicators for O&M of urban water supplies will help management evaluate the performance of this function and plan for major capital improvements.

Existence of an O&M management system

For performance indicators to be effective, it is important that a functioning management system is in place (this applies equally to rural water supplies). In order to assess the thoroughness of the management system, a 'level of perfection' (see Marcelis' philosophy, Marcelis (1979) & (1984)) could be assigned. Five categories of 'perfection' can be identified, based on the following criteria (see also Box 15):

- *structure of the management process*: how far are decisions taken according to established procedures?

- *feedback process*: how far, and how often, are decision outcomes checked with the corresponding objectives?

- *forecast horizon*: how far ahead does management look for their decisions concerning O&M?

- *integration level*: are decisions concerning O&M taken with sufficient insight and knowledge of the broader context?

Box 15 Criteria used to assess thoroughness of O&M management system (after Marcelis)

Level of perfection	Management process structure	Feedback	Forecast horizon	Integration
very low	no rules	never	no	no
low	rules of thumb	sometimes	small	a little
medium	rules	regularly	reasonable	reasonable
high	procedures	often	considerable	far-going
very high	systems	always	large	total

Methodology

When choosing performance indicators for O&M, several factors need to be taken into account. The following example indicates the types of questions required in the search for appropriate PI's.

Example: If we are planning to use performance indicator x (PIx) for measuring performance in area X, where PIx = % overtime and X = personnel utilisation, then the following types of questions should be considered:

- is X an area under the control of O&M?
- will the PIx measure record what is needed?
- will problems in area X be detected by the use of PIx?
- does PIx give an idea of the magnitude of the problem?
- is data available to compute PIx?
- is PIx accepted by the people involved?
- are there any other indicators that can help identify the cause of the problem?
- can alternative solutions be found?
- who, besides O&M, will use PIx?

It should be noted that PI results not achieving target levels do not necessarily mean that the O&M function is below standard. Instead, this may indicate that O&M works in a difficult environment (ie, with inappropriate technology, excessive delays for delivery of spare parts, etc). Awareness of this point may prevent the wrong conclusions being drawn and help motivate staff within O&M. Thus, it is crucial that with formal performance reporting systems that:

(i) a thorough understanding of the O&M function and its context has been made, ie, through the auditing procedure.

(ii) that the expectations concerning O&M performance are realistic and that a commitment to carry out corrective action is present amongst staff.

Performance indicator (PI) selection

The PI's for urban WS&S systems are grouped into the following areas:

- Service
- Equipment
- Financial
- Personnel
- Materials
- Work order control

No attempt was made to rank the performance indicators (ie, A, B, or C) in the urban environment since ranking depends too much on the specific working context. To evaluate the overall performance of O&M, indicators should not be considered on any individual basis, but as part of a bigger whole. It is hoped that the case study work in the next stage of the project will enable rankings to be investigated.

Service PI's

One way of measuring the performance of the WS&S system is through consumer perception of the water supply service, including water quality and water delivery. O&M practices will contribute significantly to the satisfactory performance of these aspects of the service.

Water quality may be expressed by its bacteriological content, depending on local water quality standards and objectives (for a more detailed discussion of this measure, the reader is referred to the rural water systems chapter).

Water quality indicator = percentage of samples > target number of E.coli per 100ml

The objective is to reduce this indicator.

In order to measure the performance of water delivery services, an indicator recording the availability of the water supply is used. This indicator records the extent to which a continuous water supply is provided over a set period.

Water supply indicator = number of hours of water supply per day /24 hours

The objective is to increase this indicator, ideally to 1 or 100%.

Equipment PI's

The availability and reliability of equipment is an integral part of the O&M management function which should be subject to regular performance evaluation. This group of performance indicators focuses on equipment which is the responsibility of O&M, such as treatment plants, pumping systems, distribution networks and maintenance vehicles.

Two commonly used indicators to evaluate maintenance practices are MTBF (mean time before failure) and MTTR (mean time to repair). The higher the value for MTBF, the less frequently breakdowns occur and the more efficiently the system operates. A low MTBF value indicates poor standards of maintenance work (incorrect or inappropriate repairs), or equipment failures (through fatigue). The objective is to increase the indicator.

MTTR indicates how long repair work takes to complete. Low MTTR values point to systems which are 'maintenance friendly', that is systems that are easy to maintain through modular design and/or efficiently organised maintenance work. The objective is to decrease the objective.

While MTBF is frequently used as a measure of the system's reliability, MTTR indicates the system's maintainability. In combination, MTBF and MTTR measure the overall availability of the system. The performance indicators are defined as follows:

MTBF = length of period considered/number of failures in that period

MTTR = total time spent on repairs/number of repairs

availability = MTBF/(MTBF + MTTR)

Although system failures and breakdowns cannot be ruled out completely, it is important to limit their incidence as much as possible. If breakdowns do occur, it is preferable that they are small in nature and quick to repair.

Several other indicators can be used to evaluate equipment performance, including: number of failures, number of severe failures, and top-ten critical item list.

Other related indicators, which are more specifically designed for WS&S systems are:

Unaccounted for water (UFW) = total annual production - total annual metered consumption + estimated annual non-metered consumption

% of UFW = UFW/total annual production

The objective is to reduce both the indicators.

% of fire hydrants in working condition = number of fire hydrants in working condition/total number of fire hydrants

% of consumer meters in working condition in domestic, industrial, commercial, institutional consumer categories = consumer meters working/total number of meters

The objective is to increase both the indicators.

Financial PI's

Effective budgetary control and measurement of costs and revenues is a key element to successful O&M management. Several performance indicators have been defined to assist in this task:

The *Year-to-date* measure (YTD) establishes to what extent the annual budget has already been used, by calculating costs incurred to the present time and comparing this figure with the budget allocation for the same period.

The *cost component percentages* (ie, labour, materials, contractors) indicator identifies the areas where money has been spent and where potential savings can be made.

The remaining indicators falling within this group focus on relative measurement of the costs and revenues of WS&S systems, by calculating the average costs and/or revenues per consumer, per connection, and per km of distribution mains served, etc (for a more detailed discussion of these measures, refer to the chapter on performance measurement in WS&S systems in rural areas). These indicators are valuable for comparisons between systems, as long as the systems in question are similar in structure.

operating revenue per capita served = operating revenue/population served

operating costs per capita served = operating cost/population served

operating surplus (loss) per capita served = operating revenue minus operating costs/population served

operating costs per connection = operating costs/number of connections

total costs per connection = total costs/number of connections

operating costs per m^3 *water billed = annual operating cost/total annual water billed*

% of O&M asset expenditure to asset value = total annual O&M expenditure /total asset value

% of expenditure for staff to O&M expenditure = total annual expenditure for staff salaries and benefits /total annual O&M expenditure

annual maintenance expenditure per new capital investments

annual maintenance expenditure per km of distribution means *working ratio = operating costs/operating revenue*

Personnel PI's

Human resources can, in the right environment, significantly improve the O&M function of WS&S systems. In the wrong environment, they can weaken and hinder the same system. Developing a way to evaluate the performance of personnel is crucial if the latter is to be avoided. The performance indicators defined in this group are designed to provide an insight into the workload of O&M employees.

If different skill groups are represented within the personnel structure, it may be preferable to calculate performance for the whole staff complement *and* the different skill groupings, since an average figure for the whole staff may be skewed by, for example, an overstaffed crew of mechanics or understaffed crew of electricians.

The following indicators can be defined:

% overtime = amount of time worked in overtime/total time worked

% time idle = amount of idle time/total time worked

% absenteeism = amount of time lost through absenteeism/total time worked

% time spent on training = amount of time for training/total time worked

Occasional periods of overtime are to be expected, especially when large repairs have to be undertaken, but in general it is preferable that the percentage of overtime should be kept to a minimum where possible to reduce costs. Idle time is a useful indicator of staffing levels: a small amount of idle time is normal (ie, reserved for emergency tasks), large idle time figures may indicate overstaffing. Absenteeism through phantom illnesses or unauthorised leave should be kept to a minimum: staff motivation is a useful tool to help reduce its incidence. Training is crucial to the effective transfer of technology and sufficient time for staff development needs to be made available.

Materials PI's

The proper functioning of O&M depends to a large extent on the availability of the (right) materials. The indicators defined below measure materials management practices:

The first three indicators reflect the financial importance of the materials component in the O&M function, and may be of use in comparing the performance of similar systems.

annual usage = annual amount of money spent on spares and materials *inventory value = value of inventory in MRO store*

number of spare parts and materials in MRO inventory

The next set of indicators evaluate the MRO. The results obtained from these indicators may be used to alter management practices, for example, by employing additional personnel to check, store, and retrieve elements if the number of issues and receipts recorded is very large.

number of issues

number of receipts

number of orders running

Frequent breakdowns may be the result of using badly repaired spares or spares that have had excessive use. If the figure for new spares is low this may indicate that the equipment is easy to maintain or that new spares are not available. The following indicators are measures that are used to determine how frequently spares are replaced.

number of new spares used

number of repaired spares used

Two other indicators can be used to measure service levels. The average lead-times is a measure of the service from the suppliers to the MRO, while the number of stockouts is a measure of the service between MRO and O&M.

average lead-time = average time between placement of the order with the supplier and receipt of the order

number of stockouts

Work order control PI's

Work order control allows the use of O&M resources to be effectively planned and applied. In the following list, the first two indicators are used to evaluate the work order system: too many small jobs are difficult to plan, as are too few large jobs. The measure for backlog indicates the future workload for O&M: an excessive backlog may require the temporary hiring of contractors.

The operating costs indicators measure the effort spent on their respective category of maintenance work. Those for planning allow a large portion of O&M work to be planned in advance.

number of jobs carried out (specified per type: equipment, distribution system, vehicles, building and grounds) *duration of jobs = average time spent on O&M job*

backlog = amount of work overdue (days)

% of operating costs spent on preventative maintenance (PM)

% of operating costs spent on corrective maintenance (CM)

% of operating costs spent on modification jobs

% planned work = hours planned at the beginning of the week/hours to be worked during week

% work according to plan = hours worked according to plan/total number of orders planned

Summary of Performance Indicators for Urban Water Supply

Service PI's

water quality
water supply

Equipment PI's

MTBF
MTTR
availability
number of failures
number of severe failures
top-ten critical list item
unaccounted-for water (UFW)
% of UFW
% fire hydrants in working condition
% of consumer meters in working condition in consumer categories: domestic, industrial, commercial, institutional

Financial PI's

YTD cost
cost component percentages: labour, materials, contractors
operating revenue per capita served
operating costs per capita served
operating surplus (loss) per capita served
operating costs per connection
total costs per connection
operating costs per m^3 water produced
operating costs per m^3 water billed
% of O&M asset expenditure to asset value
% of expenditure for staff to O&M expenditure
annual maintenance expenditure per new capital investment
annual maintenance expenditure per km of distribution means
working ratio

Personnel PI's

% overtime
% idle time
% absenteeism
% time spent on training

Materials PI's

annual usage
inventory value
number of spare parts and materials in MRO inventory
number of receipts
number of orders running
number of new spares used
number of repaired spares used
average lead-time
number of stockouts

Work order control PI's

number of jobs carried out (specified per type: equipment, distribution system, vehicles, building and grounds)
duration of jobs
backlog
% of operating costs spent on progressive maintenance (PM)
% of operating costs spent on corrective maintenance (CM)
% of operating costs spent on modification jobs
% planned work
% work according to plan

PERFORMANCE INDICATORS FOR O&M OF RURAL WATER SUPPLIES

Introduction: The State of O&M

Problems of O&M are widespread, if not universal, with rural water supplies. If a functioning management system for O&M is in place, then performance indicators can be a valuable management tool for assessing the status of O&M. That is, carefully selected performance indicators can highlight the successes and failures of the O&M management system. Indeed, a major problem to date has been setting up such functioning management systems for the O&M of rural water supplies. In remote areas, all too often the community is left to its own devices without the necessary initial or follow-up support from external agencies.

There are numerous reports which highlight problems with O&M of rural water supplies. In many cases the reason is that there is simply no effective management system in place; the necessary actions required to improve the situation may be fairly obvious, but nevertheless difficult to implement. A few examples are quoted below.

Feacham et al (1976) in an ex-post evaluation of rural water supplies in Lesotho comment that,

'..(the Ministry) have until now had no policy for the maintenance of rural water supplies.'

More recently, reporting on the Burkina Faso rural water supply programme, WASH (1986) state that,

'..the greatest failure of the project is the lack of a functioning pump maintenance system.'

Morrison-Maierle/Sheladia (1987) comment that in Lesotho,

'..the organisational plan for maintenance of handpumps has not been implemented.'

WASH (1985) report that in drought-stricken Ethiopia,

'Effective O&M, for all practical purposes, is non-existent.'

In the Solomon Islands WASH (1986) observed that,

'..plans to implement an effective maintenance programme had not been drafted.'

And so the list goes on.

Engendering the right 'cultural environment' (Koch, 1991), in which staff appreciate the very concept of O&M, is not a simple task, as illustrated by the following anecdote from South Asia (Smith 1993).

'The likely consequences of a policy resulting in poor maintenance were outlined; the engineer was asked what would happen, as the scheme would eventually cease to function. He replied that (the government organisation) would then request further aid to rebuild the scheme.'

There are some success stories; Easton (1985) reports that in Malawi most pipe breakages were repaired in two days or less. The evaluation of the rural water supply programme (WASH, 1986) observed that,

'..the division of maintenance responsibilities between the local communities and the RWS (Department of Water) is reasonable and effective.'

O&M Management Systems

There are a number of models for O&M management (WASH, 1993; Arlosoroff et al, 1987; WHO, 1992). The essential differences relate to the degree of involvement of the user community, the role of different public institutions and tiers of government, and the involvement of the private sector. The most useful document reviewed in this respect was the report by WASH (1993), which includes a succinct overview of maintenance management models and a series of field-based case studies to illustrate these different models.

In summary, the models for O&M management range from highly centralised ones which are entirely the responsibility of government, to community managed schemes owned, operated and maintained by a local community-based organisation. In between these extremes there is a continuous spectrum of models involving the community, the various tiers of government, and the private sector.

Arlosoroff et al (1987) identify three systems when considering community water supplies using handpumps.

Village level maintenance has been epitomised by the concept of *VLOM* - originally 'Village Level Operation and Maintenance', but more recently 'Village Level Operation and Maintenance Management'. All routine inspections and minor repairs are carried out by trained people from the community, hereafter referred to as caretakers. A mechanism for support, and the reporting and repair of serious faults is put in place. There is minimum intervention from external agencies. Community based O&M management is hereafter referred to as *VLOM*.

Area-mechanic maintenance in which a trained mechanic who is locally based carries out repairs, involving the communities to a greater or lesser extent.

Centralised maintenance systems use a team of trained technicians who travel out from a depot in order to effect inspection and repair of facilities. Communities have little if any input. It is most common for the public sector to carry out this service, although the private sector may be involved.

The traditional model of centralised management tends to be unresponsive and expensive to operate (Arlosoroff et al 1987). In reviewing evaluation reports, for example, SWECO (1978), Ashford and Miller (1979) and Agrell et al (1984) in Botswana; UNICEF (1984) in Uganda, it is clear that the institutional problems associated with centralised maintenance may run very deep. Recent trends have recognised that adopting the VLOM approach may be more realistic than persevering with centralised maintenance through the attempted reform of institutions which verge on the moribund.

At opposite ends of the spectrum lie the two distinct management approaches which could be encountered, namely VLOM and centralised management. Many of the performance indicators discussed below can in principle be applied to either; however, when the performance indicators are evaluated, it is important to realise that two categories of management response are possible.

1. Diagnose the cause of the problems and look for ways around bottlenecks in order to improve the rating as measured by the performance indicators. This could apply either to VLOM or to a centralised or partly centralised system which appears to be functioning.

2. The particular management system in place may not be amenable to piecemeal improvements; if the problems run so deep, an alternative response is to conceptually overhaul the management system, for example by moving away from a centralised system towards VLOM or by looking to public-private sector partnerships.

Performance indicators are a useful management tool to assess the effectiveness of an O&M management system; Box 13 describes posible criteria for assessing the management system. However, several of the documents quoted previously highlight the total absence of just such a system. If it is obvious from first sight that no system exists, then the assessment procedure whereby a list of performance indicators are evaluated need go no further. If there is no management system for O&M, the first step is to put one in place.

Performance Indicator (PI) Selection

The basic principles of the methodology have already been outlined in the Introduction and in the chapter on performance indicators for urban water supplies. The grouping of indicators used, namely

- Service
- Financial
- Personnel
- Materials
- Work order control

are the same as for urban water supply with the exception that no indicators are proposed under the heading *equipment*.

An attempt is made in the summary table at the end of this chapter to rank the performance indicators into three categories (Office of Drinking Water, 1991) thereby suggesting their relative importance.

Category 'A': indicates major performance deficiencies which should be the central focus of improvement programmes.

Category 'B': indicates factors which routinely contribute to poor performance.

Category 'C': indicates factors which contribute to a performance problem but only have minor effects

It is understood that such classification is somewhat arbitrary without the support of case study or field investigation. However, the classification is incorporated as a 'first attempt' and it is hoped to refine the system during the subsequent stages of the project. It is suggested that an O&M assessment procedure concentrates on category 'A' indicators. If serious problems are highlighted here, the probability is that the O&M management system is in crisis and performance improvement actions can be proposed on the basis of these indicators alone. It should not be necessary to proceed further to the 'B' and 'C' indicators unless the objective is a full performance audit. Conversely if no serious problems are identified under category 'A', the assessment procedure should progress down the hierarchy of 'B' and 'C' indicator categories.

Service PIs: Number of supply points in working order

Most rural water supplies deliver water to public supply points, whether they be standposts or handpumps. A simple count of the number of these which are not delivering any water is a direct indication of the O&M status.

Functioning Supply = Number in working order/total number
Points Indicator

This indicator also points to the actual benefits which the water supply provides because it is indirectly related to:

- the percentage of the population utilising the system;

- the per capita water consumption.

The objective is to increase the number of functioning supply points.

Service PIs: Reliability

A common measure of the reliability of a mechanical system is the 'mean time before failure' or MTBF, that is the length of time for which the system can be expected to operate before some maintenance input is required to rectify problems which have caused the system to breakdown. The 'mean time to repair' or MTTR is also important, because it reflects the average period for which the system will be out of service when it does break down.

In many rural water situations alternative water sources are rarely available; the concepts of MTBF and MTTR need to be used to define reliability in a way which reflects the most serious problems for people, namely the lack of availability of water due to breakdown (Arlosoroff et al, 1987). The term 'reliability' is defined as the probability that the system will be functioning on any one day.

Reliability Indicator = *Functioning time/total elapsed time*

This can be illustrated by an example.

The water supply to village 'A' has a surface water source with a stream intake structure which silts up during the rainy season. The MTBF is 6 months and the MTTR is 1 week.

The water supply to village 'B' is using handpumps. The MTBF is 20 months and the MTTR is 1.5 months.

In terms of MTBF, village 'B' is judged to have a more 'reliable' supply than village 'A'. However, in terms of reliability as defined above,

reliability for village 'A' = 26/27 x 100 = 96%

reliability for village 'B' = 20/21.5 x 100 = 93%

Therefore according to the reliability indicator, village 'A' has a more reliable water supply.

For a handpump supply, this is a relatively straightforward indicator as the problems will be due to handpump malfunction. However, for piped supplies there are a number of different components within the system which may cause failure. Examples are the intake structure, pipelines, storage reservoirs and public standposts; larger rural supplies may include simple treatment and electrically powered pumping. Different components will have different reliabilities; for example if a longer time horizon were adopted for the simple example shown above, pipeline breakages may become more frequent and the overall system reliability may reduce.

Whilst the simple definition of reliability is a good indicator to apply to an overall system, it is sensible to apply it to individual components of more complex systems. This enables 'weak points' to be highlighted.

The reliability indicator may also point to problems with the system of reporting, diagnosing and repairing faults. The objective is to increase the reliability.

Service PIs: Water Quantity

It has long been established that the provision of an adequate quantity of water is crucial if anticipated health benefits are to be achieved (Cairncross and Feacham, 1993). Public supply points (handpumps and standposts) should be planned and designed on the basis of the quantity of water to be delivered to a particular population catchment. Lack of maintenance or inadequate operation can lead to reductions in the quantity delivered; conversely, assessing the quantity can indicate O&M problems.

A thorough evaluation of handpump performance is available (Arlosoroff et al, 1987). The discharge from a sample of handpumps can be measured by timing how long it takes to fill a bucket of known volume; this can then be compared with the recommended rating as given by Arlosoroff et al.

In piped water supplies, a lack of flow may indicate leaks or breakages in the pipelines. The discharge can be measured as described above, and the values obtained should be compared with measurements taken immediately after the system has been commissioned. The problem in comparing the measured discharge with a design value is that errors in hydraulic design are not uncommon and a standpost may never be capable of delivering its so-called design flow.

A flow rating indicator can be defined.

Flow Rating Indicator = *Present discharge/discharge after commissioning*

If (as is commonly the case) the water supply system is not checked in this much detail after commissioning, the design flow or design rating could be used.

In addition, the pressure available at the standpost determines how much water is discharged. The pressure of water issuing from a tap can be measured using a simple Bourdon pressure gauge which is connected to the tap using a short length of flexible hose and an adjustable clip. Ideally, the residual pressure at the tap should not be less than 5 metres to ensure a reasonable flow. Unusually low pressure may indicate O&M problems such as breakages or leakage elsewhere in the system. However, it is important to note that low pressure can also result from the following.

1. Poor hydraulic design of the transmission and distribution pipelines, leading to zones of chronic low pressure.

2. The system has not been properly commissioned; valve settings need to be adjusted to ensure that the flow distribution throughout the system is satisfactory.

A pressure rating indicator can be defined.

Pressure Rating Indicator = *Present pressure/pressure after commissioning*

If the residual pressure after commissioning is unknown, the design value of residual pressure should be used.

The objective is to increase both the flow and pressure rating indicators.

Service PIs: Short term interruptions to supply

The concept of reliability has been applied to describe the medium and long term performance of a system in terms of the availability of water. A characteristic of many supplies is that they are discontinuous, with water only being delivered to the taps for a few hours each day. Whilst this is a particular problem in urban areas, it can also affect piped supplies in rural areas and be particularly acute in the dry season. This can be measured by the supply continuity indicator.

Supply continuity indicator = Average number of hours supply per day/24

A high value for this indicator implies good continuity of supply. The problem which arises is how to compute the average number of hours per day supplied; ideally it should be an annual average using data from each day of the year in the different supply zones to account for weekly, monthly and seasonal variations in supply and consumption. Efforts should be made to obtain a value for at least each month of the year .

Service PIs: Water quality

At the planning and design stage the water source, whether it be ground or surface water, will usually be sampled and chemical and bacteriological parameters determined. A water quality surveillance programme (WHO 1985) should be able to monitor and detect deterioration in water quality which will indicate O&M problems. It is important to realise that diagnosing problems in piped systems involving treatment and storage can be complicated.

Whilst sampling at public supply points gives an indication of problems within the system, it does not necessarily indicate the quality of water which is actually consumed within the home. Family hygiene awareness greatly affects the way water is stored and used in the home once it has been collected from the public supply point. Agrell et al (1984) comment on the results of a water quality survey in rural communities in Botswana:

'The survey revealed that although the majority of the supplies delivered bacteriologically safe water, water in containers in the home was usually grossly contaminated.'

WHO (1983) suggests that the target for drinking water quality is zero E.Coli bacteria. Recognising that such targets may take many years, it is stated that,
'It is not unusual that a protected spring without chlorination contains 5-10 E.Coli per 100 ml and in an unprotected spring the number might exceed 100.'

Depending on the frequency of water quality surveillance, a water quality indicator can be defined in terms of the number of indicator bacteria.

Water Quality = Number of samples > target number of E.Coli per 100 ml

Indicator

As with other performance indicators, the target number of E.Coli per 100 ml has to be set locally, taking account of local water quality standards and objectives.

The objective is to reduce this indicator.

Financial PI's

Lack of finance is one of the major reasons for the failure of traditional centralised management of O&M. Cost recovery from rural water supplies is poor or non-existent; the necessary public sector subsidies are often too low and too unreliable to permit this model to be effective. More appropriate VLOM models have tried to overcome this by developing a system which depends upon involvement and control by the user community for the user community. In general, financial balance sheets are not available for most rural water supplies, and traditional financial indicators can be difficult to apply .

If the O&M system is centralised, the necessary information on costs should be obtainable. However, WASH (1992) comment on the difficulties of extracting information on levels of subsidy in order to calculate meaningful financial indicators for O&M performance. A VLOM system may or may not pay the village caretakers, but a maintenance fund will normally be required in order to purchase spare parts.

Cost Indicator	=	*Average O&M cost per user*
Revenue Indicator	=	*Operating revenue/population served*
Cost Recovery Indicator	=	*(Receipts + subsidies)/average O&M cost*

A major difficulty in defining a cost recovery indicator is that the average O&M cost should represent the money actually *needed* to carry out O&M. The problem with the centralised approach is that a budgetary allocation may be made for each household or each community based on the expected income from user charges and subsidies; in other words, whilst 'the books balance', the actual demand for O&M is not met. This does not reflect the expenditure necessary to operate and maintain the system; the result is a spiralling deterioration of the assets. The initial problem here is that whoever is undertaking the performance assessment needs to be able to make an intelligent guess at the actual average O&M cost which is required. Priority-based budgeting is potentially an important tool in this respect.

If the cost indicator points to a very poor performance in a centralised system, it is appropriate to consider an alternative management system more along the lines of VLOM.

Personnel PI's

The availability and deployment of human resources are a key component in O&M management. Whilst 'shortage of staff' is often quoted anecdotally as a reason for poor O&M performance, it may be that the deployment of existing staff is inefficient. Ashford and Miller (1979) comment on pump operators in Botswana:

'These pumpers would be underemployed, in that for long periods each day they would be doing nothing except watching an engine run.'

The personnel requirements will be substantially different for the VLOM and centralised management approaches. For a VLOM system, the crucial issue is that a functioning water committee exists for each community water supply.

VLOM Personnel Indicator = No. of systems with functioning committees/total no. of systems

One possible measure of this is to check that caretakers have been identified for the community water supplies. This gives a primary indication of whether or not the system is working according to its original concept.

The objective is to increase this indicator. Similar indicators can be applied to the different levels of the VLOM system; for example, there might be an 'area mechanic' responsible for a number of water supplies. Other performance indicators e.g *functioning supply points* and *reliability* can be used to point to the effectiveness of the personnel involved.

If there are centralised mobile maintenance teams, a prerequisite is that they are mobile. The percentage of serviceable vehicles on the road gives an indication of the potential effectiveness of mobile maintenance teams.

Maintenance team indicator = No. of vehicles on-the-road/no. of vehicles in fleet

The objective is to increase this indicator. Personnel indicators for centralised systems depend upon the size, complexity and spatial distribution of the water supplies.
The effectiveness of staff, whether under a VLOM or a centralised system, depends upon the level of skill and training. For a VLOM system the different categories of people who require training include: local caretakers; operators; and area mechanics. There is evidence that women make very effective caretakers (Arlosoroff et al, 1987) and it is suggested that the VLOM training indicator be evaluated by gender (PROWWESS, 1990).

Training Indicator = No. VLOM personnel trained in each category per community (VLOM)

For a centralised system,

Training Indicator = No. of skilled staff trained/no. of skilled staff (Centralised)

This takes no account of the relevance or quality of the training, and as part of an institutional development programme, the issue of human resource development should be analysed in detail.

With centralised systems, the percentage of absenteeism, the percentage of idle time and the percentage of overtime worked can also be used as indicators of effectiveness, providing that a good record keeping system exists.

Materials PI's

The purchase, delivery and storage of materials for O&M of water supplies is an integral part of the O&M management system, whether it be VLOM or centralised, and it should be subject to performance checks. For example, the delivery time for spare parts may constitute a 'critical path' in terms of effecting repairs. 'Accessibility' of spares can be defined as the mean time from identifying the need for spare parts or materials to their arrival in the right place. In a VLOM system the process might involve the trained caretaker diagnosing the need for a spare, travelling to the nearest supplier and returning with the required part; this may require more than one journey if parts are out of stock. For a centralised system, accessibility is largely dependent on the stores procedures.

Spare parts accessibility indicator = Mean time for arrival of identified spares/materials

The objective is to reduce this indicator. Several other indicators can be used to assess performance.

1. *Number of outstanding repairs due to lack of spares.*

2. *Number of outstanding materials orders.*

3. *Number of items out of stock.*

The objective is to reduce all three indicators.

If very few spare parts are used, this suggests that O&M are not being carried out to the extent which is required. For example, Arlosoroff et al (1987) report that for handpump systems the average period between actions necessary to repair breakdowns or correct poor performance is six months. This average encompasses a wide variation depending upon pump type and service conditions.
One possible indicator would be

Spare Parts = Number of spare part requisitions per supply per year

This indicator is rather crude and difficult to define precisely; however, based on the findings of Arlosoroff et al (1987), if for example a handpump scheme had requisitioned no spare parts in four years, it might reasonably be assumed that it is not fully functional.

Work Order Control PI's

Any parts of the O&M management system which perform a service, for example a mobile maintenance team, or a VLOM area mechanic need to function to maximum efficiency. Effective control of their work is essential to avoid unnecessary delays in responding to breakdowns.

Poor performance may also point to factors which are more far reaching. For example in centralised systems, inadequate vehicle maintenance is often a serious problem; in VLOM systems, the key personnel have to be equipped with appropriate tools which are in working order. The number of visits to site which are required to effect a repair is likely to be a function of the skill and competence of the workers. Incorrect problem diagnosis can waste a lot of time, particularly with centralised systems dealing with water supplies which are widely dispersed.

Work Order Control Indicator = *Backlog of jobs*

The objective is to reduce this indicator.

Other indicators which relate more specifically to centralised systems include the number of employees per job and the average duration of jobs; these are described more fully in the chapter on performance indicators for urban water supplies

Health Indicators

Health indicators are not included in the recommended indicators for assessment of the status of O&M. Whilst many investments in improved water supply are predicated on health benefits, direct and specific linkages between improved water supply and better health status are notoriously difficult to demonstrate conclusively (Bradley et al, 1992). Additional interventions such as improved family hygiene and sanitation provision are crucial in fully realising potential health benefits. Because health indicators are difficult to interpret in terms of water supply only, they are not included in the proposed list of indicators.

Summary of Performance Indicators for Rural Water Supply

The following table summarises the preceding discussion of performance indicators. Each indicator is categorised as 'A', 'B', or 'C' which suggests its relative importance as defined in the Introduction.

Category 'A': indicates major performance deficiencies which should be the central focus of improvement programmes.

Category 'B': indicates factors which routinely contribute to poor performance.

Category 'C': indicates factors which contribute to a performance problem but only have minor effects

INDICATOR	DEFINITION	CATEGORY
Management System (O)	System in existence and being followed	A
Functioning supply points	$\frac{\text{Number in working order}}{\text{Total number}} \times 100$	A
Reliability	$\frac{\text{Functioning time}}{\text{Total elapsed time}} \times 100$	A
Spare parts Accessibility	Mean time for arrival of identified spares/materials	A
Cost	Average O&M cost per user	A
Operating Revenue	$\frac{\text{Operating revenue}}{\text{Population served}}$	A
Cost Recovery	$\frac{\text{Receipts + subsidies}}{\text{Average O\&M cost}} \times 100$	A

VLOM Personnel	No. of systems with functioning committees / Total No. of systems x 100	A
Maintenance team	No. of vehicles on-the-road / No. of vehicles in fleet x 100	A
Supply continuity	Average No.hours daily supply / 24	B
Flow Rating	Present discharge / Discharge after commissioning x 100	B
Pressure Rating	Present pressure / Pressure after commissioning x 100	B
Water Quality	% samples > target number E.coli per 100 ml	B
Training (VLOM)	No.VLOM personnel trained in each category per community	B
Training (Centralised)	No. of skilled staff trained / No. of skilled staff x 100	B
Materials and spares.	No.outstanding repairs due to lack of spare parts	B
	Number of outstanding materials orders	B
	Number of items out of stock.	
	Number of spare part requisitions per water supply per year	C
Work Control	Backlog of jobs	B

RECOMMENDATIONS FOR FURTHER WORK

Framework

The project '*Development of tools for the assessment of O&M status of water supplies in lesser and least developed countries*' was originally conceived in three phases. In essence, this report constitutes the output from Stage 1 of the original conception which is described below.

Stage 1: Literature review

See Terms of Reference for this project

Stage 2: Testing of O&M Assessment Procedure using Case Studies

During stage 2 the testing and the consolidation of the O&M assessment procedure will be carried out using checklists and questionnaires which allow a rapid comparative analysis. The assessment procedure will be applied to a limited number of selected case studies which will be representative of different O&M practices. A field investigation of operation and maintenance in selected countries/projects will be undertaken.

An interregional forum of executive sector professionals and decision makers from the countries and regions involved in the project will be convened to review results, evaluate experiences gained so far, and provide feed-back to the project in its further implementation.

The expected output of this project component is a draft Final Report with an elaborated O&M assessment procedure with indicator parameters measuring O&M performance in water supply systems.

The duration of this stage is estimated at 6 months.

Stage 3: Application of Assessment Procedure and Evaluation

A final evaluation of the O&M assessment procedure will be carried out through its application to a limited number of regions, chosen because of their great needs and the high level of investment in water supply facilities.

The results obtained will be reviewed by the Operations and Maintenance Working Group, who will test and evaluate the final results in a number of countries, and propose future actions.

The duration of this stage is estimated at 12 months.

An organisation chart, implementation charts and schedules are shown in Annex 2.

Expected Project Output

By the end of the project, the following outputs are anticipated.

1. A manual and general guidelines for O&M assessment of water supplies in LDC's applicable at regional, country and project level for sector professionals involved in the management of O&M of water supplies.

2. A set of annotated checklists and parameters for O&M performance evaluation.

3. Through the above activities, many sector professionals in both the public and private sector as well a government officials in LDC's will have been made increasingly aware of the importance of operation and maintenance.

4. Tangible improvements in O&M performance may have been achieved following the assessments and feed-back which have been carried out as part of this project.

The overall benefit of the project will be a major contribution to improved sector performance and better standards of service at lower cost; consequently, greater service coverage should be possible. The project will contribute to the long-term sustainability of water and sanitation services.

It is essential that the procedures and tools resulting from the project meet the requirements of those who will use them, and that the information generated will form a sound basis for policy decisions and planning. Therefore, the project will only generate the expected benefits if national institutions and ESA's give concrete support to the project and contribute to the outputs.

REFERENCES

---, Soft Options in Sewer Renovation, *World Water and Environmental Engineer*, April, 1992, pp 12-14.

Agrell J-O., Schultzberg G., and White R., Evaluation of the Village Water Supply Programme in Botswana, SIDA, 1984.

Alaerts, G., Ombregt, J. P. and Van Haute, A., Waterzuivering en Waterconsumptie in Derde-Wereldlanden, *Het Ingenieursblad*, Vol. 54, no 7, 1985, pp 371-376.

Arlosoroff S., Tschannerl G., Grey D., Journey W., Karp A., Langeneffer O. and Roche R., Community Water Supply - the Handpump Option, World Bank, Washington DC, 1987.

Ashford R. and Miller J., SIDA Report on Needs to Improve District Councils' Capacity to Maintain and Operate Village Water Supplies, Ministry of Local Government and Lands, Botswana, 1979.

Austin, J.H. and Bachelor, D., Trainee Involvement in the Training Process, *J. AWWA*, Vol. 73, 1981, pp 299-303.

Austin, J. H., and Jordan, J. K., Operation and Maintenance of Water Systems in Developing Countries, *J. AWWA*, Vol. 79, 1987, pp 70-77.

Barrett, A.D. and Pescod, M.B., Water Supply in Developing Countries: Improving on Current Practice, *Journal of the Institutions of Water Engineers and Scientists*, Vol.36, no 5, 1982, pp 323-342.

Bornstein, C.T. and Rosenhead, J., The Role of Operational Research in Less Developed Countries: A Critical Approach, *EJOR*, Vol.49, 1990, pp 156-178.

Bourne, P.G., Water and Sanitation for All, in *Water and Sanitation Economic and Sociological Perspectives*, Academic Press, New York, 1984.

Bradley D., Stephens C., Harpham T., and Cairncross S., A Review of Environmental Health Impacts in Developing Country Cities, Urban Management Paper 6, The World Bank, Washington DC, 1992.

Buttery, L.M., New Survey of US Maintenance Costs, *Hydrocarbon Processing*, Vol. 58, 1978, pp.85-90.

Chitnis, B. V., Transfer of Maintenance Technology: (I) Choice of Technology, *Maintenance Management International*, Vol. 3, 1982, pp 11-16.

Christer, A.H., OR and Maintenance Modelling: Tutorial Notes, *ORSA/TIMS Meeting*, Buenos Aires, 1987.

De Groote, P., Industrial Maintenance in Developing Countries, *Maintenance*

Management International, Vol. 7, 1988, pp 121-129.

De Groote, P., Guide for Action in the Field of Human Resources Development for Industrial Maintenance in African Countries, *UNIDO report*, Nairobi, 23-27 June, 1986.

De Vries Robbe, A.A.C., Wie is er Bang van een Checklist ?, *Technische Bedrijfsvoering*, Vol. 2, 1984, pp 52-56.

Dev, H. K., Transfer of Maintenance Technology: (II) The Need of Asian Countries, *Maintenance Management International*, Vol. 3, 1982, pp 17-22.

DGS International, Checklist, *Maintenance Consultants* (Industrializing Countries), Ghent (Belgium), 1987.

Easton A., Pipe Breakage Analysis of the Rural Water Supply in the Central Region, Kawinga and Zomba Projects 1983-84, Water Department, Ministry of Works and Supplies, Lilongwe, Malawi, 1985.

Feacham R., Lesotho Village Water Supplies: an Ex-Post Evaluation, London School of Hygiene and Tropical Medicine, 1977.

Fountain, B., and Shipmann, H., *Guidelines for Development of Urban Fringe and Rural Village Projects in Developing Countries*, Technical Report, Urban Resources Consultants (Washington), 1979.

Gavin, J., Darling, J., Game, R.C., Laport, R. and Stromberg Ch. Performance Indicators for Selected Water Supply and Sanitation Utilities in Ecuador. *WASH* Field Report No. 376 (1992).

Hibi, S., *How to Measure Maintenance Performance*, Nordica, Hong Kong, 1977.

Husband, T., *Maintenance Management and Terotechnology*, Saxon House, Farnborough, 1978.

Janssens J. G., Operation and Maintenance of Water Systems, in: *Water Supply and Sanitation - Beyond the Decade*, Asia and Pacific Regional Consultation, June 1990, Ed. Asian Development Bank, 137-154, 1990.

Janssens J. G., McPherson H. J., and Hueb J., Operation and Maintenance for Sustainable Improved Water Supply and Sanitation Services, Forum of the Water Supply and Sanitation Collaborative Council, Oslo, Norway, 18-20 September 1991.

Janssens J. G., Issues and Necessary Components of Successful O&M for Better Use of Existing Assets in Water Supply and Sanitation, Water Malaysia '92 Conference, 8th ASPAC- IWSA Regional Conference and Exhibition, Kuala Lumpur, Malaysia, 26-30 October 1992.

Jardine, A.K.S. (Ed.), *Operational Research in Maintenance*, Manchester Univ. Press, London, 1970.

Jordan, J.K., Establishing a Maintenance Program, *J. AWWA*, Vol. 79, 1987, pp 32-36.

Jordan, J. and Wyatt, A. Estimating Operations and Maintenance Costs for Water Supply Systems in Developing Countries. *WASH* Technical Report No. 48 (1989).

Keller, R.T. and Chinta, R.R., International Technology Transfer, *The Executive*, Vol.4, no2, 1990, pp 33-40.

Kelly, A., *Maintenance Planning and Control*, Butterworths, London, 1984.

Kelly, A., Maintenance Systems Auditing - An Aid to Effective Maintenance Management, *Maintenance*, Vol. 3, no 3, 1988, pp 6-12.

Krishnamurthy, V., Maintenance Problems in Developing Countries and International Cooperation, *Terotechnica*, Vol.2, 1987, pp 223-226.

Larrick, Ch. L. and Adams, L. W., Developing Nations Face Problems in Water and Wastewater Management, *Water & Sewage Works*, Vol. 125, no 6, 1978, pp 62-63.

Lijklema, L. and Tyson, J.M., Urban Water Quality: Interactions Between Sewers, Treatment Plants and Receiving Waters, *Water Science Technology*, Vol. 27, no 5-6, 1993, pp 29-33.

Lohani, B.N. and Thani, N.C., *Water Pollution Control in Developing Countries*, Conference Proceedings (Bangkok), 1978.

Luck, W.S., Now You Can Really Measure Maintenance Performance, *Factory Management*, Vol.114, 1956, pp 81-86.

Luxhoj, J. T. and Tao, P., Measuring the Productivity of Construction Maintenance Operations, *J. AWWA*, Vol. 82, 1990, pp 35-39.

Mann, L., *Maintenance Management*, Lexington Press, Lexington, 1983.

Mann, L., Impact of Maintenance as Chemical Plant Production Costs, *Maintenance Management International*, Vol.7, 1988, pp.77-84.

Marcelis, W.J., *Onderhoudsbesturing in Ontwikkeling*, Kluwer, Deventer, 1984.

Marcelis, W.J., *Onderhoudsbesturing op Maat*, Kluwer, Deventer, 1979.

Marcelis W.J., Checklist Onderhoudsbesturing, *Bedrijfsvoering*, Vol. 3, 1979, pp 14-17.

McGarry, M.G., Matching Water Supply Technology to the Needs and Resources of Developing Countries, *Water Resources Journal*, no 154, 1987, pp 11-19.
Morrison-Maierle/Sheladia Consulting Engineers, Lesotho Rural Water and Sanitation Project Sixth Annual Report, Maseru, Lesotho, 1987.

Muyibi, S.A., Planning Water Supply and Sanitation Projects in Developing Countries, *J. Water Resources Planning and Management*, Vol. 118, no 4, 1992, pp 351-355.

Nakajima, S., Transfer of Maintenance Technology: (III) The Role of Professional Institutions, *Maintenance Management International*, Vol. 3, 1982, pp 23-25.

Newbrough, E.T., *Effective Maintenance Management*, McGraw-Hill, New York, 1967.

Neyret, G.M.J., Some Considerations Regarding the Application of Modern Technology, *Terotechnica*, Vol. 2, 1981, pp 135-137.

Niebel, B., *Engineering Maintenance Management*, Marcel Dekker, New York, 1985.

Noiret, A., Evaluation de l'Efficacité de la Maintenance, Conférence sur l'Entretien dans les Industries des Procédés, Louvain-la-Neuve, November 1978.

Office of Drinking Water, Ed. *Optimizing Water Treatment Plant Performance Using the Composite Correction Programme*. Office of Technology Transfer and Regulatory Support, Office of Research and Development, U.S. Environmental Protection Agency, EPA/625/6-91/027 (1991).

Pickford, J., Sewage Treatment in Developing Countries, *Water Pollution Control*, Vol. 76, no 1, 1976, pp 65-66.

Pintelon, L. and Van Wassenhove, L., A Maintenance Management Tool, *OMEGA*, Vol. 18, no 1, pp 59-70.

Pintelon, L., *Performance Reporting and Decision Tools for Maintenance Management*, Unpublished Ph.D. thesis, Catholic University Leuven - Dept. of Industrial Management - Leuven, Belgium), May 1990.

Pintelon, L., *Maintenance Management*, Course Text Industrial Management Division, K.U.Leuven, 1992.

Pintelon, L.M., and Gelders, L.F., Invited Review: Maintenance Management: Decision Making, *EJOR*, Vol.58, 1992, pp 301-317.

Pintelon L and Gelders L., A Challenge for the Maintenance Management in the 90's (in dutch) *Het Ingenieursblad*, No. 6-7, pp 43-51.

Priel, V.Z., Twenty Ways to Track Maintenance Performance, *Factory*, Vol.56, 1962, pp.88-91.

PROWWESS, Participatory Evaluation, UNDP/WHO/World Bank/UNICEF, Geneva, 1990.

Pulat, B.M., and Alexander, D.C. (eds), Industrial Ergonomics: Case Studies, *Industrial Engineering and Management Press (IIE)*, Norcross-Georgia, 1991.

Roark, Ph., Hodgkin, J. and Wyatt, A. Model of Management Systems for the Operation and Maintenance of Rural Water Supply and Sanitation Facilities. WASH Technical Report No. 71 (1992).

Schiller, S., Organizational Learning for Local Control of Discretionary Cost Centers, *WP*-Göthenburg School of Economics, Götheborg (S), 1989.

Schulz, C. R. and Okun, D. A., *Surface Water Treatment for Communities in Developing Countries*, Wiley, 1984.

Simpson, J. R., Water Pollution Control in Developing Areas: Problems and Needs, *Water Science Technology*, Vol. 14, no 9-11, 1982, pp 1353-1373.

Smith M.D., Personal Communication, 1993.

SWECO Consulting Group, Botswana Rural Water Supply, SIDA, Stockholm, Sweden, 1978.

UNICEF, Joint Mid-Implementation Report on the Assisted Rural Water Supply Project Uganda, Kampala, Uganda, 1984.

Union Africaine des Distributeurs d'Eau - UADE. Plan de Maintenance. Rapport *UADE*, Abidjan (Cote d'Ivoire) (1988).

United Nations Centre for Human Settlements - *UNCHS (HABITAT)*. Diagnostic Assessment of Operations and Maintenance Problems - Guideline Framework. Nairobi (Kenya) (1989).

United Nations Centre for Human Settlements - *UNCHS (HABITAT)*. Overview of Issues and Strategic Options in Operations and Maintenance - Analysis and Synthesis Report. Nairobi (Kenya) (1989).

United Nations Centre for Human Settlements - *UNCHS (HABITAT)*. The Maintenance of Infrastructure and its Financing and Cost Recovery. Nairobi (Kenya) (1989).

Van Brussel, H., Onderhoudschecklists, *Doelmatige Bedrijfsvoering*, Vol. 2, no 5, 1990, pp 4-8.

van Vuuren, L. R. J. and Hoffmann, J. R. H., Operational Achievement of Drinking Water Quality, *Water Pollution Control*, Vol. 77, no 1, 1978, pp 39-44.

Water and Sanitation for Health (WASH), Models of Management Systems for the Operation and Maintenance of Rural Water Supply and Sanitation Facilities, Technical Report 71, 1993.

Water and Sanitation for Health (WASH), Performance Indicators for Selected Water Supply and Sanitation Utilities in Equador, Field Report 376, 1992.

Water and Sanitation for Health (WASH), Estimating Operations and Maintenance

Costs for Water Supply Systems in Developing Countries, Technical Report 48, 1989.

Water and Sanitation for Health (WASH), Development of a National Policy for the Maintenance of Rural Water Supply Systems in Solomon Islands, Field Report 234, 1988.

Water and Sanitation for Health (WASH), Malawi Self-Help Rural Water Supply Programme: Final Evaluation, Field Report 186, 1986.

Water and Sanitation for Health (WASH), Emergency Water Supply and Sanitation Assistance to Ethiopia - Operations and Maintenance Aspects, Field Report 146, 1985.

WHO-CWS, Proc. Advisory Committee of the Operations and Maintenance Working Group, WHO/CWS/91.6, Feb. 1991.

WHO-CWS, Proc. Operations and Maintenance Working Group, Vols 1 & 2, WHO/CWS/90.14 & 90.15, 1990.

WHO-CWS, Proc. Operations and Maintenance Working Group, June 1993.

WHO, Guidelines for Drinking Water Quality, Vol. 3 Drinking Water Quality Control
in Small Community Supplies, Geneva, 1985.

WHO, Minimum Evaluation Procedure, Geneva, 1983.

Winter, J.L., Zakrzewski, R.S. and King, R.E. (eds), *Maintenance Management Quality Production*, Society of Manufacturing Engineering, Dearborn (Michigan), 1987.

GLOSSARY

Accounts receivable. Money owed to the utility, usually for a service billed but for which income has not yet been received.

Condition based maintenance (CBM). Maintenance to be activated when a value or given system parameter reaches or surpasses a preset value.

Corrective maintenance. Activities in response to breakdown, or detected defects, or simply something when it breaks down.

Current assets. Liquid assets plus the value of inventory if parts and materials.

Current liabilities. Credit extended to the authority, including long and short term loans, and accounts payable.

Design-out maintenance (DOM). The focus is on improvements in the equipment design in order to simplify maintenance operations and/or increase reliability.

Fixed assets. The present value of the utility's physical assets.

Failure based maintenance (FBM). Maintenance to be carried out only on occurrence of failure or breakdown.

Liquid assets. The sum of cash on hand and debts owed to the utility, including accounts receivable.

Operating costs. The sum of all costs expended for:

(i) materials, energy, chemicals and parts
(ii) contracts for services and repairs
(iii) personnel
(iv) taxes

Operating costs do not include depreciation or the costs of capital construction projects including debt service for such projects.

Operating revenue. Income received from billing for the provisioning of water pro rata of m^3.

Opportunity based maintenance (OBM). When a component fails, the opportunity may be taken during the ensuing shutdown to carry out preventative maintenance on other components which have not yet failed.

Periodic maintenance. Activities normally carried out at intervals of more than one year, often as part of large scale programmes of predetermined cycles.

Preventative maintenance. Activities aimed at interruption of the deterioration process at an early stage based on systematic, prescheduled programmes of providing early detection of beginning effects.

Rehabilitation. Activities carried out to correct major defects, wear and tear, in order to restore a facility to a good working condition without significantly expanding beyond its originally designed function or extent.

Routine maintenance. Preventative and corrective maintenance normally not of major scale and typically carried out one or more times every year.

Total assets. The sum of fixed assets, current assets and work in progress.

Total costs. The sum of operating costs, debt services and other costs not directly related to the utility's operations. Depreciation should be considered separately since it does not require current expenditure.

Total revenue. The sum of operating revenues and income from grants, subsidies, or other sources not directly related to the provision of the utility's loans.

Use based maintenance (UBM). Time based or fixed period maintenance.

LIST OF ABBREVIATIONS

CB	Control board
CM	Corrective maintenance
DR	Detailed report
HRM	Human resource management
MMIS	Maintenance management information system
MMT	Maintenance management tool
MRO	Maintenance, repair and operating supplies
MTBF	Mean time before failure
MTTR	Mean time to repair
O&M	Operations and maintenance
OR	Operational research
PI	Performance indicator
PM	Preventative maintenance
RCM	Reliability centred maintenance
RFT	Right first time
TPM	Total productive maintenance
UFW	Unaccounted for water
WS&S	Water supply and sanitation

ANNEX 1

Background to the Project

The following background notes are taken from the report of the Working Group on Operations and Maintenance, WHO, Geneva, June 1993.

Project Title: Development of Tools for Assessment of Operation and Maintenance of Urban and Rural Water Supply

As a response to the lack of sufficient guidelines on how to assess operation and maintenance services in both urban and rural areas, the Operation and Maintenance Working Group concurred that the development of tools and methods for this purpose should facilitate the work of those responsible for project evaluation.

The ultimate beneficiaries of the methods and tools for the assessment of O&M status will be the projects conducted by external support agencies and the O&M services under the responsibility of the water supply and sanitation institutions in developing countries. The methodology will have a considerable degree of flexibility to accommodate the special needs of the different potential users. Two sets of tools and guidelines will be prepared to cover the specific needs of urban and rural operation and maintenance respectively. WEDC and IWSA are involved in the conducting of this activity.

ANNEX 2

- Recommendations for future work: flow charts and schedules.
- A checklist of sample questions used in the audit of O&M.

A checklist of sample questions to be used in auditing O&M

I. BACKGROUND

I.1 Developing country

- Population
- Climate
- Economic situation
- Urban area (city, small city, slums, etc)
- Political situation and national institutions (e.g., attitude towards WS&S technology)
- Host/donor relationships
- Location
- Infrastructure (accessibility, logistics, etc)

I.2 WS&S system

- Plant site (distance from city, access roads, size, provision for future expansion)
- Facilities (laboratories, storage for materials, and chemical products, etc)
- Unit processes, storage and transportation (+ equipment)
- Capacity (design capacity, number of customers served, demand pattern, water quality, charging principles, etc)
- Technology (appropriateness, safety, flexibility, etc)
- Interaction between sewers, treatment plants, and receiving waters

The answers to some of these questions will be qualitative, others quantitative. Performance indicators to be used are: (see Gavin et al (1992) and Office of Drinking Water (1991))

Operational area indicators:

total population density, i.e., total population in service area/sq. km of service area

coverage in service area, i.e. population served by utility/total population in service area

% of domestic consumption, i.e. domestic consumption (m^3)/total water consumption (m^3)

% of metered production i.e., metered production (m^3)/total production (m^3)

water production per connection, i.e. total production (m^3/day)/number of service connections

served population connected i.e., persons served directly by pipeline/total population in service area

number of fire hydrants

% of metered connections, i.e. metered connections/total connections

% of metered consumption, i.e. metered consumption/total consumption

(domestic) consumption per capita served, i.e., total consumption (litres/day)/population served (litres/capita/day)

consumption per water connection, i.e., total consumption/water connections

length of distribution mains in km per 1000 urban population

meters of pipeline per connection, i.e. total length (meters) of distribution piping/total number of connections

persons per connection, i.e., persons served directly by pipeline/total number of connections

Personnel related indicators:

water production per employee, i.e. water production/number of employees

wastewater collection per employee, i.e. wastewater collected/number of employees

Financial indicators:

(Refer to glossary for explanation of terms)

operating revenue per m^3 produced, i.e. annual operating revenue/population served

total revenue per capita served, i.e. total annual revenue/population served

operating revenue per connection, i.e. annual operating revenue/number of connections

total revenue per connection, i.e. total annual revenue/number of connections

ratio of operating revenue to total production, i.e. annual operating revenue/total water production (m^3/day)

operating revenue bulled per m^3 water, i.e. annual operating revenue/billed water production (m^3/year) total costs per capita served, i.e. total costs/population served

total surplus (loss) per capita served, i.e. (total revenues - total costs)/population served

total costs per connection, i.e., total costs/number of connections

total asset values

debt service as % of operating revenue, i.e. debt service/operating revenues

fixed assets per capita served, i.e. fixed assets/population served

quick ratio, i.e. liquid assets/current liabilities

current ratio, i.e. current assets/current liabilities

operating ratio, i.e. total costs/total revenues

cash coverage of total costs (days), i.e. cash assets (total costs/365)

cash and accounts receivable coverage of total costs (days) i.e. liquid assts/(total costs/365)

asset turnover i.e. total revenue/total assets

average collection period (days) i.e. accounts record turnover/(annual billed revenue/365)

II. MANAGEMENT

II.1 O&M environment

(a) Service industry

- is there a definition of the objectives of the WS&S?
- is there a long term strategy concerning the WS&S?

(b) O&M responsibilities

- what are the tasks of the O&M department (and their relative importance) concerning equipment, distribution systems, buildings and ground, vehicles, etc?
- how does the O&M department fit in to the organisation chart of the WS&S?
- is there a detailed organisation chart of the O&M department, including numbers and skills?

(c) O&M philosophy

- is O&M a major concern to management?
- are there any clear ideas about O&M?
- are concepts like terotechnology known and/or implemented?

II.2 O&M management

(a) Objectives

- state the objectives of O&M
- are these objectives specific or general?
- if these objectives are specific, are they attainable?
- how is the budget for O&M determined?
- what aspects are considered in this budget?
- how is the budget follow-up organised?

(b) Planning

- explain the strategic planning procedure
- explain the tactical planning procedure
- explain the operational planning procedure
- how much planning is there: none/a little/some/a lot/nearly all activities?
- is the current planning satisfactory?
- can work load (and potential backlog) be estimated?
- are there any support tools for the planner?
- is there a planner?

(c) Resources

Personnel

- how many people work in O&M?
- what is their workload (number and duration of jobs, idle time...)?
- are the educational qualifications of personnel satisfactory?
- can additional training programmes be easily organised?
- how much of the WS&S system depends on locals and/or foreigners?
- are the employees motivated?
- is personnel rotation low or high? Why?
- are there any socio-cultural aspects making O&M difficult?
- what are the skills of the personnel?
- how are new employees trained (on-the-job, formal classes)?

Repair shop

- is a repair shop available in the WS&S system?
- if yes, is it well equipped?
- are there any problems concerning personnel or materials here?

MRO store

- how many parts are kept in stock?
- what is their value?
- is it possible to perform an ABC analysis?
- what about item repairability, criticality?
- how much dependence on outside suppliers is there for spare part supply?
- what problems are most important for spare part supply?

Data

- is historical information on O&M jobs and equipment behaviour available?
- if yes, is this information complete, reliable, and readily available?
- what information is kept for management purposes?
- can employees be motivated to collect data?
- is a good equipment documentation system available?
- is a work order system used?
- are job descriptions available?

(d) Performance

- is performance evaluated on a regular basis?
- who evaluates O&M performance?
- which performance indicators and reports are used?
- is there a performance follow-up procedure?

II.3 Management tools

(a) MMIS

- is there a (computerised) management information system?
- if not, why not (cost, effectiveness)?
- if yes, what kind of system, what modules?

(b) Operational research techniques

- are there any optimisation techniques used?
- is data available?
- is there any interest for such decision support models?

- are there any design review methods used?
- are there potential application items?
- if it is decided to use a given method, is there knowledge in-house to perform it?
- does O&M have any impact on equipment design or purchase?
- if yes, how and how much?
- if not, who has?

(c) Human resource management

- is there a HRM policy?
- what HRM activities are organised?
- who is in charge of HRM?

= = =