PIANC WORKING GROUP 25

Maintenance and renovation of Navigation Infrastructure

WG 25 REPORT DRAFT

4 July 2005

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Contents

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Preface

Details of the members of WG25 and acknowledgement of all contributors – THIS SECTION STILLTO BE WRITTEN

1. INTRODUCTION

1.1 The Report

The navigation structures that support navigation infrastructure in many nations are approaching, or have reached and moved beyond, their design life. Preservation and extended use of existing facilities is dependant upon efficient operation, maintenance, repair and renovation of these structures. This paper seeks to identify some practical guidelines for identifying cost-effective and timely solutions to these problems.

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1.2 Terms of Reference

1.2.1 Background

Currently, decision makers have few practical guidelines for identifying cost effective and timely maintenance and repair of navigation structures. By necessity, economic trade-offs occur between costly renewal and increasing operational and maintenance expenditure through the lifecycle of these structures. Rational methods are now needed for prioritisation of infrastructure repairs.

1.2.2 Objective

The objective of the Working Group was to provide guidance to navigation infrastructure decision makers on the prioritisation of repairs and the evaluation of various decision making processes.

1.2.3 Fields of Research

The Working Group focused on:

- An inventory of existing decision making tools.
- Establishing guidelines and providing recommendations of timing and methods for periodic inspections.
- Establishing guidelines and providing recommendations for scheduling maintenance and repairs during asset life.
- Providing a rational means of prioritisation of infrastructure repairs for both site-specific requirements and system-wide effects.

1.3 Purpose of the Report

The report sets out an inventory of practices along with some technical methods which help guide investment decisions and gives brief information on those practices and methods. It also establishes guidelines and provides recommendations on the timing and scope of inspections and the scheduling of repairs during an assets lifecycle. Finally the paper suggests rational means by which infrastructure repairs can be programmed in the context of site specific needs and system-wide effects.

The paper brings together the practical experience of a number of nations faced with this common problem. The tools and techniques described can also help navigation infrastructure owners respond to the challenges posed by new uses and changing customer expectations.

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1.4 Structure of the Report

1.4.1 Key Sections

A survey of processes was carried out at an international level to establish a common language and to ascertain whether there was a consistent approach that could be applied across all boundaries (see Appendix 2). The opinion of the Working Group was that no such approach existed because of the different drivers being applied in various countries.

The paper is, therefore, set out in two key sections; 'Inventory of Decision Making Tools' and 'Recommended Best Practices for Prioritization'. In recognition that different countries will be at different levels of sophistication of asset management best practice, the latter section is subdivided into sections that deal with Essential (or basic) and Advanced asset management

The selection of the most appropriate level will depend on:

- The costs and benefits to the organisation
- Legislation of the country involved
- Size, condition and complexity of the assets
- The level of risk and tolerability associated with asset failure
- The resources (financial/people/time) available
- Expectations of the customers or the general public

At the basic or **essential** level, Asset Management (AM) is carried out to meet the minimum legislative and organisational requirements for infrastructure management, financial planning and reporting. It provides simple outputs such as statements of levels of service, forward maintenance and repair programmes, and financial projections. It is usually a snap-shot of current practices and strategies (rather than aspirations of the organisation).

Essential AM will usually include:

1. Hierarchical asset register including classification and attributes
2. A simple lifecycle approach.
3. AM plans based on the best available current inspection data (not necessarily complete) and assumptions where it does not exist.
4. Meeting existing levels of service.
5. Long term financial predictions based on local knowledge and options for meeting the current levels of service.
6. Financial and service performance measures in order that trends can be monitored.

The **advanced** approach will optimise activities and programmes to meet agreed or aspirational service standards in the most cost-effective way, through the collection and detailed analysis of key data on asset condition profiles, performance, deterioration rates, usage, lifecycle cost management, risk analysis and refurbishment options. It leads to optimisation and true asset management strategies. It will usually involve lifecycle AM.

Advanced AM would be likely to utilise (amongst others):

1. Detailed benchmarked data on asset condition, performance and historical costs with minimal assumptions and a high degree of confidence.
2. Lifecycle financial modelling
3. Asset deterioration (predictive) modelling.
4. Risk management techniques.
5. Optimised decision-making.
6. Option evaluation.
7. A holistic approach with full assessment of the impact of other strategic plans on the AM process.
8. Asset utilisation and rationalisation
9. Integrated operation and maintenance
10. A full review process.

2. INVENTORY OF DECISION MAKING TOOLS

2.1 Inventory of practices

2.1.1. Background

In dealing with operation and maintenance of navigational infrastructure, decision makers are applying, to different degrees, various tools and guidelines for the prioritization of specific activities. These tools and their application depend upon the background of the authority and their specific situation:

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Nevertheless, the working group anticipated that the definition of principal structures and tools for decision making should be more or less in common, as each navigation owner has partial or full responsibility for the safety and operability of the system, as well as for the economical use of resources (especially financial and human resources). It is important, therefore, to interpret the organisations' objectives in the context of AM, and to adopt procedures to satisfy these objectives, as well as means for monitoring and evaluating how well these objectives are being met. Although the emphasis was made on decision making tools for maintenance and repair, it was clear that these two topics could not be dealt with in isolation.

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There are various approaches in using specific tools in the decision making process. Because the working group believed that these tools existed almost everywhere but in different forms and degree of application, a questionnaire-based survey was circulated. Several common issues, problems and general structures formed the basis of the hypothesis:

Common problems identified included:

- a general lack of financial and human resources,
- the need for an extended asset lifespan in comparison with the original design-lifespan,
- an often rapidly deteriorating condition of the infrastructure

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There is a need for effective processes to ensure that resources are directed purposefully and to the best possible effect. These processes are underpinned by:

- The inspection of the assets and comparable assessment of their condition as an essential basis for every decision concerning resources.
- Due to inadequate resources it is not always possible to carry out all necessary maintenance work at the same time or even at the most appropriate time. Therefore, a planned prioritization of all actions, using common and practical criteria, is imperative.

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2.2 Survey

To gather reliable information about how navigation authorities worldwide deal with these issues, the working group asked all PIANC members to answer a questionnaire. 12 authorities from different countries answered the questionnaire (see Appendix 4). Questions were not limited to the choice of decision making tools, the grade of application and the results, but were also posed to determine the extent to which organisations were restricted by resources and the grade of deterioration of their waterways and assets. The object was to obtain comprehensive evidence of

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how resource availability determined the application of advanced decision making techniques.

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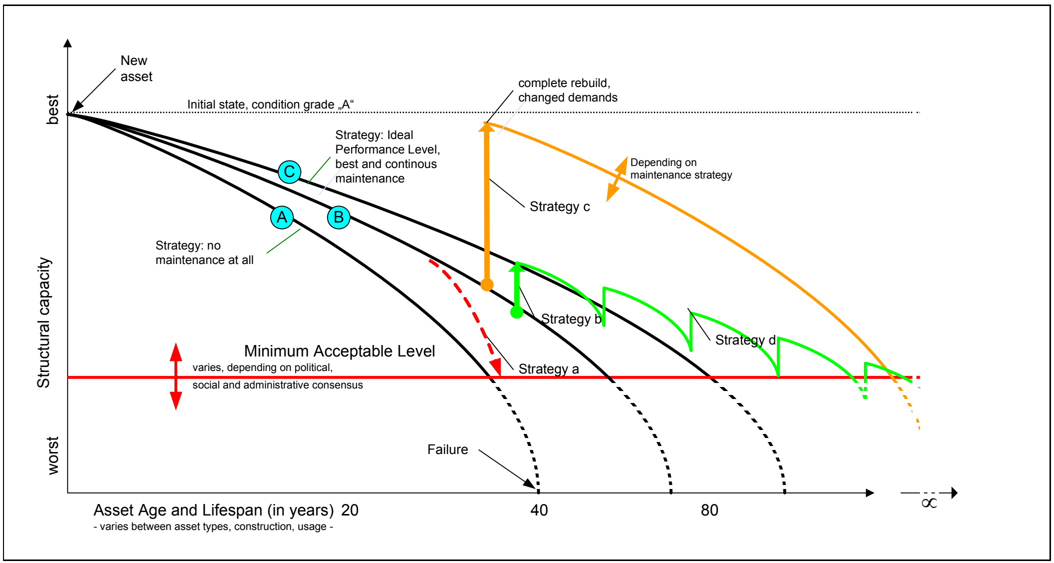
The results of the questionnaire were as follows:

Applied Maintenance Strategies

In determining the optimal maintenance strategy, various options are considered. Different idealized strategies for the maintenance of assets are shown schematically in the following graph:



Two graphs (A and C) describe theoretical levels of maintenance, whereas (B) describes the likely "real life" situation:

Graph A represents an asset that is operated without appropriate maintenance to a minimum acceptable level of safety after a relatively short life-span. Arriving at that point the asset must be strengthened/replaced or be operationally restricted until necessary replacement works can be carried out.

Graph C shows the extended lifecycle of a perfectly constructed and maintained asset. In reality, there is little evidence that either such situations exist for navigational infrastructure.

Graph B shows the lifecycle of a structurally adequate asset which offers various options for maintenance works during its life. For instance:

- The asset could be left without any appropriate maintenance, and would then reach the graph of asset A (red dotted line, strategy a) relatively quickly
- The asset could be specifically strengthened (green arrow) to reach its ideal performance level according to the assets actual age (strategy b).
- After arriving at the ideal state, it could be further improved (orange arrow) to reach a state which fulfils the performance level of contemporary assets and needs of navigation (strategy c).
- The asset could be repeatedly strengthened, as the green saw-tooth graph shows, to maintain an acceptable level of performance for an extended time (strategy d).

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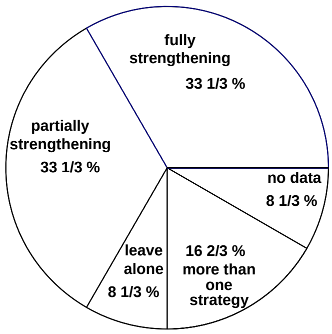
The questionnaire asked which strategy was generally applied when planning the maintenance of infrastructure, distinguishing between a strategy applied under **optimal circumstances** and the strategy actually applied under **real circumstances**.



Strategy under optimal circumstances

Under optimal circumstances, four navigation authorities reported that they would apply a strategy to fully strengthen an asset to reach its ideal performance level according to the asset's actual age, whilst four would apply a strategy to partially strengthen the asset to maintain its current level of structural capacity. One authority would prefer continuing the life cycle of the asset without changes (doing nothing) and to replace it in the near future. One authority distinguished between applying each of the three strategies. This authority stated that if financing is available then full strengthening is applied, if customer or political demands are paramount, partial strengthening may be applied, and if safety permits they may have a strategy to do nothing. Another authority distinguished between electrical and automation elements which would be kept at a fully strengthened level and machinery and structural elements, which may receive only partial strengthening. One authority gave no information about the strategy applied.

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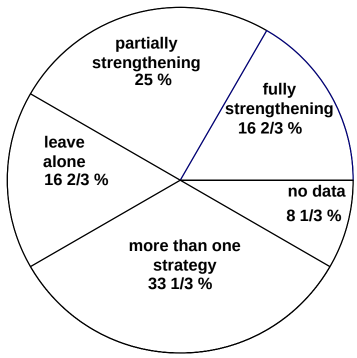
However, under real circumstances only two authorities apply a full strengthening strategy, whilst three apply a strategy of partially strengthening. Two would do nothing to the asset but seek to replace it in the near future (although one authority points out that the reason for this strategy is the lack of funding). Two authorities apply both strategies of partial strengthening or doing nothing, the first in case of breakdown maintenance or for major assets, the latter for smaller assets or when a major rehabilitation is planned. Again, one authority applies both strategies of full or partial strengthening depending on the type of asset; i.e. full strengthening for electrical and automation techniques and partial strengthening for machinery and structural elements. Another authority applies full strengthening for assets with a strategic relevance, partially strengthening for assets with lesser importance, and does nothing to assets of no strategic importance. Again, one authority gave no information about the strategy applied.



Strategy under real circumstances

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We concluded from the review of responses that there is no evidence that any single strategy is most economical or even most appropriate concerning safety, operation and service.

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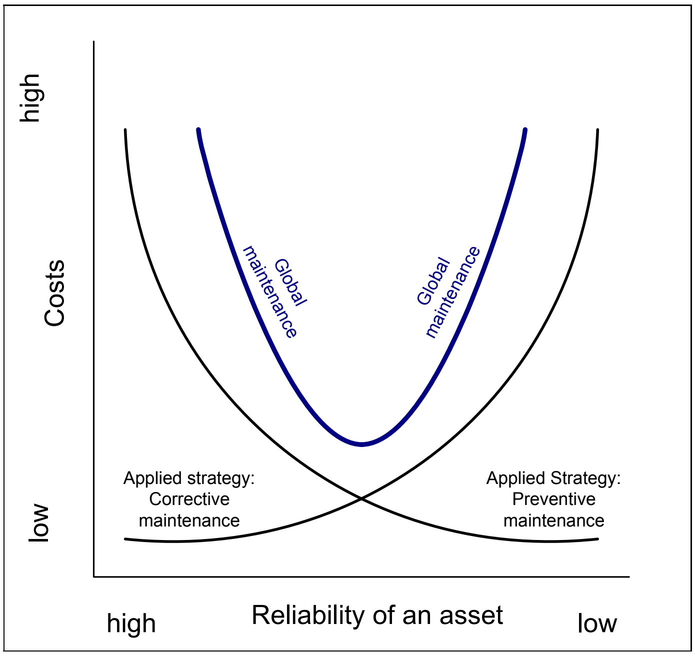
Preventative/corrective maintenance

In applying different maintenance strategies, it is important to strike a balance between preventative and corrective maintenance. It must be understood that the use of corrective maintenance may result in the restriction of navigational traffic before it shows results. There are also significant influences on cost and maintenance levels (see graph).



When determining the most appropriate maintenance strategy to be applied, there is often insufficient cost data. The extrapolation of data based on the relatively short history of typical assets often leads to the conclusion that these are valid only for an individual asset and cannot be generalized.

Financing backlog

This question referred to the annual percentage, by which maintenance and repair of the navigational infrastructure was underfinanced. It also tried to determine the size (as a percentage of the fixed assets) of the existing accumulated backlog of underfinancing.

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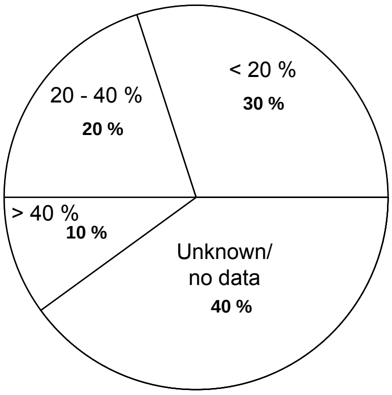
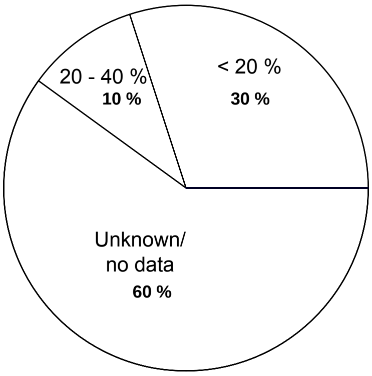


Amount underfinanced



Accumulated backlog

Answers ranged from 0% to 50% for annual underfinancing and from 0% to 25% for the accumulated backlog. There was little correlation to the type of strategy and how stringently it was applied. This should probably motivate navigation authorities to apply decision making tools more often.

Despite the fact that almost every authority reports problems (sometimes severe) with the technical or operational state of their assets, it is surprising that a remarkably high percentage of these authorities do not know how large the amount of their underfinancing actually is.

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Use of ALARP

The acronym ALARP (**A**s **L**ow **A**s **R**easonably **P**ractical) describes the fact that not only must a navigation authority solve problems in the full knowledge of the facts, but must increasingly be aware of possible risks, as well as the public and political perception of these risks. Authorities have started to calculate risks for deteriorated assets in order to prevent future damage, and to make a reasonable estimate about whether they are willing to accept a higher degree of deterioration. Risk management is increasingly becoming a central feature in the management of navigational assets.

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Levels of risk acceptability can vary with public perception, with cultural and legal differences, and with the nature of the aspect that it is applied to, but in nearly all cases public acceptability of a given level of risk will decrease with time. This decrease may occur slowly due to general societal changes in perception of risk acceptability, or quickly as an immediate response to a particular set of circumstances (e.g., a single rail disaster could significantly change a societies risk tolerance level in relation to rail travel).

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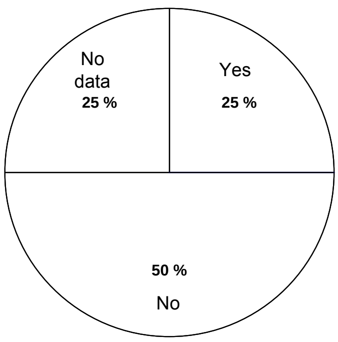
The concept of acceptable risk has a remarkable bias which has relevance for a navigation authority managing a potentially dangerous system. There seems to be a significant difference of acceptance between a risk that arises as a result of an individual's decision (i.e. smoking, fun sports, or fast driving) and that imposed by an external originator and over which the individual has little control (i.e. train or bus accidents). The fact that external risks seem less acceptable to people must be taken into account when risk-managing assets.

Another aspect to be taken into account is that if the risk consequences, likelihood or detectability are uncertain (i.e., if the asset conceals potential and not wholly measurable risks), then the theoretical distance between the minimum level of deterioration and failure must be greater than in other cases where risks are more controllable.

Answers to the questionnaire show that there are a variety of options to deal with the demands of risk management. The specific use of ALARP by different authorities shows some reasons for this uneven situation: There are problems in dealing with the accuracy of risk prognoses, the fundamental antagonism between externally induced risks and public benefits (especially for tasks that are funded by public sources), and the general problem that safety is one of the highest aims in societies - which could be seen as a monetary expressed part of a cost-benefit-ratio if safety is calculated in



Use of A.L.A.R.P

actuarial terms. But this rational view often changes substantially if any injuries actually occur.

Whole lifecycle costing

Whole lifecycle costing is not universally used as a decision making tool for navigation authorities but seems to be in more common use than ALARP. Partially it is used complementary to lifecycle management, but it seems that the relevance of information gathered by lifecycle costings is often relatively weak in the actual decision making processes.

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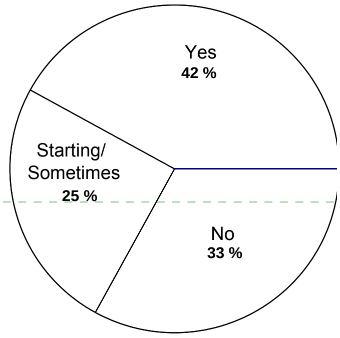
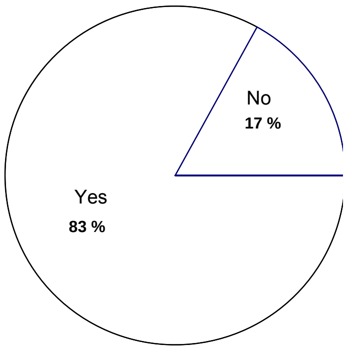


Use of whole-life costings

Cost-benefit analysis



Use of cost-benefit analysis

The majority of navigation authorities use cost-benefit analysis as a universal decision making tool. Some use it in making decisions about new construction or large projects, and large scale reconstruction and rehabilitation, but not for smaller projects or decisions about operation and maintenance. Its perceived success against other tools ranges from “not successful“ to “high“. Cost-benefit analysis is often used in combination with other methods of decision making.

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Non-monetary factors

There are many non-monetary factors, and navigation authorities deal with these in different ways. They may ascribe a monetary term to them (sometimes including the potential ‘cost’ of loss of human life), examine them in complementary rating systems or using multi-criteria analyses, and/or emphasize a general duty of care (which in itself can lead to apparently obvious but perhaps non-transparent decisions). There is clearly a substantial need for including non-monetary factors in any decision, although which are included will depend on a navigation authorities internal criteria.

Other key functional needs

Other key functional needs may arise from the waterways also being used for water transfer, power generation, military mobilization, recreation, and urban development and regeneration. In a broad sense, waterway infrastructure is also used for telecommunication as some authorities have built a telecommunications infrastructure collateral to their waterways which could be sold or let to a third party. These other functional needs are usually not in conflict with the waterways main purpose, although this changes when these other functional needs drain resources from areas of waterway operation or maintenance.

Importance of heritage and environmental protection

For all navigation authorities, heritage and environmental protection seems to be of a high or very high relevance. As measures to fulfil these special demands are often very expensive, they also have a high relevance to the decision making process. In most cases it appears that “safety“ represents a higher priority than heritage or environmental protection considerations, but value for money is often a lower priority or even not considered where heritage or environmental protection is concerned.

Other prioritization systems

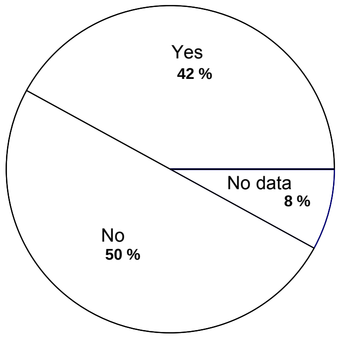
Other prioritization systems used in waterways are:

- decision trees,
- DNV International Safety Rating System,
- DNV International Environment Rating System,
- resource optimization,
- recommendations of specialist commissions
- decision of responsible specialists or the management,
- priority lists which combine safety and navigation conditions
- technical indices, based on inspections.

In the opinion of the working group, these prioritization systems can largely be related to systems described before.

Scoring systems

Five of nine navigation authorities already use scoring systems to assist decision making processes They are used mainly to compare issues which are not directly comparable (for example in monetary terms), such as safety and value for money. The target groups for the information given by scoring systems are often external, and it seems that they are used mainly to present the result of complex internal decision making process to the public or to policy makers. Scoring systems may be considered to be a subset of the prioritization process.



Use of scoring systems

Mission statement

To put a navigation authorities work into context, some have developed a “vision” often termed a “mission statement”. Every organisation has a mission, a purpose, and a reason for being. Often the mission is why the organisation was first created, to meet a need identified years ago. In that case, the organisation’s purpose does not change although how it does business has probably evolved.

However, simply because an organisation’s mission is current, alive, and well, it does not necessarily mean that the organisation has translated that purpose into a clear, concise mission statement. A good mission statement should accurately explain why an organisation exists and what it hopes to achieve in the future. It articulates the organisation’s essential nature, its values, and its work, and sets the strategic framework within which the organisation may evolve.

Therefore, an effective mission statement must be understood by people working in the organisation as well as the with the organisation's customers, partners or suppliers. It must express the organisation's purpose in a way that inspires commitment, innovation, and the will to grow and preserve its very essence.

An organisation's mission statement should express:

1. What is the purpose of the organisation?
2. What is the business of the organisation?
3. What are the values of the organisation?

A mission statement can give guidance in balancing criteria like safety, value for money, functional needs, and achieving sustainability as part of a decision making process.

Central points in the different authorities mission statements are:

General public and political aspects:

- integrity and safety of the waterway
- providing a safe and high quality environment for customers, staff and local authorities
- conserving heritage and environment of the waterways, improving it and making it work well for future generations
- safety and easiness of transport, enhancing mobility of people and goods by efficient and safe navigation
- development of all functions of the waterway
- safety of assets/infrastructure
- protection of people against floods
- political aspects

Customer needs

- passing ships through a safe and reliable waterway system in a cost-effective, efficient and environmentally friendly manner to meet the customer's transportation needs
- several business functions of the waterways as authorized by legislation
- maintenance of channels with a specific depth and width
- other business functions as hydropower production, flood damage reduction, regulatory, environmental stewardship and recreation

Operational aspects of the waterway authority

- efficient management of the waterways and of the water in it
- commercial approach and strive for excellence in every aspect of their work
- cost effectiveness/value for money

The guidance given to the navigation authorities by mission statements varies in their view from minimal, to those giving a high degree of guidance with links to their other fields of business. However, the conflicts between many differing aims may not be completely resolved by a mission statement and therefore a need arises for the use of further tools to deal with this problem.

Survey Conclusions

Referring to the theses which led the working group to carry out the survey the following findings and problems seem to be identified:

The key common decision making criteria used everywhere (but balanced differently) are:

- Safety
- Value for money
- Functional needs
- Achieving sustainability

- The use of ecological, political and heritage criteria is also widespread and growing.

- There is a general lack of financial and human resources.

- The need for an extended asset lifespan in comparison with the original design-lifespan rises.

- An often rapidly deteriorating condition of the infrastructure is expected (or already assessed!) nearly everywhere.

- The methods used for deciding between conflicting priorities (e.g. value for money versus safety) differ. They appear to be evolving from structured decision making processes, which may be strongly influenced by political or other arguments, to an approach comparable to insurance mathematics (concerning the grade and value of a possible catastrophe caused by the failure of an asset).The penal legislation in this context and the respective consequences for the personal responsible for the assets have also to be taken into account.

- Definitions of principal structures and tools for decision making should be more or less in common, but in reality are not.

- Despite the fact that almost every authority reports problems (sometimes severe) with the technical or operational state of their assets, it is surprising that a remarkably high percentage of these authorities does not know how large the amount of their underfinancing actually is.

- There is also no evidence that there is a general correlation between the decrease of asset quality, the growing lack of resources and an increasing use of decision making tools.

The working group believes that to interpret the organisations' objectives in the context of AM, and to adopt procedures to satisfy these objectives, together with means for monitoring and evaluating how well these objectives are being met, is essential. Nevertheless the group did not generally see evidence of fundamental and continually applied decision making processes.

Instead authorities sometimes use one or a few of these tools to assist their decision making, often when making decisions in higher cost ranges. Little evidence was found of the appliance of decision making tools in a systemic approach of integrating monetary and non-monetary factors, to the construction of new assets, to asset repair and maintenance, and to customer needs in the holistic context of a waterway system.

3. RECOMMENDED BEST PRACTICES FOR PRIORITIZATION

3.1 Essential Processes

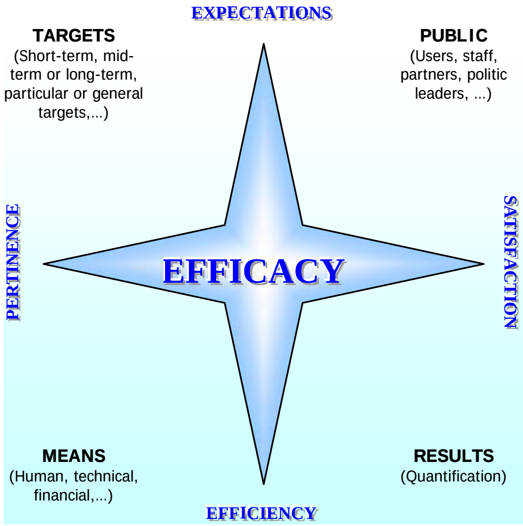
3.1.1 Overarching Theory

It is not the intent of this chapter to provide a universal comprehensive method of prioritization, but to describe theoretical prioritization elements, and to present different tools that can be customised for use by navigation authorities as deemed appropriate.

General principles

In many countries, rehabilitation needs often significantly exceed the financial resources available. Different strategies can help to optimize resource assignment to act as efficiently as possible, and to achieve the desired results.

The application of any work prioritization method demands the use of comprehensive logic, summarized in the diagram below :



The efficacy matrix[1]

In order to ensure the effectiveness of an action :

- targets have to fulfil public expectations,
- expectations must be satisfied by the action taken,
- efficient methods must be used,
- methods used must relate to the targets.

[1] In *Le contrôle de gestion dans les administrations de l'Etat – Eléments de méthodologie*, Délégation interministérielle à la réforme de l'Etat Ministère de la fonction publique, de la réforme de l'Etat et de l'aménagement du Territoire, France, 2002.

Public expectations have to be evaluated and objectives defined in terms of waterways functions. Traditionally, waterway functions can be grouped into:

- infrastructure for transportation and trade,
- infrastructure for leisure,
- hydraulic network (flood control, water collection and disposal),
- natural resource (for agriculture, energy production, fishing, etc),
- environment (landscape, heritage and ecology)

These waterway functions help in fulfilling the following factors of effectiveness:

- economy (resource exploitation, benefits from transport and tourism),
- ecology (nature and environment protection, resources preservation),
- rural and urban development (balance between different transportation modes, urbanisation, human activities localisation),
- societal stakes (employment, culture and heritage),
- image and communication

A benchmarking system may be used in order to measure, in a transparent and homogeneous way, each one of the four effectiveness factors above. Pertinence and efficiency can be evaluated through management ratios or through analytical book keeping. Other tools (opinion polls, dialogue etc) may be used to determine expectation and satisfaction measurement.

Efficacy factor	Indicative examples
Efficiency	• Amount of money spent • Operations engagement and realisation rate • Cost structure (Administrative costs, technical costs, subcontracted costs, ...)
Pertinence	• Analytic accounting • Staff composition on each project • Projects realisation duration
Expectations	• Regional plans for waterways development • Tourism and economy development studies • Local dialogues
Satisfaction	• Infrastructure use level, • Opinion polls, • Asset availability rate to a defined service level • Economy and tourism development

The continuous improvement cycle

Reasoned work planning methods may be described in a cycle leading to continuous network quality improvement, the service offered to users, and any economic, environmental or other objective that has been clearly identified and defined. Such a cycle is well known in quality assurance for industrial processing. It was developed in the 1930s[2] in the United States as a four step cycle concept (Plan/Do/Check/Act). This concept was improved[3] and became widespread in the 1950s and is now known as *Deming's Cycle.*

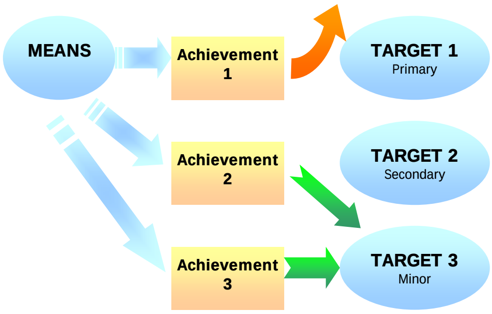
[2] By Walter Shewart, responsible for statistical control procedures at Bell Laboratories.
[3] *Elementary Principles of the Statistical Control of Quality*, W. Edward Deming, Nippon Kagaku Gijutsu Renmei, Tokyo, 1950, 1952.

Deming's cycle

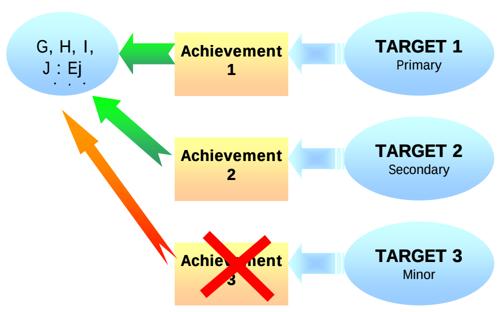
This cycle has appeared in many different forms in infrastructure management systems (IMS) around the world. In the Netherlands[4], IMS is based on three main steps in a cycle :

1. ***Needs validation*** - not limited to technical matters, but resulting from the use of the networks and their components. The validation results from balancing the different functional needs that should be satisfied by the network.

2. ***Financial evaluation and prioritization*** - driven by input parameters (input steering) or driving by means, or by objectives (output steering). Input steering is based on past experience (e.g. with current means, what has been achieved in the past) while output steering anticipates the future (taking into account the objectives, the works to be done, the methods, and the processes).



Input steering or driving by means



Output steering or driving by objectives

Budgets deduced from output steering are evaluated through forecast future costs of measures that can fulfil functional needs, whereas the budgets deduced from input steering depend only on the analysis of past costs. The output steering approach is now becoming the favoured route. (For example the French state administration will, from 2005[5], have to build budgets through action programs with clearly defined objectives, on a "zero basis" i.e. with a justification for every euro spent. Prior to 2005 "new measures" and "approved measures" were independently treated.)

Such budget justification by objectives implies a more detailed analysis than simple evaluation through past costs in order to determine and measure whole lifecycle cost. The future costs can be deduced, for instance, from maintenance plans. Nevertheless, this method ensures the pertinence of means used to reach the defined objectives.

3. **Works realization** – Following the work, its conformity to the objectives is checked. Where works have modified the use of the assets by meeting

[4] *Workshop Optimal Maintenance of Structures*, Dutch Ministry of Transport, Public Works and Water Management, Netherlands, 2000

[5] *Loi organique n°2001-692 du 1er août 2001 relative aux lois de finances*, France, 2001.

one or several functional needs, new objectives (in terms of functional needs) may need to be defined.

The zero-state

The preliminary phase of objective definition, and of zero-state data collection, is included in Deming's representation. Indeed, this cycle has been designed to be applied in industrial processes, from genesis and during the whole project. It involves the existence of a clear view and a perfect knowledge of the project's environment.

Practically, as regards maintenance and renovation of waterways infrastructure, the strategic objectives definition phase cannot be neglected. This task can be difficult, due to the number of waterway functions, and its stakeholders.

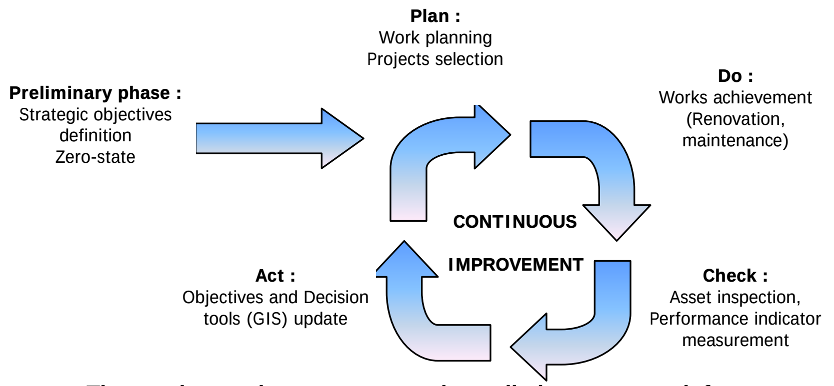
The detailed knowledge of a navigational network and its assets is often non-centralized and imprecise (incomplete knowledge of the exact numbers and details of different assets, their use, their condition etc). The building of an initial coherent zero-state is an opportunity to better understand the whole network and its close environment. The quality of the zero-state is very important although it is not necessary to be exhaustive, and can be built progressively, when the data structure has been clearly defined. At first, it may be sensible to restrict data collection to a geographic area or a type of asset and then to progressively extend the data collection to other areas or assets.

Data is often represented in a geographical information system (GIS). The extension of the underlying database will necessarily be done during the inspection phases or during the update of GIS.

Whatever methods are used for data collection, they must be formalized, simple to use, and provide homogeneous and reproducible results for similar assets, independently of the staff employed to collect the data.

Conclusion and key success factors

For waterway infrastructure Deming's cycle may be represented as below:



The continuous improvement cycle applied to waterway infrastructure

The main key success factors are the following :

Phase	Key success factor
PRELIMINARY PHASE	• Clear and precise definition of data structure for the zero-state • Step-by-step data collection • Clear, easy-to-use checkpoints with reproducible results
PLAN	• Precise definition of the objectives • Prioritization of the objectives • Pertinence check of the objectives versus public expectations • Clear definition of the realizations necessary to meet the objectives
DO	• Pertinent means provision for works achievement (if necessary by postponing the achievement of secondary objectives) • Means efficiency check
CHECK	• Public expectation measurement • Improved network and assets knowledge (performance measurement)
ACT	• Input data update (public expectations, regulation evolution, ...) • Objective update and research of potential new objectives

3.1.2 Practical Techniques

<u>Programmed Inspections Frequency</u>

The primary purpose of asset inspection is to identify and manage risks associated with those assets. It is essential to identify faults that may affect the business of the navigation authority, the planned level of service for its assets, threats to the safety of its customers, neighbours, staff or the public, and to ensure that remedial works are properly prioritised.

Where asset performance relates to the ability of the asset to meet target levels of service, inspections allow the monitoring of that performance with time. Monitoring asset condition and service throughout the asset lifecycle is important to identify under-performing assets or those that are about to fail or go out of service. This helps avoid premature asset failure and leaves open the option of cost-effective renovation rather than replacement (usually the most costly solution).

The results of inspections, properly recorded in an asset register, allow continuous monitoring of the status of the navigation authority's assets. This allows the authority to take a strategic view of condition and performance, and helps it manage the ability of its assets to meet future targets. It facilitates corporate prediction and planning of expenditure and resources, and allows long term forecasting.

Organisations that undertake regular formalised (programmed) inspections and condition assessments of assets can determine, using predictive curves, expenditure patterns based on knowledge of the age of the assets and a verifiable assessment of their remaining life (or service).

Most navigation authorities recognise the need for a structured hierarchical inspection regime, the need for inspections to be carried out by competent people, and for their reports and recommendations to be acted upon. They also recognise the requirement for additional or specific inspections. Such inspections are often the result of damage or exposure of the asset to extreme events (such as impact damage or flooding).

Inspection frequencies (and standards) differ between navigation authorities, asset types and facilities. Differing construction types, planned maintenance regimes, exposure to environmental (e.g., marine corrosion) and human factors also have a significant influence. However, there is a clear hierarchical structure of short, medium and long cyclicity inspections as shown in the table below.

Cycle	Inspection Type	Asset Type	Inspection Format	Inspection Output	Inspector Competency
1 day to no more than 3 months	**Routine** or Length Inspection (Short Term)	All infrastructure assets + operating equipment + earthworks	Visual + tactile looking for change, damage and safety defects	Simple exception report or standard report with work identified to manager	Local staff familiar with the operation of the asset type and certified to carry out inspections
6 months to no more than 5 years	**Intermediate** or Monitoring Inspection (Medium Term)	All infrastructure assets + earthworks + buildings	Visual + tactile + measurement, looking for rates of change	Standard report with condition grade, conceptual repair solutions + estimated costs to manager. Data input to asset register	General Civil or Structural Engineer certified to carry out inspections
3 years to no more than 20 years	**Principal** or Comprehensive Inspection (Long Term)	All infrastructure assets (above and below water) + earthworks + buildings	Visual + tactile + measurement + intrusive investigation, looking for significance of change	Comprehensive technical report to manager with condition grade, cause assessment, recommended solutions, detailed construction and hydromechanical data for design. Data input to asset register	Specialist Professional Engineer certified to carry out inspections
When required, (response to damage or extreme event)	Specific or Diagnostic Inspection (Non-cyclic)	All assets	Visual + tactile + measurement + intrusive investigation, Damage diagnosis	Damage focused technical report to manager with condition grade, fault diagnosis, recommended solutions, detailed construction and hydromechanical data for design. Data input to asset register	Specialist Professional Engineer certified to carry out inspections

While asset inspection frequencies may be driven by local, national or international standards, best practice suggests that the following **maximum** inspection frequencies should not normally be exceeded. Navigation authorities may adopt more frequent inspections dependant on local standards and circumstances.

Asset Type	Routine Inspection Maximum Cycle	Intermediate Inspection Maximum Cycle	Principal Inspection Maximum Cycle
Aqueduct	1 month	5 years	10 years
Bridge (Fixed Road)	1 month	5 years	10 years
Bridge (Moving)	1 month	1 year	5 years
Bridge (Pedestrian)	1 month	5 years	10 years
Lock	1 month	5 years	10 years
Pumping Station	1 month	5 years	10 years
Sluice	6 months	5 years	10 years
Safety Gate	1 month	5 years	10 years
Weir	1 month	5 years	10 years
Boat Lift	1 month	1 year	5 years
Reservoir/Dam	1 month	5 years	10 years
Electromechanical assets	1 month	1 year	10 years
Waste Disposal Site	3 months	5 years	10 years
Embankment	3 months	5 years	20 years
Cutting	3 months	5 years	20 years

Dyke	1 month	5 years	10 years
Bank Protection	3 months	5 years	20 years
Fender	1 month	1 year	10 years
Channel bed	Not normally accessible*	Not normally accessible*	20 years
Tunnel	6 months	1 year	5 years
Culvert	6 months	10 years	20 years
Siphon	6 months	10 years	20 years
Underwater assets	Not normally accessible*	Not normally accessible*	20 years
Dock	1 month	5 years	10 years
Dry Dock	1 month	5 years	10 years
Pier	1 month	5 years	10 years
Quay	1 month	5 years	10 years
Buoy/Navigational Aid	3 month	5 years	10 years
Building	1 month	5 years	10 years
Road	6 months	5 years	10 years
Fence	6 months	5 years	10 years
	* Consider use of remote sensing		

Many navigation authorities adopt a time based inspection cycle. However, as they develop detailed knowledge of their assets and rates of deterioration, through those inspection regimes, it may be possible to move on to a risk based approach. This can allow more effective targeting of resources to those assets in the poorest condition with the highest consequences of failure.

The simple example given below shows how the principal inspection cycle for a structure could be driven by risk. As condition grade deteriorates, or the consequence of failure increases, the maximum allowable cycle for inspection (in years) decreases. Such an approach needs to be customised for each asset type, as the risk will vary with type, construction, usage etc. Local requirements and standards would determine the actual values of the maximum cycles shown.

		Condition Grade				
		V Good A	Good B	Acceptable C	Poor D	Bad E
Consequence of Failure Grade	Low 1	**20**	**20**	**10**	**10**	**5**
	2	**20**	**20**	**10**	**10**	**5**
	Medium 3	**20**	**20**	**10**	**5**	**5**
	4	**10**	**10**	**10**	**5**	**2**
	High 5	**10**	**10**	**10**	**5**	**2**

It is important that inspection reports are produced to a standard format, in order that the outputs can be interpreted consistently by those responsible for planning or authorising expenditure. Each hierarchical level of inspection will require reports with differing levels of detail.

At the routine inspection level, a simple exception report clearly identifying those elements of assets that may be deteriorating, damaged, or failing to give the required level of service is probably adequate. The report should be a clear record of those assets that have, and have not been inspected. Such records are valuable in the event of legal proceedings being taken against a navigation authority, and in monitoring asset condition and service levels.

At the principal inspection level, a comprehensive report would normally be required to provide a detailed record of the details of each element of an asset and to record the condition of those elements as well as the structure as a whole. The inspection would consist of a qualitative assessment of the each element of the structure with dimensional checks where necessary. The Inspector would normally review any past reports and then apply engineering knowledge in assessing the significance of any defects and whether they indicate a more complex failure mechanism than those indicated by a cursory inspection.

Outputs from a Principal Inspection would take the form of a full report which would identify any urgent work as well as making recommendations for less urgent work to be included in work programmes in the longer term. While individual report styles may vary between authorities, it should normally include:

- **Cover sheet** giving the name or identifier of structure inspected and the date
- **Executive Summary** of the condition of the structure, key actions, significant costed recommendations and constraints to works (to assist the Manager in interpretation of the more detailed technical report).
- **Main Report**

  (a) Introduction including when was it inspected and by whom, the weather on the day, whether any previous routine, intermediate or principal inspections were available to assist.

  (b) Description of the structure, it's location, function, materials, and architectural features

  (c) Observations dealing with each of the main elements in turn. The following table gives examples of the main elements for some asset types, although the list is by no means exhaustive.

Bridge/ Aqueduct	**Culvert**	**Earthwork**	**Sluice**	**Lock**	**Building**
Elevations	Catchment Area	Channel	Cover	Chamber Walls	External Building Details
Abutments/ Piers	Upstream Watercourse	Bank Protection	Valve	Invert	Internal Building Details
Spandrels	Upstream Headwall	Crest	Chamber	Wingwalls	Services/ Installations
Wingwalls	Culvert Lining	Slope Face	Operation	Forebay	Exterior Features
Arch Barrel	Downstream Headwall	Toe	Gates	Paddles/ Chambers	Hazards
Deck/ Trough	Downstream Watercourse	Adjacent Land	Culvert	Culverts	Documentation
Beams/ Members	Access Details	Drainage	Outfall Headwall	Gates	
Parapets		Other Integral Structures	Culvert	By-wash	
Track incl. Weight Limits		Geotechnical Matters	Outfall Watercourse	Lock Sides	
Towpath				Side Ponds	
Approach Walls				Tail Bridge	

(d) **Discussion** of the defects, their diagnosis, risk assessment, fitness for purpose of the structure, urgency of repairs etc. Any heritage or environmental constraints should be identified.

(e) **Assessment** including detailed analysis of load bearing capacity, flow capacity, volume etc

(f) **Grades** with summary of Condition, Serviceability and Consequence of Failure Grades etc with explanation if appropriate.

(g) **Inspection Requirements** for any future inspections including recommendations for the inspection frequencies.

(h) **Works Recommendations** including estimated costs, any constraints, and priorities for works or further investigations required.

(i) **Photographs** for reference with details of the features recorded

(j) **Appendices** including plans, sketches, measurements, assessments, calculations, references to previous reports, references to heritage registers etc

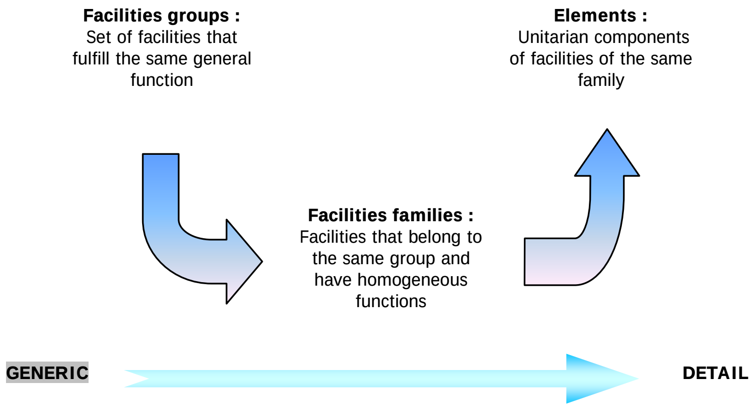
The inspection would be the primary means of informing the Manager of the condition of the asset stock. Relevant summary data would be entered into the navigation authorities' asset register as appropriate, and the report would be signed off by the Manager.

3.2 Advanced Processes

3.2.1 Overarching Theory

Data structure:

In order to know precisely the state of the assets on a network, and to be able to interrogate the database to help work prioritization, it is necessary at an early stage to precisely define a coherent asset hierarchy or data structure, that allows the groupings of similar information, and able to adequately describe the facilities. An example of data structure could be as shown below :



Example data structure for assets

Practically :

- **facilities groups** could include linear facilities, water regulation facilities, water level control facilities, other crossing facilities etc

- groups may have one or more **facilities families**. So, the water level control facility may be composed of locks, ship lifts, inclined planes, fish passes, canoe facilities etc

- a facility family may comprise several **objects**. For example, the locks family includes the chamber walls, floor, gates, sluices etc

This data structure needs to be adapted to the particular circumstances of the network concerned. For instance, for port infrastructures, a berthing facilities group could be added, with the family “quay” and the objects “vertical wall” or “bollard” etc

The division of a facility into objects cannot be based on technical considerations alone. It is important to consider the facility’s environment. For instance, a linear facility may be composed of different objects depending on the nature of the nearby environment (i.e. rural land is not as important as a towing path, or as a major road).

An area of influence may be determined around the facility. Problematic legal issues (i.e., land or property) or land stability related to geotechnical matters will be taken into account to determine the limits of the influence of the facility on its nearby environment.

Evaluation of the facilities condition

The condition of a facility should be evaluated both through its physical state (is it in a good state and able to fulfil its functions?), and also be measured through its strategic importance (the value of the facility for the community).

The physical state – The condition index I_C

The physical condition of a facility can be represented by the mechanical state of its components (mechanical index $\mathbf{I_{CM}}$ of the objects), and by the ability of those components to fill the functions they have been designed for (use index $\mathbf{I_{CU}}$). (Note that in the context of indices, the word ‘mechanical’ is used to define all structural, mechanical, hydraulic and electrical components essential to an assets function and operation).

- The **mechanical index** $\mathbf{I_{CM}}$ describes the mechanical functioning of an object (bridge, mass gravity wall etc) and the condition of its components (concrete, steel, wood etc) It is evaluated by comparison to common problems associated with that facilities’ family. The problems to consider are defined on the basis of the knowledge of the object’s function, on experience, and if required on a fault mode analysis. For instance, for the *lock gate (or door) object* in the lock *family* within the *water level control facilities* group, $\mathbf{I_{CM}}$ may take into account factors such as dynamic clearance, manoeuvrability, structural corrosion, wear of timber elements, wear of supporting structures, watertightness etc.

- The **use index** $\mathbf{I_{CU}}$ measures the operational safety of the functioning object for staff, public, navigation, and other potential users. For the *lock* *gate*, for instance, it may measure the *risk of being injured by the mechanism itself*, the *risk of an accident during operation (including potential loss of water in the reach above)*, the *safety of any ancillary elements (footbridge, lifelines, walkways) etc.*

The condition index $\mathbf{I_C^O}$ of *object* 'O' is then determined by combination of the mechanical index $\mathbf{I_{CM}^O}$ and of the use index $\mathbf{I_{CU}^O}$ of the object. The overall condition index $\mathbf{I_C}$ of a *facility* can be, by simplification, the minimum condition index $\mathbf{I_C^O}$ of its component objects[6].

To each condition index is related a generic description of the facility state, the kind of measures, the precise actions to undertake and the intervention time limit. The example below may be adapted to suit local circumstances:

I_C	Facility condition	Measures	Time limit
5	The immediate safety is not assured	Curative maintenance / Renovation Precise actions to remedy to the cause of the lack of safety of the structure and equipment Detailed inspection	Immediate
4	The facility has serious disorders that may impact upon the service level in the short-term period	Curative maintenance (and/or) Detailed inspection	Short term (1 / 2 years)
3	The facility needs important or specialised repair works, in order to guarantee its function and the service level in the mid-term period	Curative or specialised preventative maintenance	Medium term (2 / 3 years)
2	The facility needs important or specialised repair works, but service level is not affected in the medium-term period	Specialised preventative maintenance	Medium term (2 / 3 years)
1	The facility needs standard maintenance	Preventative maintenance	Long term (>3 years)

The usefulness of the facility– Strategic index I_S

Planning of renovation works does not only depend on facilities condition. Indeed, a lack of funding often leads to prioritization between several facilities that should, according to their condition index, be repaired immediately.

To help in this prioritization, it is useful to describe the interest of the facility for the community, or for the particular objective of its owner, through a strategic index $\mathbf{I_S}$. Strategic indices should allow the importance of the facility to be evaluated for the different waterways functions and stakeholders. They take into account different parameters, the balance of which can vary from one organisation to another.

An inquiry was carried out in 1997 in order to define the business of French waterways . The strategic importance of each canal was evaluated for each function through different indices. As an example, the following table is derivated from the indices used in 1997:

[6] Note : This approach may seem very reductive as each component of the facility has a different weighting as regards the facility lifespan. Undertaking such a detailed approach involves defining a balance for each kind of facility on a network. In practice this is difficult to achieve.

Deleted: object

Deleted: weight

Deleted: lifetime. Nevertheless, practically, it's quickly noticeable that having

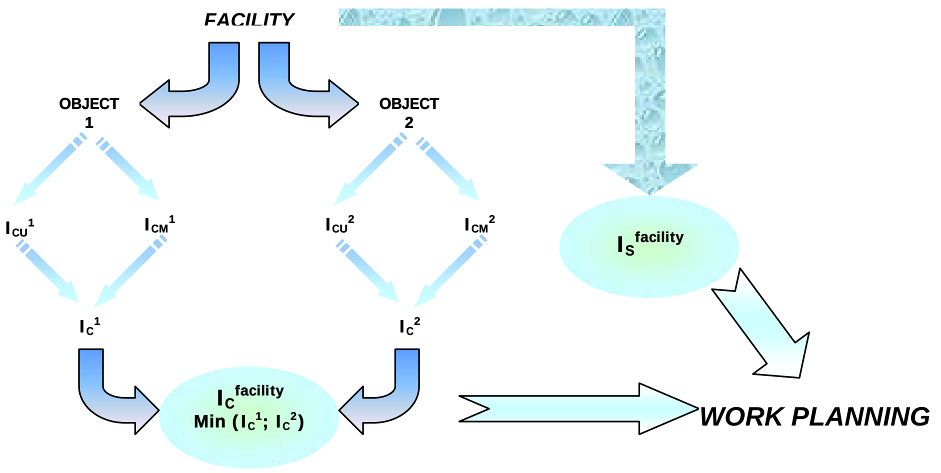
Deleted: very

Deleted: , which is a very hard task.

Function	Index	+	++	+++	++++	+++++
Freight transport	• Traffic density last year(Σ ton.km/ length) • Growth five past years	50000 t - 250000 t	250000 t- 500000 t	500000t – 750000 t	750000 t – 1 Mt	>= 1 Mt
Tourism	• Traffic density last year (Σ ton.km/ length) • Growth five past years	200 – 1000	1000 – 2000	2000 - 3000	3000 - 4000	>= 4000
Water transportation, pumping	• Volumes by user nature (pumping) • Amount of hydraulic tax collected last year	5 M m^3 - 10 M m^3	10 M m^3 - 50 M m^3	50 M m^3 - 100 M m^3	100 M m^3 - 200 M m^3	>= 200 M m^3
Flood protection	• Approximate number of protected inhabitants	< 10000	10000 - 50000	50000 - 100000	100000 - 200000	>= 200000
Energy production	• MWh produced last year	<30 MWh	30 MWh - 100 MWh	100 MWh - 200 MWh	200 MWh - 500 MWh	>500 MWh
Nautical activities	• Number of days requiring a specific authorization • Count of clubs or associations that have a permanent authorization	<5 days	5 – 10 days	10 - 15 days	15 - 20 days	> 20 days
Environment (oil slick control, water complements in dry season, dams water oxygenation, urban or natural sites promotion, plantations, fishing, water game hunting, walking, residential boats …)	• Description memo	Fishing, cycle path, …			Major site	

Combination of both indices

When the condition index I_C and strategic index I_S of each facility has been determined, these indices may be balanced to define a global index for the facility. The balance ratio depends on the owners objectives. By applying a GIS view to this data, the global index highlights those sites where works are urgent.



Example of resource optimization process for strategic facilities from facility to work planning

Exploitation plan

The above method is useful to determine the strategic facilities on which efforts have to be concentrated. However, on its own it is not sufficient to ensure the adequacy of objectives versus public expectations. One approach may be the definition, by negotiation with waterway partners and users, of service levels to fulfil various objectives, in terms of use, of canals and rivers. Some example of possible service levels are given below.

Objective			Service level				
Title	Definition	Unit	1	2	3	4	5
Closure	Maximal number of closure days (public holidays)	*Days/year*	3	6	---	0 between 1st April and 11th November	---
Opening hours	Difference between seasons	*(yes / no)*	no	no	no	yes	Yes
	Opening hours/day (high season)	*Hours*	24	12	10	9	9
	Opening hours/day (low season)	*Hours*	24	10	8	---	---
Length of stoppages for work	Maximum length/year	*Months/year*	0.5	1			
	Maximum length every 2 years	*Months/year*	1	2	<= 5	<= 5	<= 8
	Maximum length every 5 years	*Months/year*	1.5	5			
User information	Minimum information time / work time modification	*days*	90	30	8	8	8
	Maximum information time / stop – non foreseeable navigation restriction.	*hours*	3	24	24	24	24
	Minimum information time / foreseeable navigation restriction	*days*	6	2	2	2	2
Breakdowns	Maximum number of breakdowns of less than 6 h (*)	*No./year*	3	5	---	---	---
	Maximum number of breakdowns of less than 24 h (*)	*No./year*	0	5	---	---	---
	Maximum number of breakdowns of less than 48 h (*)	*No./year*	0	0	10	3 (High season)	---
Winter exploitation	Ice breaking	*(yes / no)*	yes	yes	no	No	No
Depth guarantee	By bathymetry and dredging / minimum number	*Days/year*	365	350	300	High season	No
	By water level keeping / minimum number	*Days/year*	365	350	---	High season	No
Water collection and feeding system	Maximum count of stoppages due to compliance with minimum flow and other water regulations	*Days/year*	0	15	---	10 (High season)	---

Some examples of service levels

Service levels can then be gathered together in an exploitation plan. The exploitation plan can be considered both as a technical tool and as a communication document.

Renovation plan

Depending on the condition of the facilities, on their strategic importance and on their service level, different financing strategies can be considered for renovation and subsequent maintenance. However, it is important to set up a system that allows the verification of the pertinence and efficiency of these with time. An example of a decision tree which could be used for this purpose is presented in Appendix 3

3.2.2 Practical Techniques

Use of indices for prioritization of repair activities

General considerations

As described before, when a judgement has to be made about a repair, condition considerations and strategic considerations have to be taken into account.

Condition considerations reflect the condition of the asset materials and any surroundings which influence the stability of the construction. The service level of the asset is also a condition consideration. However, the condition quality is measured by many kinds of inspections, which may result in one or more condition quality indices of the asset. The general condition may be expressed by the condition index I_C, which can be build up by a mechanical index I_{CM} and a use index I_{CU}.

When utilising life cycle asset management, a decision can be made whether a repair activity is to be done sooner or later, so that over the expected lifetime the maintenance is done by the most economical way. However life cycle asset management is not evident for all kinds of assets and even for more obvious elements there may be unknown details. Moreover, the available budget is often restricted, so there is a need for further prioritization that may not be based on the purely technical-economical considerations alone.

Strategic considerations can help to complete this judgement. For instance, the risk arguments take into account the consequences of failure of an asset. Those risks deal with human harm, property damage and ecological damage. They depend on the kind of asset, the frequency of its use and the kind of the area influenced by its failure. A risk analysis can result in one or more risk indices of the asset.

Safety and environmental protection are often important to the functional needs of a waterway, but there are also leisure, heritage, landscape and other considerations. The importance of the asset for all those needs can expressed by various indices, summed up in an overall strategic index I_S of the asset.

Use of asset indices

For the management of an asset, two general characteristics may be visualised:

The global condition characteristics give the "engineer" view of the asset and the general condition situation can be expressed by a condition index. The strategic characteristics give the "owner" view of the asset and the general strategic condition can be expressed by a strategic index. Each index can be the combination of other indices, which focus on some aspect of the overall index.

Condition index

This represents the actual condition of an asset at a certain moment, in accordance with specific standards which have been defined in the management system. This index normally gives an idea about the general maintenance state of the facility. The condition index can be subdivided in a mechanical index and a use index.

Mechanical index

The mechanical index indicates the technical or structural condition of the components and materials of the asset and the surroundings.

Use index

The use index indicates if the asset can be used for the designed purpose or if there are some restrictions that may affect its use by customers.

The method of evaluation of these indices must be defined in the management system manual, and will be usually be the result of an inspection.

Condition index determination

The inspection is normally made by an engineer, and will assess both major faults and provide a general assessment. Any work executed since the last inspection is recorded, followed by the conclusions of the present inspection and a general quality level determined by one or more technical indices. If necessary, maintenance can be proposed. Finally, the document is signed and dated and passed to a Manager for a decision

Strategic index

The strategic index deals with the different waterway functions: transport, hydraulics, safety, nature, leisure, resources, heritage, landscape (urban and rural).

A strategic index needs a specific approach to define. It is not the result of an inspection but of a general assessment of the function of an asset.

Index Levels

For simplicity and to aid comparison, for all indices it is useful to adopt five levels.

For example, for the mechanical index these may be:

1. Perfect condition
2. Superficial damage
3. Structural damage
4. Collapse of a non-essential element
5. Collapse of an essential element

And for the use index:

1. Use without restriction
2. Use with slight discomfort
3. Use with considerable discomfort
4. Use under certain restriction
5. Out of service

If there is a preference for only one overall index, the two indices can be combined in one scale, which may indicate the importance of the maintenance to be done:

1. In order
2. Normal repair required
3. Structural repair required
4. Functional restriction
5. Out of service

The combination of the mechanical and use indices in one condition index can also be done by giving a weight to each index. The principles are explained later, with a proposed formula as a help for prioritization.

Strategic index determination

The strategic index depends on the several functions of the waterway and its assets.

The authority can determine for each asset an overall strategic index which is an indication of its importance. For each function a single index can be defined and the strategic index is then the combination of those indices by weighting each index.

An interesting index for decision makers is that connected with safety. An index can measure the relationship between either the failure or collapse of a certain asset connected with the probability that an accident occurs, and the cost of the repair. There are again five levels, ranging from high costs and probability (level 5) to low costs and probability (level 1).

Another index may relate to the damage to the surroundings of the asset, if the asset collapses (for example an inundation of a town has potential to do more damage than the inundation of rural land). Again five levels can be defined with 1 being the level without damage and 5 the level with the highest damage.

These indices give an indication about the risks in case of a failure of an asset. For simplicity, an initial general risk index can be defined for each asset, combining all costs in case of a failure. This general risk index may be a first step to an overall strategic index.

Formula

To combine the two overall indices described above the following formula can be used:

$$I = (a * I_C + b * I_S) / (a + b)$$

The value of the coefficients a and b can be chosen depending on the importance given to each index. However the result is an index from 1 to 5.

The formula is easily extended to more indices (e.g. the components of the condition and strategic index) and their coefficients, but the result will remain between 1 and 5.

The advantage of this formula is that every single index, and also the resulting index have the same range (from very good to very bad). The weight of each index in the final result depends on the value of the coefficient. This is a system of multi-criteria analysis.

Appendix 1 – Definition of Infrastructure Terms

To assist understanding, it is important to have a definition of commonly used terms that describe navigation infrastructure. The following list is sub-divided into three groups. The first concerns commercial facilities for sea-going ships, the second for inland waterways facilities and the third for coastal and lake .

It should be noted that the lists are not exclusive

A) Port and harbour structures

Sheet pile cell structure	Enclosed cellular structure formed by interconnected steel sheet piles, filled with granular material. 3 basic configurations: (1) Circular cell, (2) Diaphragm cell, (3) Cloverleaf cell
Concrete caisson	Heavy cubic box structures constructed in dry docks or on shore. Can be constructed in 2 stages, lower part constructed on shore or on floating equipment, and completed by slip-forming. Floated into position, sunk onto a prepared foundation, and interior voids are filled with ballast. Often used at exposed sites where construction which relies heavily on the use of floating equipment can be delayed by unfavourable sea conditions.
Timber crib	Assembly of open or closed face compartment, either floored or unfloored, assembled on land and floated out and sunk onto a prepared foundation. Interior filled with suitable ballast . Top of crib usually decked in timber or concrete. Flexible and better able to adjust to differential settlement than concrete caissons
Buttress wall	Typically L-shaped concrete retaining structures reinforced with stiffener ribs. Wall stability depends upon the weight of the fill directly behind it and on the foundation conditions.
Cantilever wall	Series of interconnected sheet piles driven to sufficient depth to form a vertical retaining structure.
Anchor wall	Series of interconnected steel sheet piles driven into the ground and tied back by an anchoring system.
Open-pile timber structure	Typically a timber deck floor supported on stringers which transfer the vertical loads to the foundation piles through timber pile caps. Lateral loads are resisted by batter piles as well as horizontal and diagonal bracing.
Open-pile concrete structure	Typically a solid deck platform installed on concrete caps, supported on concrete piles. Can also be accomplished by an anchoring system. Deck system can be cast-in-place concrete, or precast-prestressed deck panels with cast-in-place topping, or a composite section comprising a structural steel pile cap embedded in the cast-in-place slab
Open-pile steel structure	Very similar to concrete structures, and pile caps and the dock are often constructed of concrete. A distinction is that the support piles are steel instead of concrete.
Floating structure	Floating berths for short or long term mooring of small craft. Typically comprise flotation units anchored by piles or a chain and block anchor system. The types of float construction are: - Timber floats (with time submerged timber flotation units can become waterlogged and lose buoyancy). - Concrete floats comprising a hollow or foam filled shell constructed of lightly or unreinforced concrete.

	The units are relatively maintenance free. - Fibreglass floats. Very similar to concrete. - Metal floats. Relatively light and sturdy flotation unit. - Foam floats comprising expanded polystyrene or polyurethane billets strapped together. Extremely lightweight and flexible but subject to rolling/pitching under wave action at exposed sites. - Rubber floats. They are essentially a variation of the previous comprising rubber tyres filled with foam. Floating berths are connected with the shore through gang ways, hinged at the shoreside and the other end is free to roll on the deck of the floats to adjust to water level fluctuations.
Fendering system	Designed to absorb kinetic energy of a berthing ship. The two basic fendering systems are: - Structural deflection fenders comprising individual fender piles or a group of cantilever piles assembled to form a flexible dolphin. Suited to use at facilities which accommodate a wide variety of ships since they can make contact along the entire length of the pile. - Rubber fender units . There are a large number of units on the market and care must be taken to ensure suitability of a proposed fender system under various usage conditions. The frame assembly can be supported on fender piles or hung from the vertical face of the structure.
Rip-rap revetment	Slope protection comprising quarried heavy armour rock placed over a filter layer (smaller rock materials or an artificial membrane).
Gabions	Rock filled wire baskets placed along the shoreline. They are relatively expensive, require good foundation conditions and can be difficult to maintain.
Concrete revetment	Vertical or inclined retaining structures constructed along the shoreline to provide protection against wave action
Soil cement revetment	Mixture of approximately 10% cement and 10% water by weight of dry soil, placed in stepped horizontal layers.
Containment dykes	Constructed to retain dredged fill material, or to protect low lying areas, or to create ponds for cooling water or sewage treatment. Slope protection materials are similar to those described in the preceding section.
Breakwater	An artificial means of creating a sheltered harbour. They can be: - Vertical wall breakwater, variations are (a) Vertical concrete caisson, (b) Vertical timber crib and, (c) Vertical piled. - Rubble mound, with a main armour layer constructed of natural stone or artificial concrete units.
Dredged channel	Vessels normally gain access to a berth by navigating along channels that are not always natural and access must be created and maintained by dredging.
Shore based facilities	Basic infrastructure required to ensure safe and efficient handling of cargo. Groups include - Transit sheds - the lightest and lowest cost construction possible with low maintenance costs, that provide temporary shelter for goods.

	- Ferry ramps - adjustable to accommodate varying ship draft and freeboard conditions, and the full range of water level encountered at the facility. Tower or headframe structures satisfy these requirements. - Utilities and services - including electrical, water, sewage and fire protection services. - Pavements - including asphaltic, cement or paving blocks, situated along access roads, storage and parking areas, corridors, etc.

B) Inland waterway facilities

Aqueduct	A structure carrying a canal or feeder over an obstruction such as a river, road or valley. It includes the trough, approaches, invert, river protection walls, cut-waters, footpaths, and draw off sluices within the aqueduct.
Minor Access Bridge	A bridge constructed to provide access across the canal, feeder or river for an adjacent landowner or to maintain a Right of Way. These bridges do not carry a public road. Includes approach walls, approach ramps, surfacing , canal invert, warning or information signs, stop-plank facilities and mechanical and electrical equipment.
Road Bridge	A bridge carrying a public road over a canal, feeder or river and used by road vehicles. Includes bridge control cabins or ancillary buildings, approach walls, approach ramps, surfacing, canal invert, weight restriction signs, stop plank facilities and mechanical and electrical equipment.
Towpath Bridge	A bridge carrying the towpath from one side of the canal or feeder to the other. May also carry the towpath over an obstruction, canal arm or junction. Includes approach walls, approach ramps, surfacing , canal invert, stop plank grooves and planks and mechanical and electrical equipment.
Culvert or Siphon	A drainage structure that allows a small watercourse to pass under a canal or feeder. May be horizontal or siphonic. May also accommodate utilities assets such as electricity cables. Includes culvert structure, headwalls, catch pits, inspection accesses, stream upstream and down stream within sphere of influence.
Major Cutting	An excavated earth structure that contains the canal, where canal water level is more than 3m below surrounding ground level. Includes slope face, bank protection, towpath, surfacing, inspection accesses, drainage pipes, ditches, retaining walls and vegetation.
Dry Dock	A chamber for boats that can be dewatered. Includes chamber, gates, work areas, sluices, electrical, mechanical or hydraulic equipment, safety equipment, accesses, pedestrian bridges or walkways, stop plank facilities, and any associated buildings.
Dredging tip	A licensed area of land, that may be bunded and designed to contain dredged materials. Licensed dredging tips may be on Navigation Authority land or on land in other ownership. They may be active or dormant but will be available for use if required. Includes fencing, drainage, monitoring equipment, accesses, run-off and leachate monitoring systems.
Major	A constructed earth structure that supports the canal where

Embankment	canal water level is higher than surrounding ground level by more than 3m over a length of 200m, or by more than 6m at any point. Includes crest, slope face, toe, bank protection, towpath, surfacing, inspection accesses, drainage pipes, ditches, retaining walls and vegetation.
Lock	A structure designed to raise or lower boats on a canal by the operation of lock gates. May be found singly or in flights. In a staircase flight the top gates of one lock form the bottom gates of another. Includes chamber, gates, lock side, furniture, sluices, landings, by-pass weirs and culverts, pedestrian bridges, control cabins, electrical, mechanical and hydraulic equipment, safety equipment, accesses, stop plank facilities.
Pumping station	A facility designed to pump water to or from the canal. Includes intake, outfall, pipelines, electrical and mechanical equipment, drainage, emergency equipment, fixed lifting equipment, power supply, any building used solely to house the pumps or control equipment, and any other ancillary structure regarded as part of the Pumping Station
Reservoir	An artificial lake for water supply to a canal. Includes dam or head bank, draw off, flood weirs, emergency draw down arrangements, valves and valve houses, feeders into the reservoir, access, user facilities, safety equipment, fencing, bridges, spillway and downstream channel within sphere of influence. Also any other ancillary structure or building that forms part of the operation of the reservoir.
Sluice	A valve mechanism to allow drainage of a canal or flood control on a river. May occur singly or in combination. Includes approach walls, discharge channel within sphere of influence, locking mechanism.
Stop/Safety/Flood Gate	Gates that span canals or rivers for the retention of water in case of emergency or to protect property from flooding, including tidal fluctuations. Includes body, gates, access.
Tunnel	A tunnel designed to carry a canal through a physical obstruction (such as a hill). Includes tunnel, portals, towpaths, accesses, ventilation shafts, and signage.
Canal Weir	A weir, not part of a lock structure, to convey surplus water away from the canal. Includes approach walls, crest, apron, discharge channel within sphere of influence, integral sluices, crest planks, access for clearance, over bridge, safety boom.
River Weir	A weir on a river navigation to create and maintain adequate depth of water for navigation. Includes approach walls, crest, apron, discharge channel within sphere of influence, integral sluices, crest planks, access for clearance, over bridge, safety equipment, accesses, and stop plank facilities
Weired Lock	A Cascaded lock on an abandoned canal or a non operational lock now used as a weir. Includes chamber, weir, lock side and lock side furniture, sluices, pedestrian bridges, electric and hydraulic equipment, accesses, stop plank grooves and planks.
Dock	A facility where ships may berth for the purpose of loading or unloading. Includes chamber, walls, gates, work areas, sluices, electrical and hydraulic equipment, safety equipment, accesses, pedestrian bridges or walkways, stop plank facilities and any associated buildings.

Boat lift	A mechanical device designed to raise or lower boats between different canal levels. Includes vertical lifts, inclined planes and rotating lifts. Includes structure, gondola, caissons, gates, work areas, sluices, electrical and hydraulic equipment, safety equipment, accesses, pedestrian bridges or walkways, stop plank facilities and any associated building.
Navigation Authority Office	A Navigation Authority operational building whose primary function is an office.
Navigation Authority Workshop	A Navigation Authority operational whose primary function is a workshop.
Navigation Authority Dwelling	A Navigation Authority dwelling occupied by operational staff.
Customer Service Building	A Navigation Authority operational building whose primary purpose is to provide service functions for customers (e.g. sanitary station).
Quay wall	A vertical construction owned by the Navigation Authority designed to allow the mooring of ships.
Landing stage	A horizontal staging owned by the Navigation Authority and constructed to moor ships.

C) Other structures that may need to be included in planning maintenance

Artificial lake or pond	A basin not classed as a reservoir, excavated and filled with water from run-off, by pumping or by diversion of a natural water body. May include settling ponds, gravel pits, stone quarries etc.
Artificial beach	A bathing beach created by removing soil and subsequent filling with sand or fine gravel. Sand may also be spread over a clay shore to create a more desirable beach. May be created by the construction of groins to trap natural shore drift.
Bank	Vertical or sharply rising slope, often wave cut, bordering a canal, or shoreline the sharply rising ground, or abrupt slope, usually wave-cut and presenting a nearly vertical front, bordering the shore or water line.
Slipway or Boat Ramp	A location on a canal or shore of a lake where the slope is gentle enough to permit the use of vehicles and trailers for boat launching and loading. Usually improved by the installation of surfacing sand, gravel, metal matting, macadam or concrete.
Boathouse	A structure built on the shoreline of a lake for the storage of boats. May be built over water on piling or on a floating base, or on land and provided with a ramp and a dry floor.
Groin (groyne)	Low narrow wall-like structure extending into a lake normal to the shore. May be constructed of timber, stone, concrete or steel and is usually impermeable. Its purpose is to catch littoral drift, to trap sand, or to protected a beach from erosion.

Appendix 2 – Definition of Asset Management Terms

Advanced Asset Management	Employs predictive modelling, risk management, and optimised decision making techniques to establish asset lifecycle treatment options and long term investment predictions
ALARP	**A**s **L**ow **A**s **R**easonably **P**ractical
Asset	A physical component of a facility that has value, enables a service to be provided, and has an economic life. Dynamic assets have moving parts whilst passive assets have none
Asset Hierarchy	Framework for segmenting an asset base into appropriate classifications. The hierarchy can be based on function, asset type or a combination of the two
Asset Management (AM)	The combination of management, financial, economic, engineering and other practices applied to physical assets with the objective of providing the required level of service in the most cost effective manner
Asset Management Information System	A combination of processes, data and software applied to provide the essential outputs for effective AM such as reduced risk and optimum infrastructure investment
Asset Management Plan	Plan developed for the management of one or more infrastructure assets that combines technical and financial management techniques over the lifecycle of the asset to cost effectively deliver the specified level of service.
Cost benefit analysis	Method to value overall benefit against cost. Usually the sum of the present values of all benefits (including residual value if any) over a specified period, or the lifecycle of the asset or facility, divided by the sum of the present value of all costs
Decision Tree	A graph of decisions and their possible consequences, (including resource costs and risks) used to create a plan to reach a goal. Decision trees are constructed in order to help with making decisions.
DNV International Environmental Rating System	Det Norske Veritas' (DNV) eenvironmental rating system which provides the means for a systematic analysis of all aspects of an organization's environmental management .
DNV International Safety Rating System	Det Norske Veritas' (DNV) comprehensive 10 level system for measurement of management's safety performance and comparison between industries.
Essential Asset Management	AM relying primarily on the use of an asset register, maintenance management systems, resource management, inventory control, condition assessment and defined levels of service, to establish treatment options and cash-flow predictions.
Facility	A complex containing many assets, which represents a single management unit for financial, operational, maintenance or other purposes.
Geographical Information System (GIS)	Software which provides a means of spatially viewing, searching, manipulating and analysing an electronic database
Infrastructure	System forming a network serving a whole community or organisation, and where the whole must be maintained at a particular service level. The network may contain assets as components

Lifecycle	Cycle of activities that an asset (or facility) goes through while it retains an identity as a particular asset i.e. from planning to design, operation, decommissioning or disposal
Lifecycle AM	Assessing the lowest long term costs (rather than short-term savings) by consideration of all options and strategies as part of the asset lifecycle, from planning to disposal or demolition. It involves reducing lifecycle costs through improved practices and the use of new technologies and methods.
Lifecycle Cost	Total cost of an asset throughout its life including planning, design, construction, operation, maintenance, rehabilitation and disposal costs
Maintenance	Actions necessary for retaining an asset as near to its original condition, but excluding rehabilitation or renewal. May be fixed interval maintenance or condition based maintenance
Mission Statement	A statement of why an organisation exists, and what it hopes to achieve in the future
Preventative Maintenance	Maintenance that can be initiated without routine or continuous condition based checking (e.g., using data contained in maintenance manuals or manufacturers' instructions
Rehabilitation	Generic term for works to repair or renovate assets
Renovation	Works to rebuild or replace components of an asset to restore it to the required functional condition and extend its life (also known as rehabilitation)
Renewal	Works to upgrade, refurbish or replace existing facilities with those of equivalent capacity or performance capability
Repair	Action to restore an asset to its previous condition following failure or damage
Resource Optimization	An optimization process for considering and prioritizing various resource options
Risk Management	Application of a formal process to the range of possible values relating to key risk factors in order to determine the resultant ranges of outcomes and their probability of occurrence
Service Level	A defined service level for a particular asset or activity against which service performance can be measured. Usually relate to quality, quantity, reliability, responsiveness, environmental acceptability and cost
Zero-State	State of reference: The condition of the infrastructure or assets at the beginning of the work-planning process

Appendix 3 – Decision Tree

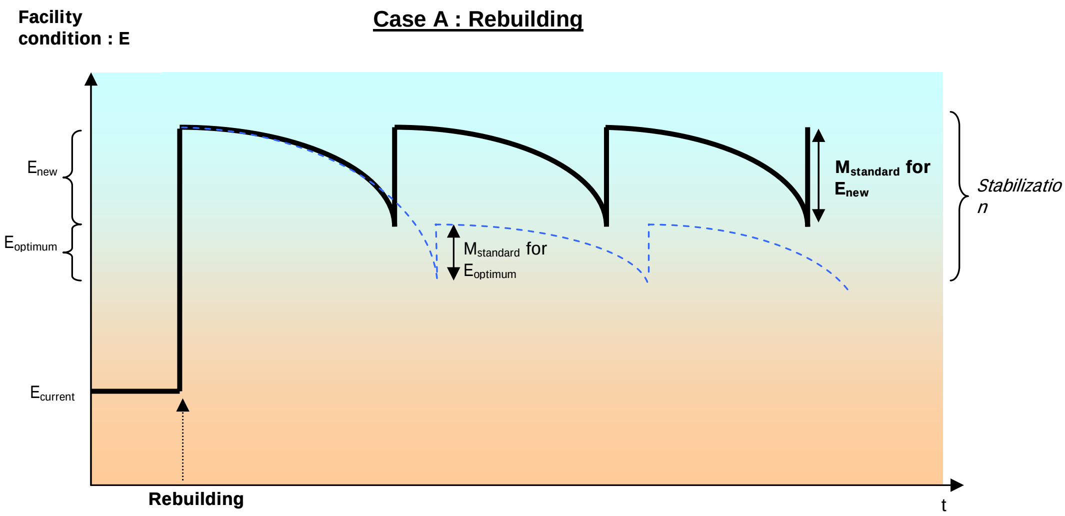
The evolution of facilities conditions related to maintenance options are shown on the subsequent diagrams.

The use of this decision tree is based on the definition for each facility of the service levels **N_i**. On the basis of this, and dependant on the condition **E_j** of the facilities, and of the forecasted evolution of this condition during coming years, it is possible to determine the works to undertake.

For a given facility there are two possibilities:

1. The current condition **$E_{current}$** is better or equal to the optimum condition **$E_{optimum}$** **(**the minimum condition needed to fulfil the facility's service level **N_i**) - if the facility condition is adequate to ensure the provision of the service level **N_i** , then it will fall within a preventative maintenance regime.
2. **$E_{current}$** is lower than **$E_{optimum}$** - if the condition of the facility cannot meet service level **N_i** requirements, then it will fall within a repair, renewal or renovation regime.

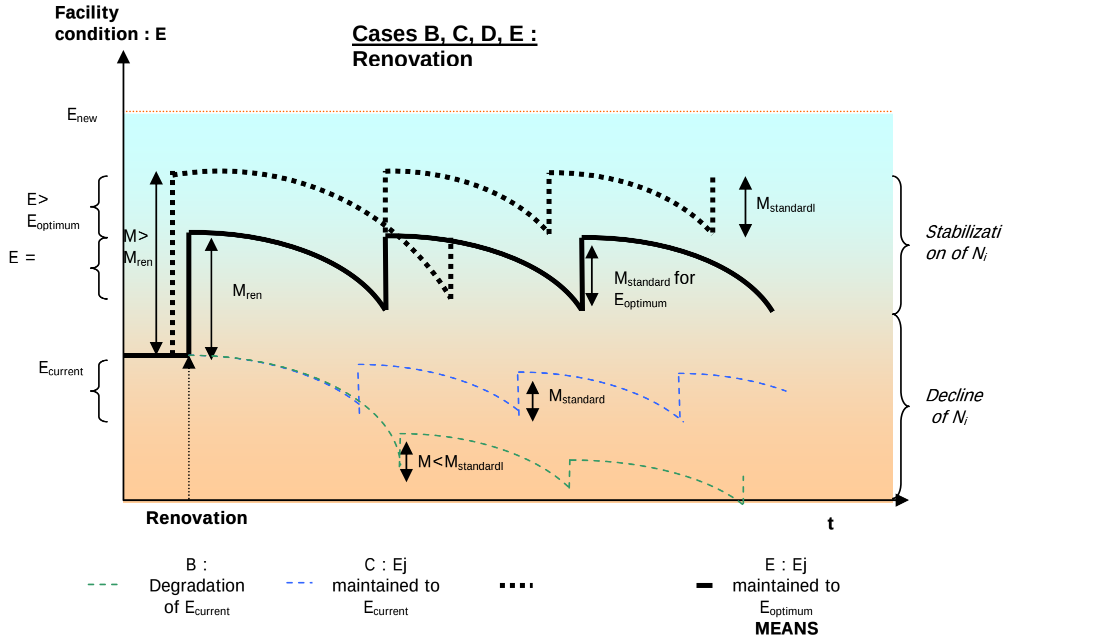
Providing the necessary finance **R** for the asset to be rebuilt, and the means **M** for subsequent maintenance are available, and the rebuilding of the asset is economically justified, then the asset can be replaced by a new asset that will satisfy the service level **N_i** (see case A below)



If the necessary finance for rebuilding is not available, renovation of the asset should be considered. If the means **M** that can be mobilized for the renovation of the asset are greater than those necessary to get the asset to its optimal condition **$M_{renovation}$**, the **$E_{current}$** will be brought above **$E_{optimum}$** , and the condition of the asset will remain over this optimum level for some time (case D).

If the means **M** that can be mobilized for renovation are equal to **$M_{renovation}$**, the service level **N_i** will be achieved but subsequent maintenance of the asset must immediately be planned to maintain the service level (case E).

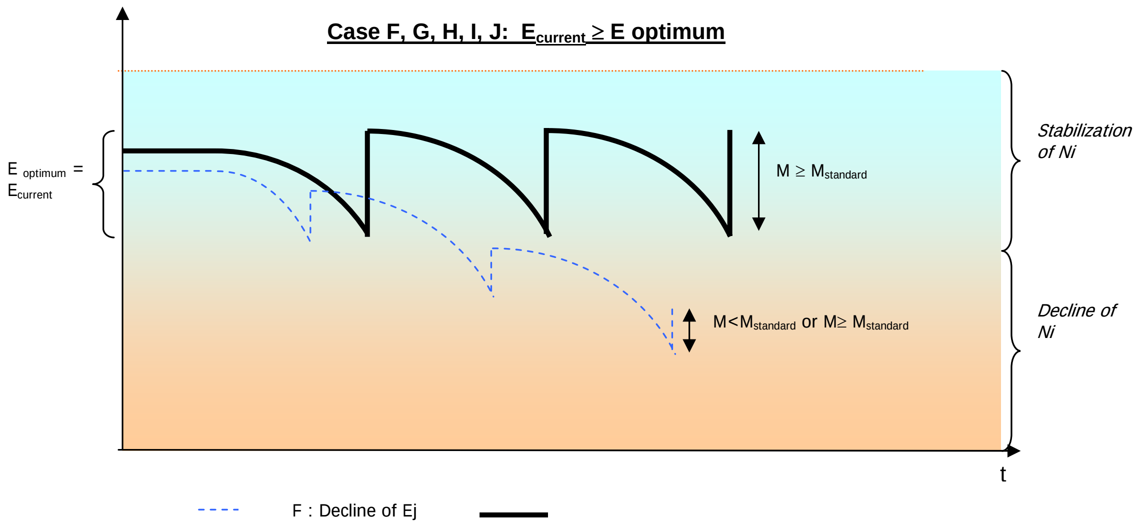
Where finance for renovation is not available (cases B and C), the target service level must be reduced.



For an asset that is currently in a good condition, if the maintenance means **M** are lower than the available means **$M_{standard}$** to ensure the stability of the service level, a reduction in **N_i** must be considered, or a decision taken to renovate or repair the asset on a short term basis, before its condition falls below **$E_{optimum}$**(case F)

If the maintenance means **M** are higher than **$M_{standard}$** and if the condition of the asset improves, **M** may be reduced (case G). On the contrary, if the asset continues to deteriorate the definition of **$M_{standard}$** should be reviewed or the deterioration may be explained by the occurrence of accidental or unexpected events (case **I**).

Finally, if the maintenance means are equal to **$M_{standard}$** , the condition of the asset is maintained at the service **N_i** ,or if it declines the standard means **$M_{standard}$** should be increased.



APPENDIX 3 DECISION TREE TO BE INSERTED HERE

Appendix 4 – List of Contributors to the Survey Results

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