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water
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INTERNATIONAL

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US utilities unite to ensure infrastructure sustainability

The US Environmental Protection Agency, along with six US water and wastewater utility organisations, has announced a statement of intent to promote effective long-term utility management. The formal partnership will focus on improved water and wastewater utility performance through education, management tools and performance measures.

The announcement follows a Collaborative Working Session held in May 2005, where 140 asset management professionals from the US and 11 other countries voted to adopt common standards of best practice as a top priority.

Over the next 12 months, EPA and the associations will work with utilities to identify the key attributes of sustainable management. They also will develop measures to use in gauging utility effectiveness, and develop a strategy to promote widespread adoption of sustainable management practices across the water sector. Additional contributions will be solicited through focus group meetings and other communications with individual utilities.

The six signatories of the statement are: the Water Environment Federation, National Association of Clean Water Agencies, American Water Works Association, Association of Metropolitan Water Agencies, American Public Works Association, and the National Association of Water Companies. ●

Thames Water agrees £150M extra spend on leakage after fierce criticism from regulator

Thames Water has found itself in hot water after its high leakage levels landed it in trouble with economic regulator Ofwat. The company narrowly avoided a large fine by accepting a legally-binding undertaking to spend an extra £150M ($275.6M) on combating leakage, at its shareholders' expense rather than – as would normally be the case – out of customer bills.

Neither will the new pipelines become part of the regulated asset base, according to Ofwat chairman Philip Fletcher, which means that neither shareholders nor the company can benefit from the increase in its value.

Mr Fletcher noted:'Thames Water's failure on leakage is unacceptable. Our job as regulator is to protect customers, who have been outraged by Thames' inability to control leakage sufficiently in London.

'Thames has bound itself to spend an extra £150M, at the cost of its own shareholders, to replace more ageing pipes than planned. This will directly address the issue of London leakage and achieve more secure supplies. It is more than double the maximum possible fine which the regulator could have imposed. A fine would not have gone to protect customers, but to the Exchequer. This is the right answer for Thames' customers and for London.'

The extra spend will involve Thames replacing at least 368km of mains in addition to the 1,235km which it is already in the process of replacing in London, between 2005 and 2010.

Ofwat has also reset the company's leakage targets, which it had failed to meet three times in succession, so that it has a gentle start at 840MLD for 2006 to 2007 but has to reach a much tighter 720MLD by 2010. It currently loses 894MLD from its ageing London network, 34 million litres over Ofwat's maximum current limit of 860MLD.

Various bodies including the Consumer Council for Water and the Federation for Small Businesses endorsed the alternative to a fine as better for customers. The FSB called for the drought order that Thames has requested to be turned down 'until their performance in stopping leaks improves dramatically'.

Their sentiments also chime with the London Assembly's Health and Public Services Committee report, which had noted ahead of Ofwat's announcement that it would be wrong for any punitive cash return to go to Government rather than to customers.

Environment Minister Ian Pearson said: 'The cornerstones of government policy on regulation of the water supply industry are value for money for consumers and environmental sustainability. We welcome the fact that the powers extended in the 2003 Water Act have given the regulator the necessary weight to take action against companies who are not serving those interests.

'£150M of additional investment in replacing leaking mains – more than double the maximum imposable fine – which comes from the shareholder and not the bill payer, added to a more stringent leakage target by the end of the review period – 2010 – stands squarely behind those principles.'

However, some analysts warned that the punishment would mean German parent group RWE would be likely to get a lower price for Thames when it puts it up for sale shortly. One analyst noted that future shareholders 'are signing up to extra costs with no benefits to themselves.' ● **Lis Stedman**

water asset management INTERNATIONAL

Water Asset Management International is an international newsletter on asset management in water and wastewater utilities. The focus of the newsletter is on the strategic aspects of this developing field, providing utilities with international perspectives on infrastructure planning and maintenance as they seek to deliver cost-effective services to their customers.

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Report on capital spending puts global water needs at $2.3 trillion

A new PFI report from Thomson Financial, *Financing water and wastewater to 2025: From necessity to sustainability*, provides a comprehensive survey of the state-of-play in the international water and wastewater industries. The global report estimates total water and sewerage capital spending needs of $2.3 trillion, of which $1.77 trillion will need to be financed by private funds unless there is a dramatic change in utility tariff structures.

Targeted at water sector financing professionals in the fields of project finance, water service and engineering, law firms, consultants, municipalities and governments, and debt and equity markets, the report reviews the capital spending needs for water and sewerage for 59 leading markets to 2025.

The report is the first to quantify the global cost of meeting obligations, from Water & Sanitation Millennium Development Goals to the challenges of European legislation. In his analyses the report's author matches the projects to the current and forecast funding flows into the sector, thus identifying the scope and scale of the contribution needed from the financial markets. These private funding flows are discussed in detail, highlighting those areas where the greatest opportunities and scope for innovations exist.

Extensive case studies of corporate and municipal funding models illustrate and offer insight into how products have been developed to meet particular funding needs. A series of scenarios support analyses of market drivers to outline the anticipated size of the market, while further scenarios explore how money can be generated through charging for services and grants, in order to illustrate how much additional funding will need to be raised from external sources.

The report is compiled by Dr David Lloyd Owen, an experienced author who has worked as an equity analyst for 20 years and written several hundred reviews and articles on the water sector, plus management reports for Financial Times Energy and CWC. He has also written seven editions of the Pinsent Masons Water Yearbook, is a columnist at Global Water Intelligence and regular contributor to Global Water Report.

Financing water and wastewater to 2025: From necessity to sustainability is available from www.pfie.com, or email neil.clasper@thomson.com. ●

EPA signs up to infrastructure asset management technology exchange

The US Environmental Protection Agency (EPA) and the United States Department of Transportation Federal Highway Administration (FHWA) have signed a 'Memorandum of Understanding' which will enable both bodies to further their pursuit of national strategies in a spirit of close cooperation.

The aim of the MOU is to 'facilitate and encourage working arrangements between the agencies and amongst other Federal Agencies, and other State and local partners'. The memorandum will serve as the basis for dialogue and information sharing between the agencies, in order to identify common ground and advance practice in state-of-the-art asset management.

The EPA and the FHWA will exchange information, coordinate activities, provide opportunities for cross-training, and provide technical expertise and assistance in support of each other's Infrastructure Asset Management Programmes.Underlying the endeavour is the fact that in many cases, the local authorities that own, operate and maintain the transportation infrastructure also own, operate and maintain the water and wastewater management utilities. ●

Underground vision for 2007

The National Underground Assets Group (NUAG) has set out the vision for the future of buried services in the UK. It aims to develop and implement standardised procedures on how location information is recorded and stored by the end of 2007.

This is to ensure that every organisation with an interest in buried services can access and share information easily, to help themselves as well as others carry out works more effectively. The ultimate goal is to have the ability to visualise and distinguish – on demand – all underground asset records in any one given area.

NUAG was set up last year to champion better coordination between different organisations, including highways agencies, utility companies, pipelines companies, civil engineers, surveyors and regulators. The group is now working with the Department for Transport to develop standard processes to help coordinate activities that underpin the Traffic Management Act.

'We want to ensure delivery of a more coherent approach to collecting, accessing, sharing and exchanging data on buried services,' says James Brayshaw of ICE/ICES. 'We need defined data definitions, standards, protocols and processes in place so we can find the most effective and efficient means of displaying information on underground assets for the benefit of everyone.'

Currently, there is no national common approach to the way information such as the location of underground infrastructure is recorded or stored. There are varying degrees of accuracy and referencing approaches (relative and absolute) between companies. The amount of time it takes to store data, the way it is stored and the codes of practice followed also differ. Even scales of diagrams, the level of detail, and symbolism are not standard across industries.

NUAG wants to change that to ensure every organisation that deals with buried assets will, in the future, be able to share information. The first step will be to create a common achievable national platform for all to work towards. Only then will the progression to real-time intelligent data exchange using web-based technology be possible. Organisations will be able to plan their own progression towards the vision with confidence that the standards for referencing and display are agreed – and will be used – by all in the industry.

NUAG has recruited members from all sections of the industry for working groups, which are now starting to tackle issues over standardisation. These will enable ideas to be discussed and subsequently published and implemented. The candidates were chosen from highway authorities, utility companies and contractors to ensure that all stakeholders' input is taken into account. ●

Getting the Balance Right

● **KEVIN WHITEMAN**, CEO of Kelda Group Plc and Managing Director at UK's Yorkshire Water, outlines his asset management philosophy of a balanced approach to continuous improvement.

Knowledge of assets and how they should be managed has increased tremendously over recent years. However, we must never lose sight of why assets exist…quite simply to deliver a service to our customers.

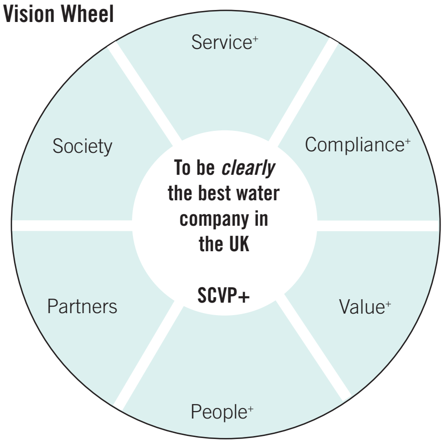
Everything we do, from turning valves in the street, to regulatory submissions, should be focussed on providing an ever improving service to customers, and ensure any contact a customer may have with our company is an enjoyable experience.

In England we are now in our fourth regulatory Asset Management Plan (AMP) period, which really means 16 years of a regulatory environment, where the whole industry has driven improving service for minimum price increases to our customers – more for less.

To be successful in this environment it is clear we can not do it alone and we must get the balance right.

Alignment of business objectives/processes, partnering agreements and ensuring all stakeholders are considered, are all key ingredients to providing excellent customer service. Continuous improvement is now a 'way of being' at Yorkshire Water and engendered throughout our organisation. This can be visualised by our 'Vision Wheel' shown below. The Vision Wheel encapsulates everything we need to get the balance right, and ensure we are seen as 'clearly the best water company' by all we have contact with.

Vision Wheel



Excellent asset management processes are essential to deliver all aspects of this vision. One thing is clear, to be successful in our vision we have to strive to ensure we make the right investment, in the right asset, at the right time, first time every time. This is an easy statement to make, but takes a great deal more effort to deliver.

Continuous improvement through both incremental change and more radical step change improvements are required to ensure the service is continuously enhanced as effectively and efficiently as possible. An example of this is detailed value chain analysis, this is nothing new in concept but quite easily overlooked. For example, reducing the response time to asset failure alarms creates additional time for rectifying the problem, this helps reduce loss of failure experienced by the customer. In turn this would lead to reduced verbal or written complaints. This gives a win/win for both the customer and the company.

Interaction with assets by our employees is one area that is high on our agenda. It is hard to believe in this day and age, we still have employees who physically enter tanks to remove sludge. Large enhancement programmes in the past leave a maintenance legacy going forward, so investment prioritisation is essential. We need to ensure the needs of our people operating existing assets are considered with equal importance to compliance and environmental impacts. Get the investment in people correct and the rest will follow.

Science has now entered the world of asset management, as everyone tries to predict when assets are going to fail and what impact any failure may have. The accuracy of the science is dependent on one thing, the data used to support it. Once again there is a balance to be found, regarding the accuracy, frequency of collection, connectivity and availability of the data. This is an expensive commodity, the impact of which we should not underestimate.

Strategically we must also consider what sustainable asset management is. This can vary from ensuring all costs are undertaken on a whole life cost basis, to considering what the carbon footprint is, of any investment we make. Whilst compliance with an environmental driver should be perceived as good, we should also consider the chain of events taken to reach a point of pouring concrete into a natural environment.

Sustainable will always mean many things to different groups and we need to ensure these are considered, Yorkshire Water has gone some way to achieving this through cost benefit analysis, based on our customer preferences for the services we provide, and by starting to look further ahead than traditional planning horizons.

One thing is for sure, assets and asset management are here to stay. Each organisation has a duty to provide a clear vision of their asset management plan, both internally and externally. Whilst this takes some achieving, the benefit it will bring will far outweigh the effort to get there.

Kevin Whiteman
Managing Director
Yorkshire Water, UK

biography

KEVIN IAN WHITEMAN, as an engineering graduate (chartered engineer and member of the Institute of Mining Engineers) held a number of senior management positions with British Coal before joining the National Rivers Authority as Regional General Manager in the early 1990s. This was followed by a period as Chief Executive and Accounting Officer leading up to the formation of the Environment Agency in 1996. After a short period as Regional Director of the Environment Agency, Mr Whiteman joined Yorkshire Water as Business Director Waste Water in 1997, and was appointed Managing Director of Yorkshire Water in April 2000. In September 2002, Mr Whiteman took on the additional role of Chief Executive of Kelda Group plc. ●

Strategic municipal asset management: use your options wisely

The City of Hamilton in Canada has undertaken an asset management exercise that has provided insight into the best options for asset maintenance. **LEO GOHIER** looks at the background to the study, and its findings.

Leo Gohier
Infrastructure Dynamix (IDx)
Canada

In 2005, the city of Hamilton, Canada prepared a 2005 life-cycle state of the infrastructure (SotI) report on public works assets. The focus of this assignment was to evaluate the current state of various public works assets within the city, to quantify the required level of sustainable funding and to predict their status in 2020 should current policies and practices be maintained.

The following assets were included in the study: water, wastewater, roads, storm, waste management, facilities and open spaces, transit and fleet. Water, wastewater and roads were reviewed in greater detail as more data were available. In addition, a 2005 SotI report card was developed to provide an easy-to-understand reference that could be updated regularly to track the city's path toward sustainability. This effort won a national award from Canada's InfraGuide.

In summary, the framework that was used to systematically evaluate each asset category answered these basic questions:

- What do we have?
- What is it worth?
- What condition is it in?
- What do we need to do to it?
- When do we need to do it?
- How much money do we need?
- How do we achieve sustainability?

A critical issue that municipalities will face as they move towards sustainability of services is a permanent and ongoing level of debt. There is a need to review past financing strategies, and there may be a need to differentiate between the initial construction of an asset and replacement of that asset. More will be said on that topic in a future article.

The need for tactical analysis

The SotI report was a strategic document focused mainly on sustainable revenues, and not a detailed document identifying specific projects and solutions. It was mainly a communication and financial exercise. There was a need to develop a tactical document that would help to analyse and develop various investment strategies at a fairly high level.

Figure 2 shows the analytical process that governed this progression. This tactical step was accomplished using software developed by Harfan Technologies. This software, referred to as an Integrated Decision Support System (IDSS) allows development of tactical plans (as well as strategic and project plans) across large geographical areas, taking into account multiple options for assets over their individual life-cycles.

There is a common misconception that it is cheaper to include all work on underground assets in a road reconstruction contract. Although savings can be achieved on a project-by-project basis, these savings can in fact be quite misleading. Overall life-cycle costs may increase significantly if assets are replaced too early in their life-cycles or if the wrong renewal decision is made.

This increase in cost is not only calculated in terms of real overall costs but also in terms of value for money and lost opportunities for using scarce funds on other assets in terms of preventative and life-extending decisions. There exist a number of technical options when it comes to rehabilitating underground assets in an integrated way, and these options (as

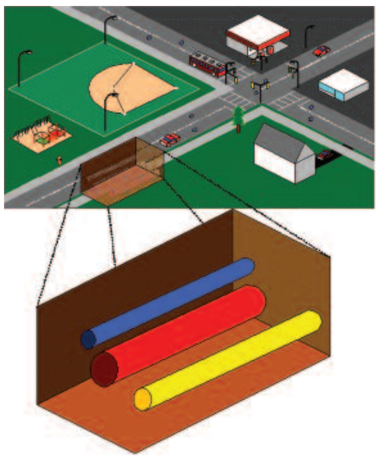


Figure 1
Water, wastewater and roads assets were included in the City of Hamilton's SotI Report.

A full copy of the 2005 SotI report can be downloaded from the city's website at: www.myhamilton.ca/myhamilton/CityandGovernment/CityDepartments/PublicWorks/CapitalPlanning/Asset+Management.htm

well as their timeliness) should be considered in the decision-making process.

Definitions
(Ranges for renewing assets are illustrated in Figure 3)

ASAP (as soon as possible)
- As soon as an asset's condition enters a window of opportunity for a level of intervention – as soon as it's needed
- For example: The window of opportunity for a water main replacement might be when its condition index is between 5 and 3 (on a scale of 10 to 0). The ASAP scenario would choose to do the water main replacement at 5
- Result: brings forward a lot of work

JIT (just in time)
- Wait until the last minute – just before the asset condition would require another level of intervention, ie, go from rehabilitation to replacement
- As per example above, the JIT scenario would then choose to do the water main replacement only at 3, just before the end of its service life
- Result: pushes back a lot of work, yet still maintains prescribed service levels.

EOL/state of infrastructure (end of life)
- Run to end of service life – only considers replacement option, never rehabilitation – that is, lets assets deteriorate to the point when they have to be replaced
- Result: this could be cheaper under certain circumstances

Rules of analysis
These represent the ones used for this project, but they can be customised in order to develop numerous scenarios to suit others' needs.
- If the road needs replacement, check the underground assets
- Replace the water main at CI 3 (condition index)
- Replace the sewer at CI 2 (condition index)
- All options (repair, rehabilitate, or replace) are considered for all assets and all scenarios (except for EOL, which is run to end of service life only)
- If work can be coordinated within five years of the next window of opportunity, then bring the work forward in order to do it on an integrated basis. If the next window of opportunity for a particular asset is beyond the five-year window, then work on that asset will be done on an individual basis. Logic: We don't want to force work too early because of costs – on the other hand, there would be less disruption to the community with the integrated approach, and the asset would be dealt with before it deteriorates further – five years is the arbitrary balance, and can be modified to suit a community's or programme's unique circumstances.
- Hamilton's deterioration curves were used to project the condition of the asset in the future, for analysis and decision-making
- Rehabilitation for water and sewer: considered trenchless, which is somewhat independent of roads (except for a utility cut and some disruption to the community)
- If the water main needs to be replaced, then the road is repaired with a utility cut/trench restoration
- If the sanitary sewer needs to be replaced, then the road is automatically replaced as a result of the significant road cut requirements.

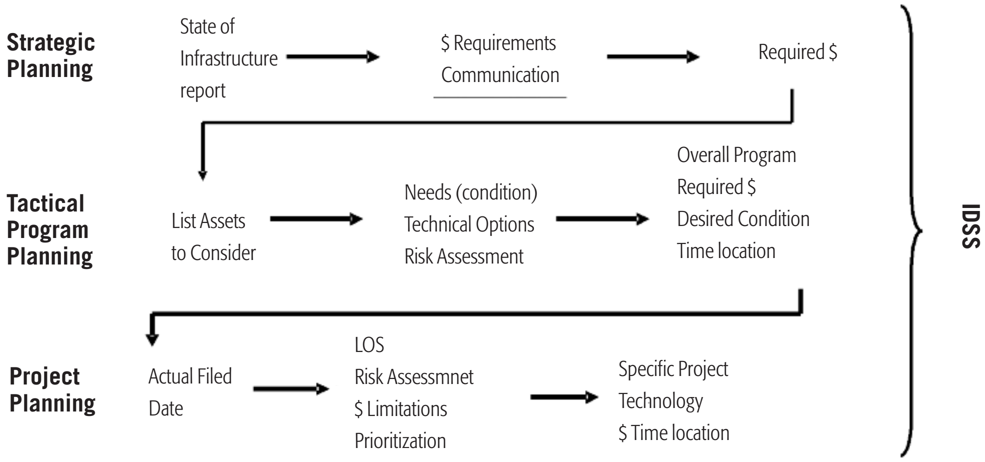


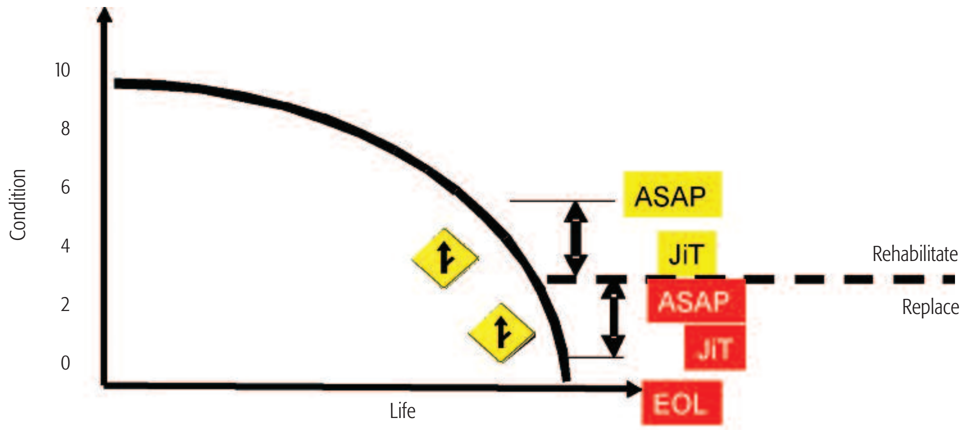
Figure 2
The analytical process used in compiling the SotI tactical document.

Risk considerations: probability and consequence of failure
Risk, by definition, is the product of probability of failure and the consequences of that failure. Asset management is therefore, by extension, risk management: risks to level of service, environmental risks and financial risks. Any asset management strategy requires an estimation of the potential degradation of an asset over its life cycle, an analysis of the impact from asset failure and a set of actions (such as maintenance, replacement, and so on) to be taken to mitigate those combined risks. The three key components to optimised spending and risk management are:
- Choosing the right asset (prioritisation)
- Selecting the right renewal option
- Choosing the right time to do the work.

The measurement of consequences of a failure is defined in terms of the importance or criticality of the asset. Even though the consequence of failure is easier to quantify if there is an amount of money related to it, sustainable asset management needs to also consider qualitative criteria when assessing the impact of a failure.

The definition of criticality is also partly subjective and can differ from one manager to another. For each criterion, the user can define its weight and then identify the critical assets, that is, the one with the highest impact or consequence. It is possible to combine more than one criterion so that all

Figure 3
Ranges for determining asset renewal.



	ASAP ($M CAD)		JIT ($M CAD)		EOL ($M CAD)	
	Integrated	Individual	Integrated	Individual	Integrated	Individual
Ward 2 – roads		$188.3		$212.7		$212.7
– sewer	$509.8	$166.0	$403.9	$139.2	$478.0	$143.3
– water		$100.9		$79.1		$63.9
Ward 2 Total	$509.8	$455.2	$403.9	$431.0	$478.0	$419.9
Ward 3 – roads		$264.0		$330.3		$330.3
– sewer	$698.1	$223.7	$507.2	$201.0	$559.8	$206.4
– water		$137.8		$109.6		$86.2
Ward 3 Total	$698.1	$625.5	$507.2	$640.9	$559.8	$622.9
Ward 15 – roads		$229.4		$219.7		$219.7
– sewer	$440.3	$133.2	$306.5	$66.7	$344.4	$79.3
– water		$46.9		$35.2		$39.2
Ward 15 Total	$440.3	$409.5	$306.5	$321.6	$344.4	$338.2
TOTAL/100 yrs	$1648.2	$1490.2	$1217.6	$1393.5	$1382.2	$1381.0
$M Avge/year	**$16.5**	**$14.9**	**$12.2**	**$13.9**	**$13.8**	**$13.8**

Figure 4
Costs of each ward analysis by 100-year time periods.

projects can eventually have a consequence index value. This results in development of a risk index that is then included in the decision-making process.

The Integrated Decision Support System (IDSS) then uses this information to assign a priority to each asset and to optimise spending on asset renewal, while maintaining the asset at a minimum preset Condition Index that reflects the asset manager's position on risk management (failure and the consequence of that failure) in their community. This allows asset managers to achieve an optimised level of spending on asset renewal, while minimising risk and maintaining a prescribed level of service.

The Project

The project included detailed analysis of three of the city's 15 wards (wards 2, 3 and 15) for detailed analysis, as well as the entire city for a higher-level analysis. These three wards were chosen because they represent some of the older segments (wards 2 and 3), and Ward 15 represents a newer segment.

These extremes provide us with a good measure of ROI and other benefits of integrated ROW management. Ward 15 is also a rural ward, which will help to make a comparison between sustainable costs per capita for a ward with fewer hard services but a higher amount of road assets and downtown wards with proportionately fewer road assets but a higher concentration of hard services. The industrial areas within ward 3 also give a better picture of what it costs to provide assets to maintain major centres of employment.

The parameters for the analysis of wards 2, 3, 15 were as follows:

- Assets covered: water, road, sanitary sewer, storm sewer, combined sewer
- Time period: 100 years
- Three separate scenarios/ward: the ASAP, the just in time and the end of life
- Each scenario also had two variations: the integrated plan (where all assets are integrated in a project) and the individual plan (where each asset is taken on an individual basis, regardless of other assets).
- In other words: three wards with three scenarios and two variations each, giving 18 runs in total.

This approach provided the city with the best useful information, by providing depth and variety rather than broadness of scope. An extra two computer runs were made looking at the city as a whole, to briefly examine some of the potential issues that other wards may have and to guide future, more detailed analysis as on wards 2, 3 and 15.

The parameters for the analysis of the entire city were:

- Assets included: water, road, sanitary sewer, storm sewer, combined sewer
- Time period: 100 years
- One scenario only: end of life (except for roads, where rehabilitation was considered)
- Two variations: the integrated plan (where all assets are integrated in a project) and the individual plan (where each asset is taken on an individual basis, regardless of other assets)
- In other words: one city with one scenario and two variations, giving two runs in total.

Results

Figure 4 summarises the costs of each ward analysis, by 100-year time periods.

	ASAP		JIT		EOL	
	Integ.	Indiv.	Integ.	Indiv.	Integ.	Indiv.
Total	$16.5 M/yr	$14.9 M/yr	$12.2 M/yr	$13.9 M/yr	$13.8 M/yr	$13.8 M/yr
ROI	–	12%	31%	19%	20%	20%

Figure 5
Return on Investment (ROI) results of the City of Hamilton ward analysis.

The table clearly shows that what we would have believed to be the least expensive option may not necessarily be so. Review of Figure 4 illustrates that:

- In all cases, under all scenarios and options, the least expensive option is the 'integrated just in time'
- Both 'end of life' options are about the same price as the 'individual just in time', but are still less expensive than either of the ASAP options;
- The most expensive option is to proceed with asset management initiatives ASAP. This option is a significant 35% (or $4.3 million /year) more expensive than the cheapest option
- The integrated JIT' scenario offers the following advantages:
  - It does not incur any additional risk (financial or environmental) since the condition index for failure is still considered to be higher than the actual physical condition index for complete physical failure
  - No funds are expended before an asset is at the end of one state of condition and about to enter another stage. This not only reduces costs overall, but it also frees up funds for preventative action on other assets in order to extend the service life of those assets
  - The condition of all of the assets in the public ROW never fall below a pre-determined condition index, which provides the community with the pre-determined service levels.
- The least-expensive option also clearly illustrates that the cost of services in a rural area is mostly driven by the larger proportion of roads per capita, when compared to urban districts (based on 2001 population statistics on the city's website). In other words, even though rural areas have fewer hard services, the cost to service their assets is roughly the same as that for urban areas:
- Ward 2: cost per capita = $4.04 million/38,349 = $105/capita/year
- Ward 3: cost per capita = $5.07 million/40,869 = $124/capita/year
- Ward 15: cost per capita = $3.1 million/24,662 = $124/capita/year

The two city-wide scenarios suggested savings in the order of 12% with the integrated option.

Return on investment (ROI)

Underground assets are often managed on an individual basis, or are not managed by using a sophisticated IDSS. The ROI results are summarised in Figure 5.

It is clear from this that the return on investment from using an IDSS is approximately 31% for the JIT/ integrated scenario. Interestingly enough, the most expensive option is the ASAP/integrated scenario.

Conclusion

The ROI or cost-recovery of implementing an IDSS such as Harfan's is incredibly short and is measured in terms of a few months. It would easily provide a payback period within a single budget cycle for a municipality.

Using an IDSS helps turn data into information and knowledge. It can help in the top-down approach as well as the bottom-up approach, by filling a great need for analysis at the tactical level. It allows users to change a 'window of opportunity' into a 'window of multiple opportunities', all the while minimising costs, risks and inconvenience to the community.

Figure 6 illustrates the potential of using such a tool in the life cycle management of water and other services. This project has clearly demonstrated the value of such an assessment tool. The City of Hamilton will continue to assess the value of such tools, in its ongoing approach to undertaking integrated planning on the basis of life cycle with proper consideration of risks and sustainability factors.

There are many variables in undertaking a study such as this one, and one needs to be careful in the interpretation and transferability of the results. However, this study does illustrate that there are potentially significant benefits in managing right-of-ways in an integrated manner, and that the tax/ratepayers can benefit greatly when different asset managers coordinate their activities.

More importantly, this study shows that there is a real need to make the right decision, on the right asset, at the right time along its deterioration curve. This can only be achieved through long-term planning, and not shorter-term project definition. ●

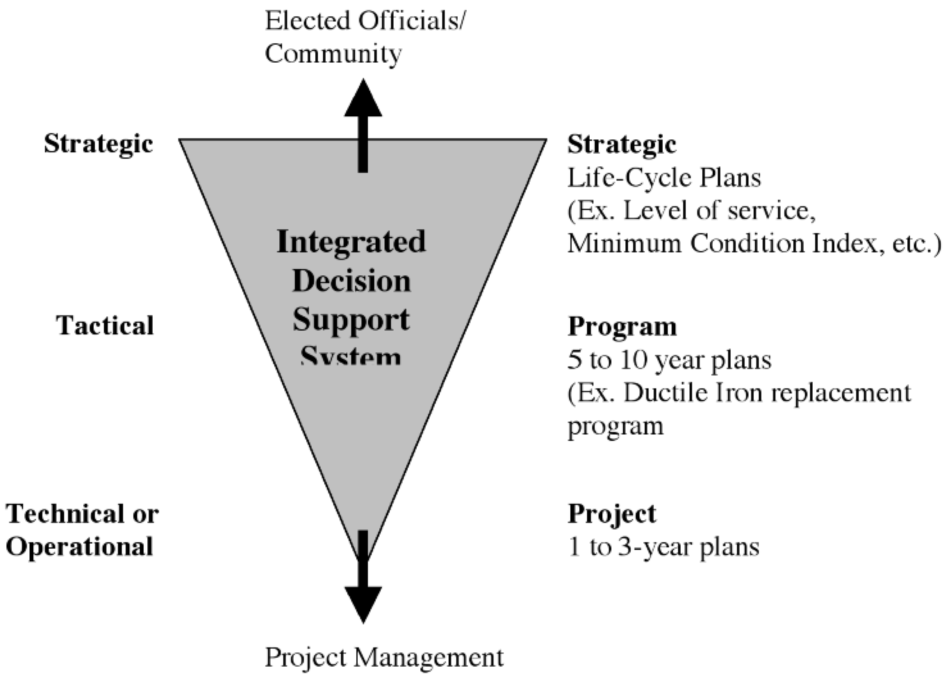


Figure 6 Potential value of the Integrated Decision Support System.

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An independent review of the EU-funded CARE-W programme

The CARE-W project has involved many utilities in assessing a unique solution for asset management. **ANNIE VANRENTERGHEM-RAVEN** looks at the outcomes from the completed trials.

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The US Environmental Protection Agency (EPA) awarded a grant to a Polytechnic University to conduct an independent evaluation of the European CARE-W (Computer Aided Rehabilitation of Water networks) programme. Purposes of the evaluation included acquiring proficiency in using the various modules, disseminating knowledge, evaluating the resources deployed and conducting an assessment of the modules. An EU-sponsored research programme pertaining to sewers, CARE-S was also recently finished. This review focuses on CARE-W.

A few characteristics of CARE-W and CARE-S have made them noteworthy to US-based asset management (AM) professionals and the US EPA:

- Australian and New Zealand experience and tools received substantial attention, while in the US there was until recently little or no mention of CARE-W and CARE-S. Because, in the field of water AM, funds are limited, tasks multiple, and problems shared by most utilities in developed countries, the GAO recommended that programmes developed by other industries or countries should be examined. (GAO, 2004)
- CARE research was undertaken jointly by research centres and utilities from 15 European countries. In some cases surveys were also run, with the participation of additional utilities.
- The research scope is applied, geared toward adapting existing models to the water and waste water industries, making them compatible and synchronised with each other rather than developing new fundamental algorithms or analytical approaches.
- Research output is in the form of two non-commercial computer-based tool-kits.
- Commercialisation is to be considered at the end of the projects to ensure that they stay applied in nature.
- The extent of the investment ($10 million) made by a public venture (EU) indicates that substantial social and economic benefits are expected in return.
- Each project took three years. CARE-W ended in 2004; CARE-S in 2005.
- CARE-S was joined by CSIRO, the Australian research institute, which participated with its own funding. The fact that the Australians joined CARE-S underlines the universality of the problems, the need to rely on many skills and tools, and therefore the merit of a collaborative and comprehensive approach.

The CARE-W programme

Description of the tools

CARE-W is made up of a logical succession of tools. Each tool serves a specific sub-objective belonging to a core comprehensive framework; it can be used separately or, for added benefits, as part of the whole. In addition, a software solution with a built-in GIS was conceived by UK-based WRc. SINTEF from Norway coordinated the project.

Performance indicators (CARE-W PIs)

This module was developed principally by LNEC in Portugal. Based on the IWA PIs, the PI tool provides rigorous definition of variables and acceptable ranges for each PI. Validation was provided through consultation with three dozen European utilities, which helped identify the PIs of interest and put them into quantitative perspective. PIs allow for benchmarking or time series, support network level diagnosis, and facilitate macro prioritisation.

Failure forecasting (CARE-W Fail)

This module was developed principally by Cemagref and INSA, in France. Embedded statistical models allow prediction of the probability of break and the number of breaks, per pipe or family of pipes within a three to five-year planning horizon. Risk factors and time between failures are taken into account. Five years of good failure data may suffice.

Hydraulic reliability (CARE-W REL)

Cemagref in France, Sintef in Norway and Brno in the Czech Republic each developed and tested a different model (F-Reliab, Aquarel, and Relnet). They assess the relative importance of each pipe in terms of its hydraulic reliability in the form of an index that ranges from 0 to 1. All require hydraulic modelling. Aquarel and Relnet require Epanet-compatible data while F-Reliab only works with a proprietary hydraulic model developed by Cemagref, called PORTEAU.

Long term planning (CARE-W LTP)

Three tools were developed by Dresden University in Germany. Kanew is the core piece of this module; it had been developed previously through an AWWARF grant (AWWARF, 1997). It is enhanced here and accompanied by two additional programmes, Scenario Writer and Rehab Strategy Evaluator:

- Scenario Writer allows users to see how various key factors evolve qualitatively based on socio-economic trends.
- Kanew provides an indication of what the long-term budget should be in order to support a strategic rehabilitation plan. Allows for simulated prediction of long-term network behaviour for predefined rehabilitation scenarios. Kanew is based on the distribution of the life expectancy of subgroups of pipes. Minimal specific pipe information

is needed (diameter, year of installation, material) and degradation information is introduced in generic terms not at pipe level.
- Rehab strategy evaluator helps select the best strategy amongst options identified thanks to Scenario and Kanew.

Annual rehabilitation planning (CARE-W ARP)
ARP was developed principally at INSA, France. It helps prioritise pipes for short-term rehab planning through the use of a multi-criteria decision support system, itself based on reference profiles to mitigate uncertainty. Criteria that express both the risks and the consequences of failure (breaks, leaks, hydraulic and water quality deficiency) may be derived from other CARE-W tools; necessary parameters have to be specified by the users. ARP includes sensitivity analysis.

Module 2 (Failure forecasting/ probability of failure) and module 5 (ARP/short term planning) both rely on analytical models (statistical models Weibull PHM and Poisson for module 2 and Electra for module 5) previously developed and widely used in other industries, and specifically adapted for water network rehabilitation.

The objectives they serve could have been met with other models. Before the selection was made, a full review of other possible models, their merits and shortcomings, was conducted (Le Gauffre, 2002, for ARP; Eisenbeis, 2002, for failure forecasting). The ones selected were found to be most suitable.

In some cases several models were kept (for failure forecasting or hydraulic reliability). In the latter case, as explained previously, some specific limitations made it necessary to keep all alternatives. In the case of Poisson versus PHM, PHM was found to be stronger because of its results at pipe level, but it also demanded information at pipe level.The Poisson option was kept so that organiaations would be given the option to work with group of pipes if need be.

CARE-W's scope
Before developing the tools themselves, the partners made important preliminary decisions about:
- The point of view to adopt;
- Problems to address, and
- The overall objective to pursue.

CARE-W focuses on buried water networks; above ground infrastructure can be directly inspected and therefore does not present the same challenges. CARE-W attempts to answer the following questions:
- What should the long term strategy of rehabilitation be?
- Given a certain yearly budget and multiple decision criteria, which pipes should be rehabilitated first?

While problems linked to pipe degradation include weakened hydraulic pressure, water quality deficiency and structural deterioration (leaks and breaks), the CARE-W team made the decision to address the latter problem first, and to introduce water quality and hydraulic pressure as criteria in ARP.The rationale for this point of view was that:
- Structural deficiency is the most pressing and damaging problem; break and leak rates are increasing; non intrusive inspection is still expensive and can not be systematic enough to constitute a valid decision making alternative;
- Hydraulic capacity can and is often directly measured;
- The issues of water quality and physical degradation need preliminary research in order to link a problem seen at the tap to a specific segment. Furthermore, water quality problems experienced at the tap may also originate from service lines that belong to the homeowner.

The objective of CARE-W is prioritisation (replacing the 'right' pipe); full economic optimisation (to replace that pipe at the 'right' time) is still beyond CARE-W's scope. Long term planning is also addressed, but through simulated scenarios based on acquired knowledge.

Research Center	Module developed	Utility	Module tested
WRc, U.K.	GIS, Manager	Bristol Three Valley	PHM, Poisson PHM, Poisson
Sintef, Norway	Coordination, hydraulic criticality	Oslo Trondheim	All
Dresden university, Germany	LTP	Stuttgart Dresden	All ARP, LTP
LNEC, Portugal	PIs	Oeiras-Amadora	All
University of Bologna, Italy	None ; coordinated multiple testing centers	Condigoro, Ferrara, Reggio Emila, Lisbon	All
INSA, France	ARP Poisson	Reggio Emilia, Lyon	ARP
Cemagref, France	PHM	Lausanne, Switzerland	PHM

Figure 1
Research centres and utilities visited or interviewed for the EPA study.

The development and testing process
Seven research centres and seven utilities were interviewed or visited for this review (Figure 1) between November 2004 and July 2005 after all the modules had been developed and initially tested. In addition, reports and relevant papers pertaining to model selection, development, testing or validation were consulted. Utilities were chosen to represent a variety of sizes, resources, level of accomplishment in AM, access to in-house technical help, structure (public, private), regulatory contexts.

Utilities enrolled for the following reasons:
- A feeling that costly rehabilitation decisions have often been too pragmatic; a realisation that AM can be complex and therefore required assistance
- Acquisition of a GIS, an important investment that should be put to work at forward looking tasks besides daily operations
- A tradition of innovation with strong AM already in place particularly in countries such as the UK where a regulatory incentive exists; a desire to work with trusted and long time partner that initiated the CARE-W collaboration; and to be recognised as a leader.
- It was a project of an applied nature with tangible results.

The terms of the collaboration between utility and research partners have varied greatly. In all cases, a strong involvement with the research centres has been necessary.

In some cases, a 'hands off' approach was adopted: data was provided for analysis by the utility to the researchers who authored the testing report. This approach was often taken by partners with a satisfactory existing AM programme, the curiosity to see what added value CARE-W could bring, no urgent AM need to fulfil, and a limited capacity to dedicate personnel to this task. This approach is practical and acceptable at an early stage of development of the software but partiality can be at stake.

In contrast, some utilities insisted that modules be installed on their computers, their personnel be trained and closely assisted in using the modules. This tended to be the case for utilities with no significant AM programme in place prior to joining CARE-W, in great need of a road map and open to the kind of process changes implied by CARE-W (introduction of new forms, collection of new data, collaboration with departments, and so on).

Some intermediate cases were also found: utility personnel were briefly trained in using one module and then tested the software on their own or a CARE trainee remained in residence for a few weeks at the utility. All had exceptional access to the research team in charge and a great deal of expertise. In several instances, the utility employee in charge of testing at the utility was previously (or was still, in the case of a trainee also working on his PhD) associated with the research centre.

According to the testing report (Saegrov, 2004) the toolkit was to be tested at 13 locations, though only nine sites (Figure 2) have produced a report. The focus was on testing tools within the Rehab Manager rather than as standalone modules, but this was not always possible. Utilities were free to choose which modules they wished to test, where and to what extent. Some limited themselves to only one module, some tried to test them all.

As seen in Figure 2, the size of the testing zone varied considerably. Lausanne and Oeiras-Amadora (interviewed for this review) do not appear in Figure 2 because Switzerland is not part of the EU and joined with its own funding; Oeiras became a very active participant after the list was compiled. In addition, new case studies have actually emerged since the end of the project, which shows its dynamic nature.

Testing was to be conducted in order to assess functionality and relevance. Figure 2 lists the modules each utility intended to test. In order to assess the level of success and the nature of the difficulties encountered we found it necessary to break down the testing process into the following steps:

- Level 1: data preparation and compatibility.Is the necessary data available and compatible with the module? How much change of procedure will be necessary to get data compatible in the future?
- Level 2: Computing, 'debugging'. Once a set of data is prepared, does the program run?
- Level 3: Practical. Once the program runs, could results be generated and seen?
- Level 4: Relevance. Once results have been generated, do they make sense? Are they useful?

In its testing report, Codigoro offered a similar breakdown of tasks (See Figure 3):

- Import pre-existing input files necessary to run the tool
- Create a dataset from these files
- Generate all input files for the tool from the dataset
- Run the tool
- Return the results to CARE-W central database
- View and analyse results

Unfortunately there was a lack of homogeneity in the testing process and reporting of results: a protocol should have been provided by CARE-W to all partners. Furthermore, testing was limited to one round. If testing was halted due to technical issues, it might not have resumed if the technical problem was resolved after testing was completed.

Testing results

While the installation of the individual tools presented few problems (even though it was not found to be straightforward), the installation of the original Rehab Manager has posed more difficulties that have been corrected in the subsequent upgrades.

Data storage system, database structure and compatibility did represent serious drawbacks for most utilities. All utilities, even the ones that could not run a model, proceeded to draw useful conclusions. At a minimum, CARE-W was credited with providing the utility with the opportunity to evaluate and improve its current practices.

Testing results varied widely. For modules tested early in their development, testing was sometimes merely and disappointingly limited to bug detection and did not reach levels 3 or 4 (run modules, analyse results). Many of these classic computing problems were actually corrected later on so listing them now is of little interest.

Unfortunately, more rounds of testing would have been useful including full scale testing of all modules once they had been completed and debugged, to test not only the relevance of the modules but also their connectivity. This is now taking place but, unfortunately, not as part of the CARE-W study.

Test Network	Size of network / main test zone (km)	CARE-W PI	CARE-W FAIL	CARE-W REL	CARE-W ARP	CARE-W LTP
Bristol, UK	150		✓			
Brno, Czech Republic	1200	✓		✓	✓	✓
Codigoro, Italy	85		✓	✓		✓
Dresden, Germany	11				✓	✓
Ferrara, Italy	33		✓	✓		✓
Lyon, France	1100	✓	✓		✓	
Oslo, Norway	8	✓	✓	✓	✓	✓
Reggio Emilia, Italy	652	✓		✓	✓	✓
Stuttgart, Germany	1420	✓	✓	✓	✓	✓

Figure 2 CARE-W testing sites and modules.

A summary of the performance of each module is provided below.

PI

PI production does not present any technical difficulty but it depends on data availability, which varies highly. This module had a different impact on utilities depending on their level of advancement: more advanced organisations felt like they had already defined their indicators and did not find it necessary to revise them. On the other hand, PI definition constituted an essential roadmap for those utilities that were building their AM system.

Fail

This is a module with a very sophisticated mathematical basis; it provides results that, unlike PIs or even to a certain extent ARP, cannot be obtained by utilities unless highly specialised assistance is available. While PHM could be tested in some cases, more usefully when run directly by the researchers in charge of developing the model (who also developed validation tools, Le Gatt, 2000), there were often problems with data availability and the module itself – too few segments to provide usable results, or problems in inputting data. Many utilities have been unable to run Poisson at all.

RelNet

RelNet was found to be easy to use but requiring long computing time.

Aquarel

Unfortunately this was not tested.

ARP

ARP brings a clever, systematic and transparent approach to the decision-making process without replacing engineering judgment. A thorough, careful and valuable review of all decision criteria, as well as their mathematical definition, has been provided by the research team. Most of the criteria require, for their computation, that the value of the future probability of failure be known – an output of PHM, a module that proved more difficult to run.

However, if need be, this could eventually be replaced by a more

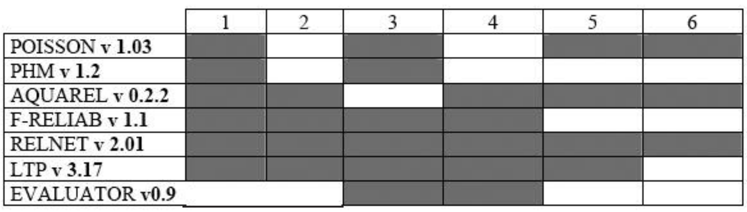

Figure 3 Breakdown of tasks for the Codigoro testing.

simplistic evaluation based on the past history of groups of pipes classified according to the most relevant risk factors (but not based on the projected values that PHM provides.) ARP's major drawback is that it requires a lot of subjective data (factors for each pipe + weights, parameters for profiles, and so on) which may actually be regarded as an opportunity for the managers to reflect on their system. Simplified versions could be developed.

LTP

Kanew presented no specific difficulties. It is a model that was developed and applied a long time ago and does not require a great amount of field data. Expert judgment may be enough. Testing was found to be more difficult with the new Rehab Strategy Manager, because of the assessment of efficiencies on rehab methods. The Scenario Writer was found to be easy to use even though the definition of key factors required much data gathering.

Review of CARE-W modules

Polytechnic University was able to install and run all the modules on its own computers for demonstration purposes, but solely under CARE-W's supervision. The installation was not straightforward; it required careful designation of paths. Similarly, running modules required cautious manipulation to avoid crashes or invalid results.

Some modules came with built-in examples or data sets, but, in some cases, it was necessary to go back to the research centres to gather the data necessary to run the module. Some data sets were kept deliberately small to facilitate the demonstration. Unfortunately, it was not possible to run all modules with one single set of data, where the output from one module would become the input for another module. Also, all data sets were not necessarily based on real life situations, so this review does not include comments on the real life applicability of CARE-W. This will be the object of full-scale demonstrations being planned in Europe and the US.

Comments are as follow:

- CARE-W is likely to be one part of an overall master plan (for which other tools will be needed) where a decision has to be made in terms of how much resource should be allocated to each single component of the whole water system and when, not only for the buried network but also the treatment works, aqueducts, pumping stations, valves, hydrants, tanks, and so on. Other tools are needed to manage the non-buried infrastructure. Inspection devices may be used for the underground elements. The connection with these other tools must be synchronised.
- CARE-W allows the selection of candidates for rehabilitation in general. There is no integrated tool to help decide what type of rehabilitation (repair, relining or replacement) is best depending on the specific deficiency that each pipe has and simple life cost analyses. Such tools do exist and will also need to be synchronised with the CARE-W modules.
- Similarly, synchronisation with other IT tools is needed when a utility is already equipped with particular programs that are likely to be connected to the CARE-W suite of tools. Also, though CARE-W comes with its GIS, utilities that have their own GIS would rather use it for data input and visualisation of results; this also requires specialised input.
- It was noted that 75% of the CARE-W effort goes on data preparation. However, this statistic applies to using 'recycled' data not originally collected for rehabilitation planning analysis. For such situations, systematic detection of inconsistencies ought to be incorporated to facilitate data intake. One could also imagine IT systems where CARE-W modules would be fully integrated - data collected in the appropriate format would automatically feed the modules. The testing did not reach a level at which data handling would become less important. Full scale testing with system integration will achieve this.
- In some cases CARE-W, with its heavy reliance on data, may appear to be quite difficult to run. This may be more an indication of the outdated way in which operations are still run, or the lack of adequate data at a particular organisation, rather than a problem with CARE-W itself. For example, to be fully operational CARE-W does require the utility to be equipped with historical failure data (at least knowing which pipe broke and when over the last five years, a requirement which is not very unrealistic), a digital database and a full scale hydraulic model. Ideally, it would also have a GIS. Instead of regarding these requirements as onerous, it should be considered that GIS and hydraulic modelling are now part of the standard battery of tools for a modern water utility and that CARE-W is, in a way, adding value to them and offering the opportunity to maximise their utility.
- Similarly, it is very likely that CARE-W, even when fully developed and commercialised, will never be an off the shelf, one-size-fits-all kind of software. It should instead be regarded as a flexible consulting tool for high-level technicians who can provide responses to advanced investigations. Instead of regarding this as an extra burden it could be seen as an opportunity to advance a field that provides crucial services, but unlike other essential industries (public health and transportation among others) has often placed the bar very low in terms of its analytical demands. So if it is true that at the present time, the typical US utility may not be staffed with the type of people who could easily embrace CARE-W, this does not mean that US water utilities do not need to consider bringing their level of analytical 'appetite' up to the necessary level. Education of current engineering students must take this need into consideration.
- All previous concerns relate to IT synchronisation and data collection and are quite typical with data-based approaches. Such difficulties were reported at length by the testing partners and have already been or can probably be easily addressed. However the question of CARE-W's cost efficiency remains: once the CARE-W process has been streamlined, will results generated thanks to CARE-W be worth the added requirements in data and functions (compared to simpler approaches)?
- Indeed, parties showing an interest in CARE-W are quick to demand evidence of its cost efficiency. This is a valid but very complex request as evidenced by the research projects that have attempted similar work (Elnaboulsi, 1997; Male, 1990). Only a serious study that observes all of the interconnected expenses over a planning horizon of at least 20 years would constitute a reliable business case study. In effect, for example, a programme that would arbitrarily cut some necessary investments would de facto achieve savings in the short run even though this might result in a greater outlay later on. Each module could have developed, when possible, validation mechanisms that allow for the computation of gains similar to the benefit index curve developed by Cemagref for PHM (le Gatt, 2000). Such a curve plots the number of breaks avoided (based on forecast failures) as a function of the percentage of pipes that have been replaced (these have been chosen

based solely on their risk of failure). A similar curve, which this time incorporates the consequences of failure, would pave the way toward the business case demanded by the industry.

- The reliability tools (Relnet, F-Reliab and Aquarel) require a hydraulic model. In this respect, in Europe the whole system (both transmission and distribution) tends to be fully modelled, while in the US most utilities limit themselves to the transmission trunk mains (skeleton.) This is a challenge that will be alleviated with time when more utilities build full system models. Another issue will then need to be addressed: CARE-W modules will have to respond to the upgrades of the outside models they rely on (for instance GIS, hydraulic modelling). This is a concern that is typical of IT-based tools. Like all software, CARE-W, the modules and its necessary input data will need to be regularly upgraded.
- Specific constraints set by each utility will always have to be taken into account. For example, in one city, work orders for replacement are issued for no less than 1km of continuous pipe. After having run all of the modules that culminate in ranking valid candidates, the manager still needs to manually regroup segments already ranked by ARP, making a pragmatic judgement. In another city, if a gas line is changed, or the road is paved and the water pipe has had a break rate over the last five years higher than a given value, it is automatically replaced when the road is opened. While CARE-W may still have to adapt to local practices, it may also actually provide the tools to help challenge the validity of such entrenched practices.
- The connection between water quality and physical degradation needs to be further investigated. That would allow refinement of the introduction of this criterion within CARE-W's ARP approach.
- Some tools (such as failure forecasting) require a wide array of data and have been developed based on the premise that many risk factors play a significant role in the structural failure of a pipe, while other tools like LTP were geared toward the data-poor utility with little advance knowledge of failure patterns besides generic survival information. In some cases, these varying levels of analysis may result in missed opportunities or even incoherent approaches. For example, in Kanew, the order of replacement is based solely on age, while one principle and result of a PHM analysis is that age is not the most relevant risk factor. Once utilities become more data rich, all tools will have to take better advantage of the knowledge accumulated.
- Most CARE-W modules need the whole linear pipe system to be itemised into statistical individual elements that are not necessarily physical entities. To do so, most utilities use their GIS objects or the segments that appear in their hydraulic model database in order to benefit from an already digitised database. However, for instance, CARE-W PHM's approach requires a new statistical individual to be (this is done automatically by the module) artificially introduced after each break and for the number of previous breaks experienced by a segment to be accounted for as a risk factor, often, the most relevant one. To what extent are results affected by this itemisation? After all, if the network was broken down into short individual elements, most may end up experiencing either one or no break. If of varying lengths, and if the break rate is considered, very short pipes are favoured; when the number of breaks is taken into account, very long ones have the advantage. A study of the importance of itemisation of a linear pipe network into a population of individual elements and how to control this must be undertaken to fully evaluate the relevance of various scenarios.
- PHM is a module based on Cox's complex analytical model. To make the process as user-friendly as possible, many stages of the analysis were automated, apart from the fitting of the model. This results in the elimination of risk factors that may be significant when tested one by one but whose relative significance is small compared to other, much more important risk factors. In addition risk ratios, value that are easy to understand, no longer appear. Unfortunately, these simplifications result in a loss of information that could be very useful in a prevention plan. For example, in a certain data set, a pipe is shown to have three times more chances of breaking if located in soil A rather than soil B. A manager may make good use of such information when choosing a replacement material. However, soil no longer appears in the final model because the relative importance of 'soil' in terms of predicting future breaks is small compared to, for example, the past history of breakage or the installation year (Vanrenterghem-Raven, 2003). In other words, overly simplifying an analysis for the sake of user-friendliness can result in the loss of some useful information.
- Some utilities may use only particular modules or parts of them, or find some of the background research that has contributed to the development of a module very valuable. For example, the PIs or the ARP criteria were the subject of very careful identification and definition. It would be unfortunate if a utility engaged in the process of, for example, drawing a decision-making matrix from scratch did this without making any use of such useful background research. Similarly, many utilities that attempt to create a home-made methodology assign subjective weights to risk factors and, by doing so, simplify a process that can actually be quite complex particularly if more than three factors are involved. The risk ratios obtained in the fitted model of a PHM for instance could provide a more scientific evaluation of those weights, one that avoids redundancy and takes bias and inter-dependency of various risk factors into account.

CARE-W's impact and penetration

Comments from the partnering utilities remained in general positive, but more because of the promise of what CARE-W can do rather than what it actually accomplished at most testing grounds. As explained previously, few were able to test their module fully, none was able to test all modules at full scale. Few utilities (except for Lausanne and Oeiras-Amadeira) have taken further action since the testing of their module(s) to either integrate some modules into their current process or to re-test the same module after it was improved, or to test additional modules. This is not due to a lack of interest: all the utilities interviewed expressed the desire to further extend their collaboration.

Lausanne was so eager to adopt PHM that it decided not to wait for CARE-W's commercialisation. It entered into a contract with a computer programmer/statistician to have PHM reprogrammed from scratch based on its original statistical model (which is in the public domain). This took approximately one man-year, which was more then expected. At the beginning of the interview for the EPA study, Lausanne engineers insisted their interest was limited to the PHM module.

At the time of the interview there

was a recognition that the decision-making process, undertaken on a regular basis, could possibly be systematised by adopting ARP. At the same time, there was doubt about whether the political will and financial funding could be found to introduce new procedures. However, the CARE-W leadership reported that Lausanne has begun to adopt ARP since then.

Lausanne's experience is a reminder that even though CARE-W models may benefit from technical improvement, the main mission of CARE-W, which was to provide a common framework and adequate analytical tools to all utilities facing similar complex decisional problems, has been accomplished. While there is room for improvement and tailored solutions, there is no need for everything to be reinvented, particularly by smaller utilities that do not have the resources to engage in a similar level of effort.

Oeiras-Amadeiras had no AM system in place before its involvement with CARE-W, and therefore is following the CARE-W framework, one step at a time, and is committed to its full implementation however long it takes. It is simultaneously collecting the necessary data and rebuilding relevant processes.

The effort has generated a lot of interest in Portugal and, after Lisbon asked to be given access to the modules (through a very hands-off approach this time conducted by a Bologna University researcher trained at SINTEF), a network of smaller Portuguese utilities has joined the new phase of the project.

The organisational structure of this recent Portuguese development is highly praised by both the utility and research engineers interviewed for this project: a point person has been designated at the partnering research centre, LNEC, to answer any pressing questions by telephone or e-mails. It is felt that the grouping of a number of utilities allows not only for economies of scale but also for sharing experiences and difficulties, and learning from each other in the monthly meetings conducted by LNEC experts.

The Portuguese experience is worth reporting because it offers a model of continuous involvement where local leadership and funding took over right after CARE-W was officially completed, which allowed the Portuguese participants to draw further and immediate benefit from the project. A similarly successful situation exists in Scandinavia, where in addition to EU funding, multiple other levels of funding came to play offering many opportunities to continue to build on and benefit from the massive initial investment by the EU. Similarly, France's Cemagref and INSA have continued research on CARE-W topics with national funding.

Lyon is now quite experienced in using ARP, which was facilitated by the fact that the person in charge at the company managing the utility (as often in France, Lyon is managed by a private entity through a long-term contract with the municipality that owns the assets) is also doing his PhD under the direction of the researcher who developed the module. So this may be more a result of an exceptional convergence of experience, skills and 'how to', than a strong interest on the part of the municipality.

By the end of the research phase, CARE-W was not entrenched and running among most participating utilities. This is less an indication of its lack of current or potential future success than possibly of the expectations at the beginning of the project not matching local resources. CARE-W was a research project whose current output is not without flaws, whether functional, technical or even scientific. However, it should be regarded as a strong starting point for an ambitious and very complex agenda. Gauges of success other than testing results and current application should also be considered:

- CARE-W has been exposing the industry to a new way of thinking about rehabilitation planning, one that is preventive and based on data analysis and advanced tools. This should ultimately generate capital savings and lower levels of disruption, which are extremely valuable goals. CARE-W tools can be improved technically and is being improved through follow-up research projects. At Cemagref, in Bordeaux, France, another failure prediction model, YULE, is being developed; SIROCO is being developed as an alternative to ARP and Electra, and so on. However, the logical thinking framework based on data and risk, the backbone of CARE-W, has constituted a mini 'cultural' revolution in terms of the way utilities are expected to make decisions.
- CARE-W's relevance sustained interest throughout Europe, which meant that new partners became involved after the start of the project (Lausanne, Oeiras) or even after its completion. Stockholm, in Sweden, and Trondheim, in Norway, are planning or in the midst of major projects involving the use of CARE-W. Results have already been obtained at Trondheim that have helped to upgrade the financial elements. Demonstration projects are also planned in the US.
- A new generation of high-level professionals and engineers have been exposed to the new approaches and analytical tools promoted by CARE-W. The project has provided research grounds for numerous Master's degrees and PhDs based on the theme of computer-aided, data-based, analytically-driven rehabilitation planning of water networks, a far-reaching concept. Such professionals in Europe are now employed by utilities or provide consulting services. They do not necessarily use CARE-W in a single way, because they were trained to be more than software operators. They bring creativity to the process, and may use some of its modules, ignore others, or add new features in order to serve the current needs of an organisation and its management demands, or to suggest modifications to the present status quo. CARE-W provides them with that kind of creativity and level of impact.

Conclusion

CARE-W has the commendable merit of having set new standards in water AM practices. It also recognises the fact that water AM issues are complex and that an attempt to resolve them in a realistic and scientific way requires tapping into advanced tools that are already common in other industries. Simple tools cannot deliver solutions at the level of the challenge now faced by US utilities and society.

CARE-W has paved the way toward a comprehensive and flexible framework of analysis. Clear steps have been defined, tools can be added on, modified, and improved. In addition, a community of researchers from many different countries was able to work collaboratively and train future professionals to think creatively about AM within the CARE-W analytical spirit.

In its current condition, each module can already be used by trained professionals to help make decisions for future rehabilitation projects. There is a need for further full-scale demonstration projects. Some are already under way but each country would benefit from drawing its own conclusions, specific to its own circumstances. Because CARE-W is sufficiently advanced, demonstration candidates would be left with a tailored product. Generic conclusions could also be drawn from a body of demonstration results, in view of the possible commercialisation of the software, and more user-friendly development of the software could be undertaken. New research topics must also be defined. ●

Captured by data:

Enterprise asset management systems

DARYL MATHER examines Enterprise Asset Management Systems (EAM) and the aims of modern maintenance, looking at the latest approach to asset management.

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Since the late 1980s EAM vendors throughout the world have pitched their products based partly on the ability to capture, manipulate and analyse historical failure data. Part of the stated benefits case is often the ability to highlight the reasons why assets are performing poorly, provide the volume and quality of information for determining how best to manage the assets, and inform decisions regarding end-of-life and other investment points.

This benefits case covers the principal drivers for most maintenance managers today and it has been used to justify millions of dollars worth of investment. It has also placed the modern EAM system at the centre of corporations that are driving to improve asset performance. On the surface it appears to be a logical approach for problems relating to asset performance, and using this approach companies do, of course, achieve results.

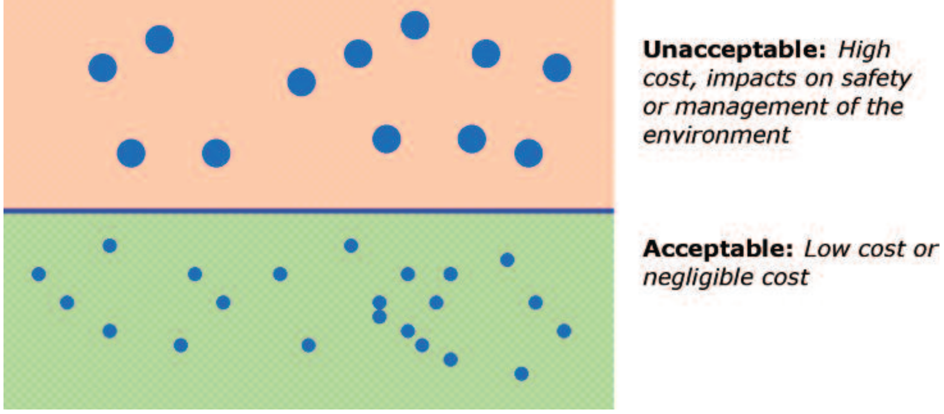
The implementation of these products, when bought for these reasons, often focuses on optimising processes to capture the dynamic data on asset failures, which is then used throughout the system. MRO[1] style inventory management algorithms, for example, use this information as one of the key inputs to determine minimum stocking levels, reorder points and the corresponding reorder quantities.

If we want to understand the validity of this line of thinking it is necessary to first explore the aims of maintenance, and how asset data can be used to further those aims.

'Maintenance' is a term generally used to define the routine activities undertaken to sustain standards of performance throughout the in-service, or operational, part of the asset life cycle. In doing this, the maintenance policy designer needs to take account of a range of factors. These include the complexities of the operating environment, the available resources for performing maintenance, and the ability of the asset to meet its current performance standards.

In the past, this would be the extent of the maintenance analysts' role. One of the realities they face is that at times assets are under a demand greater than, or extremely close to, their inherent capabilities. As a result, analysts often find themselves recommending and analysing activities not only of maintenance, but also other areas of asset management, namely those of

Figure 1
Acceptable and unacceptable failures.



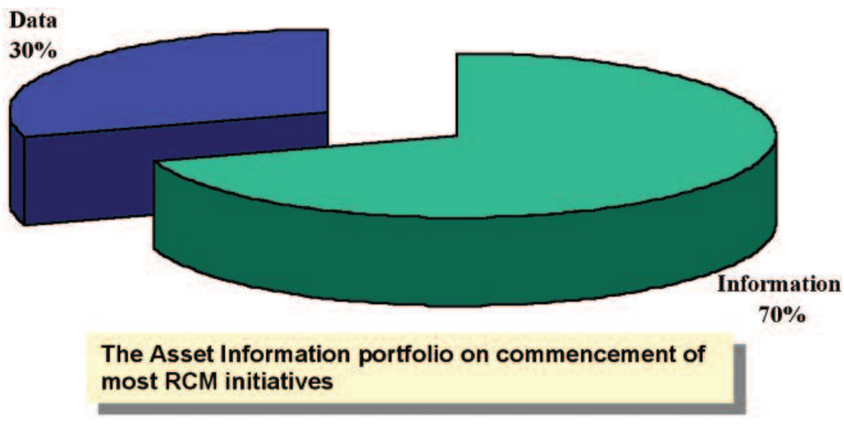


Figure 2 Corporate knowledge = data + information.

asset modification and operations.

Safety and environmental compliance play their part in creating the drive for this activity, particularly given the changing legal and regulatory frameworks that surround these two areas; in some industries they are even the principal drivers. However for most businesses the goal remains that of obtaining maximum value from their investment. This means getting the maximum possible performance from the assets for the least amount spent.

In the original report and appendices that produced Reliability-centered Maintenance (RCM) the authors defined critical failures, initially, as those failures with an impact on safety. Today the term 'critical failure' is often used to group failures that will cause what companies consider to be high-impact consequences, a definition that is too variable for a general discussion. For the sake of simplicity, 'critical failure' in this article refers to all failures that will cause the asset to perform to a standard less than that required of it.[2]

If an asset management programme is aimed at maximum cost-effectiveness[3] over an asset's life, then it must look at the management of critical failures. By definition, this approach is centred on the reliability of the asset (or reliability-centred).

So, in essence, the role of the policy designer can be defined as formulating cost-effective asset management programmes, routine activities and one-off procedural and design changes, maintaining standards of performance through reducing the likelihood of critical failures to an acceptable level, or eliminating them. This is also the essence of modern RCM.

The data dilemma

Immediately we start to see a contradiction between the aims of maintenance, and those often quoted for EAM systems. Non-critical failures are those of low or negligible cost consequences only. These are acceptable and can be allowed to occur. Therefore a policy that focuses on data capture and later analysis as its base can be used effectively. Over time the level of information will accumulate to allow asset owners and policy designers to determine the correct maintenance policy with a high degree of confidence.

However, critical failures, those that cause an asset to underperform, have unacceptable consequences and cannot always be managed in a similar way. For example, if a failure has high operational impact or economic consequences, then allowing it to fail before determining how to manage the results is actively counterproductive to the aims of cost-effective asset management. Moreover, recent history reinforces the fact that failure of assets can lead to consequences for safety[4] or breaches of environmental regulations.[5]

So, if our policy for determining how best to manage physical assets is based around data capture, then we are creating an environment that runs counter to the principles of responsible asset stewardship in the 21st Century.

The underlying theories of maintenance and reliability are based on the theory of probability and on the properties of distribution functions that have been found to occur frequently, and play a role in the prediction of survival characteristics.[6]

Critical failures are, by their very nature, serious. When they occur they are often designed out, a replacement asset is installed, or some other initiative is put in place to ensure that they don't recur. As a result the volume of data available for analysis is often small, therefore the ability of statistical analysis to deliver results within a high level of confidence is questionable at best.

This fundamental fact of managing physical assets highlights two flaws with the case for capturing data for designing maintenance programmes. First, collecting failure information for future decisions means managing the asset base in a way that runs counter to the basic aims of modern maintenance management. Second, even if a company was to progress down this path, the nature of critical failures is such that they would not lend themselves to extensive statistical review.

By establishing an effective, or reliability-centred, maintenance regime, the policy designer is in effect creating a management environment that attempts to reduce failure information, not increase it. The more effective a maintenance programme is, the fewer critical failures will occur and correspondingly less information will be available to the maintenance policy designer about operational failures.[7] The more optimal a maintenance programme is, the lower the volume of data there will be.

Designing maintenance policy

When maintenance policy designers begin to develop a management programme, they are almost always confronted with a lack of reliable data to base their judgments on. It has been the experience of the author that most companies start reliability initiatives using an information base that is made up of approximately 30% hard data and 70% knowledge and experience.

One of the leading reasons for this is the nature of critical failures and the response they provoke. However, there are often other factors such as data capturing processes, consistency of the data, and the tendency to focus efforts in areas that are of little value to the design of maintenance policy. With EAM technologies changing continually, there are often upgrade projects, changeover projects and other ways in which data can become diluted.

There are still other key reasons why data from many EAM implementations are only of limited value. Principal among these is the fact that even with well-controlled and precise business processes for capturing data, some of the critical failures that will need to be managed may not yet have occurred. An EAM system, managing a maintenance programme that is either reactive or unstructured, will only have a small impact on a policy development initiative.

At best it may have collected information to tell us that faults have occurred, at a heavy cost to the organisation, but with small volumes of critical failures and limited information about the causes of failure. RCM facilitates the creation of maintenance programs by analysing the four fundamental causes of critical failures of assets, namely:

- Poor asset selection (never fit for purpose)

- Asset degradation over time (becomes unfit for purpose)
- Poor asset operation (operated outside the original purpose)
- Exceptional human errors (generally following the GEM[8] principles).

The RCM analyst needs to analyse all of the reasonably likely[9] failure modes in these four areas to an adequate level of detail. Determining the potential causes for failures in these areas, for a given operating environment, is in part informed by data, but the vast majority of the information will come from other sources.

Sources such as operators' logs are strong sources for potential signs of failure, as well as for failures often not found in the corporate EAM. Equipment manufacturers' guides are also powerful sources for gleaning information about failure causes and failure rates. However, all information from a manufacturer needs to be understood in the context of how the asset is being used, and the often conservative estimates made by the manufacturer. For example, if there are operational reasons why your pumping system is subject to random foreign objects, for whatever reason, then failure rates for impeller wear can become skewed.

Other sources of empirical data can be found in operational systems such as SCADA or CITECT, commercial data banks, user groups, and at times consultant organisations. As with information from manufacturers, there is a need to understand how this applies to the operating environment of the assets. As asset owners require more and more technologically advanced products, items come onto the market with limited test data in operational installations, further complicating the issues of maintenance design through data.

The factors that decide the lengths that an RCM analyst should go to collect empirical data are driven by a combination of the perceived risk, (probability x consequence), and of course the limitations set on maintenance policy design by commercial pressures. Even when all barriers are removed from the path of the RCM analyst, they are often confronted with an absence of real operational data on critical failures.

The vast majority of the information on how the assets are managed, how they can fail and how they should be managed will come from the people who manage the assets on a day-to-day basis. Potential and historic failure modes, rate of failure, actual maintenance performed (not what the system says, but what is really done), why a certain task was put into place in the first place, and the operational practices and reasons why, are all elements of information that are not easily found in data, but in knowledge.

This is one of the overlooked side-benefits of applying the RCM process, that of capturing knowledge, not merely data. As the work force continues to age, entry rates continue to fall compared to other managerial areas, and as the work force becomes more mobile the RCM process, and the skills of trained RCM analysts, provide a structured way to reduce the impact of diminishing experience.

RCM and the role of the EAM

One area where modern EAM systems do provide substantial benefits is in driving out inefficiencies in business processes. Through the capture, storage, manipulation, and display of historical transactional data, companies can take great leaps forward in the level of efficiency with which they execute maintenance programmes – for example, by ensuring that delays in executing work are captured, analysed and resolved, or by being able to display trends in performance and cost over time.

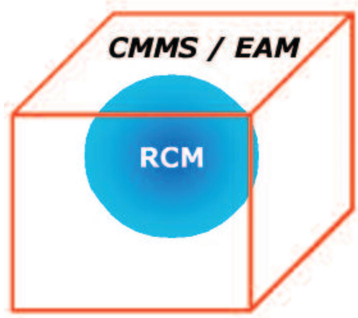


Figure 3
Integration of EAM and reliability centred maintenance.

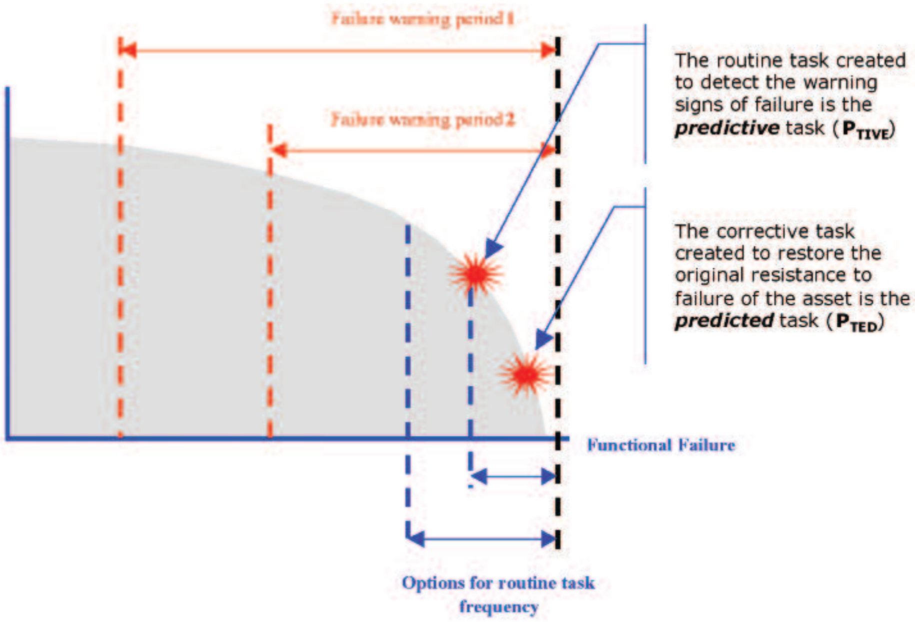


Figure 4
Tasks involved in predictive maintenance.

The effectiveness of a maintenance task comes from how it manages failure modes, not from the level of efficiency that it is executed with. The original RCM study revealed that many routine tasks could actually contribute to failure, or to lower cost-effectiveness, by having limited or no impact on the performance of the asset (in effect wasting the maintenance budget). Executing these tasks with greater efficiency would have either have no impact at all on effectiveness, or could possibly even magnify the effects of unsuitable tasks.

For example, after a lot of time working with a utility company in the UK it became clear that the reported schedule compliance was not an accurate figure. Schedules were regularly coming in with 100% compliance, while the reality was that they were actually performing at around 25%.

After some investigation it turned out that the craftspeople recognised that most of the regimes that were coming out of the system were either counterproductive or not applicable. So they were, fortunately, omitted. Prior to installing the EAM system they were working with job cards in separate systems. Once the EAM went 'live' these were collated and assigned to all similar assets regardless of operational context.

This is where RCM-style methodologies contribute to the modern EAM or CMMS system. By providing the content that the system needs to manage, they are ensuring that the right job is being executed in the right way. This is common sense, and practitioners of RCM have been emphasising this point for many years.

What is often not emphasised, however, is that having an effective maintenance programme in place, integrated with the EAM system, ensures that future efforts in data capture are executed in a way that supports the principles of responsible asset stewardship. The effect of building a data capture programme on the back of an effective maintenance programme is to reverse, over time, the ratio of hard data to human knowledge that is available for decision making.

On performing the analysis, the structured approach within the decision diagram drives RCM analysts to develop an asset management programme that is practical, cost effective and tailored to a given level of performance and risk. There are two main outputs for any correctly performed analysis. The first is one-off changes to procedures, software, asset configurations, asset types, company policies and asset designs.

The second area is a group of routine maintenance tasks designed to manage the failure mode under analysis. Apart from combinations of policies, RCM supports five different maintenance policy options[10] as detailed below. These make up the bulk of the content that the EAM system is installed to manage.

- Predictive maintenance (PTive)
  A task to predict when a failure mode is about to occur.
- Preventive restoration (PRes)
  A task to prevent failure through applying a task, at a time or usage based interval, to restore the assets' original resistance to failure.
- Preventive Replacement (PRep)
  A task to prevent failure through replacing an asset or component, at a time or use-based interval.
- Detective maintenance (DTive)
  A task to detect whether an item has failed or not. This task is only applied to failure modes that RCM classifies as hidden.
- Run-to-fail (RTF)
  A policy to allow an asset to fail, rather than applying any form of routine maintenance. Failure modes that are allowed to run-to-failure have low, or negligible, consequences in terms of cost only. These are the non-critical, or acceptable failures that were referred to earlier in this article.

An RCM-based process selects these tasks based on their applicability and effectiveness as defined within the decision algorithms. These issues have been commented on many times and will not be dealt with in great detail within this paper.

For modern RCM analysts the routine maintenance tasks are of interest not only because of the impact they have on asset performance, but also because of the way they can be used to develop the asset information portfolio, contribute to whole-of-life costing, and provide an additional tool for proactive monitoring of asset performance and corporate risk exposure.

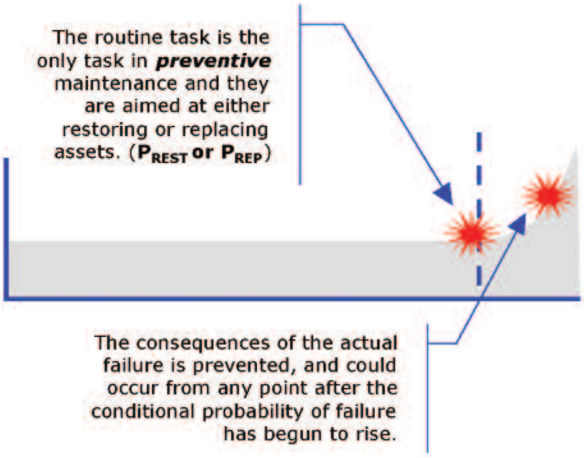


Figure 5
Tasks involved in preventive maintenance.

As in the logic of the decision diagram, the criteria and characteristics of each of these policy choices has been detailed many times, and it is not necessary to describe them in detail in this article. However, it is necessary to detail how they affect the collection, management and use of dynamic asset data.

Predictive maintenance

As shown in Figure 4 below, predictive maintenance (PTive) tasks are established to try to detect the warning signs that indicate the onset of failure, thus allowing for actions to be taken to avoid the failure. However, there is another aspect of PTive tasks that is often overlooked – that of the corrective, or predicted (PTed), task once warning signs have been detected.

Immediately following the analysis, the information established at this point can be used to create proactive whole-of-life costing models that are directly tied to performance and risk.

Whole-of-life cost of an asset, or component, subject to predictive maintenance tasks = (Cost (PTive) x n) + Cost (PTed), where 'n' represents the number of times the PTive task is likely to be executed. This also drives estimates of the time between installation and likely failure. It needs to be recognised that the corrective, or PTed, task is executed at a time less than end-of life (although small).

As time passes, the amount of data that is collected on these tasks will grow, collected now in a responsible manner, which can also be used in statistical models of asset degradation and predictions of capital spend requirements. By the inclusion of these outputs of an RCM analysis, asset managers can use the results with increasing confidence as predictors of whole of life cost profiles and end of life points.

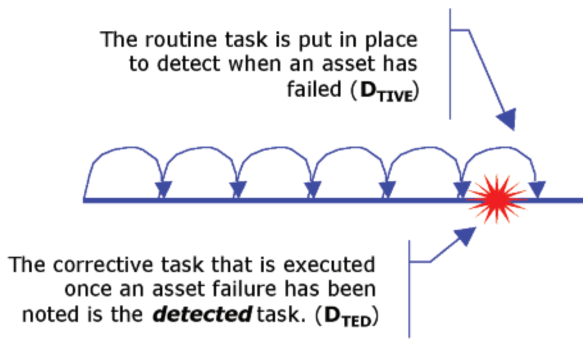


Figure 6
Tasks involved in detective maintenance.

Preventive maintenance

Where predictive maintenance tasks cannot be applied, for whatever reason, the next two options on either side of the decision diagram are preventive maintenance tasks. These are tasks that are aimed at either restoring an asset's resistance to failure (PRes), or replacing the asset at a time before a failure can occur, (PRep) thus preventing failures. These tasks have limited use and are based on age, use, or some other representation of time.

When applied correctly these tasks are part of the approach to maintenance that, by necessity, reduces the volume of failure data available for statistical analysis. However, with the component out of the operational environment, it can safely be tested to try to establish the extent of its remaining economically-useful life.

Whole-of-life cost of an asset, or component, subject to preventive maintenance tasks = (Cost (PRes) or (Cost (PRep).

This is an additional task and one that would not be generated from the RCM analysis. Yet it represents another aspect of responsible data capture and is an important element of businesses where confidence in statistical life prediction, and whole of life costing models, are of importance.[11]

Detective maintenance

As with predictive maintenance tasks there are actually two tasks that are being implemented here. First the detective (DTive) maintenance task, and second the detected (DTed) maintenance task. The result of this is the same as with predictive maintenance tasks. That is, it provides further information about the likely failure rate, collected in a responsible manner, which can be used to inform decisions on optimising the frequency of this task.

Whole-of-life cost of an asset, or component, subject to detective maintenance tasks = (Cost (DTive) x

n) + Cost (DTed), where 'n' represents the number of times the DTive task is likely to be executed. This also drives estimates of the time between installation and likely failure. It needs to be recognised that the corrective, or DTed, task is executed at a time greater than end-of-life due to the characteristics of this task. As time passes, the data collected can be used to inform decisions and whole-of-life models with increasing certainty.

This is particularly relevant for hidden failures, or hidden functions as they are sometimes called. When implementing the outcomes of an RCM analysis, some of the tasks are DTive tasks. That is, they are tasks put in place to detect if a failure has occurred. Often, the items being tested have not been tested for a long period of time, sometimes years. And often nobody knows if they are working or not!

So when establishing the initial DTive task frequencies, often the information used is not very certain and backed by only the experiences and memories of those involved in the exercise. Fortunately manufacturers do often have a good level of information about failure rates in these sorts of devices. But the result is still quite conservative and not tuned for the specific operational climate. Performing DTive tasks will immediately help the company to establish some baseline information about failure rates of the device.

Run-to-failure

The last policy option, aside from redesign and combinations of tasks, is that of run-to-failure. This option is for the acceptable, low or negligible cost failures detailed in Figure 1. The EAM will allow these failures to be captured for analysis to inform whole-of-life cost models, spending forecasts, and to be used in reviewing maintenance policies when relevant.

Along with the responsible data capture forced by these policy options, configuring and managing the EAM in line with RCM thinking will also allow exceptional failures to become visible.

Because of the way that RCM is by necessity carried out, there is the possibility that some failures may be missed. Modern methods of execution have expanded the original default method of team-based analyses to include expert analysis sources outside the team, but the possibility always remains that the analysis will miss a critical failure despite the best efforts of the analyst and those involved.

In these circumstances the data recorded in these exceptional failures will provide the impetus for the analyst to revisit the analysis to factor in this failure mode and to put in place a relevant management policy. It is not an area that is used for capturing data for statistical analysis and is, as the name suggests, the exception rather than the rule.

It can be seen that part of the role of the modern RCM analyst is not only to minimise the volume of failure data that is collected for later analysis, but also to maximise the quality and usability of data that is captured via collection methods that support the principles of responsible asset stewardship. It can also be seen that advances in modern technology, combined with the growing needs of asset-intensive companies, have enabled this information to be used in newer and more comprehensive ways than originally conceived of and correspondingly not mentioned in previous work on RCM.

In particular, it fuels the shift by the company away from the static methods of life cycle costing, and towards the proactive methods of whole-of-life costing. This is a step that enables companies to set up the data capture techniques and practices required to propel it towards the stochastic, or probabilistic, model of whole of life costing.

Measurement of maintenance performance

Measurement is worth mentioning within this article because the data that will be generated from applying an effective maintenance programme will allow companies to look further at how their programme is functioning than they previously could. It is another example of the fundamental importance of effective maintenance policies.

When applying measurement programmes to asset management or maintenance, companies generally look directly to direct performance measures. These are things such as failure rates, mean time to repair, availability, quality and a whole list of other measures of how a machine is operating at any given time (often trended to give a view of improvement or deterioration).

These are perfectly reasonable measures, and they give a company a snapshot of how a machine is performing to the standards that have been set for it. Regardless of how these measures are selected or generated, they are almost always lagging indicators. That is, they are indicators that tell you how your machine is performing after the fact.

Yet the data collected through establishing an effective maintenance programme also allows the company to

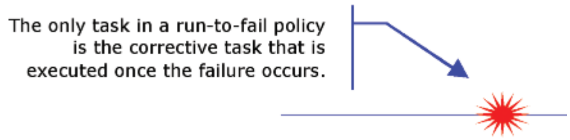


Figure 7
Tasks involved in run-to-failure policies.

generate a range of leading indicators – measures that lead performance, or tell you that something is likely to begin to perform badly before it actually does.

The diagram in Figure 8 depicts the relative impact of these areas of leading indicators, and the smaller impact of performance measures established in the traditional lagging approaches. These are the key areas of the RCM scorecard, a tool first published in the book, *The Maintenance Scorecard*, and the subject of a separate article in this area.

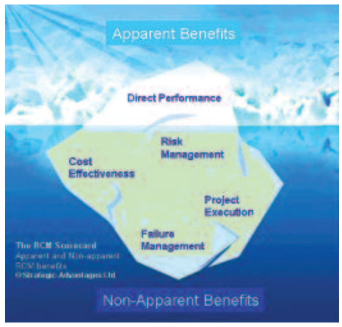


Figure 8
Areas covered within the RCM scorecard.

However, the basic thrust of the RCM scorecard is to allow companies to measure the effectiveness of their maintenance policy initiatives. By applying measures to the data captured in the course of doing day-to-day work, RCM aare able to establish things such as:

- Is it more cost-effective to manage the asset over its whole-of-life profile, or not? (leading to incorrect whole-of-life management, not just costs)
- Was the task really more cost-effective than the estimates of failure? (leading to incorrect whole-of-life costs)
- Was the cost of failure really more cost effective than the estimated costs of the maintenance policy? (leading to incorrect whole-of-life costs)
- Are the tasks actually predicting or preventing failures?
- What is the increase in risk due to late performance of DTive tasks? (leading to higher than acceptable levels of risk exposure)
- What is the increase in risk due to late performance of PRes or PRep tasks? (leading to higher than acceptable levels of risk exposure)
- What is the increase in risk due to late performance of PTive tasks (leading to higher than acceptable levels of risk exposure)?

The actual measures contained within the RCM scorecard are detailed fully within the book. It provides, arguably, a stronger level of benefit to a company than direct measures because it allows them to tap into the results of mainly leading indicators, thus heading off poor performance before it appears on the management report. Regardless of the actual measures used, the point remains that this is only possible due to the creation, in the first instance, of the effective maintenance programme.

The foremost consideration of maintenance managers

We began this paper discussing the three key drivers of maintenance that EAM systems often target. Without considering the different operating environments of different companies, these do cover the basic drivers of most maintenance departments.

- To develop a maintenance policy designed to minimise the total cost of managing and operating assets throughout their entire life cycle for a given level of performance and risk
- To obtain maximum efficiency out of the resources used to carry out the maintenance policy, driving unit costs further towards the optimum level
- To steadily build the asset data portfolio to allow future decisions about the asset base to be made with increasing levels of confidence.

It could be argued that methods based in RCM style thinking alone could satisfy all three of these primary drivers of maintenance management. But the business processes that would be required to do so would be onerous and would restrict the ability of the company to manipulate and analyse data effectively, as well as being a burden to those trying to manage the maintenance workload.

It could also be argued that implementing EAM or CMMS without implementing a parallel, or leading, initiative to create effective maintenance policies will produce limited results, and may possibly exacerbate the current situation by allowing the company to undertake incorrect work efficiently. It could also potentially create an environment where the assets are being managed in a way that is contrary to principles of responsible asset stewardship.

This line of thinking can lead to only one conclusion. The development of effective maintenance policies is the foremost consideration for modern asset managers. When done correctly, it provides the base for business processes, inventory management techniques and methods, software configurations and selection, and the numbers and skill requirements of the labour force.

Apart from these tactical advantages, it also offers the strategic advantages of improving the whole-of-life management and understanding of the physical asset base, and the way that it is monitored and managed through performance measures. However, once the programme is created, attempting to manage the asset base without leveraging off the advances in modern maintenance software deprives the organisation of a tremendous opportunity for improvement.

This viewpoint is not new, nor is it particularly complex. It is a common-sense approach and is an extension of the basic way that maintenance managers acted before discovering technology and being drawn down the path of increasing functionality, graphing, mobile devices and other gadgetry. It just seems to have been lost in the maze of tools that we are faced with today!

Of particular importance in this article is the growing role of the RCM analyst. Once a separated facilitator or a sole analyst, the RCM analyst's role is by necessity becoming a lot broader, covering a range of additional areas of expertise. A 20th Century facilitator was generally driven to apply a team-based method and to complete the analyses. A 21st Century analyst is generally the owner of the programme for their area or region. They are responsible for its upkeep, implementation, ensuring that it is effective, establishing the links to whole-of-life costing and capturing the knowledge of the organisation by applying the method in a flexible fashion. A new role for a new set of challenges! ●

About the author
Daryl Mather has assisted companies to increase the profitability of their physical asset base in over 23 countries including the USA, Europe, Asia and Latin America. He is the author of the book The Maintenance Scorecard, ISBN 0831131810, and works with Knowledge Based Management Ltd, a joint venture of Lloyds Register Capstone and WSP Group. Email: daryl.mather@wspgroup.com

Footnotes

[1] *MRO stands for maintain, repair and operate and is an acronym widely used within the EAM/ERP industry that is associated with inventory management from an asset perspective rather than from a production perspective. The difference is that with ERP style inventory management the focus is on 'just-in-time' methods, while MRO-style inventory management focuses on 'just-in-case', or probabilistic methods.*

[2] *The author acknowledges that the definition of what is an acceptable, or unacceptable, standard of performance is an extremely complicated area and one that would take several articles to cover in adequate detail.*

[3] *Within asset management, cost-effectiveness is not merely low direct costs, rather the minimum costs for a given level of risk and performance (maximum value).*

[4] *The Iowa Division of Labor Services, Occupational health and Safety Bureau, issued a citation and notification of penalty to Cargill Meat Solutions, on 30 January 2006. This citation and notification or penalty required corrective actions such as the establishment of a preventive maintenance programme and training of maintenance personnel in potential failure recognition among a range of initiatives to be implemented. This is just one of a number of recent safety events where maintenance has been flagged as a contributing factor.*

[5] *Anecdotal information provided to the author from senior sources in the UK water industry places asset failures as being responsible for approximately 40% to 60 % of breaches of consent. In this context 'consent' relates to guidelines designed to protect the environment to an agreed level. In infrastructure this is thought to be even higher. This particular industry represents one of the world's first water networks and much of the infrastructure is ancient.*

[6] *Mathematical aspects of reliability-centered maintenance, HL Resnikov, National Technical Information Service, US Department of commerce, Springfield.*

[7] *Mathematical aspects of reliability-centered maintenance.*

[8] *GEM stands for generic error modeling and was first developed by Professor Rasmussen of MIT following his review of the incidents leading up to the Three-Mile island disaster in the US. The field of human error is a fundamental area of modern reliability management and has been advanced greatly by the works of James Reason of Manchester Business University in the UK.*

[9] *Reasonably likely is a term used within the RCM Standard, SAE JA1011, to determine whether failure modes should, or should not, be included within an analysis. 'Reasonableness' is defined by the asset owners.*

[10] *The strategy options, or policy options, offered within RCM are detailed in the RCM standard SAE JA1011.*

[11] *This could theoretically be suitable for all companies that need to manage physical assets. However it has particularly importance for financially-regulated institutions and companies that need to prove the case for funding.*

[12] The Maintenance Scorecard, *ISBN 0831131810, is published by Industrial Press.*

Development of a GIS-based data collection and software utility for asset management

The Cu Chi irrigation system in Vietnam proved a useful testing ground for a sophisticated asset management software solution. **BIJU A GEORGE**, **HECTOR M MALANO**, **BRIAN DAVIDSON** and **HUGH TURRAL** explain its development and application.

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Management of irrigation and drainage infrastructure is a complex and difficult task, given that planners and managers have to make long-term strategic decisions and adequate financial provisions. Both these activities must be based on effective monitoring of the current condition of assets and performance of the asset base.

Irrigation and drainage infrastructure often consists of a large number of individual assets dispersed over large areas. The development of an asset management program requires effective tools for rapid collection of field data, storage, manipulation and retrieval of asset information. As part of the development and implementation of a comprehensive modelling framework and development of an asset management program for the Cu Chi irrigation system in Vietnam (George et al 2004; Malano et al 2005), a software utility called Asset Manager was developed to collect, store and model alternative asset management strategies. The conceptual aspects of asset management programs have been presented in several papers (Burton et al 1996, Malano et al 1999, Burton et al 2003, Malano et al 2005).

It is often the case that the information base on asset performance maintained by irrigation authorities is either incomplete or out of date. The first task in the development and implementation of an asset management program is the construction of an up-to-date and reliable database of asset condition and performance. A geographically-distributed database and mapping of the system assets is vital in auditing the existing asset condition and performance and determining the current worth of assets. This initial survey of assets involves a substantial effort and it is often the largest cost item in the development of an asset management program.

Geographical Information Systems (GIS) software has the ability to integrate spatial data from different sources, with diverse formats, structures and projections and provides a platform for those models that incorporate information in which spatial data has a relevant role (Goodchild 1993). The capability of GIS functions to collate data from diverse sources into a consistent input form helps modellers to integrate GIS and simulation models. The main objective of this paper is to present an integrated process of rapid data collection and the capabilities of a GIS based software algorithm used to manage infrastructure data of the Cu Chi irrigation system in Vietnam.

Canal details (Lined canals)	**Canal details** (Unlined canals)	**Canal stuctures** (Cross regulators and gated offtakes)	**Other structures** (Bridges, culverts, etc)
Canal name Canal ID Location Cross section details Canal capacity condition Outer side slope condition Lining condition	Canal name Canal ID Location Cross section details Canal waterway condition Canal bank condition	Structure name Structure ID Location (longitude & latitude) Gate condition Stuctural condition Staff gauge condition Lifting mechanism	Structure name Structure ID Location (longitude & latitude) Stuctural condition Discharge condition

Table 1 Description of details surveyed.

Software development

The main objectives considered in developing the Asset Manager computer utility were to provide:

- The irrigation authority with a structured approach to maintaining an up-to-date information system and analysis of the main irrigation and drainage infrastructure
- A way to integrate an asset management module within the rest of the agency's Information Management System (IMS)
- The managers of the water authority with a tool to develop and evaluate alternative scenarios for planning the long-term needs for infrastructure investment
- Easy adaptability for application to other irrigation systems as well as for future enhancements and modifications.

The software integrates the real-time field collection of asset location, condition and other relevant asset features and provides a simple way to view general asset statistics and carry out financial calculations related to future asset renewals.

The management of the software development project was based on the participation of the intended users of the software in the planning, design, testing and implementation phases of the project. User participation ensured that the user's point of view was taken into account and incorporated into the software, which was tuned to provide a better and more user-friendly operation. This is of particular importance as the initial front end of the software was designed in English and subsequently translated into the Vietnamese language. Alpha and Beta testing (Turner 1984) was carried out simultaneously. Alpha testing was carried out with Cu Chi personnel as part of the overall software development process. Beta testing was carried out by testing the software at the East Branch Canal of the Zhanghe irrigation system in Hubei province, China.

Algorithm

Asset Manager was developed to include the following capabilities:

- Capturing and storing geo-referenced asset data gathered from field surveys including canals, off-takes, regulators, pumps, diversion off-takes and roads, and rating of asset condition and performance
- Calculation of asset statistics including tallying by condition, performance and asset classes
- Calculation of investment profiles and annualised investment costs
- Graphical and printed display of asset reports.

Asset data collection

The field GPS-based system used to collect the asset data is shown in Figure 1. The system has two main field components: a Differential Global Positioning System (DGPS) to locate and geo-reference asset location and a hand-held computer (HPC) to store the gathered information. The field-gathered data can be uploaded to a desktop computer.

Base system maps, including area boundary, soils, roads, irrigation and drainage canals, were initially digitised and formatted in the correct projection (spheroid) and units using Arc Info software. Arc Info files were imported directly into ArcView to carry out general processing, and were used as base maps for the asset survey.

Data entry forms for real-time surveying of field assets were prepared using Map Pad software run on the HPC and directly interfaced with the DGPS. All relevant geographical information about the asset (ID, latitude and longitude coordinates) and data entry forms are displayed for on-the-spot recording by the operator. Field data collectors involved in this process have been trained to assess the various condition and performance aspects of assets. This training is vital to ensure the application of consistent criteria across the entire system. The irrigation and drainage infrastructure surveyed in Cu Chi consisted of 132 offtakes, 15 regulators, 27 drainage orifices and 165km of canal dispersed over an area of 8500ha.

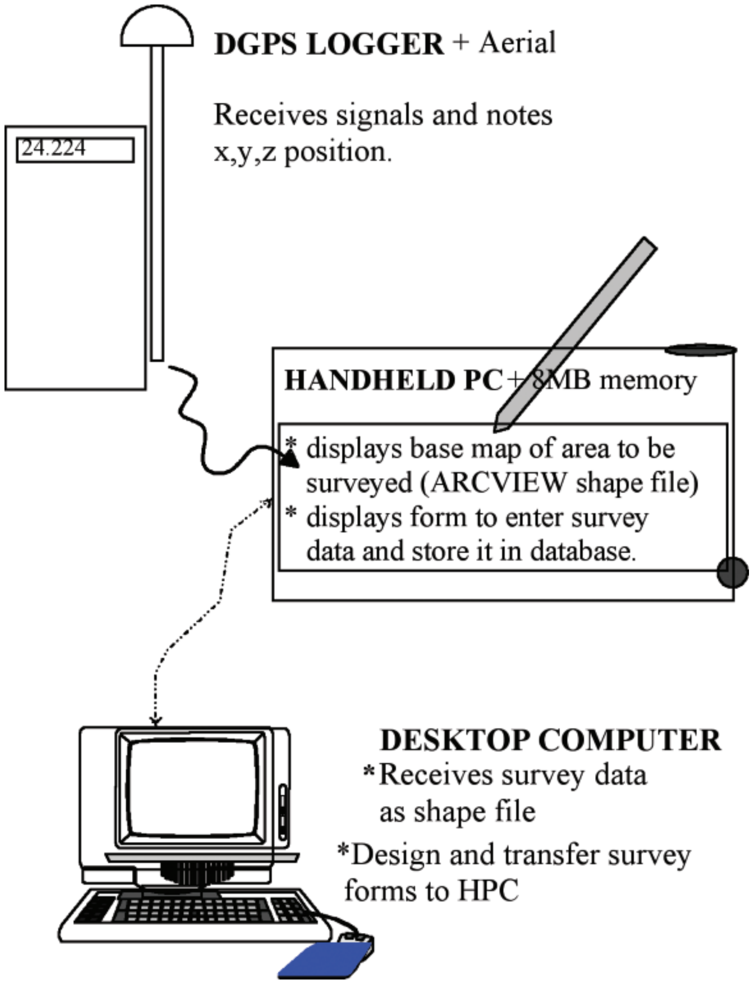


Figure 1
Integrated asset survey and software system.

Map Pad data collection forms are designed to provide explicit menu-driven options from which the data collector must choose. Additional asset data may be added later as they become available. These may include items that are not directly observable at the time of the survey and require either dismantling of the asset to assess them, such as pump impeller condition, or that rely on data from other sources such as hydraulic performance and replacement costs.

Hydraulic performance was measured in terms of the capacity of the asset to meet a certain service requirement. Certain aspects of hydraulic performance, such as a structure's ability to handle the required flow, require exogenous modelling data of flow demand for comparison (George et al 2004). The data collected during field survey are listed in Table 1. Maintenance and repair requirements at the time of the survey were also recorded to enable an estimate of the maintenance backlog for the entire system.

Financial calculations

The approach taken to calculate annuities is based on:

- An asset condition rating based on its ability to perform its function and overall decay
- Ascribing asset importance and calculation of overall condition rating
- Estimation of residual life based on condition
- Estimation of asset replacement cost and annuity based on residual life.

The asset condition rating is carried out on the basis of two parameters, condition, and hydraulic performance (Tran et al 2003). Asset condition refers to the ability of the asset to perform the function for which it was intended. The condition of assets is the result of several factors including wear and tear, quality of maintenance, age and quality of construction. The criteria used for the survey of asset condition are given

Structure	1	2	3	4
Cross regulators, gated offtakes & drainage orifices	Recently constructed, rehabilitated or repaired	Some wear and tear, small cracks, operation is not affected hydraulically	Significant structure cracking, need major structural repairs, frequent failure to achieve required standards	Severe structure cracking, stuctural collapse, not at all in working condition and needs major repair or replacement
Canal waterway	Recently constructed, rehabilitated or repaired	Occasional patchy de-silting/ de-sanding required. No hydraulic constraint.	Frequent patchy de-silting/ de-sanding or local de-weeding required. Significant hydraulic constraint	De-silting/de-sanding or de-weeding required in continuous length. Severe hydraulic constraint
Bridges and culverts	Recently constructed, remodelled, repaired or rehabilitated	Some wear and tear or structural cracking, potentially leading to loss of load capacity	Significant structural cracking/ major stuctural repairs. Possible reduced load capacity	Severe structural cracking/ structural collapse or non-operational. Severe reduction in load capacity

Table 2
Condition rating criteria applied to channels and structures in Cu Chi Irrigation scheme.

in Table 2.

The individual asset component is weighted on a scale of 0 to 1. The overall condition rating is then estimated as the product of individual component rating and component weighting as shown in the equation:

$$A = \sum_{i=1}^{z} a_i w_i$$

Where ai = component condition rating; wi = component weighting; A = overall asset condition rating; and Z = number of rated components.

The condition of each individual asset is used to calculate the residual life of the infrastructure on the basis of the overall rate of decay experienced during the life of the scheme. In this model, the rate of decay of assets is described by a continuous function of asset age and is calculated using the equation:

$$A = br^{\ln(t^*)}$$

where A= overall condition rating;

b= lowest condition rating (highest condition rating = 1);

$$e^{\frac{\ln(\frac{1}{b})}{\ln(r)}}$$

t*= dimensionless time (<t<1); and
r = decay factor.

The residual life of the asset is then calculated as:

$$RL = n(1 - t^*)$$

Where RL = residual life of the asset and n = Asset life (Years).

Asset replacement costs are then calculated after accounting the inflation rate for the residual life as follows:

$$RV = P * (1 + IF)^{RL}$$

Where RV = asset replacement value;
RL = residual life of the asset;
IF = inflation rate; and
P = present value of asset replacement.

To account for the full cost of providing irrigation and drainage services in perpetuity, it is necessary to use a renewals accounting process that ensures adequate funding for the renewal of assets when required. This entails setting up a renewals fund that ensures sufficient capitalisation over the renewal planning period, so the management company can invest in asset replacement, rehabilitation or modernisation. The calculation of this annuity is based on the current rate of interest earned by fixed-term deposits.

Three alternative forms of annuity calculations available in the software are:

- linear depreciation
- full renewal annuity
- partial renewal annuity.

The linear depreciation annuity is: calculated using the equation:

$$DA = \frac{RV}{n}$$

Where DA = depreciation annuity; RV = replacement value; n = asset life (in years).

The full annuity approach assumes that the full replacement cost of assets will be recovered during the residual life of the asset. The full renewal annuity is calculated as:

$$FA = \frac{RV * i}{((1 + i)^{RL}) - 1}$$

The replacement value is calculated including the expected inflation rate as:

$$RV = P \ (1 + IF)^{n}$$

Where RV = replacement value of the asset; FA = full renewal annuity; P = principal (initial capital); i = interest rate; and IF = inflation rate

The partial annuity approach assumes that the recovery of the residual value of assets based on their current condition occurs during the residual life of the asset.

$$PA = \frac{RE * i}{((1 + i)^{(RL)}) - 1}$$

The residual (written down) value is calculated as:

$$RE = RV - D$$

Where RE = residual value and D = depreciation.

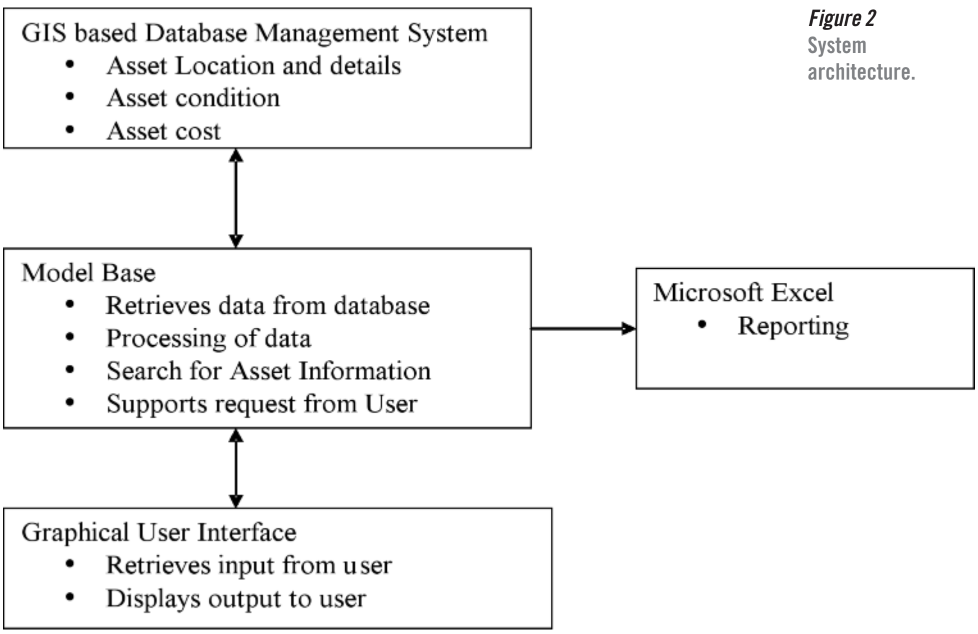


Figure 2
System architecture.

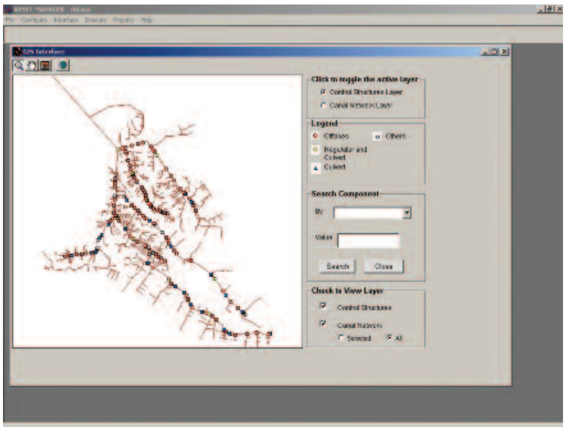


Figure 3
Screen capture of GIS interface window.

Software architecture: structure and capability

Asset Manager has three main components: a graphical user interface (GUI) built on Map Objects and Visual Basic, a modelling component and a GIS-based database management system. The primary functions of these three features are described in Figure 2. Spatial databases related to the canal network and structure locations were created by digitising original system maps using ARCVIEW GIS software.

The model has special features to search and update asset information resulting from condition changes due to maintenance or other events. Map Objects enables the user to display the GIS files so that the database can be retrieved and updated easily using the GUI. The main window of the software consists of six pull down menus (Figure 3), namely: File, Configure, Interface, Simulate, Reports and Help.

Inputs

The main inputs needed for the calculation are:

- The asset database which consists of asset details, location, asset condition rating, replacement cost and year of construction
- Asset parameters which includes asset ratings, decay factor and asset life
- Canal cost which includes unit excavation and lining cost for canals
- Financial parameters based on interest rate and inflation rate.

Outputs

The main outputs from the Asset Manager model are asset condition tallying, investment profile and annuities. The results can be displayed either in graphical and textual form. The reporting facility is built using Microsoft Excel. The main graphic outputs generated by the model include:

- A tally of asset condition by asset types: this is presented as a bar graph with asset number in the Y–axis and asset condition in the X-axis. The user can select different asset types to view the number of assets in each condition (Figure 4)
- An investment profile: this presents the aggregate of replacement cost of assets occurring over an annual time series
- Renewal annuities: the software can be used to develop three different annuities for each asset: linear depreciation, full renewals and partial renewals (Figure 5). The calculation of annuity is important because it will give the company adequate information about the expenditure that the company has to invest to replace a particular asset after a particular number of years of life.

Model application

Asset Manager was installed at the Cu Chi Irrigation Management company (IMC) in Vietnam as part of an integrated information technology suite, which also includes the operation model IMSOP (George et al 2004). The information technology system is intended to provide decision support capability to improve the operation of the water supply system and management of the water supply infrastructure. Asset Manager was later tested at the East Branch canal of the Zhanghe irrigation system in Hubei province, China to prove the adaptability of the software to various irrigation system configurations.

The development and implementation of the software involved the participation of company staff from the beginning of the development process. This process of the following phases:

- Design and conception of the software capability
- Training for field data collection and scoring asset condition
- Training in basic asset economics
- On-the-job training of staff in software use and analysis and interpretation of results.

Modelling results

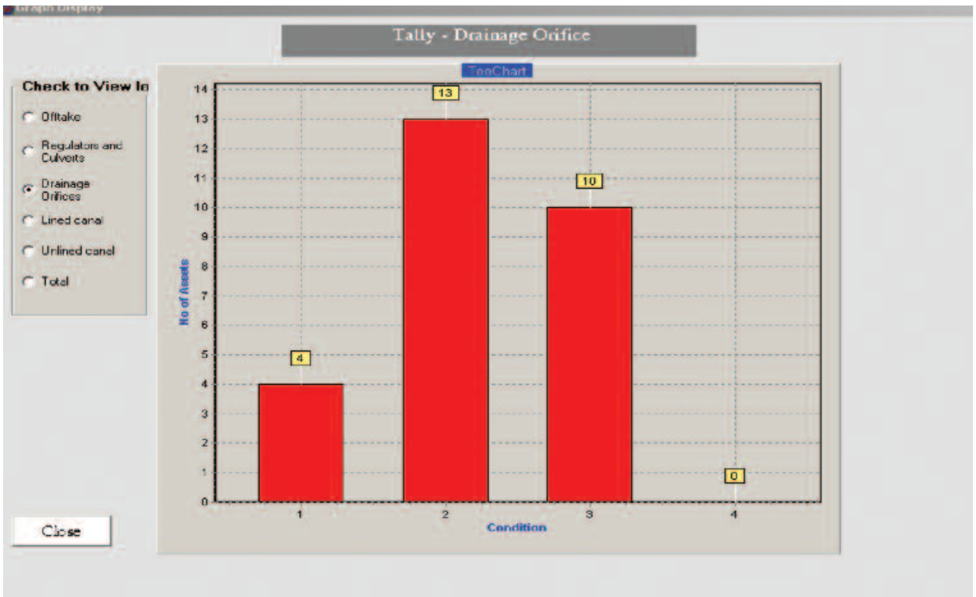
Asset Manager was used to develop an asset management plan for the Cu Chi irrigation system in Vietnam. The tally of asset condition for Cu Chi shows that off-takes, regulators, culverts and drainage orifices are in fair condition with some assets in poor condition and requiring renewal in the short term. In Cu Chi, 105 assets including off-takes, regulators, culverts and drainage orifices are in condition 2 (fair) and 10 structures are in condition 3 (poor).

The investment profile shows that a large investment is required in the next 10 years, as a group of assets (off-takes, regulators, culverts and drainage orifices) will reach the end of their lives. The IMC will need to invest $0.6 million in the next 10-year period to replace assets in poor condition. This translates into high cost-recovery annuities to make provisions for that level of investment over this period.

Canal excavation costs only occur once in the life of the asset and are therefore not included in the renewals calculation, although the initial cost must be taken into account. On the other hand, the cost of lining is included in the annuity calculation, as it requires future replacement and regular maintenance. The main and secondary canals in Cu Chi have been concrete lined very recently and therefore the current condition rating is high.

The linear depreciation, full and partial replacement annuity are estimated on average as $24, $41 and $21 per ha (at 3% interest and 3% inflation rate). The renewal annuity is

Figure 4
Example of tally of asset condition.



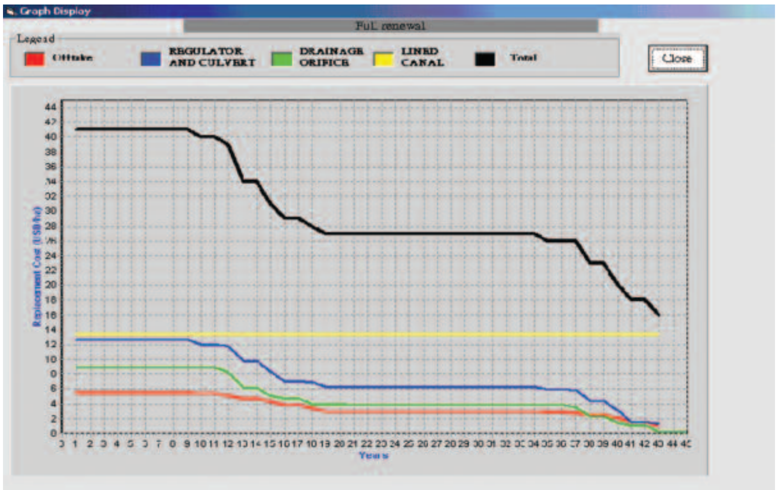


Figure 5
Example of renewals annuities chart.

very sensitive to prevailing interest rates and inflation rates. As the interest rate increases, the full and partial annuity decreases as a result of the renewal funds invested by the IMC, producing a higher return.

Model adaptability

The software developed for the Cu Chi system can readily be adapted to other irrigation systems in Vietnam and elsewhere. The GIS map forms the basis of the asset management model to interface with DGPS data collection devices and to display geo-referenced location of assets. The GIS map and DGPS collected data can be directly uploaded into the Asset Manager program. While the software is designed to include most of the typical asset types present in Vietnamese systems and around the world, additional asset features can be accommodated with minimal alterations. ●

Acknowledgement

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AM UPDATES

Diary

A listing of upcoming asset management-related events and conferences. Send event details to WAMI for inclusion.

3rd International Symposium on Integrated Water Resources Management
26–28 September 2006
Ruhr-University Bochum, Germany
This symposium addresses the theme 'Reducing the Vulnerability of Societies Against Water Related Risks at the Basin Scale'. The event is hosted by the Ruhr-University Bochum, Germany, (Institute of Hydrology, Water Resources Management and Environmental Engineering), in cooperation with UNESCO-IHE Delft, The Netherlands, United Nations University Bonn, Germany, (Institute for Environment and Human Security) and UNESCO-IHP/WMO-HWRP, Koblenz, Germany. Further information can be found at **www.conventus.de/water**.

Leading-Edge Strategic Asset Management
17–19 October 2006
Lisbon, Portugal
Water and Wastewater companies operating all around the world have faced rising asset management and replacement costs, often to levels that are financially unsustainable. LESAM 2007 will provide an opportunity to discuss developments at the leading-edge in key fields to an audience of utility personnel, regulators and consultants. Focus will be on the techniques, technologies and management approaches aiming at optimising the investment in infrastructure while achieving demanded customer service standards. Topics will include:

- Global approaches to asset management
- Target definition and performance assessment
- Cost and benefit valuation
- Target definition and assessment of risks.

Web: www.lesam2007.org
Email: lesam@lesam2007.org

Advanced Asset Management for Utility and Service Providers
8–9 November 2006
Vancouver, USA
This popular workshop – held previously around the nation – is focused on the needs of utility and service provider managers. This Pacific Northwest workshop will focus on 'state of the practice' advanced asset management concepts, tools, techniques and technologies for cost-effective management performance. This approach focuses on providing sustained performance of value to the customer at the lowest life-cycle cost and at an acceptable level of risk to the organisation.

The workshop:

- Incorporates a real world 'storyline ' to realistically demonstrate an advanced asset management way of approaching difficult asset-driven problems
- Is built around participatory exercises that demonstrate the concepts, techniques and tools of advanced asset management
- Is centered on 'case-based ' mentoring by expert asset management practices.

The workshop focuses on demonstrating step-by-step how an agency would select and deploy the best and most appropriate asset management practices suited to that agency. Registration deadline is November 1, 2006. For more information visit:
http://www.epa.gov/owm/assetmanage/index.htm
Email: AMUG@comcast.net