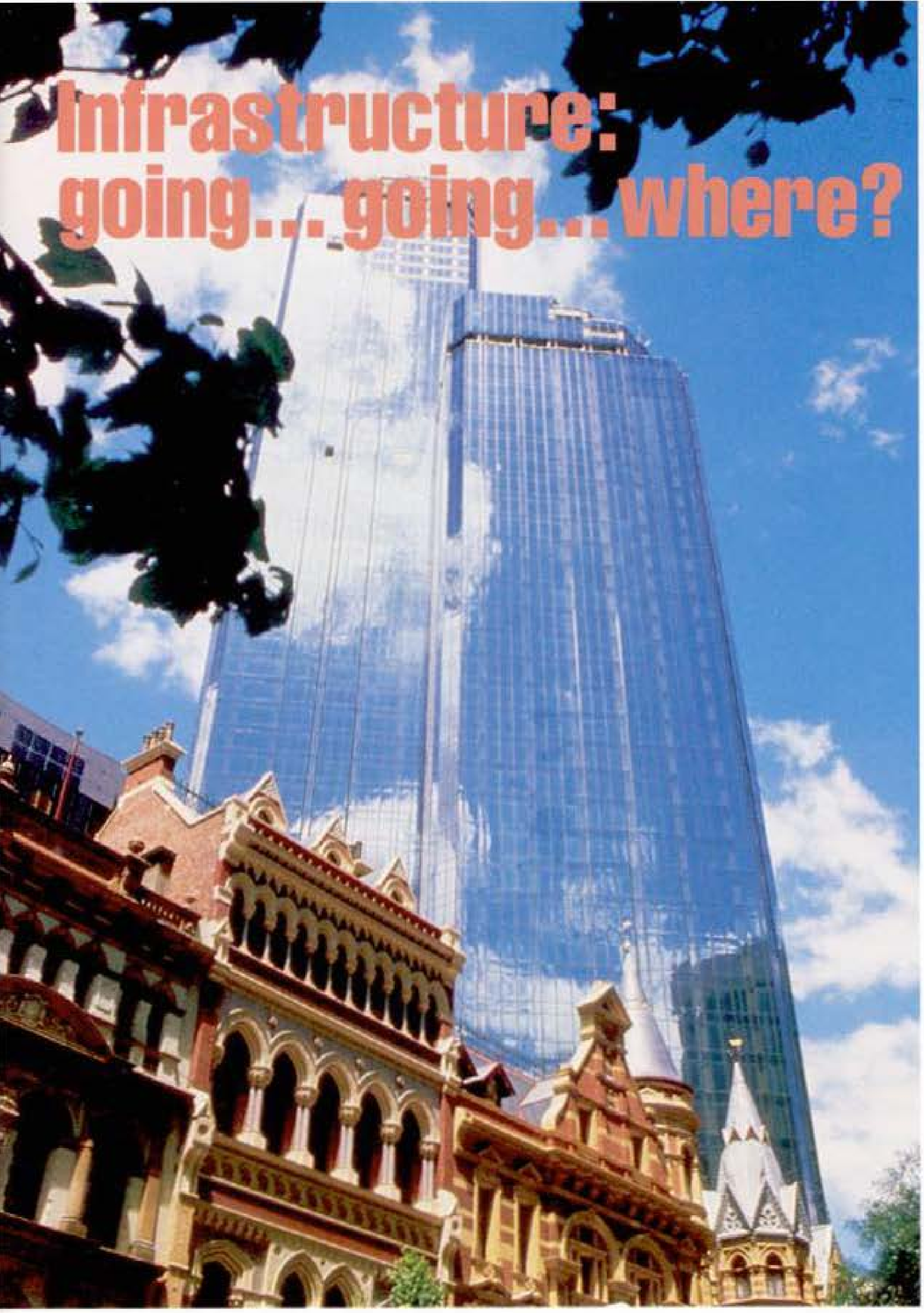
Infrastructure: going... going... where?



Changing skylines reflect the complexity of infrastructure management.

Decay: it's a natural process. Left alone long enough all buildings will fall down, all pipes, pylons, and rails will rot away, all bridges and dams will collapse.

Perhaps it's not the sort of thing that you like to think about while driving over the Sydney Harbour Bridge, although you may get some solace from knowing that, with regular maintenance, the bridge has a long life ahead of it.

Judicious maintenance and the use of more durable materials are two ways we usually cope with decay. Another is by replacing the bits that are rotten or worn out. Sometimes, we decide to replace a whole structure with something new. In practice we tend to do some of each. Many people are concerned, however, that we're not preparing for the financial cost of our infrastructure's continuing maintenance and replacement and that, unless we act soon, in 50 years the bill will be so big we simply won't be able to afford the level of infrastructure that we have now, let alone add more to it.

Many of those concerned attended the National Infrastructure Conference held in Canberra in April 1988, a meeting that closely followed the release of a report prepared by a Parliamentary committee chaired by Mr John Langmore, MP. The Conference was the second organised by the National Infrastructure Committee — a diverse group, formed from representatives of community organisations, unions, business, and research bodies, who are taking a watching brief over Australia's buildings and service structures (rail lines, sewer mains, and so on).

What do they see?

According to the Langmore Report and delegates to the Conference, Australia's infrastructure — like those of Europe and North America — is wearing and rusting out at rates much faster than we are replacing it.

Despite our 'young country' tag, Australia's infrastructure has a lot in common with those of Europe and the United States. Once our early settlements were established they evolved in much the same way as their counterparts there. Along with the spread of residential and industrial suburbs moving out from the metropolitan centres came the need for an

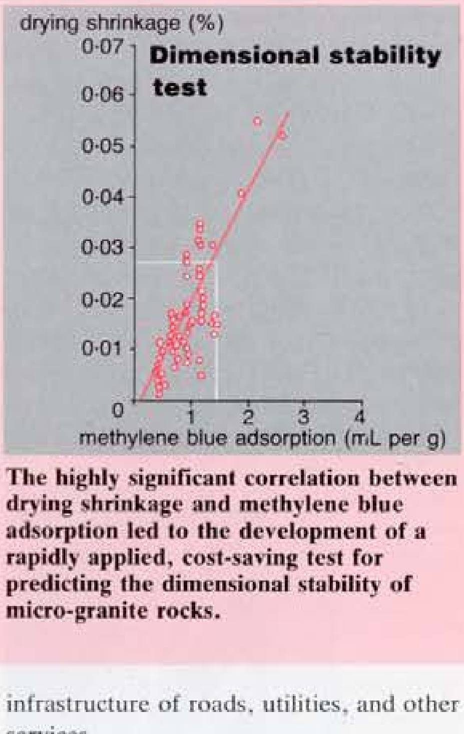
Victorian terraced houses — now sought-after real estate — were once low-cost housing like these more recently built high-rise flats. Will they become the trendy pied-a-terre of 2050 or another maintenance nightmare?

Aggregate — it's about as good as it's cracked up to be

High-rise office blocks, bridges, dams, and highways; most of them are built from a mixture of those familiar ingredients — cement, sand, water, and stone — that together make the building material we call concrete. Like other processes that use chemical reactions to produce a finished product (baking for example), making good concrete depends not only on the proportions of the ingredients but on their quality. It also depends on an adequate time for curing and on ingredients that don't react adversely with each other and with things like steel reinforcing.

However, rather worse than throwing away a souffle that falls flat, scrapping a new dam because it's structurally unsound is not an action many engineers and architects would relish. Before construction begins they need to be sure that when it's complete the concrete it's made from will be strong, as well as stable and durable.

The quality of stone — aggregate as it's called in the trade — is critical to concrete's performance. Large concrete constructions such as dams and bridges need large amounts, preferably originating close to the construction site to keep transport costs low. But any old stone won't do. As well as having the necessary mechanical strength that can resist crushing and abrasion, it should not absorb too much water, or shrink or expand excessively.



The highly significant correlation between drying shrinkage and methylene blue adsorption led to the development of a rapidly applied, cost-saving test for predicting the dimensional stability of micro-granite rocks.

In fact, excessive shrinking and expansion of concrete, leading to cracking, are major causes of its deterioration. Among other aspects of concrete durability, Dr Ahmad Shayan of the CSIRO Division of Building, Construction and Engineering has been examining shrinking and expansion. He has also developed new durability tests, and recommends that we look again at some of our standards.

Like other countries, Australia has developed a number of standards that apply to concrete and its constituents. The Division works closely with the Australian Standards Association to amend specifications and to develop cheaper and quicker ways to test whether products meet them. Usually, improvements come out of the Division's collaboration with industry.

For example, the Queensland Water Resources Commission sought Dr Shayan's help to examine the suitability of a local stone the Commission wanted to use in the construction of the proposed Burdekin Falls Dam in the northern part of the State. Results from the Commission's preliminary testing of the stone's suitability were inconclusive. Dr Shayan's approach to this particular assessment not only gave the Commission the information it needed, resulting in considerable savings through the use of the local aggregate, but led to the development of a new testing procedure with a much wider application.

Tests for shrinkage are normally carried out on core samples drilled from the rock. But as these are expensive to obtain Dr Shayan's team looked for another way of measurement that could be performed more easily and cheaply on small pieces of rock that come from simple percussion drilling.

The result of alkali–aggregate reaction.

From previous research in Australia and overseas, Dr Shayan — and his colleagues, Mr Christopher Lancucki and Mr Stephen Way — knew that an important factor adversely affecting the durability of an aggregate is the presence of swelling clay. Too much clay lowers the aggregate's strength by decreasing its resistance to dimensional changes due to water absorption, resistance to abrasion, and salt crystallisation. As excessive shrinkage of aggregate is often associated with a high clay content, they reasoned that, if they could find a strong correlation between these two factors, a simple test indicating the amount of clay present would be a low-cost way of predicting strength and dimensional stability.

They thought that the methylene blue adsorption (MBA) test, which had been

infrastructure of roads, utilities, and other services.

And even though many European cities have some buildings that were put up well before the 18th and 19th centuries, the infrastructure that was a major phase of our urbanisation and industrial development is similar in age to that overseas. Considering utilities, for example, we find that London was sewered in the 1880s and Melbourne around 1900. On the other hand, Melbourne had a reticulated water supply in 1853, while London's was not completed until 1899. Parts of London were supplied with town gas in 1810, but general distribution was not implemented until some time later. In Melbourne, distribution of gas to dwellings began in 1860.

In Australia, we've yet to experience infrastructure 'horror stories' like the fatal explosion in the United Kingdom caused by a large bubble of gas that had escaped from a decayed main and seeped into the surrounding soil. Further investigation revealed that steel gas-pipes had decayed to the extent that gas was travelling through a cylindrical hole in the clay.

But we have our own potential problems. Some of them — Australia's oldest sewerage system in Launceston, for example — were identified in the Langmore Report. The system uses common sewer and stormwater mains built out of brick, and these are no longer coping with the demands placed upon them. A stormwater overload could trigger their collapse — a potential problem magnified in the centre of town by the buildings built on top of them.

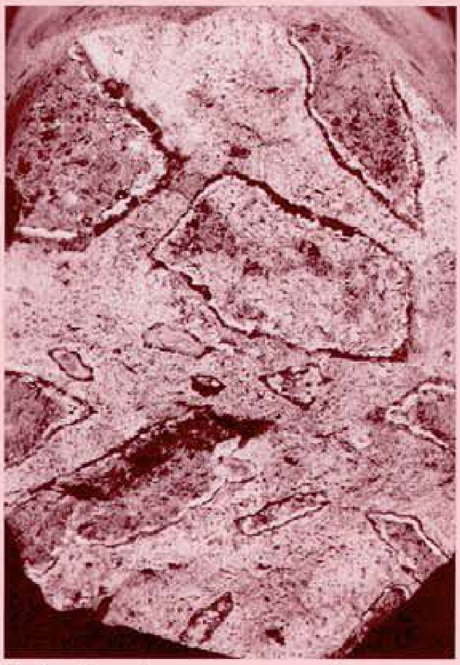
used by other scientists to indicate the amount of swelling clays in rock samples, might be suitable. Using samples of powdered rock they compared the amount of methylene blue adsorbed by the samples with the results of tests for shrinkage — such as drying small water-saturated prisms of the rock and measuring changes in length. The results showed a very high correlation (see the graph) and gave them the confidence to propose that rocks passing the MBA test by adsorbing less than 1·5 mL of methylene blue per gram would be stable enough for structural purposes.

In the future, expensive shrinkage tests could be replaced by using this technique. And the particular case in Queensland? They considered that most of the rock that the Commission wanted to use was stable and acceptable for the construction of the dam.

Too much clay in aggregate is not the only problem for engineers. The presence of components such as amorphous silica and/or microcrystalline quartz can lead to a phenomenon known as alkali–aggregate reaction (AAR). In this case, the alkali in the cement reacts with the aggregate to form water-absorbing chemical products that surround the pieces of aggregate, leading to expansion and subsequent cracking of the concrete.

Reported cases of AAR in Australia are few, although Dr Shayan says that it affects a number of structures — including a major jetty, bridges, dams, and possibly buildings. He reports that two dams he examined, and the Causeway Bridge, Perth, are all suffering from AAR.

The Causeway Bridge was built in 1949–51 with local aggregate and several imported and local cements, some of which were high in alkali content. Some 18 years ago, the authority responsible noted that parts of the bridge were showing signs of cracking, which was gradually getting worse. Interested in the cause, late in 1983 Dr Shayan and his colleagues began to evaluate several Western Australian aggregates and concluded that the standard tests for predicting the alkali reactivity of these aggregates were inadequate. Part of the problem has been the adoption of overseas standards that seem to be inappropriate for some Australian rocks.



Under the microscope, a core from a 60-year-old Australian dam. The white rims within the aggregate boundaries are water-absorbing chemical reaction products that lead to expansion and subsequent cracking of the concrete.

Using four Western Australian aggregates and five from South Africa, Canada, and Japan, the research team tested their performance using a modification of standard tests that measure dimensional changes to concrete prisms and mortar bars made from cement and aggregate. Normally, engineers monitor the changes that occur after several months.

The approach taken by Dr Shayan's team was to accelerate the process by immersing the prisms and bars in a solution of sodium hydroxide kept at a constant 800 °C. This method identified reactive aggregates in 10–22 days. By comparison, for some of the Western Australian aggregates, the standard mortar-bar test had not identified AAR after 2 years. Dr Shayan is currently collaborating with the Standards Association of Australia to make the standard tests more appropriate for Australian aggregates. It's possible that the scientists' accelerated test will form part of these new standards.

What about the structures suffering from AAR? Dr Shayan says that, despite the cracking, at the moment the dams and bridges are basically sound. What does concern him is that their life-span will be shorter than originally envisaged because we didn't know enough about the performance of our own rocks. For us, that means we'll have to pay to replace them sooner rather than later.

Clay mineralogy of a weathered granophyre from north Queensland, Australia. A. Shayan, C.J. Lancucki, and S.J. Way. *Proceedings of the International Clay Conference, Denver 1985*, 1987, 111-20.

Alkali–aggregate reaction in the Causeway Bridge, Perth, Western Australia. A. Shayan and S.J. Lancucki. *Proceedings of the 7th International Conference, Ottawa, Canada, 1986.*

Alkali–aggregate reaction in a 60-year-old dam in Australia. A. Shayan. *The International Journal of Cement Composites and Lightweight Concrete*, 1988, **10**, 259–66.

Accelerated testing of some Australian and overseas aggregates for alkali–aggregate reactivity. A. Shayan, R.G. Diggens, I. Ivanusec, and P.L. Westgate. *Cement and Concrete Research*, 1988, **18**, 843–51.

Launceston is not a lone Australian city with a unique problem. Right across Australia our aging infrastructure is causing maintenance headaches. One of the Langmore Report's main conclusions highlights the pattern of aging that will substantially increase our maintenance and replacement needs during the next 20 years.

Public awareness is crucial

What should we do about it? Dr Peter Newton of CSIRO's Division of Building, Construction and Engineering, who is

Thanks to the men who sweated it out at the tunnel face seventy years ago, Sydney-siders can still pull the plug after their morning ablutions.

secretary of the National Infrastructure Committee, considers that an important first step is to create a greater public understanding of the infrastructure issues. This is one of the Committee's major priorities. As for solutions, Dr Newton acknowledges that half the story is about financial resources; each year we face a larger and larger infrastructure-replacement bill, yet as a percentage of GDP we are spending less.

He suggests that the conclusions of a recent South Australian study provide pointers for the rest of Australia. The study, carried out by the South Australian Parliamentary Public Accounts Committee, projected the costs of asset replacement that eight government agencies responsible for about 80% of State government infrastructure will face in the next 50 years. It showed that very large increases would occur in the amount of asset replacement falling due towards the end of this century and that the increased levels will be sustained well into the twenty-first century (see the chart below right).

Infrastructure: what it is

The National Infrastructure Committee has identified the following four major components of infrastructure:

- public buildings and community facilities — child-care centres, schools, universities, hospitals, retirement villages, prisons, public housing, public offices, recreational facilities, parks and gardens
- energy and water supplies — dams, water reticulation, power-generators, electricity and gas reticulation
- waste disposal — stormwater drainage, sewerage, treatment plants, incinerators, and tips
- transport and communication — roads, railways, ports, airports, storage telecommunications

In its calculations, the Committee deliberately distinguished between capital-intensive replacement and labour-intensive maintenance. Keeping these two components separate helps to counter the erroneous perception that with a little bit of maintenance our infrastructure will last forever. Yet, often, when we talk about maintaining something we are really replacing it — albeit in a piecemeal fashion.

Obviously, we don't actually replace all our assets by bulldozing and rebuilding. If we did, the costs would be much easier to identify. From experience we know that some assets wear out in large lumps and are replaced as an entire structure; others wear out and are renewed bit by bit.

For example, tightening the loose screws in the hinges of your front door is easily recognised as necessary preventative maintenance. But if you renew your carpets after 15 years, most of the electrical wiring and your hot-water system after 30–50 years, and the roof after 75–100 years, you are really maintaining your house in a habitable state by replacing its components. The committee likens the perception to the '1000-year axe syndrome', referring to the axe that has had 138 new handles and 17 new heads but is still the 'same axe'.

Think of your house again; we all know that, most of the time, the longer we defer repairs and maintenance, the more they tend to cost. Deciding when to do them is crucial. Managing your house maintenance schedule is one thing; managing larger structures or facilities, like the reticulation of potable water, poses more of a challenge.

Dr Newton thinks that efficient asset management supported by an interested and informed public is the other half of the infrastructure story. He says that as both funders and consumers of public services we need to consider alternatives open to us — such as trading off lower-quality services against reduced infrastructure-replacement costs. For example, if we accepted a lower water pressure during summer, maintenance costs would be lower.

Fifty years after the biochemistry building was put up, component replacement for that year — if it takes place when it needs to be done — will cost more than 10 times the normal cost of operation and maintenance (shown here with the effects of inflation removed). The total replacement bill for that year alone would be 29% of the initial cost of the whole building.

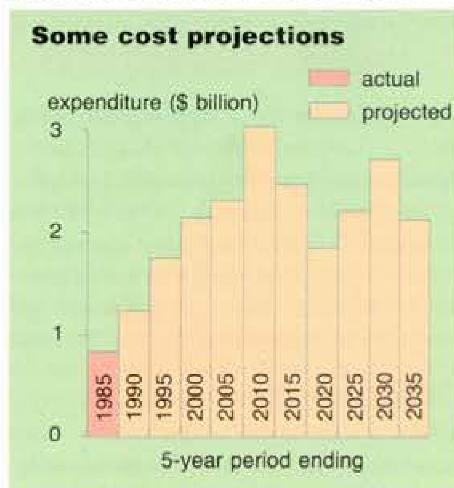
At the moment, both management and administration of our public assets vary in style and quality. One of the recommendations of the Langmore Report was that the federal government should give high priority to research and development aimed at improving the efficiency and effectiveness of the provision and management of infrastructure.

In fact, CSIRO has the nucleus of such a research program already in place. For some years scientists at the Division have been working with administrators and managers of public assets to help them improve their operational and planning decisions. This work complements other research being undertaken in the Division that focuses specifically on the use and durability of construction materials such as concrete (see the box on page 10). Research aimed at supporting infrastructure managers covers a wide range — from studies with life-cycle models of buildings to the development of expert systems designed to assist local authorities.

Life-cycle models

Put simply, life-cycle models attempt to answer several questions. What will I need to do to this building, year by year, during its foreseeable life? What will it cost? And at what stage would it be cost-effective to

Calculations by the South Australian Parliamentary Public Accounts Committee show that asset replacement costs faced by eight State government agencies will increase rapidly over the next 20 years. Other States are in much the same position.



rehabilitate or replace it? The models can assist managers schedule maintenance operations, calculate the costs needed to keep a building at a given standard of performance, and choose the rehabilitation strategies required and the conditions under which the building or its components should be replaced.

Dr Frank Bromilow has been studying the life-cycle costs of Australia's university buildings; these currently absorb more than $30 000 000 a year in maintenance and rehabilitation work. According to Dr Bromilow and his collaborator, Mr Maurice Pawsey of the University of Melbourne, the universities' history of property management is similar to that of other property-owners in Australia.

The scientists say that, before the mid 1970s, Australian universities were more concerned with the provision of new buildings than they were with maintaining and operating their old ones. In the 1980s, they have felt the financial impact of legislation concerning such things as equal opportunity, occupational health and safety, preservation of historic buildings, and access for the disabled — along with changes in building codes for fire and safety — with no additions to their grants to meet the very significant costs involved. While some programs to reduce costs were introduced in the late 1970s, most owners and managers of buildings have only recently felt a need to improve their approach to the management of their physical assets.

From a recent detailed study of Melbourne University's 30-year-old biochemistry building — the average age of the University's buildings — Dr Bromilow and Mr Pawsey have demonstrated the importance of knowing the annual amounts that will have to be spent to maintain a building during its foreseeable life. Using the best available estimates of maintenance and replacement costs and the lives of the building's major elements, their model showed that the need to replace components creates high peaks of expense at irregular intervals (see the chart top left).

University administrators, and others who operate a budget based largely on annual funding, need accurate estimates of the future costs of keeping a building operating at a given level of serviceability. The researchers used the model to estimate the annual rate of contribution to a sinking fund that would provide for future costs of maintenance and rehabilitation. (After only 30 years, the required cumulative annual maintenance and operating bill, in real terms, equals the original construction cost; this will double after 50 years and rise to four times after 100.) To ensure that money is available the researchers estimate that, each year, the university should invest between 1% and 1·5% of the initial cost of the building, at 6% p.a. real interest.

Inspecting the new decline tunnel in Sydney's much talked about ocean outfall project.

They also used the model to estimate when it would be economic to demolish the old building and build a new one. It seems that, unless the biochemistry building became completely inadequate in terms of its facilities, at no time would it make financial sense to replace it. The benefits conferred by a new building would need to be worth about two-thirds of the existing one's construction costs — converted to current dollar values.

In a further development, CSIRO's Dr Selwyn Tucker has incorporated life-cycle concepts into a micro-computer spreadsheet package (FINFEAS) that will help organisations budget their building maintenance costs.

Expert systems

Since the early 1980s, the Division of Building, Construction and Engineering ('Building Research', as it was then) has also pioneered the development of several expert systems to support infrastructure managers. (An expert system is a piece of computer software, containing knowledge on a specialised technical subject, designed to simulate the performance of a human expert. Its purpose is to make knowledge from individuals and groups of experts more widely available. *Ecos* 55 gave a more detailed explanation.)

Examples developed by the Division include systems that deal with water penetration into structures, building regulations, detection of the deterioration of pipes and sewers, and systems concerned with Australian building standards for wind loading and timber structures. The Division collaborates with industry groups in the development and application of these systems.

For example, two of its scientists — Dr Ron Sharpe and Dr Bertil Marksjo — have collaborated with project engineers Mr Alistair Grant, Ms Denise Raimondi, and Mr Michael Prior, and water experts Mr Walter Arnold and Mr Michael Arban, from the Melbourne and Metropolitan Board of Works (MMBW), to develop a prototype expert system to help manage Melbourne's water-supply, sewerage, and drainage networks when faults occur.

The system uses data provided by a computerised telemetry network that continuously checks for pump faults, pressure-limit violations, flow rates, valve positions, water levels, etc. at more than 400 automatic pumping stations in the metropolitan area, and reports any abnormal conditions to operators who work shifts to monitor the network, 24 hours a day.

Because of the diversity of the activities being controlled, the operators are not expected to have a detailed knowledge of each station. Immediately the network indicates a fault, the operators notify relevant field personnel who determine whether action is required. By making some of the knowledge possessed by field personnel and Board experts available to the operators, the expert system will help them to make the most appropriate response to any alarm.

At present, instruction sheets for operators give only a single action to take for each alarm, without taking into consideration the additional information that could be deduced from combinations or sequences of alarms. By combining the knowledge of the configuration of the automatic pumping stations with the knowledge of the Board's personnel, the expert

Phillip St, Sydney, 1892: an era draws to an end. Transport systems were about to change, bringing new demands for roads and services.

system provides considerable scope for improving operator responses.

The MMBW is currently fine-tuning its prototype system and ultimately intends to install this across its full network. The application of similar expert systems clearly has potential in managing other complex infrastructures, where more appropriate and timely responses would mean less damage and lower maintenance costs.

The future

Dr Newton thinks public interest in infrastructure is increasing, albeit slowly, with the Parliamentary Inquiry and the well-attended National Infrastructure Conference having helped create a more positive attitude towards needed research. Along with CSIRO colleagues Dr Joe Flood and Dr Selwyn Tucker, he has recently secured financial support for a 3-year research program, which will tackle various research needs identified by the Langmore Report and complement other work being undertaken in the Division.

The program comprises four elements. The first will assess Australia's future infrastructure requirements by establishing computer-based inventories of what we have now and what we are likely to need. The second element will develop techniques to help us work out the cost of future asset replacement and development. The third will concentrate on the application of computer techniques to improve our infrastructure management. The final part of this integrated program will be concerned with ensuring that we make the best use of technological developments such as robotics and advanced materials. Initially, the research focus will be on telecommunications and rail infrastructure, reflecting the source of external funding for the project.

And the long-term prospects for our infrastructure? As with so many things, what we do now determines future outcomes. Our grandchildren will not thank us for a legacy of decaying structures and services, nor for a level of infrastructure that they cannot afford to support.

David Brett

More about the topic

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The law of inevitable decay

Dr Lex Blakey, former Chief of the CSIRO Division of Building Research (and the inaugural chairman of the National Infrastructure Committee), uses three simple graphs to explain the phenomenon of decay of man-made structures. The vertical axis of each shows the level of any performance attribute that we care to measure, such as strength, cost, or value; the horizontal axis denotes time. The curve can vary widely in its shape, but the essential point is that, as the first graph illustrates, the inevitable deterioration initially proceeds at an ever-increasing rate and that this rate only reduces at a very advanced state of decay.

If we assume that the cost of repairs and maintenance to bring a facility back to some required level of performance is directly proportional to the amount of deterioration (a useful rule-of-thumb guide), then a maintenance regime can be represented by the sawtooth in the second graph.

Where maintenance is deferred the graph begins to look like our third one. Such a situation cannot be remedied by more frequent injections of small amounts of money, but can only be corrected by a succession of increasing expenditures or by a single very large injection of funds. Although Dr Blakey points out that these graphs are very simplified representations, he says that they are an excellent representation of the data coming from the United States and Britain, where the deterioration of the infrastructure has reached alarming proportions.