SUSTAINABLE ASSET MANAGEMENT

FINAL INDUSTRY REPORT, PROJECT 3.48

Selecting optimal maintenance strategies based on multi-criteria decision making

Peng Wu, Xiangyu Wang, Simon Colquhoun and Seong Mok Paik. May 2017.

Sustainable Built Environment National Research Centre

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Preface

The Sustainable Built Environment National Research Centre (SBEnrc), the successor to Australia's Cooperative Research Centre (CRC) for Construction Innovation, is committed to making a leading contribution to innovation across the Australian built environment industry. We are dedicated to working collaboratively with industry and government to develop and apply practical research outcomes that improve industry practice and enhance our nation's competitiveness.

We encourage you to draw on the results of this applied research to deliver tangible outcomes for your operations. By working together, we can transform our industry through enhanced and sustainable business processes, environmental performance and productivity.

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Executive summary

The concept of sustainable development calls for a change in the way projects should be appropriately managed. It is important that the concept is integrated into the asset management decision making process for projects to achieve optimal lifecycle performance.

According to the Australian Local Government Association, there is a forecasted shortfall of $17 billion for maintenance and renewable expenditure for local roads across Australia between 2010 and 2024, representing 39 percent above the estimated funding availability for the corresponding period. Based on the fiscal limitations on governments across Australia, a key aim of this project was to effectively integrate the various aspects of sustainable development, including economic, social and environmental sustainability, into the decision making process for building and road maintenance schemes. The objectives included:

- Developing a total building maintenance management framework which provides performance-based, instead of prescriptive-based, evaluation of building maintenance work in Australia.
- Integrating social and environmental sustainability into the decision making process for selecting maintenance strategies and allocating maintenance budgets for road projects in Australia.

It is expected that the outputs will be implemented to assist the integration of sustainability into the maintenance schemes for buildings and roads. The project helps bridge the strategic assessment and operational assessment of building maintenance by government agencies. It also helps improve the current maintenance selection and budget allocation of road agencies.

1. Introduction

Why is asset management important? The challenge is to increase operational effectiveness while simultaneously reducing operating cost. Why is sustainable asset management important? The challenge is to integrate the emerging requirements of sustainable development, including environmental and social considerations, into traditional asset management approaches.

This SBEnrc report is strategically divided into two sections. The first section addresses how sustainability can be integrated into a building maintenance management framework through a benchmarking analysis against the best practices from other developed countries. The public building maintenance schemes/initiatives/frameworks in a number of developed economies, including the United States, Hong Kong and the UK, were investigated. In addition, the maintenance frameworks and asset management documents from a Queensland Government Department were reviewed to outline opportunities and options for improving decision making with regards to maintenance of office buildings.

The second section deals with the integration of environmental sustainability (represented by emission cost) and social sustainability (represented by road user costroad user costs) in the decision making process for road maintenance. The emission cost was calculated using the lifecycle assessment approach. The integration of road user costroad user costs was done at two levels: a case study level and the network level.

This project aimed to help both building agencies and road agencies to integrate sustainability into their current maintenance decision making process. For many agencies, understanding sustainability is obvious; but this research project showed how it can be quantitatively evaluated and integrated into the decision making process.

2. Industry deliverables

This project has delivered to industry:

- A total building maintenance framework, covering the following eight general assessment areas: cost, work execution (related to time), quality, staff requirement, maintenance strategy/program, occupant satisfaction, environmental sustainability and health/safety. The framework is useful to inform the development of an agency-specific building maintenance framework for the future. This total building maintenance framework is innovative because it can help transform maintenance management from prescriptive-based specification towards a performance-based evaluation.
- For road projects, the methodology and tools to calculate the environmental cost of maintenance treatment strategies and road user costs, which is a representation of the impact of road maintenance on road users.
- The demonstration of the use of the methodology and tools to guide decision making in selecting maintenance strategiestreatments in road projects and identifying optimal budget requirements for rehabilitation.

3. Data sources and analysis

The methods used in this project were based on internationally recognised evaluation methods, as described below.

The environmental impact analysis was based on Lifecycle assessment (LCA), which has been widely adopted to evaluate the environmental impacts in both the manufacturing industry and construction sectors (Harris 1999; Petersen and Solberg 2002). LCA assigns elementary flows and potential environmental impacts to a specific product system.

The methodology for the road user costs calculation is part of a method provided by ATAP (Australian Transport Assessment and Planning) guidelines (Transport and Infrastructure Council, 2016).

Data were gathered from various credible sources. While Federal, State and Local Government data were preferred, other international sources from the World Bank and credible academic databases were included if Australian-specific information could not be identified.

Explanation	Sources of data for building maintenance
This standard covers the classification of the serviceability of an office facility.	United States ASTM E1670-95a: Standard Classification for Serviceability an Office Facility for Management of Operations and Maintenance — https://www.astm.org/Standards/E1671.htm
This guidebook provides building owners with essential information on building maintenance matters in Hong Kong.	Hong Kong Building Maintenance Scheme — http://www.bd.gov.hk/english/documents/code/bmg/BDG_ENG.pdf
This standard gives guidance on the maintenance management of facilities.	British Standard BSI 8210-2012: Guide to facilities maintenance management — https://shop.bsigroup.com/ProductDetail/?pid=000000000030231187
This is available on the Queensland Department of Housing and Public Works. It is the government policy for managing building maintenance to ensure departments have a consistent approach.	Maintenance Management Framework — http://www.hpw.qld.gov.au/SiteCollectionDocuments/MMF.pdf
This is available on the Queensland Department of Housing and Public Works. It provides guidance for managing performance of government buildings (in terms of their condition, use, financial impact, environmental impact and social significance).	Building Asset Performance Assessment Framework — http://www.hpw.qld.gov.au/SiteCollectionDocuments/BAPF.pdf
This workbook was published by the Transport Authorities Greenhouse Group in 2013 and was the main source for emissions analysis.	The Greenhouse Gas Assessment Workbook for Road Projects (Transport Authorities Greenhouse Group, 2013) — http://www.rms.nsw.gov.au/documents/about/environment/greenhouse-gas-assessment-workbook-road-projects.pdf
This toolkit was published by the World Bank in 2010 and was referred to when Australian specific emission factors could not be identified from the workbook.	Greenhouse gas emissions mitigation in road construction and rehabilitation: a toolkit for developing countries (The World Bank, 2010) —http://siteresources.worldbank.org/INTEAPASTAE/Resources/ROADEO_User_Manual.pdf
This guideline was published by the Australasian Transport and Infrastructure Council in 2016 and was referred to as the main method for road use cost calculation.	Australian Transport Assessment and Planning Guidelines (Transport and Infrastructure Council, 2016) — https://atap.gov.au/parameter-values/road-transport/files/pv2_road_parameter_values.pdf
The road performance data were retrieved from the MRWA central management system – dTIMs	Deighton's Total Infrastructure Management System (dTIMS) (provided by Main Roads Western Australia)

For more details on methodology of this project, please refer to: *Sustainable asset management: carbon emissions modelling of road pavement treatment strategies.* Available at: http://sbenrc.com.au/app/uploads/2015/11/4.-P3.48-Road-maintenance-emissions-modelling-V2.pdf

Sustainable asset management: integrating road user costss into the decision making process of road maintenance. Available at: http://sbenrc.com.au/app/uploads/2015/11/5.-P3.48_IntegratingRoadUserCostintoDecisionMakingRoadMaintV2.pdf

4. A total building maintenance framework

Buildings have been considered as one of the most valuable assets of a nation, providing people with shelter and facilities for work and leisure. As time passes by, maintenance of buildings becomes an essential process in retaining the value and quality of a building (Vijverberg, 2002). Building maintenance accounts for over half of the total output of the building industry (Wordsworth, 2001). In Britain, building maintenance activities have reached a level of 50 per cent of all annual construction activities (Kherun et al., 2002). In Hong Kong, the gross value of general trades such as decoration, repair and maintenance, and construction work at minor work locations has increased over the past five years. Governments across the world have considerable expenditure directed toward maintenance and operation projects (Al-Arjani, 2002).

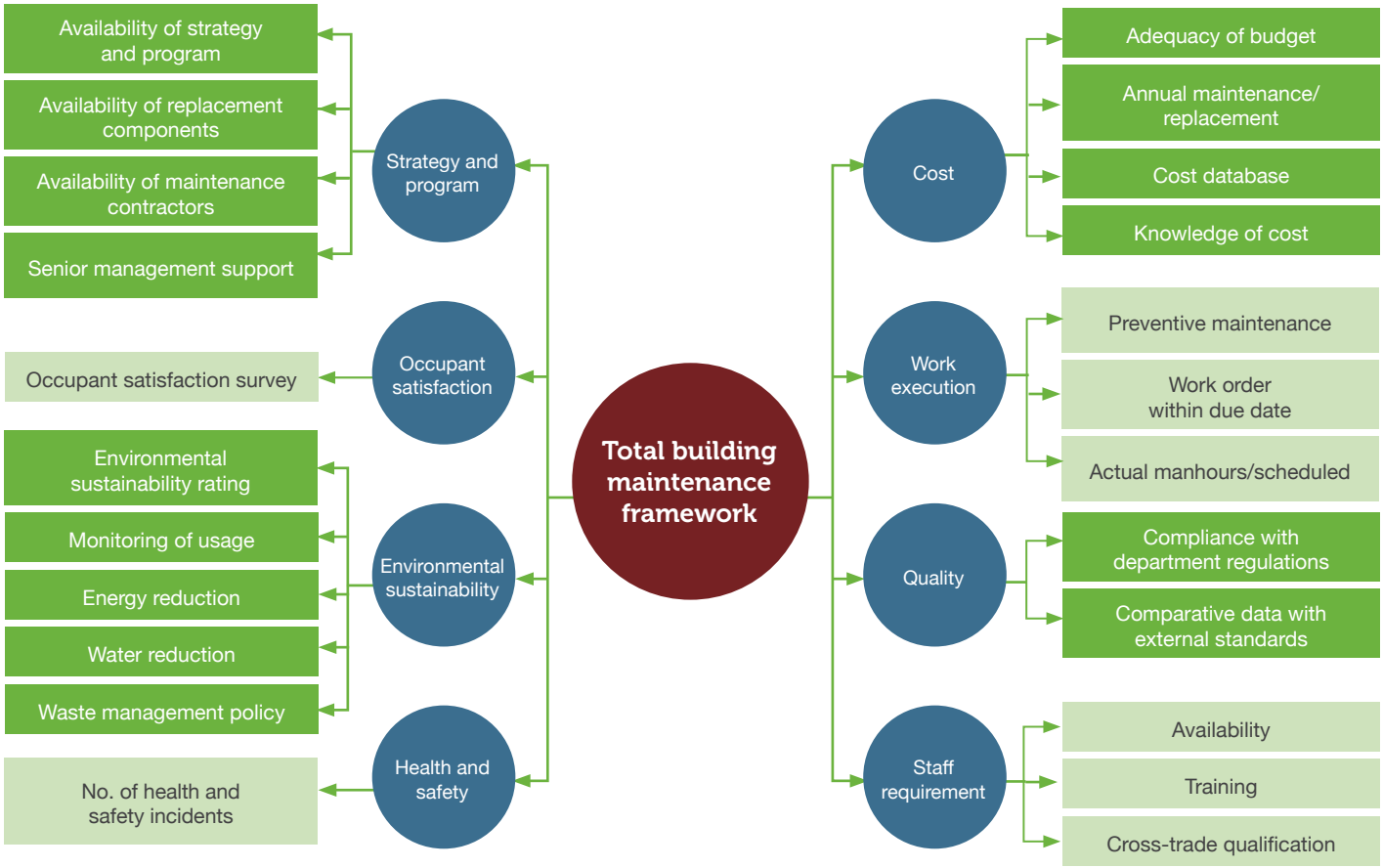
It is argued that there should exist a comprehensive, objective, reliable and practical performance evaluation model for maintenance projects. However, measuring maintenance projects is a complex task and there is a lack of common base for comparison. Wood (2005) claimed that building maintenance is even under-researched and an investigation into the project success for building maintenance projects can help set a benchmark for future projects.

The total building maintenance framework developed in this project identified eight general assessment areas:

- Strategy and program
- Occupant satisfaction
- Environmental sustainability
- Health and safety
- Cost
- Work execution
- Quality
- Staff requirement

This project found that maintenance management is in transition from prescriptive-based specification towards a performance-based evaluation. The U.S. and Hong Kong have developed detailed set of metrics to evaluate building maintenance work. The traditional way is a prescriptive standard based on preventive maintenance of the mechanical systems. The standard implies the appointment of a facility manager responsible for administering all necessary preventive and breakdown maintenance activities to maintain the building at safe and sustainable condition.The standard does not indicate performance levels by which the building performance may be monitored; furthermore, the standard does not allow any consideration of the performance level of building by the owner of the facility.

The assessment areas were identified from the best practices of other industrialised countries to develop performance-based evaluation criteria for sustainable building maintenance in the future. Improving building maintenance requires many supportive facilities from both management and technology aspects. How to successfully capture this information using information technology is a growing research trend. This project's total building maintenance framework can be used as a basis to developing agency-specific building maintenance frameworks.


Total building maintenance framework
Strategy and program
Availability of strategy and program
Availability of replacement components
Availability of maintenance contractors
Senior management support
Occupant satisfaction
Occupant satisfaction survey
Environmental sustainability
Environmental sustainability rating
Monitoring of usage
Energy reduction
Water reduction
Waste management policy
Health and safety
No. of health and safety incidents
Cost
Adequacy of budget
Annual maintenance/ replacement
Cost database
Knowledge of cost
Work execution
Preventive maintenance
Work order within due date
Actual manhours/scheduled
Quality
Compliance with department regulations
Comparative data with external standards
Staff requirement
Availability
Training
Cross-trade qualification

5. Environmental cost of road treatments

Global climate change has been recognised as one of the biggest threats to human development. In order to address the challenge, environmental considerations, especially greenhouse gas emissions, should be integrated into the decision making process of businesses, individuals, government departments and policy makers.

In recent years, better road maintenance has been a preferred option compared to new road construction. Road maintenance and rehabilitation activities can be very resource-intensive. As such, calculating the emissions produced in maintenance and rehabilitation activities is important.

Treatment types	Total emissions (kg CO_2e/m^2)	Environmental cost (A$/m^2)
ASDG	3.15	0.074
ASIM	4.20	0.099
ASOG	3.15	0.074
ASRS	9.92	0.234
GrOL	6.30	0.148
RipSeal	5.59	0.131
Slurry	4.36	0.103
CS	2.15	0.051

Note: The carbon emission values were estimated based on the lifecycle assessment method and the environmental cost was calculated based on the carbon price of Australia (using A$23.58/tonne CO_2-e as an indicative figure).

Lifecycle assessment (LCA) has been widely adopted to evaluate the environmental impacts in the manufacturing industrial and construction sectors (Harris 1999; Petersen and Solberg 2002). LCA assigns elementary flows and potential environmental impacts to a specific product system. It was adopted in this project to evaluate the emissions and environmental cost of different road treatments.

Eight pavement treatment strategies, adopted by Main Roads Western Australia, were considered in this study:

- **ASDG:** Dense Graded Asphalt Overlay/Replacement
- **ASIM:** Intersection Mix Asphalt Overlay/Replacement
- **ASOG:** Open Graded Asphalt Replacement.
  The activities in these three types of pavement treatment strategies include asphalt mixing, paving and compacting. The equipment used in these three types of treatment strategies includes asphalt mixing plant, asphalt paver and asphalt compactor. The depth of ASDG and ASOG is assumed to be 30mm while the depth of ASIM is assumed to be 40mm.
- **ASRS:** Structural Asphalt work. ASRS aims to increase the structural capacity of the pavement as well as provide a surfacewith adequate properties. Based on the information obtained, the full depth asphalt (one major rehabilitation with top 150mm replaced, once every 50 years and 5% of road replaced to full depth every 50 years for patching/repair) in the workbook was chosen to best simulate the ASRS.
- **GrOL:** Heavy rehabilitation – Gravel Overlay/Stabilisation. Granular + sprayed seal. (Assumes two resealings and one major rehabilitation within 50 years;. 150mm of aggregate replaced). In addition, pavement stabilisation and seal are also included in GrOL.
- **RipSeal:** Light rehabilitation treatment for strong pavement, mainly for roughness reduction. RipSeal includes a 150mm cement stabilisation, a placement of 50mm gravel and a seal of 10mm.
- **Slurry:** Rutting smoothing treatment with slurry. Slurry refers to slurry/micro surfacing. It is cold mix surface treatment which consists of applying a 3-20mm layer of in-situ mixed: aggregate; (polymer modified) bitumen emulsion; adhesion agents; water; and cement or lime.
- **CS:** Sprayed Seal. This refers to the spraying of bitumen on a road surface followed by the spreading of a layer or layers of aggregates.

6. The impact of maintenance on road user costs

Road user cost (RUC), including the vehicle operating cost and value of travel time saved, is used as an indicator for the social impact of road maintenance activities. While rehabilitation work brings down the vehicle operating cost, small and minor repairs do not have a significant impact on vehicle operating cost.

Using data provided by Main Roads Western Australia on one road segment from the Albany Highway, this project analysed the lifecycle cost of different maintenance programs over a 20-year lifecycle. The options were:

- Option 1: Routine works only at A$3.33/$m^2$
- Option 2: Rehab treatment of granular overlay at A$60/$m^2$
- Option 3: Prep + resealing (8 years life)

The Net Present Value in a 20-year whole lifecycle cost analysis was calculated with a 7.0% discount rate.

It was found that rehabilitation work influences the roughness and safe speed of the road, which can bring down the road user cost, in this example creating a benefit of A$1.5m for the whole community. Road user cost is therefore a key factor for decision making in infrastructure asset management and should be integrated into the decision making model when selecting maintenance strategies.

Options	Option 1	Option 2	RUC reduction (Option 2)	Option 3
Value of new/improvement works	A$0.00	A$0.00	A$0.00	A$0.00
Maintenance works	A$869,407.08	A$789,050.61	A$1,570,003.44	A$643,665.23
Residual value	A$0.00	A$0.00	A$0.00	A$0.00
Total agency costs	A$869,407.08	A$789,050.61	Not applicable	A$643,665.23
Savings on RUC	Not applicable	A$1,570,003.44	Not applicable	Not applicable

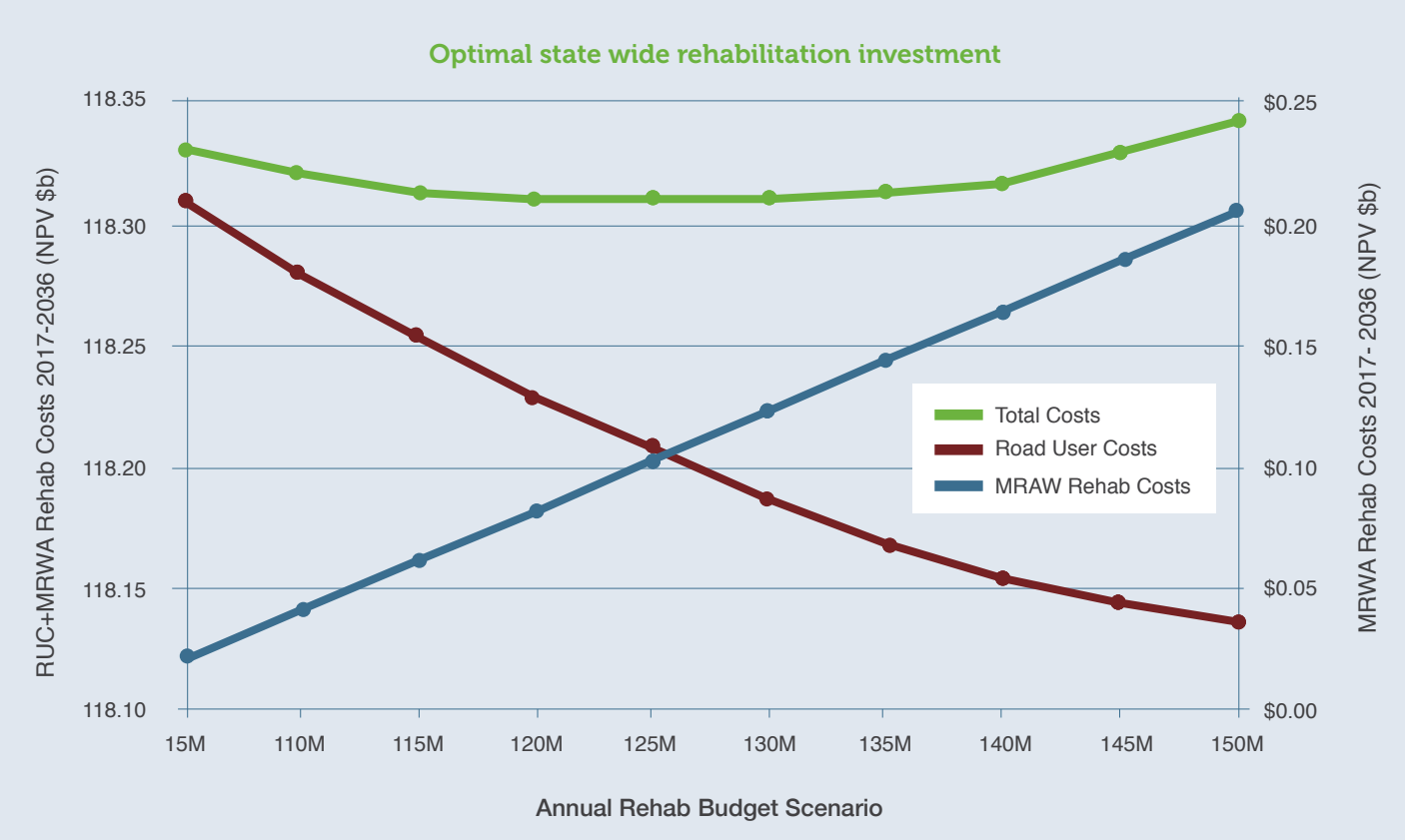
7. Allocating maintenance budgets for rehabilitation

According to Fwa and Farhan (2012), maintenance budget allocation is critical to ensuring that various asset types are adequately maintained. Maintenance budget allocation at the State network level is based on factors including the direct cost of maintenance and the pavement performance improvement. An integrated approach to evaluating budget allocation, considering the impact of road works on road users, was developed in this study using the lifecycle costing approach.

The road user costs of all the road segments in Western Australia was calculated. The methodology used in this report is part of the method provided by ATAP (Australian Transport Assessment and Planning) guidelines. The road user costs were integrated with the direct cost to the road agency to identify the optimal budget level for rehabilitation.

Ten budget allocation scenarios (A$5m, A$10m, A$15m, A$20m, A$25m, A$30m, A$35m, A$40m, A$45m and A$50m) for rehabilitation were investigated.

With a discount rate of 7%, this project found that the total lifecycle cost of the road network for the A$20m, A$25m and A$30m budget scenarios (with a value of approximately A$118.31b) is relatively lower when compared to other scenarios. As the budget for rehabilitation increases from A$20m, the total lifecycle cost of the road network does not reduce to a significant amount further to justify the higher investment. It is concluded that the optimal budget level for rehabilitation costs should be A$20m annually in this example.



Note: RUC is Road User Cost; NPV is Net Present Value

8. Industry benefits

A key challenge of this research was to demonstrate how the methodology and tools developed in this project can be implemented in real life cases.

This project has demonstrated industry value for building and road agencies at various levels, including:

- **A total building maintenance framework which integrates various aspects of sustainability.** It can assist the transition of building maintenance from the traditional prescriptive-based evaluation towards a systematic and comprehensive performance-based evaluation.
- **Provision of reliable and accurate maintenance treatments, addressing the Australian Government's strategic direction, Optimising Maintenance Investment.** Because maintenance plans generated using the research outcomes of this project will be based on improved lifecycle cost and benefit analysis and calibrated prediction of performance using historical and local data, it is envisaged that optimal maintenance resources will be allocated to specific maintenance activities at the right location and time.
- **Truly low-cost maintenance activities.** According to the Australian Local Government Association (2013), there is a forecasted shortfall of $17 billion for maintenance and renewable expenditure for local roads across Australia between 2010 and 2024. The approach developed in this project significantly addresses this projected shortfall by supporting asset management that can and will be carried out with lower lifecycle costs.
- **A new sustainable asset management model for road infrastructure.** This research focused on establishing a new sustainable asset management model for road infrastructure, which can capture the constantly changing requirements for economic, performance and environmental considerations.The proposed new model is expected to achieve a new maintenance management paradigm which can establish treatments that fit real behaviours and conditions of roads, achieve cost-effective maintenance and deliver environmental benefits.

9. Conclusions and next steps

This SBEnrc research project has provided those working in the buildings and road sectors with the necessary frameworks and tools for considering the environmental cost and social cost of their activities:

- Through a benchmarking study against other developed countries, a total building maintenance framework has been developed to help transform the traditional prescriptive-based evaluation towards a performance-based evaluation.
- Through the lifecycle assessment methods, eight road treatments have been evaluated and their environmental cost, in terms of their contribution towards global climate change, investigated.
- The social impact of road maintenance activities, in terms of their impact on road users, was evaluated and integrated into two decision making models for use at: the project level and the network level.

It is expected that when the economic, social and environmental considerations are integrated into decision making for maintenance, the true lifecycle cost of assets can be identified and appropriately managed, with optimal allocation of funds to meet maintenance needs.

Our industry partners have adopted these models to truly integrate sustainability into their decision making processes. Moving forward, we encourage more industry practitioners to implement these models and provide valuable feedback to realise the full potential of sustainability in the built environment.

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- See our YouTube video: https://youtu.be/Pry-HPGL9P8
- Go to our project webpage: http://sbenrc.com.au/research-programs/3-48-sustainable-asset-management/

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