THE FUTURE OF MOVEMENT

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NTRO NATIONAL TRANSPORT RESEARCH ORGANISATION

FOREWORD

The journey to become the National Transport Research Organisation (NTRO) has been 62 years in the making. From the inception of the Australian Road Research Board (ARRB) in 1960 to serve its Main Roads Agency members, the mission to provide research excellence and sound technical support to advance knowledge and deliver best value for money solutions remains at the core of the emerged entity, the NTRO.

Driven by values of Collaboration, Transformation, Energy and Passion and Integrity, the NTRO will work with its Transport Agency members across Australia and New Zealand in partnership with industry to shape the transport future.

The confluence of transport, energy and technology will fundamentally bring change to the sector and enable mobility and freight tasks that are new, different and innovative. The challenges that the NTRO will be seeking to develop solutions for are inherently new and driven by many factors external to traditional transport thinking. Working across Road, Rail, Ports and Airports, the NTRO staff will truly drive mode-agnostic solutions for the future.

The NTRO Journal will be the source of information, insights and news about advancements in the transport field. The Journal will showcase the work of many professionals from across Australia, New Zealand and the world, and will become the go-to place for access to published materials that showcase the creative new knowledge that has been developed to support the fundamental changes that are emerging in the transport sector.

Michael Caltabiano
Chief Executive Officer

IN THIS ISSUE

Much has happened in the world since the previous issue of this journal: a pandemic; unprecedented global disruptions to commuting and commerce; and the aftermath thereof. Most of the content of this issue was ‘ready to go’ when we made the decision to hold off on publication until contributors had the time and mental energy to finalise their work. Fortunately, the work is no less relevant today than it was 18 months ago.

It is always our intention to create a publication with a range of topics to a provide something for everyone. This issue covers topics as diverse as recycled rubber and rail vandalism through to value capture and social license.

Brook Hall and Lydia Thomas provide an overview of some work done on value capture and creation on road projects. Sticking to the theme of benefits, Dr Clarissa Han and her co-authors from ARRB and Queensland Department of Main Roads explore the benefits that accrue as a result of investment in major projects.

Dr Amy Killen from Monash University outlines the work that won her an ARRB Research Rising Star award in 2019, about combatting the issue of train vandalism through smart design. Also from Monash University, Professor Jayantha Kodikara gives a brief overview of the Monash-led SPARC Hub, of which ARRB is the major industry partner.

Steve Patrick and his co-authors turn the focus to sustainability issues in infrastructure, describing the set-up and conduct of a major crumb rubber asphalt trial in Victoria. Sticking to the road infrastructure theme, Dr Tim Martin and Lith Choummanivong summarise the outcomes from a 20-year investment in a national long-term pavement performance (LTPP) study.

Paul Hillier and Gavin Lennon provide an exposition on evidence in accident reconstruction and how we can derive maximum benefit from such investigations. In the final paper in this collection, Professor Bill Young and Dr Mike Shackleton provide some food for thought with respect to the notion of social license and road network operation.

Finally, we provide a short technical note on one of the top PhD research projects being conducted in the SPARC Hub, co-supervised by Monash University and ARRB staff on secondment to the Hub.

Mike Shackleton, PhD
Chief Research Officer

Danielle Garton
Leader, Research Office Programs

Issue #2

NTRO Journal ToC

Brook Hall

Brook is a Transport Economist in ARRB's Sustainability and Materials Performance business group. He leads a Life Cycle and Economic Analysis team to deliver applied research and economic analyses and provide expert technical advice for governments and industry that drives sustainable transport infrastructure and operations. Brook is accredited as an Infrastructure Sustainability Professional with the Infrastructure Sustainability Council (ISC), advisor on the Environmental Sustainability Leading Practice in Transport Infrastructure initiative and a member of the World Road Congress' (PIARC) Sustainability Technical Committee.

Lydia Thomas

Lydia is an Environmental Engineer who contributed to a range of sustainability, safety, technology and placemaking projects in the Sustainability and Materials Performance business group. She graduated from RMIT in 2018 with a Bachelor's degree in Environmental Engineering (Honours), majoring in Chemical Engineering. In 2022, Lydia moved to the Suburban Rail Loop Authority to advise on environmental aspects on Australia's largest infrastructure project

Dr Clarissa Han

Clarissa leads the ARRB Sustainability and Materials Performance Business Group and she is the Chief Technology Leader of network sustainability and resilience. Clarissa has 25 years of engineering and research experience in traffic studies and analysis, congestion cost estimation, transport management and operations, emerging ITS technologies and infrastructure sustainability and resilience. Clarissa has been a major contributor to various national guidelines, standards and specifications in transport operations. She is the current Australian member of the PIARC Mobility Strategic Theme TC2.4 Road Network Operations/ITS. (2020-24).

Kevin Wu

Kevin is a Senior Professional Engineer at ARRB. He joined ARRB in 2016 and has since worked on a range of road safety and transport operation related research projects such as crash evaluation, network operation planning tool development, urban freight modelling, and congestion cost evaluation. He holds skills in large data analysis, modelling, geographical information systems processing, micro-simulation, and RStudio or Excel VBA programming.

Dr Robert Kochhan

Dr Robert Kochhan is a Senior Professional Leader at ARRB with 10+ years of experience in future urban transportation and mobility projects. At ARRB, he has contributed to a range of projects across the Sustainability & Material Performance and Mobility Future teams. Robert is currently leading the Transport Futures Portfolio, and he has a particular interest in low and zero emission vehicles (LZEVs), LZEV charging and refuelling infrastructure and emissions reduction.

Dr Merle Wood

Merle is a Principal Traffic Engineer at Queensland Department of Transport and Main Roads. Her role involves in the road network performance reporting and data analytics using emerging traffic data collection technologies. She is interested in applying various data sources to provide customers insights of the traffic network state, along with her experience in the operation of ramp signalling, traffic modelling and signal coordination.

Frans Dekker

Frans is a Principal Traffic Engineer at Queensland Department of Transport and Main Roads. His role includes analysing and reporting of road network operation performance. He is passionate about turning traffic data into information and insights, to help provide safer, simpler and smarter journeys

Dr Amy Killen

Amy Killen is a designer and educator. As a Teaching Fellow at Monash University, she coordinates units across the Collaborative and Industrial Design degrees. Her PhD and research work partnered with industry to explore design's contribution to mitigating rail vandalism and was positioned within the Monash Mobility Design Lab. Her current interests lie in exploring and implementing interdisciplinary and collaborative approaches to design while developing opportunities for cross-pollination between disciplines.

Professor Jayantha Kodikara

Professor Jayantha Kodikara is Director of ARC Hub for Smart Pavements – SPARC at Dept. of Civil Engineering, Monash University. He is also the leader of Monash Pipeline Research Group. He has over 300 publications on a diverse range of topics. He is a Chartered Professional Engineer and a Fellow of Engineers Australia. He has received several awards for innovation and industry collaboration including International Water Association Award and B/HERT Award in 2016 and ARRB Impact Award in 2019.

Steve Patrick

Steve Patrick is a Senior Technology Leader in ARRB's Safer Smarter Infrastructure business group and holds a Master of Pavement Technology. Since 2009, Steve has primarily worked on projects related to bituminous surfacings. Steve has experience in undertaking research activities in sprayed sealing practices, bitumen sprayer calibration, related field testing, and the preparation of guidelines and standards.

Melissa Lyons

Melissa Lyons is a Senior Technology Leader in ARRB's Sustainability and Material Performance business group. At ARRB, Melissa immerses herself in applied research and consultancy projects in the bitumen, asphalt, and pavement materials space. Her current focus has been primarily on sustainability which has kept her working closely with State Road Agencies and bodies such as Sustainability Victoria and Tyre Stewardship Australia, tackling projects on the use and specifications surrounding recycled materials in road infrastructure.

Dr Simon Xue

Simon is a Transport Economist, who worked in the Sustainability and Material Performance team at ARRB. During this time he undertook sustainability, economic, and strategic assessments for a range of transport and sustainability projects. In this paper, Simon contributed to the documentation of project background, impacts and technical details based on related ARRB reports and the advice of the co-authors. Simon holds a PhD from the University of Melbourne and his research interests are applied microeconomics and transport economics

Dr Tim Martin

Tim is Discipline Lead: Performance Modelling at ARRB. Tim designed and implemented a major observational study using long-term pavement performance (LTPP) sites and experimental studies with accelerated loading facility (ALF), resulting in the development of pavement deterioration and works effects models for arterial roads. Other research has involved estimating levels of service and the basis for estimating the marginal cost of road wear

Lith Choummanivong

Lith has over 20 years of research experience in pavement-related areas including pavement construction quality management, material characterisation, pavement trials with accelerated load testing and asset management. Over the last 15 years, he has been involved in several long-term pavement studies including sealed and unsealed local roads deterioration modelling, long-term pavement performance (LTPP) and the effects of maintenance on long-term performance of pavement (LTPPM).

Paul Hillier

Paul Hillier has worked in road network safety for over 30 years, initially with TRL in the UK before emigrating to Australia in 2000. He joined ARRB in 2005 and has been an integral member of the organisation's road safety infrastructure team for the last 17 years, with involvement in a wide mix of incident investigations and associated research, drafting of industry guidelines and capacity building.

Gavin Lennon

Gavin Lennon joined ARRB in June 2022 after 15 years with the NSW Police Force. Gavin was the principal Collision Reconstruction expert for the NSW Police, having investigated in excess of 500 serious and fatal motor vehicle collision and other major incidents, including plane, train, boat and helicopter crashes. With a degree in Advanced Medical and Radiation Physics, Gavin applies his knowledge of physics and motion to analyse the dynamics crashes, identifying crash trends and developing strategies for the prevention of similar incidents.

Emeritus Professor William (Bill) Young

Bill has worked at Monash University since 1975. Prior to this he worked in transport in England, Germany and several Australian States. He has also held positions at Tokyo (Japan), Leeds (England), Oxford (UK), Nanyang (Singapore), Karlsruhe (Germany), Michigan State (USA), Central South (China) and Hong Kong (China) Universities, and the Australian BTCE and ARRB. He has researched, consulted and published widely in the land-use/transport/environment, traffic, parking, safety, transport modelling, engineering management and education areas.

Dr Mike Shackleton

Mike is Chief Research Officer at NTRO and a civil engineer with 35 years' experience in research and consulting in road infrastructure and transportation matters on three continents. He has a passion for unsealed and low volume roads serving regional and remote communities because of the impact those roads can have on quality of life. His current research interests involve community attitudes to changes in policies and technology, the future of movement, and research governance.

Chathuri Jayamali Maha Madakalapuge

Chathuri is currently a PhD scholar at SPARC Hub, Monash University who currently works on modelling moisture variation underneath sprayed sealed pavements. She graduated from the University of Moratuwa, Sri Lanka in 2018 with a first-class honour's degree in Civil engineering. Before commencing her PhD at Monash University in July 2019, she worked as a structural design engineer for one and half years.

Creating and capturing value in major road projects

Brook Hall, ARRB
Lydia Thomas, SRLA

Introduction

Not all road projects are the same. Some include thought-provoking road-side art, stylish overpasses, delightful walking and bike paths, geographically appropriate landscaping, or are built using innovative recycled materials that produce fewer greenhouse gas emissions.

As road users and local communities, we delight in such features that go beyond the asphalt, line-markings, drainage and street signs. So why don't all road projects include these enhancements?

Firstly, road authorities are experts in roads – how they are made, how they perform and what their core purpose is. Typically, major road projects will aim to connect communities and workplaces, improve road quality and safety, as well as reduce congestion and travel times. By thinking more broadly, road projects can be designed and delivered in a way that creates enhanced public value beyond that achieved by the core project scope. This concept is known as value creation.

Secondly, roads are costly and budgets are tight. Who pays for the extras, the 'nice to haves', when there are core objectives to be met? Where government investments deliver benefits to individuals and businesses, some of this value can be captured by government, reducing its overall financial investment and helping to fund current and future projects. This concept is known as value capture.

Major Road Projects Victoria (MRPV) represents a new face of road agencies in Australia. An agency that aims to do more for the entire Victorian community – not just drivers – by delivering cost-effective projects.

To help MRPV incorporate Value Creation and Capture (VCC) mechanisms into its road projects, MRPV engaged ARRB to:

1. Develop a tailored process for identifying and assessing VCC opportunities.

2. Provide detailed information on VCC mechanisms that are applicable to MRPV's projects.

"We engaged ARRB for this piece because we sought to build understanding of the VCC Framework within MRPV and how it could be applied in major road projects, as few examples were available. ARRB have since produced a report that is a valuable resource in many instances and which we have shared across the organisation. It provides an in-depth background on the framework for anyone new to it and acts as a touch-point for project managers looking for a concise VCC roadmap and highly relevant potential mechanisms."

– Kathleen Hare, Project Development Officer, Major Road Projects Victoria

Victoria's Value Creation and Capture Framework

In 2017, the Victorian Government released Victoria's Value Creation and Capture Framework. The framework establishes an expectation on government agencies, such as MRPV, to think beyond the core project outcomes of a project (e.g. reducing congestion and travel times, improving safety, connecting communities) and consider the wider opportunities available. For example, when building infrastructure or developing precincts, government can enable economic opportunities, build green space, community services, housing and education opportunities, as well as create more value for the community than would otherwise be the case.

"A core objective of all government activities and investments is to create public value"

– Victoria's Value Creation and Capture Framework, State of Victoria (Department of Premier and Cabinet), 2017

In adopting a Value Creation and Capture Framework, MRPV can harness the potential of its investment to create additional value for the community.

Value creation

The VCC Framework defines value creation as:

Delivering enhanced public value, in terms of economic, social and environmental outcomes. This enhancement of public value is above and beyond what would ordinarily be achieved as a direct consequence of the relevant government investment.

Major road projects can create value by incorporating smart thinking or additional investments beyond the core project scope that enhance the overall project benefits. Benefits from road-project value creation can include:

- Economic benefits: increased growth and job opportunities; improved workforce participation.
- Social benefits: improved access to housing, employment, education or recreation; enhanced public safety (road safety, improved street lighting); increased recreational infrastructure such as bike paths and parks; and improved social connectivity.
- Environmental benefits: greening and enhancement of natural catchments in cities and towns; increased energy and/or water efficiency; building sustainability; climate change adaptation; and decreased greenhouse gas emissions.

Figure 1: Repurposed open space beneath the bridge

Source: West Gate Tunnel Project (2020).

Major road project beneficiaries can be diverse, including among others: transport users; property owners/occupiers; developers; infrastructure operators (e.g. road operators such as Transurban, tram and train franchisees); businesses and workers; governments; and the wider community.

Value capture

Value capture is a form of infrastructure funding that aligns the cost of infrastructure more directly with those that benefit from government investment or planning decisions. This is also known as beneficiary pays funding (Infrastructure Victoria, 2016).

The VCC Framework defines value capture as:

Government capturing a portion of the incremental economic value created by government investments, activities and policies. These actions may generate alternative revenue streams, assets or other financial value for Government which could assist in funding those investments and activities.

Value capture revenue can partly offset the costs of delivering additional government services and enhance the wider social benefits and objectives associated with capital investment.

Value capture is not a new practice, although more attention has been paid in recent years to using value capture as a distinct way of raising revenue to fund public infrastructure. Victoria already uses various forms of value capture, including:

- 'Automatic uplift' in existing taxes – land-based taxes such as State land tax and stamp duty, Commonwealth Capital Gains Tax and local government rates (only where a growing revenue base is translated into higher rates through the rate-setting process); and taxes such as State payroll tax and Commonwealth income tax where infrastructure raises economic productivity and incomes. In the past, levies were used to partially fund Melbourne's City Loop.
- Developer charges and related mechanisms – one-off or in-kind contributions to the cost of providing infrastructure in a development area, including the Growth Area Infrastructure Contribution (a contribution scheme designed to cover 15 per cent of State infrastructure costs in Melbourne's growth areas); Development Contribution Plans and legal agreements under the Planning and Environment Act 1987 for funding early, basic and essential local infrastructure; the new Victorian Infrastructure Contributions system; and other charges such as Places Victoria's Infrastructure Recovery Charge.
- Property development, asset sales and leases – including the sale of air rights or government-owned land around new infrastructure (such as the development rights associated with Southern Cross Station and Melbourne Central Station); and the lease of advertising rights and significant telecommunications services. These are relatively common in infrastructure provision in Victoria.
- User charges – applied for the use of a specific asset each time the asset is used, in-principle providing the clearest form of value capture mechanism. Road tolls and public transport fares are common forms of user charges applied for transport in Australia (Infrastructure Victoria, 2016).

Figure 2: Off-road paths and roadside landscaping

In 2016, Infrastructure Victoria identified opportunities for new or enhanced value capture mechanisms for capturing some of the indirect benefits of infrastructure, including:

- Developer contributions.
- Betterment levies.
- Major beneficiary contributions.
- Property development, asset sales or leases (Infrastructure Victoria, 2016).

Figure 3: Roadside advertising billboards

Source: BroadGroup (2016)

Developments from ARRB's review

An extensive desktop review was undertaken for Major Roads Projects Victoria covering:

- Victorian Government policy and guidance, including the VCC Framework and Guidelines and its infrastructure investment procurement policies and guidelines.
- VCC theory, mechanisms and case studies from other Victorian, interstate and international sources.

Interviews were conducted with key MRPV stakeholders and potential VCC partners, including officers from the Department of Premier and Cabinet, the Department of Transport, the Department of Jobs, Precincts and Regions, Infrastructure Victoria and Sustainability Victoria.

The results of this work included a tailored VCC identification process and a long list of candidate value creation and capture opportunities for use by MRPV in its project planning and business case development.

Victoria's VCC Framework provided a generic approach for VCC and lacked the specific detail needed by engineers and project managers. ARRB created a tailored process to identify and assess VCC mechanisms. The processes purposely align with phases of the Investment Life Cycle for high value and high risk projects to ensure seamless integration with existing Victorian Government procedures.

Value creation categories

Next, ARRB prepared a long-list of candidate value creation opportunities – known as a 'shopping list' – that MRPV could draw on to build into new road project plans.

There are many different types of public value that can be generated through value creation mechanisms. The VCC framework identifies seven types of value, or value creation categories as shown in Figure 4 (identified in light green):

- Productivity and cost efficiency.
- Asset values'
- Commercial opportunities
- Accessibility.
- Public safety/health and amenity.
- Social capital.
- Environmental, cultural and heritage.

Based on wider research and discussions with some of MRPV's stakeholders, three additional value creation categories were identified: future proofing; future enabling; and social licence/reputation as shown in Figure 4 (identified in dark green):

- Future proofing.
- Future enabling.
- Social licence and reputation.

Figure 4: Value creation categories

Value Creation									
Productivity and Cost Efficiency	Asset Values	Commercial Opportunity	Accessability	Safety and Amenity	Social Capital	Protect and Enhance the Environment and Cultural Heritage	Future Proofing	Future Enabling	Social Licence and Reputation

Value creation mechanisms

ARRB identified 17 individual value creation mechanisms, which were grouped into six categories:

- Use of recycled materials (reclaimed asphalt pavement, crushed concrete and brick, crushed glass, crumb rubber and recycled plastic).
- Active transport infrastructure (cycling and walking paths and associated infrastructure).
- Public open spaces (new and improved open space, roadside furniture, electric vehicle charging stations, green noise walls/barriers, greening and rehabilitating natural environments).
- Climate adaptation (heat and flood resilience).
- Commercial opportunities (roadside advertising on adjacent land and incorporated into infrastructure).
- Procuring to deliver broader government policy objectives (e.g. Victorian industry participation policy, major projects skills guarantee, social procurement policy, ecologiq).

To assist MRPV's project planning activities, ARRB detailed important information for each mechanism, such as the value type, applicability to different road project types, implementation experience or risks, case studies and quantifiable measures (e.g. costs).

Figure 5: Western Roads Upgrade using recycled materials such as reclaimed asphalt pavement (RAP), crushed concrete and crushed glass

Source: Greenroads (2019).

Value capture categories

As with value creation, there are different types of value capture. The VCC Framework identifies four broad value capture categories (Figure 6). Other documents (Infrastructure Victoria 2016; Committee for Melbourne 2012) identify similar variations on these categories.

Of all the different value capture mechanisms identified through the wider research and discussions with some of MRPV's stakeholders, all could be categorised within the framework's four identified value capture categories. Figure 6 shows the key value capture categories.

Value capture mechanisms

ARRB identified seven value capture mechanisms, grouped into two categories as follows:

- Lease and sale of rights and assets (lease of advertising space and adjacent land, sale of surplus land and lease or sale of air rights).
- Other beneficiary payments (planning levies and contributions, user charges and shared private asset manager dividends).

In our advice to MRPV, ARRB recognised the role of existing taxes and rates (land-based and activity-based taxes) as a form of value capture. However, as MRPV does not have any direct control over these revenue instruments, existing taxes and rates should not be included in the VCC plans (except to acknowledge the existing contribution, or tax burden, of project beneficiaries and how this may affect the selection of other value capture mechanisms).

Figure 6: Value capture categories

Value Capture			
Levies, Taxes & Rates	Commercial returns	Fees and Charges	Beneficiary Payments

Conclusion

The research found that there are many opportunities to incorporate value creation and value capture mechanisms into major road projects, although not all opportunities are suitable for all project types. The most promising value creation opportunities for road projects include:

- Using innovative and recycled materials in pavements and surfacings, including crumb rubber additives and reclaimed asphalt pavements, and using climate-resilient technologies.
- Incorporating active transport infrastructure into road designs, including high-quality cycling and walking paths and associated infrastructure.
- Creating new or improved public open spaces for community and commercial uses.
- Generating land-value uplift from improved productivity, accessibility and amenity (e.g. integrating transport modes, active transport links, open space and landscaping).
- Encouraging businesses to increase the social value and inclusion of their work by rewarding and recognising businesses that support their communities through social procurement.

While value capture opportunities are well established in mass-transit-oriented development (i.e. developments in and around public transport infrastructure), there are fewer opportunities for road projects. Simple, acceptable and implementable value capture opportunities for road projects include commercial opportunities linked to roadside advertising and the sale or lease of surplus land, easements and air rights. Governments could also consider a range of road-user charging mechanisms, planning levies and contribution schemes to generate a return on their investments, although these mechanisms can be complex to implement and may lack public support.

The key to identifying VCC opportunities that meet diverse needs is to engage and collaborate with a wide range of government, business and community stakeholders early in project planning. Stakeholder engagement helps to understand project site/area context and issues; address diverse government policy objectives (e.g. increasing the use of recycled materials and supporting local industries and employment); learn from case studies; and tailor approaches to benefit local businesses and communities.

In assessing VCC opportunities, it is important to consider broad government policy objectives, across all portfolios, and the costs and simplicity of implementation.

In engaging ARRB to prepare a tailored value creation and capture process and identify a long-list of candidate mechanisms, MRPV is demonstrating leadership and delivering enhanced outcomes for all Victorians, whether road users or not.

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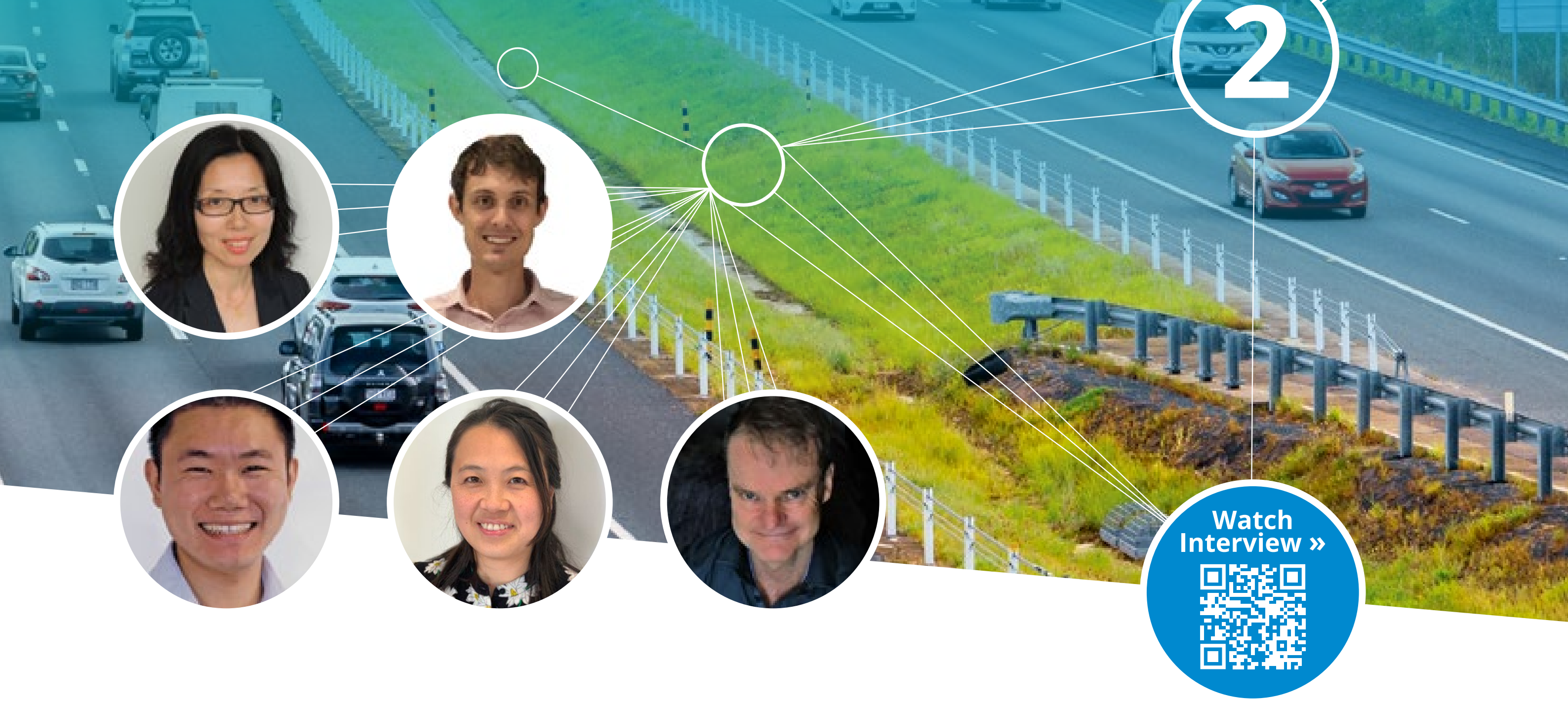
Benefits achieved by major infrastructure projects: a case study on the Bruce Highway

Dr Clarissa Han, Kevin Wu, Dr Robert Kochhan, ARRB
Dr Merle Wood, Frans Dekker, TMR



Introduction

The Queensland Department of Transport and Main Roads (TMR) engaged ARRB via the National Asset Centre of Excellence (NACoE) program to undertake project R104 to evaluate the impacts of smart motorway treatments on the Bruce Highway and three other infrastructure projects in the vicinity of the study area. The objectives of the evaluation were to:

- Better understand the past and current economic cost of excessive congestion (CoC) on the Bruce Highway.
- Evaluate the effectiveness of smart motorway treatments that were implemented progressively for inbound traffic on the Bruce Highway since 2015.
- Assess the potential impacts of a series of major infrastructure projects between 2016 and 2018 on the performance of the Bruce Highway southbound (citybound) and the broader road network.

The study results can also assist in determining the effectiveness of past investments, inform future investments and benchmark performance.

Scope and method

A 24 km section of the Bruce Highway (which connects Brisbane with the north), between Bribie Island Road and South Pine River Bridge, was selected as the study site. Four major infrastructure projects relevant to the Bruce Highway, which included smart motorway treatments and response strategies, were identified for benefit evaluations as follows:

- Ramp metering, variable speed limit (VSL) and automatic queue detection and queue protection (QDQP) systems .
- Boundary Road interchange upgrade.
- Gateway Upgrade North (GUN).
- Redcliffe Peninsula Rail Line (RPRL).

Figure 1 shows the location of the Bruce Highway study area and the major infrastructure projects.

Figure 1: Study area/corridors of concern

This assessment was conducted in two parts:

- Part 1: Bruce Highway traffic performance evaluation. This focused on the before-and-after comparison for the Bruce Highway southbound to assess the individual impacts of the first three projects listed above.
- Part 2: Travel choice changes investigation. This investigated how the infrastructure works influenced mode choices and their impact on the Bruce Highway and the broader road network, focusing particularly on evaluation of the RPRL and GUN projects.

In this paper, the total congestion cost is defined as the sum of excessive delay cost and travel time reliability cost. Other congestion cost components, such as environmental costs and vehicle operating costs, are not relevant to the travel time reliability measurement. They have been researched and implemented in TMR cost-of-congestion practices but were out-of-scope for this project.

Data specifications

For Part 1, Bruce Highway speed and flow data from January 2015 to December 2019 along the selected study site were extracted from the STREAMS National Performance Indicator (NPI) system. This covered a total of 18 road links for the analysis of congestion cost. Data cleansing and gap filling were then conducted to ensure high quality data. Vehicle composition data between 2015 and 2019 from traffic classification counters were also used as to cover the multi-modal CoC evaluation.

For Part 2, TransLink provided monthly average public transport ridership data for the bus routes and rail lines in the study area. A reference data set was also acquired for the same time period, containing the total public transport ridership for the remainder of South East Queensland (SEQ). In addition, daily traffic volume (flow) data in 15-minute intervals for all selected arterial road and motorway links were extracted from STREAMS. Annual population statistics for the suburbs in the study area were sourced from the Australian Bureau of Statistics. The study period of Part 2 was defined as June 2016 to December 2019, which was shorter than for Part 1, because sufficiently reliable data were available for this period only.

Highlights of key findings

Part 1 of the study focused on an analysis of average weekday peak period congestion cost between 5am and 10am, when the managed motorway was operating. The congestion cost reductions identified on the Bruce Highway southbound between 2015 and 2019 are as follows:

- Although the average daily vehicle-kilometre-travelled (VKT) increased by 17% from 2015 to 2019 (see Figure 2 below), the peak period congestion cost was reduced by 35% on a typical weekday. The bulk of these cost savings originated from reduced excessive delay cost, which experienced a 74% reduction. The travel time reliability cost also reduced by 15%.
- When normalising by VKT to account for the natural traffic growth over time, more significant cost savings were identified. Reductions of total congestion, excessive delay and reliability costs per VKT were found to be 45%, 78% and 28% respectively.
- Figure 3 shows a holistic picture of the change in the three-month rolling average total congestion cost and VKT for the weekday peak period between 5am and 10am from 2015 to 2019, including the four major projects' commissioning and construction time spans. Over the five years, the Bruce Highway demonstrated significant performance improvement and congestion cost reductions. A decreasing trend of congestion cost was observed as various infrastructure projects completed.

Figure 2: 2015-19 yearly congestion cost and VKT at Bruce Highway study site

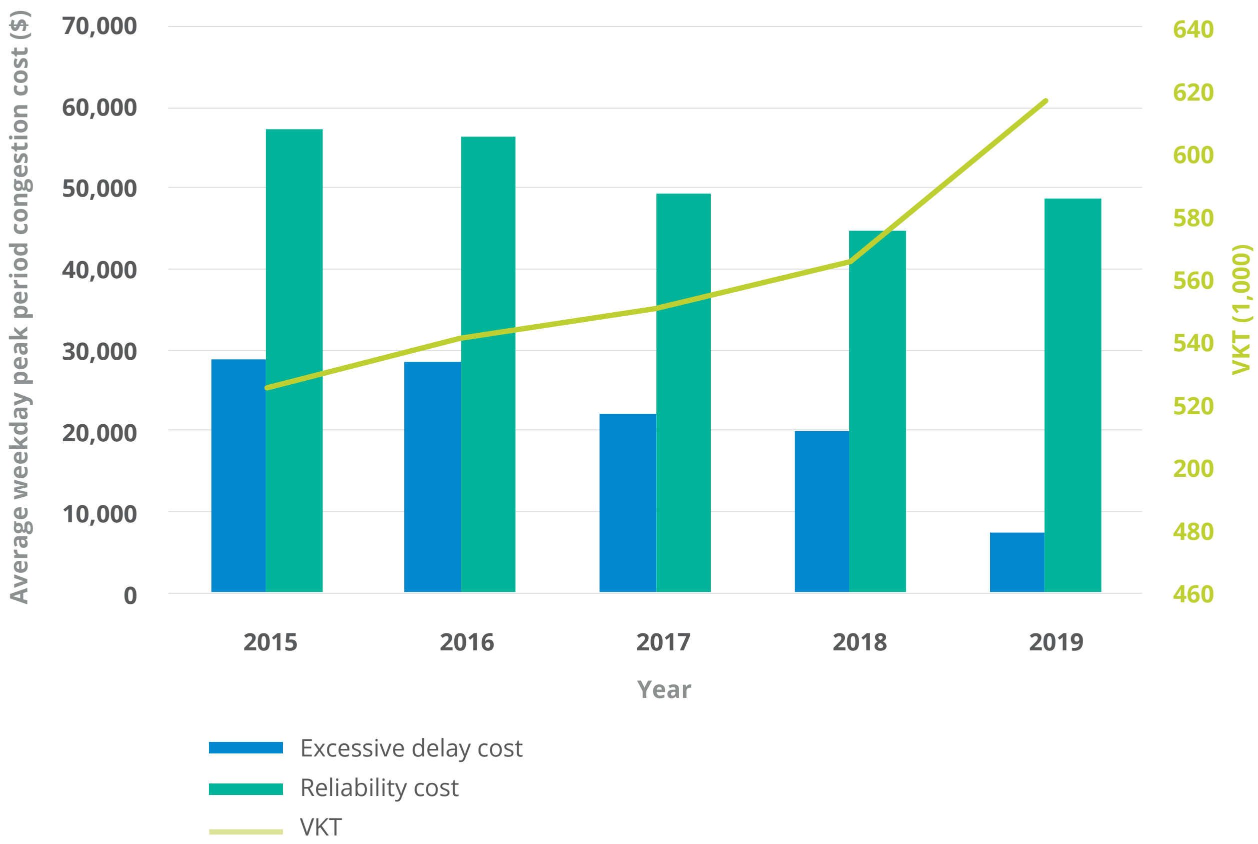
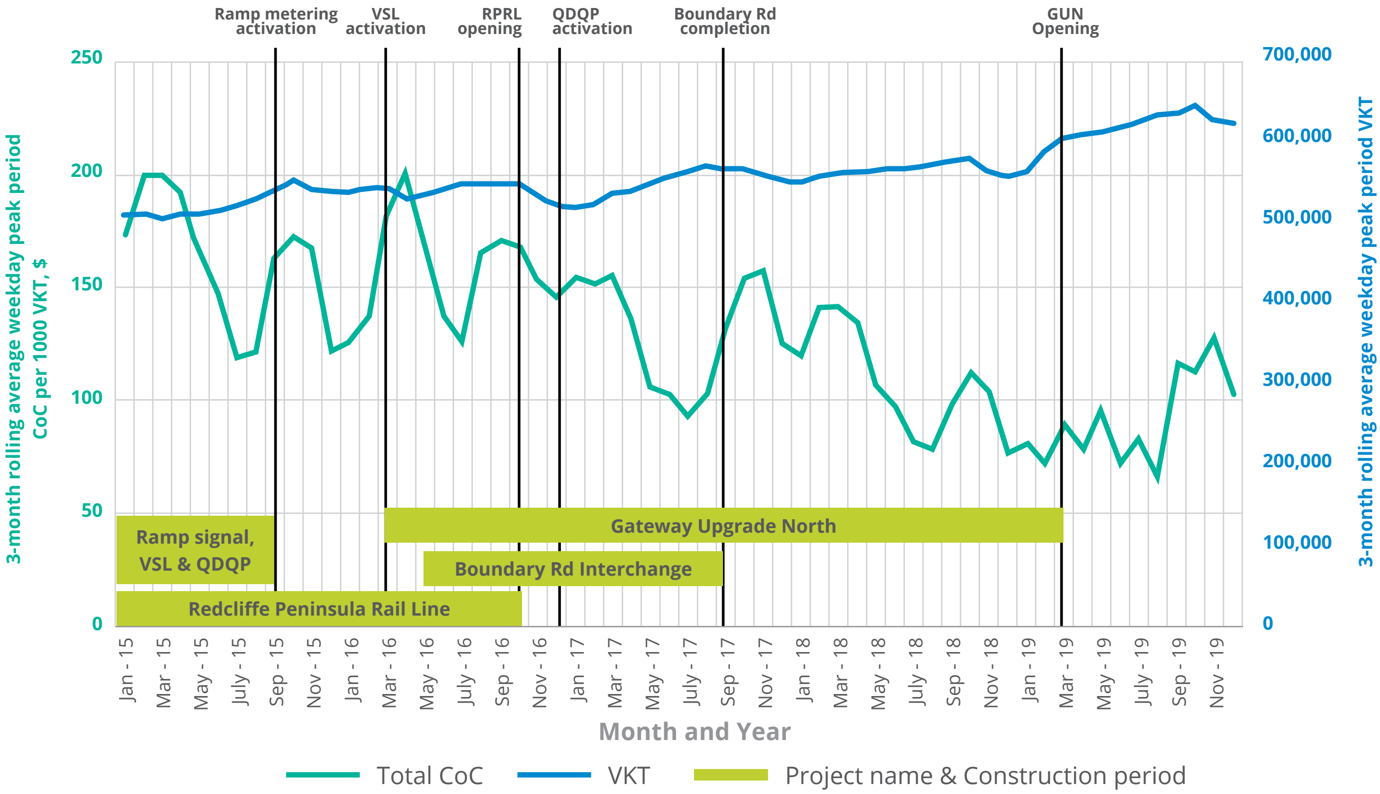


Figure 3: 2015-19 average weekday normalised congestion cost, VKT and projects' construction time span



Part 2 considered the changes in two modes of travel – private road usage (passenger vehicle occupants) and public transport (rail and bus passengers). The focus was on overall trends between 2016 and 2019 and on the impact of two of the major infrastructure projects, namely the completion of the GUN in early 2019 and the opening of the RPRL in October 2016. Five screenlines (SLs), as shown in Figure 1, were defined to capture traveller numbers at different parts of the road and rail network. Similar to Part 1, average weekday peak period traveller numbers were analysed. The key findings were:

- Traveller numbers on the road and public transport networks in the study area increased over time. Between the first year of the study period (June 2016 to May 2017) and the last year of the study period (January 2019 to December 2019), traveller numbers across most SLs increased, with SL 3 showing the highest increase (17.6%).
- The public transport mode-share gradually increased over time, which is demonstrated by a higher percentage of travellers using public transport between 2016 and 2018. The increase of public transport ridership in the study area was also higher compared to the South East Queensland (SEQ) average. Again, the differences were particularly noticeable on SL 3, where rail passenger volumes on the new RPRL grew up to 30.3% more than the average SEQ (relative change in March 2019 based on February 2017 baseline).

Conclusions

In general, findings from Part 1 and Part 2 are consistent, in particular those about the impact of the GUN project, which was investigated in both Part 1 and Part 2. The benefits and impacts of the four major infrastructure projects are summarised as follows:

1. Ramp metering, VSL and QDQP systems

It was observed from the data that the ramp metering, VSL and QDQP systems were best utilised and performed best when all systems were activated. For example, the before-and-after comparison (2015 versus 2017), where all ramp metering, VSL and QDQP systems were activated, revealed significant congestion reduction on the Bruce Highway. While there was still ongoing traffic disruption from the GUN project, after-period data revealed a 21% reduction in normalised excessive delay cost and a 23% reduction in both normalised reliability cost and total cost. QDQP added significant benefits to the Bruce Highway congestion reduction.

The implementation of ramp metering and the VSL and QDQP systems also increased the Bruce Highway's operational capacity before the flow breakdown and maintained higher operational capacity after the flow breakdown.

2. Boundary Road interchange upgrade

Significant reduction in motorway congestion cost was observed from a before-and-after comparison (2016 versus 2018) for the links directly impacted by the upgrade. While the average weekday peak period VKT increased by 3%, the normalised excessive delay cost, reliability cost and total cost were reduced by 55%, 45% and 47% respectively. However, due to over-lapping of project time frames, a portion of the reduction in congestion cost should be attributed to the benefits of ramp metering and the VSL and QDQP systems.

3. GUN

Completion of the GUN project led to an operational capacity improvement, attracted a large increase in demand for the Bruce Highway southbound, and at the same time eased peak period congestion significantly. The comparison of the selected periods between 2018 and 2019 showed that while 2019 had an increase of 12% in average daily peak period VKT for the links directly impacted by the GUN, the normalised excessive delay cost and total costs reduced by 67% and 17% respectively. However, the completion of the GUN also led to a stagnation of public transport usage in the study area, despite consistent population growth.

4. RPRL

Following the opening of the RPRL in October 2016, an instant shift towards a higher public transport (rail) mode share was observed. Comparing June to August 2016 (before-period) to June to August 2017 (after-period), the mode share at SL 3 increased from 0.1% to 5.7% (+5.6%). This trend of above-average values for the RPRL continued into 2018. The mode share shifts at the other SLs were lower (+1.4% to +3.9%), but also increased, indicating an uptake of public transport usage. It is concluded that the above average figures for the RPRL were due to the particularly high population growth near the new RPRL (SL 3), as well as the availability of the new rail line with its increased capacity, and the truncation/rerouting of bus services.

As part of the project, ARRB also developed a beta version of a Bruce Highway CoC analysis Excel spreadsheet tool that enables fast processing of the before-and-after analyses. This tool can readily measure the excessive delay cost, reliability cost, average volumes, average speeds, vehicle delay and other key performance indicators on a link level or route level of the Bruce Highway study route.

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Mitigating rail vandalism through design intervention

Dr Amy Killen, Monash University

Introduction

Rail vandalism can cause a variety of social, time and monetary impacts on rail operations. In 2019, MTM estimated that $10 million is spent annually on tackling vandalism across the rail network (MTM 2019). This expenditure is not limited to the cleaning, repair or replacement of rolling stock and infrastructure. It also encompasses security measures, including implementing CCTV, installing fences and employing security staff. Administering fines and arresting perpetrators again increase the resources required, both human and capital. Vandalism-related disruptions that lead to missed performance targets can also result in significant revenue loss.

Table 1 below lists the types of costs associated with rail vandalism.

Table 1: Costs associated with rail vandalism

Costs Associated with Rail Vandalism		
Design and Materials	**Community Measures**	**Lost Revenue**
Target hardening/ anti-vandal materials	First time and repeat offender programs	Government imposed penalties
Sacrificial components	School engagement programs	Reduction in ridership (damaged perception)
Updating designs of affected components	Dedicated hotlines	Delays/cancellations
Security (Human)	**Security (Physical)**	**Maintenance**
Authorised Officers	Restricting access (e.g. fences)	Cleaning
Protective Service Officers	Surveillance (e.g. CCTV)	Repair and/or refurbishment
Additional security staff (e.g. depot security guards)	Detection/alarm systems	Replacement

Deterrence methods

Upon review of prominent international and local cases relating to reducing vandalism, with a focus on rail environments, deterrence measures fell largely within six key areas: maintenance; materials and design; technology; authority and law enforcement; community involvement; and holistic approaches. The most common methods in each of these areas are detailed in Table 2 below. Approaches embedded in a holistic framework, partnered with a core understanding of underlying motivations and culture, yielded the most effective results. To be financially viable, these approaches also need to be tailored towards long-term results, rather than quick fixes.

Preventive, immediate and proactive responses can also reduce vandalism. Enlisting wider community support helps address the issue from multiple angles, while engaging both first-time and repeat offenders helps break the cycle of behaviour. Introducing innovative materiality and design choices, coupled with smart technology systems, can also greatly assist in developing targeted responses.

Table 2: Prominent vandalism deterrent approaches

Maintenance	Materials & Design	Technology	Authority & Law Enforcement	Community Involvement
Rapid removal processes	Target hardening/ anti-vandal materials	Closed-circuit television(CCTV)	Legislation reducing access to tools	Early intervention, first time, and repeat offender programs
Updating reporting systems	Updating the design of affected components	Applications/ databases	Increasing fines and punitive measures	Community policing models/helpline
Identifying and targeting hotspots	Sacrificial components	Geomapping offences	Increasing security staff	Legal graffiti walls

Holistic Approaches

Beyond understanding the culture and motivations of vandalism, ten prominent strategic lessons emerged from the literature review. These should, where possible, be incorporated into future abatement programs and are detailed in Table 3 below.

When considering these lessons, questions arose regarding what additional research was required to better inform future prevention, intervention and reactive strategies in the context of Melbourne's rail environment. This included identifying gaps in knowledge as well as the opportunities surrounding current approaches.

Table 3: Strategic lessons to follow when seeking to mitigate vandalism

1	Tailor investments towards long-term solutions rather than quick fixes.
2	Embed rapid-removal programs into a holistic framework for more effective results.
3	Invest in innovative vandal-proof materials and designs.
4	Implement CPTED principles where possible when designing rail environments.
5	Implement intelligent technology systems to assist with collection, analysis and dissemination of information, with such systems also able to support reporting and maintenance processes.
6	Include partnership approaches between transport authorities and outside organisations such as schools and councils to reduce problem-displacement issues.
7	Isolate breakdowns between rail-operated security and law enforcement groups.
8	Incorporate creativity when engaging with young people, as law enforcement and situational crime- prevention measures are not suffcient.
9	Enlist community support to assist in establishing ownership of the rail environment.
10	Enforce effective and consistent measures with regards to the criminal justice system.

Identifying Melbourne's "at-risk" rail asset

The review of common mitigation techniques and available MTM data confirmed two prominent gaps in knowledge surrounding existing vandalism-deterrence approaches.

The first gap was that mitigation techniques often aim to protect a wide scope of targets in an affected area, rather than having a narrow focus such as a single asset. Protecting an at-risk asset, or a discrete set of assets, may instead provide a more targeted and sustained approach in reducing the effects of vandalism. Such at-risk assets can be identified through their links to high-consequence outcomes, such as those which result in train delays and/or cancellations. A targeted approach was, therefore, hypothesised to have a high cost–benefit ratio. The second gap was a lack of understanding of how this issue can be addressed with a design intervention or set of interventions.

Identifying the rail asset at risk of causing the greatest operational impact (delays and/or cancellations) when vandalised was explored through both qualitative and quantitative research methods, as shown in Table 4.

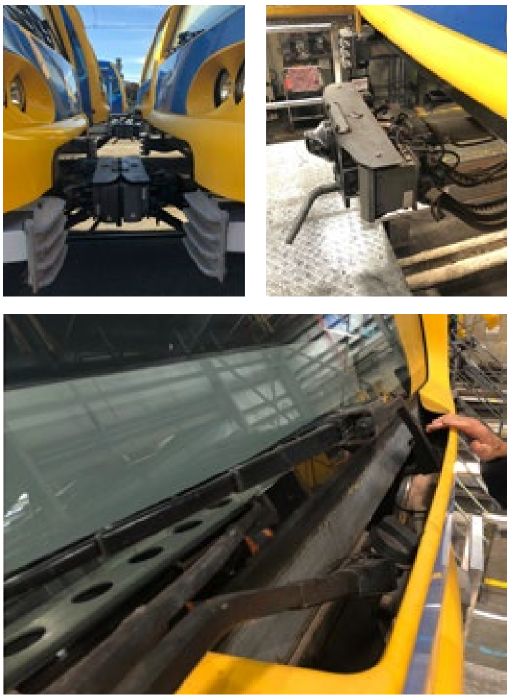
Table 4: Research methods used to identify Melbourne's "at-risk" rail asset

Semi-structured Group Interview	Vandalism Incident Data Analysis	Maintenance Facility Inspection
Interview conducted with: • GM Safety, Security & Resilience • GM Station Operations • GM Authorised Officers	MTM's vandalism incident data, as recorded over a 14 month period (from 19/3/2015 - 25/5/2016) was evaluated using statistical analysis	Trains within the X'Trapolis Fleet were inspected during multiple maintenance facility inspections at MTM's Epping location
Qualitative data from a managerial perspective	**Quantitative data from an operations perspective**	**Qualitative data from a maintenance perspective**

During a semi-structured group interview with MTM subject matter experts, the term "critical fault" was introduced – that is, a fault that results in the removal of a service. One prominent critical fault includes types of vandalism that affect the windscreen, particularly those that impinge on the driver's line of sight or eliminate their ability to operate the train safely. Even small amounts of graffiti or other types of vandalism to the windscreen can cause significant disruptions to service, with such types highly reported in incident-response data – with graffiti represented most heavily.

Upon identifying the windscreen as the at-risk asset, it was important to determine what makes it susceptible to vandalism. Observations from the semi-structured group interview and maintenance facility inspection noted that vulnerabilities in this area were largely linked to accessibility, materiality and surveillance. Of particular note was the rail coupler, which provides a flat, accessible surface to stand or crouch on, with the open cavity surrounding the windscreen wipers affording a secure level of grip, as shown in Figures 5.

Figures 5: Rail coupler and windscreen wiper cavity (author's own images)



Design intervention

The insights gained from exploring best practices in deterrence approaches guided the design phase. These were distilled into three primary design objectives:

1. Protect the identified assets through physical design interventions.
2. Streamline the maintenance and security processes of operators.
3. Involve the users through intelligent technology systems.

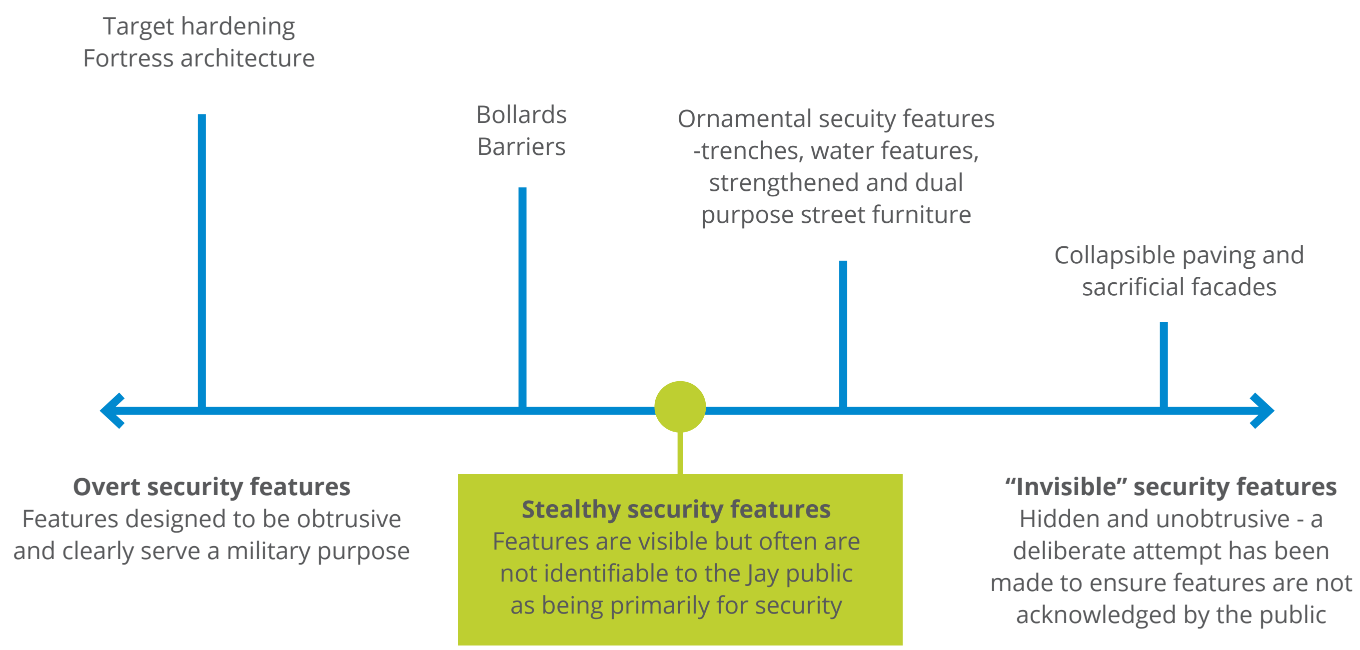
To meet these objectives, concept ideation was divided into two streams: physical interventions; and system-based interventions. Physical interventions took prominence, the designs of which sought to shift the reactive approaches commonly taken by rail operators to more effective, proactive responses. This addressed the accessibility and detection vulnerabilities identified in the data collection and analysis stage.

Accessibility was addressed by limiting proximity to the windscreen, including reducing physical affordances with regards to stance and grip. The next initiative sought to reduce the length of time vandals could remain unnoticed by security, should they successfully access the windscreen. This included detecting the vandals' presence, while also alerting both vandals and operators to this detection.

The aesthetics of security

The security afforded by an intervention can be perceived in a number of ways. Although its level of security is easy to assess from a technical standpoint, evaluating it from an aesthetic viewpoint proves more problematic. While target-hardening approaches are often intended to engender a sense of safety, they may instead induce anxiety and fear in the public by drawing attention to the idea that their security is at risk (Coaffee et al. 2009). Furthermore, overt deterrence measures may be viewed by potential offenders as a direct challenge, while also identifying assets as targets by highlighting their presence. Considering this, there is a delicate balance to strike when evaluating the aesthetics of the proposed design interventions. This balance may lie in the application of "stealthy security measures" (Coaffee et al. 2009) that is, measures visible to the public and potential offenders but not identified as being primarily for security. Such approaches were, therefore, implemented during concept development. Figure 6 describes the aesthetics of security.

Figure 6: The aesthetics of security (adapted from Coaffee, O'Hare & Hawkesworth, 2009)



Protoyping and evaluation

The next stage involved presenting the concepts to MTM stakeholders, who assessed their suitability and recommended modifications based on MTM's evaluation criteria. Their feedback was incorporated into design revisions and prototyping techniques were then implemented, including a proof-of-concept prototype.

A six-axis CNC robot arm then fabricated the design interventions and exterior shell (the yellow fiberglass component attached to the front of the driver's cabin) from expanded polystyrene (EPS), as shown in Figures 7 below. This 1:1 scale prototype meant the design interventions could be more fully realised, which assisted in evaluating their efficacy and communicating important details and features. Using 1:1 scale for the protype also assisted in providing proof-of-concept, demonstrating the concepts' feasibility and practical potential.

Two refined retrofit interventions emerged from the prototyping and evaluation processes. The first intervention, a protective coupler cowl, greatly reduces access to the windscreen. Its angled design was trialled through user testing (as shown in Figure 8 below), confirming its effectiveness in limiting balance when standing or crouching. Should vandals access the cowl, weight-detecting sensors alert both the vandal through a visual alarm, and operators through an incident-alert system. The second intervention, a protective, automated cowl, encloses the open cavity surrounding the windscreen wipers. This ensures that the windscreen wipers cannot be leveraged for grip, while also protecting them when not in use.

Figures 7: 1:1 Scale prototype fabricated using EPS and CNC machining (author's own images)

Figure 8: Evaluation of proposed coupler cowl angle

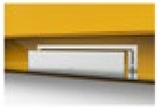
A selection of final detailed renders can be seen in Figures 9. These images are in relation to the immediate-focussed retrofit interventions only.

Figures 9: Physical retrofit interventions

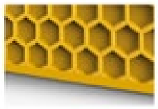
Remote-activated retractable cover assists in eliminating grip opportunities

a.

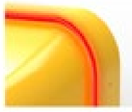
b.



c.



d.



a. The hinge mechanism allows for greater accessibility should the coupler require field-based maintenance
b. Electronics securely stored within aluminum housing (accessible by key)
c. Internal honeycomb structure provides an effective crumple zone, resulting in safer collisions
d. Upon trespass, weight detecting sensors activate LED strip to warn vandals while MTM is also notified through an incident alert

Windscreen wiper cowl

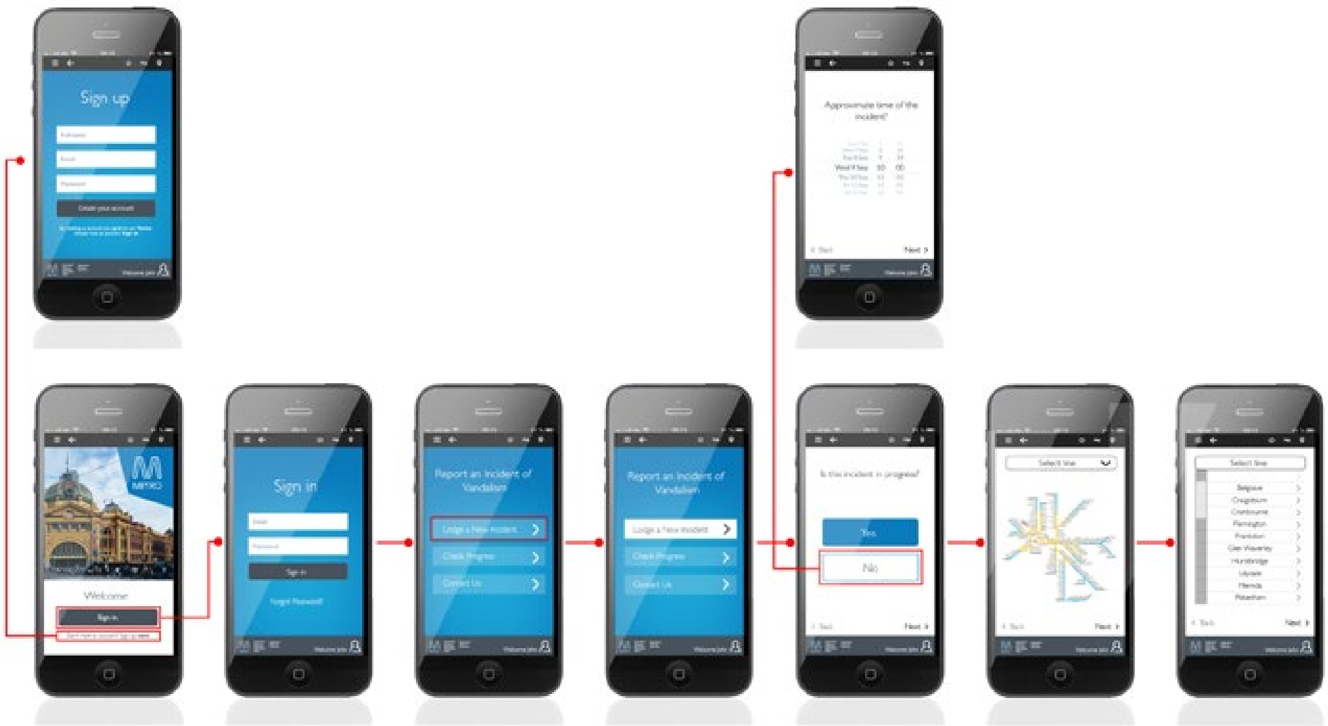
Coupler cowl

System-based intervention

Lastly, to provide a holistic solution, a system-based intervention was developed, guided by the third design objective: involve the users through smart technology systems. This objective lent itself to the creation of a community reporting app, which the MTM semi-structured group interview had also encouraged. At present, the connection between users, mobile apps and assets appears limited within the context of public transport operations in Melbourne. Upon review, many apps within this space are centred around providing users with information to navigate the network and its services, rather than allowing active participation from an operations perspective.

An example of the app's interface is shown in Figure 10.

Figure 10: "Lodge a new incident" application workflow



Conclusions

By taking a coordinated approach to tackling rail vandalism, the project acknowledged it as a multifaceted and complex issue and that, as such, it was essential to consider redesigns both in the context of the rolling stock and the wider context of this behaviour. Interventions, therefore, sought to integrate the assets, the users and the operators within a proactive and holistic mitigation framework.

Reducing vandalism to at-risk assets increases the reliability and efficiency of services, which in turn assists MTM in reducing maintenance efforts and meeting performance targets. When considering the costs around fabricating and integrating new components, it is worth contextualising them with the level of impact caused by vandalism that targets the windscreen. For example, the 164 incidents recorded in relation to this at-risk asset delayed services by 2181 total minutes and 1,677,157 total passenger weighted minutes (PWM) from 19 March 2015 to 25 May 2016. The 124 incidents caused by graffiti alone, as largely targeted through the retrofitted interventions, delayed service by 1700 total minutes and 1,407,457 total PWM. Additionally, redesigning vulnerable rail components would largely benefit the general public; aesthtically, reducing vandalism creates a cleaner, more visually appealing rail environment while instilling a sense of pride in the community. Lowering the frequency and/or salience of vandalism incidents lessens the perception that there is no authority over the network while cultivating a more positive journey experience for commuters. Lastly, by providing reliable and efficient services, the overall satisfaction of commuters with both the network and its operators is further improved.

Acknowledgement

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Smart Pavements Australia Research Collaboration

Professor Jayantha Kodikara, SPARC Hub, Monash University

Watch Interview »

Significance

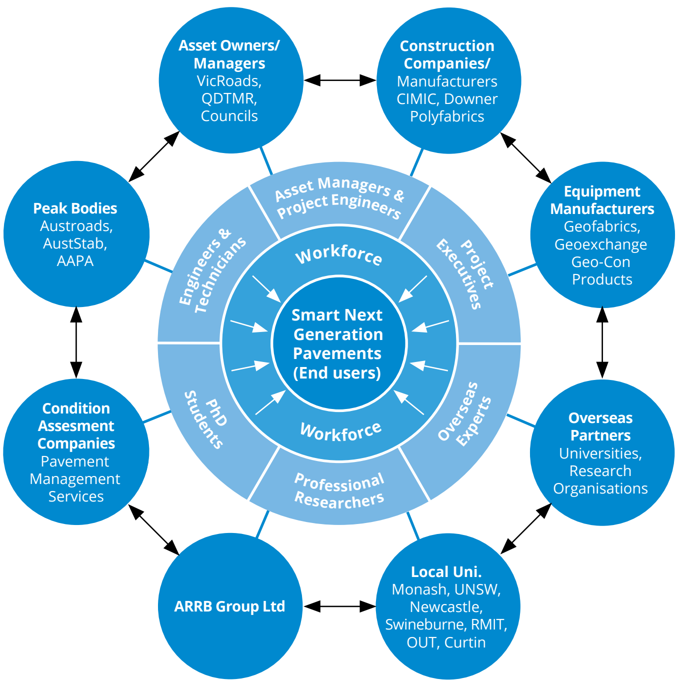
Strong road transport networks underpin the social, economic and cultural fabrics of nations. From Roman roads to Eisenhower's US Interstate Highway System, nations have flourished with well-developed transport networks. Roads are Australia's largest publicly owned infrastructure asset, with a replacement value of $200-¬300 billion. Australia spends approximately $30.25 billion annually on roads (BITRE 2019), with up to $7 billion a year spent on maintaining its 900,000 km road network, the world's highest per-capita maintenance expenditure thanks to our large land mass and relatively small population. Australia therefore needs to be ingenious in constructing, operating and maintaining its roads. This is apparent in its road network, with over 90% of it constructed from relatively low-cost unbound materials with thin seals suited to local climates. Nonetheless, we face a regime of increased road deterioration with increased traffic loads and volumes exacerbated by declining maintenance budgets.

Furthermore, we are facing material scarcity, climate change pressures, the need to reduce our environmental footprint, and the rapid digital transformation of the physical world and vehicle automation. These challenges call for unprecedented, focussed innovation and skill enhancement in the Australian transport pavements sector, and the SPARC Hub provides a university-led collaborative platform to achieve this.

Inception

I felt that the Industrial Transformation Research Hub (ITRH) Scheme of the Australian Research Council (ARC) would be a fitting vehicle to establish such an innovation think-tank. After discussions with ARRB, Austroads, AfPA (previously AAPA), Department of Transport (previously VicRoads), QDTMR and construction companies led by CIMIC Group/EIC Activities, we applied for a Linkage grant from the ARC ITRH scheme in 2018. After winning it, we established the SPARC Hub in July 2019, whose hallmark is its stakeholders' collaborative spirit as encapsulated in our name SPARC – Smart Pavements Australia Research Collaboration (see Figure 1). An intuitive name – we thought – for a Hub aspiring to innovate.

Figure 1: Interactions of partners and stakeholders



Operation

SPARC (www.sparchub.org.au) operates from within the Department of Civil Engineering of Monash University. Our goals are embedded in:

- Our vision is to make pavements smarter, longer lasting, safer, more economical and with a lower environmental footprint.
- Our mission is to provide an unprecedented, university-led research platform to innovate materials, designs and adaptive technologies, facilitate skill development and drive commercial benefits.

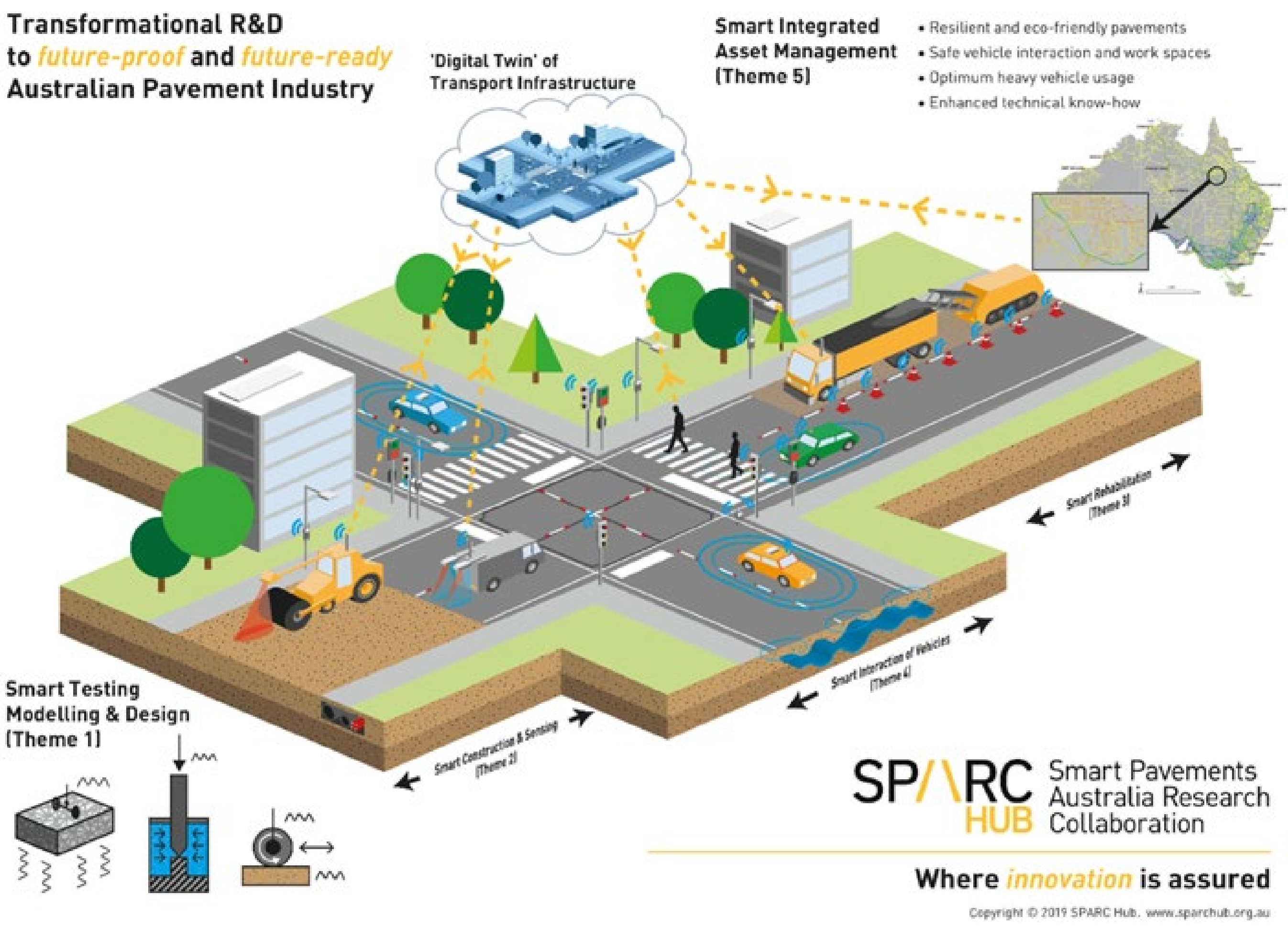
SPARC has a well-developed governance structure, with an executive committee assisted by the Industry Advisory Board (IAB), comprising industry partner representatives and an independent Scientific Advisory Board (SAB).

Figure 2: The SPARC Ignition Function, April 2019, at ARRB's headquarters

Research Program

The SPARC research program runs across five themes led by five leaders, supported by 26 academics from eight Australian universities, with a further 20 industry and seven overseas collaborators. Overall, there are 42 projects undertaken by 37 PhD scholars and six Research Fellows, mostly with doctoral qualifications. Innovatively, a number of experienced and early career ARRB researchers have been seconded to work with the PhD scholars. This provides an unprecedented, vibrant culture of innovation and practical R&D work. Details of some current research projects are included in the current volume of this journal. The overall program is shown in Figure 3.

Figure 3: The SPARC research program



Theme 1 – Smart testing, modelling and design (led by Professor Jayantha Kodikara, Monash University)

This theme targets the development of innovative materials for long-life pavements with reduced maintenance costs and enhanced resilience against repetitive traffic and environmental loads. It will make advancements in unbound pavement systems, including more rational laboratory testing methods that lead to more advanced design methodologies and remaining-life estimations. For example:

- Testing methods that cater for principal stress rotations and material dilation that take place from lateral strains, which can influence the rutting development and evolution of resilient states.
- Enhancing unbound materials through modification or stabilisation for elevated traffic loads.
- Life-of-pavement research to cater for short-term, high-volume pavements such as those that occur in re-routing of major roads through temporary roads.
- Increasing strength/stiffness and ductility (or failure tensile strain) to produce superior enriched unbound materials.
- The use of geosynthetics to enhance soft subgrades.

The influence of climate is not directly considered in Australian unbound pavement design. SPARC research will advance this issue, potentially developing a practical approach incorporating climate in pavement design.

Theme 2 – Smart construction and sensing (led by Professor Jeffrey Walker, Monash University)

This theme works on smart pavement construction techniques and condition assessment methods when the pavement is in operation. Intelligent compaction (IC) is a recent, evolving technology that uses vibratory rollers equipped with sensors, such as accelerometers. While not widely used in Australia, it is widespread in the USA and Europe. This theme will:

- Lead IC's Australian implementation and adoption, including research, analysis, laboratory and field-testing to evaluate current IC technology and develop enhancements.
- Use the analytics developed in Theme 1 to specify the key parameters to be measured and controlled to compact a pavement to meet the performance criteria for long-term performance.
- Research the use of L-band radiometers for moisture measurement and LIDAR for density measurement through surface settlement analytics.
- Extend the use of Ground Penetration Radar (GPR) for internal information gatherings such as layer thickness and moisture content determination.

In partnership with industry, novel sensors such as graphene-embedded geotextiles will make future generations of pavements smart and usable for condition assessment through 'crowd sourcing', such as using private vehicles to undertake condition assessment.

Theme 3 – Smart rehabilitation and eco-friendly pavements (led by Professor Jay Sanjayan, Swinburne University of Technology)

This theme will develop the use of unutilised fly ash to make geopolymer concrete suitable for pavement construction with a much-reduced environmental footprint. It will also:

- Investigate the use of recycled concrete and waste glass in concrete as cementitious and aggregate components in pavement construction.
- Investigate 3D printing technology for the rehabilitation of degraded roads using reseals.
- Investigate the use of the condition assessment data and developed analytics, and how to place an optimal amount of reseal material over depressed road surfaces for long-lasting pavements.

Pavements fail at 'hot spots' where either compaction is not adequate and/or material is weakened due to excessive localised settlement. The innovation of this technology will also lead to long-lasting pavements, producing economic and environmental benefits and providing infrastructure resilience.

Theme 4 – Smart transport demand adaptation (led by Professor Hai Vu, Monash University)

Connected and autonomous vehicles (CAVs) will completely change our mobility patterns and transportation network. This theme researches how smart, next-generation pavements and infrastructure can safely operate and manage CAVs. We will:

- Study the role of distributed sensors (such as smart pavements) as part of the connected infrastructure supporting a network of CAVs where road infrastructure or pavement can sense traffic and communicate information to the vehicles travelling on them. This is in stark contrast to efforts that develop technology just for a vehicle to merely capture the condition of the environment surrounding them.
- In partnership with industry and government, research and evaluate smart traffic management options offered by these traffic-aware infrastructures.
- Monitor and maintain where the smart pavement and infrastructure could self-report its condition to facilitate better and more efficient networks with lesser costs.

Together with Theme 2, multiple smart sensing technologies both in pavement and above the ground, such as mobile GPS, drone and camera-based computer vision, will be fused and assessed for accuracy, reliability, scalability and cost-effectiveness.

Theme 5 – Smart integrated asset management (led by Professor Sujeeva Setunge, RMIT University)

This theme will integrate the outcomes of themes 1-4 to develop a smart, optimised road-asset management platform incorporating big data, sensing technologies, traffic data, community impact and engagement. This will be founded on the cloud-based Central Asset Management System (CAMS) developed by RMIT for optimised management of road pavements, which is being refined to receive input data from inspections, sensors and machine vision. We will:

- Incorporate input from dynamic traffic models (e.g., DynaMel, Monash Civil Engineering) developed for real-time traffic simulations, including freight movements.
- Link the dynamic traffic models to traffic pavement interaction, resulting in damage evaluations and optimisation of asset management funds.
- Incorporate the impact of degradation of other assets occupying the road space and the impact of maintenance and repair activities on the community in decision making. This will help more effective pavement asset management, including prioritising pavement rehabilitation or renewals and freight-traffic management.

This sophisticated platform will enable dynamic changes to the degradation models for pavement condition considering the use of new sustainable materials in road pavements and the impact of new design and construction methods in prolonging the life of pavements.

Expected Outcomes

Scientific and technological advances and economic benefits

The project expects to deliver the above innovations. SPARC is pursuing the concepts of ASSURED innovation developed by Mashelkar (BITRE 2019), to consider ideas that have 'legs' in the practical domain. According to Mashelkar, in evaluating an innovation idea, one needs to consider that it will lead to outcomes embedding these features: A – affordable; S – scalable; S – sustainable; U – universal or user-friendly; R – rapid; E – excellent; D – distinctive.

Already a patent has been filed for proximal measurement of pavement material density in real-time during compaction and several other ground-breaking innovations are underway.

With $20 billion spent annually on road construction and maintenance, even an efficiency of dividend of 1% achieved through more durable pavements and reduced maintenance costs may be estimated as $200 million per annum. Since a large portion of citizenry accesses the road network every day, the outcomes would provide significant community benefits daily.

Enhancement of skills

One of SPARC's key contributions is skills enhancement, making the transport pavements sector competitive locally and globally. The Hub is expected to graduate 37 PhD graduates proficient in a wide range of aspects within the pavement sector. To make these PhD graduates conversant and effective in practice, SPARC has adopted several special measures. These include:

(a) selecting relevant projects with industry partners and identifying practising partner investigators to provide advice to the projects.

(b) Working with experienced ARRB researchers who have been seconded to the Hub, so that PhD scholars can appreciate the Development phase also, not only the Research phase of R&D, which is more common in traditional PhDs.

(c) Providing unprecedented opportunities to interact with industry through brain-storming sessions, forums, presentations and internships.

Impediments and COVID-19 Impacts

While SPARC has developed an unprecedented collaborative research platform, the constraints of COVID-19 means that 12 of our second cohort of PhD scholars are still to start their projects due to visa and travel delays. Another major difficulty was undertaking fieldwork and some laboratory work.

Another issue is the tight funding base that SPARC has to operate within, especially in relation to our research agenda and fieldwork. In this regard, we invite our current partners to consider additional funded research work or new partners to propose funded research in future.

Our Partners

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Field trial and performance evaluation of crumb rubber asphalts under heavy traffic conditions

Steve Patrick, Melissa Lyons, ARRB
Dr Simon Xue, ACCC

5

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Introduction

In 2018-19 an estimated 14% of the 450,000 tonnes of waste tyres generated annually in Australia were used productively in domestic end markets; 55% were recovered via exporting shredded or whole tyres to offshore markets; and the remaining 31% went unrecovered (Department of Agriculture, Water and the Environment, n.d.). Apart from being a source of health and environmental concern, dumped and landfilled tyres also represent a loss of potentially valuable resources, as scientists have discovered many ways of modifying end-of-life (EOL) tyres for reuse. This case-in-point involves transforming EOL tyres into crumb rubber and incorporating this into asphalt mixtures for constructing pavements.

Overseas studies have demonstrated that recycling EOL tyres as asphalt material not only ameliorates an environmental problem but also, in some cases, creates no-regret benefits through pavement performance improvements. Specifically, pavements built with crumb rubber asphalt are found to produce lower road noise and exhibit higher durability, especially in a hot climate, than conventional asphalt pavements (Losa et al, 2012 and Khan et al, 2016).

Whilst crumb rubber asphalt products are available in Australia, they are not widely adopted by road owners for resurfacing existing pavements or constructing new pavements. A key concern leading to this low acceptance is the lack of credible evidence demonstrating that crumb rubber asphalt can meet the performance standard required by road owners.

Field trials – a well-accepted approach for establishing engineering requirements and performance properties of innovative pavement materials under realistic conditions – have been undertaken for crumb rubber asphalt products at several locations in Queensland and South Australia to address such uncertainties. However, these have so far been on either rural roads (Queensland) or council-owned roads (South Australia) that experience relatively light traffic. Consequently, a gap remains in the knowledge of how crumb rubber asphalt performs under heavier traffic conditions.

The crumb rubber asphalt demonstration trial

The crumb rubber asphalt demonstration trial (referred to as 'the trial' hereafter) was one such field trial designed to address this knowledge gap. It was a collaborative effort organised by Tyre Stewardship Australia (TSA), Department of Transport (DoT) Victoria and the Australian Road Research Board (ARRB). The trial was organised so that the performance of crumb rubber asphalts could be assessed in the field under real traffic and climatic conditions, compared to other asphalts under standard testing conditions, and to characterise their material properties in a laboratory. Importantly, this project represented a rare opportunity for crumb rubber asphalt suppliers to have their products independently evaluated.

The primary feature of the trial was the type of road selected for testing the crumb rubber asphalt: a state road located in metropolitan Melbourne with an annual average daily traffic (AADT) of 19,000 vehicles (6% commercial vehicles). Results obtained from this project have been used to help inform DoT of the capabilities of crumb rubber asphalts under comparable traffic conditions and will assist in generating the required information for them to be included in specifications for wider use.

Another noteworthy aspect of the trial was its highly collaborative approach, enabled by a wide range of stakeholders in the spaces of product development, environment and infrastructure. This collaborative approach lowered the project risk inherent in implementing new pavement products for individual stakeholders and enabled fast dissemination of project knowledge across the industry, governments and research bodies.

Specifically, major contributors towards the trial and their respective roles were:

- DoT – funding for construction and management, road owner
- ARRB – trial management, laboratory analysis, monitoring, reporting
- TSA – funding, marketing, champion for material usage
- AAPA – developed pilot specification for CRA designs, industry liaison/advisory role
- Boral, Downer, Fulton Hogan – internal time and funding for design and provision of CRA mixes
- Bitu-mill – paving contractor.

Trial site

The trial site is a 1.5 km section of the East Boundary Road within the suburb of East Bentleigh in Victoria, between Centre Road and South Road (Figure 1). East Boundary Road features a parking lane and two through lanes in each direction, separated by a median. The trial encompasses all three lanes of the southbound direction of East Boundary Road. This section is straight and flat.

Figure 1: Crumb rubber asphalt at East Boundary Road

Crumb rubber asphalt products tested

The trial had several unique features. First, it was based on not just one type of crumb rubber asphalt product, but four supplied by three manufacturers. Having crumb rubber pavement products vary both within and between suppliers enabled the trial results to reveal which performance characteristics are common across all crumb rubber options and which are specific to brands or products.

The construction of the trial site was completed in March 2020. The 1.5 km trial site was divided into six sections and each section was paved with a different asphalt product. Four of the six sections were paved with crumb rubber asphalts and the remaining two sections were paved with two types of conventional asphalt products as the control group. Table 1 lists the specific asphalt product laid in each of the six sections.

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Table 1: Summary of the trial sections

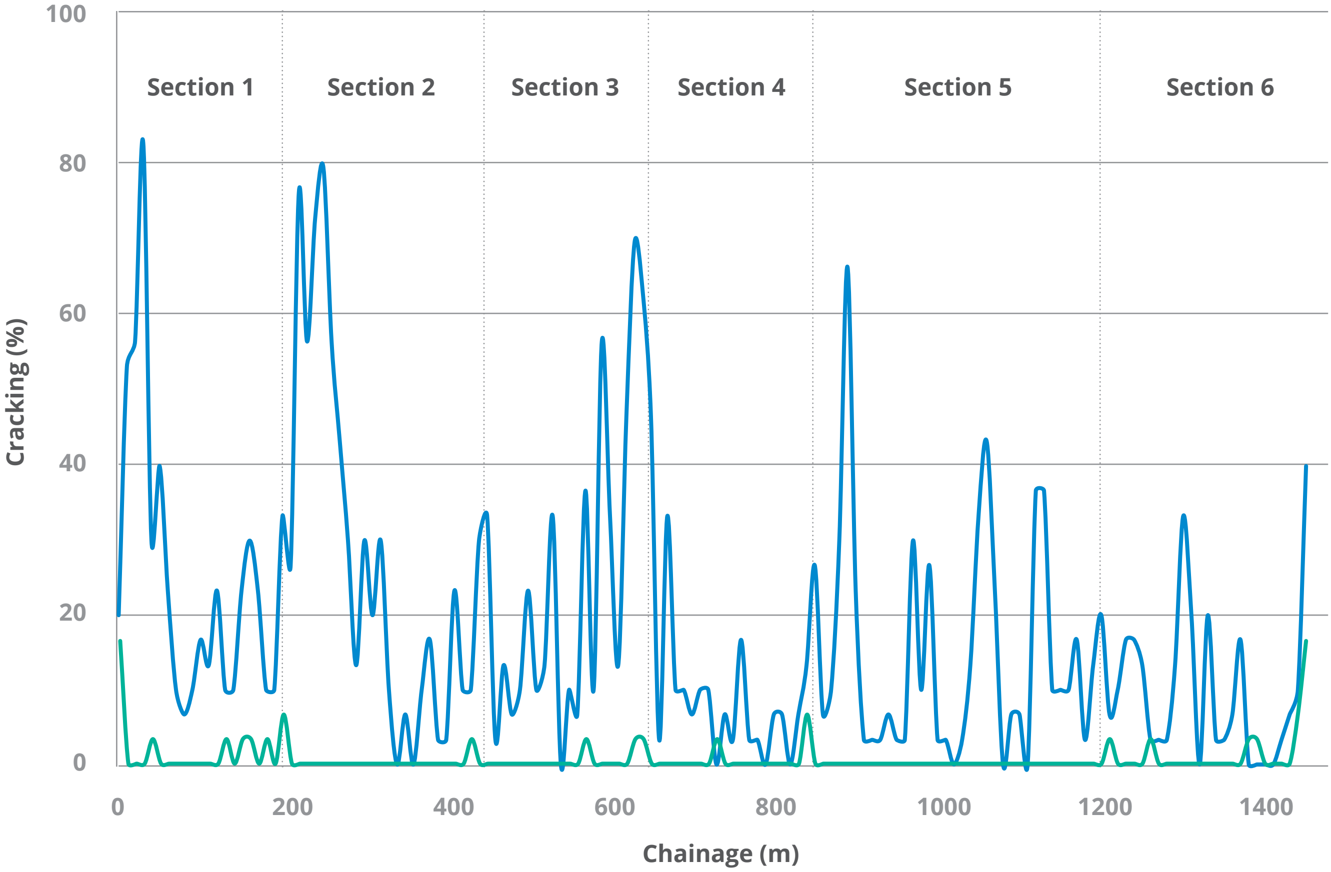
Section number	Supplier	Product
1	A	Crumb rubber asphalt (Type 1)
2	B	Conventional asphalt (Type 1)
3	C	Crumb rubber asphalt (Type 2)
4	B	Conventional asphalt (Type 2)
5	A	Conventional asphalt (Type 3)
6	B	Crumb rubber asphalt (Type 3)

Site monitoring and preliminary results

The primary objective of the trial was to demonstrate the capability of the selected crumb rubber asphalt products under real traffic and climatic conditions. Data required to support this objective was collected in a two-year site monitoring program that ended in June 2022. Specifically, surface performance data measured in levels of cracking, roughness, rutting, texture and skid resistance were collected every 6 months by the ARRB Network Survey Vehicle (NSV) vehicles.

Figure 2 provides an example of the cracking data collected one month after the construction of the trial site, showing that cracking was consistent throughout the site prior to the trial and that the new surface eradicated the surface cracking.

Figure 2: Cracking at the trial site 1 month after the completion of construction



Environmental emissions monitoring

The trial also included environmental emission monitoring during the construction phase of trial roads. The monitoring was designed to measure the fuming exposure experienced by pavement installers. The emission data collected provided a relative measure on the fuming hazard associated with the four crumb rubber asphalt products. Specifically, monitored hazardous emissions included volatile organic compounds, benzothiazole, total suspended solids, bitumen fumes and polycyclic aromatic hydrocarbons.

To assess the potential fuming exposure from crumb rubber asphalt mixes, emissions monitoring was undertaken by personal sampling for several airborne contaminants in the breathing zones of operators involved in the paving, including paving operators, screed operators and rake hands.

The monitoring devices were assembled into small backpacks worn for the extent of the paving operations by the nominated members of the paving crew (Figure 3). The devices collected samples for all the asphalts paved, both crumb rubber asphalts and control mixes, allowing comparison.

Figure 3: Emissions monitoring equipment loaded into backpacks

The results of the monitoring were compared against established workplace exposure standards and guidelines, such as those published by SafeWork Australia and the American Conference of Governmental Industrial Hygienists (ACGIH), as applicable.

Laboratory testing program

The trial also included laboratory performance tests, which took place during construction of the pavement. The purpose of the laboratory tests was to establish an expected performance benchmark, albeit under laboratory conditions. Since real road conditions cannot be perfectly replicated in a laboratory, the comparison between laboratory test results and in-field performance data can be used to highlight any difference between expected and actual performance for crumb rubber asphalt products. Specifically, the three types of testing undertaken for the laboratory testing program were binder testing, plant mix testing and core testing.

For binder testing, samples of all bituminous binders used in the crumb rubber asphalt trial, including control mixes, were collected at the asphalt mixing plant to check their adherence to their relevant specifications.

For plant mix testing, samples of each trial asphalt mix were collected at the plants from the delivery truck at the time of production, as they were being prepared for delivery (Figure 4). The samples were prepared and tested in the laboratory to verify the manufacturer-supplied designs for bulk density, average maximum density, and air voids by either the Marshall method or Gyratory method.

Figure 4: Collecting crumb rubber asphalt samples

For core testing, asphalt cores were collected (Figure 5) from the paved asphalt sections to verify layer thickness and test the strength capabilities in situ.

Figure 5: Extracting cores from completed trial sections

Concluding remarks

After the trial construction and laboratory assessment were completed, the remaining project activities consisted of site monitoring. This was undertaken frequently by the ARRB NSV and DoT SCRIM vehicles over the first two years of life of the trial sections, with results detailed in the final project report issued in June 2022.

Assessing the inherent properties of the crumb rubber asphalt mixes in the laboratory, and their performance in the field, informs the Department of Transport as to how the mixes may be implemented in its specifications. Incorporating these mixes into the specifications will allow their use alongside and potentially in place of traditional mixes, to maximise the use of innovative recycled materials and improve the sustainability of road building.

Beyond crumb rubber, other recycled waste materials can be used as road construction materials, such as plastics and glass. The processes and outcomes of the trial may inform a framework for implementing the use of these recycled and innovative materials not included in traditional specifications.

Experiences gained in the topics of project management, design, construction, performance monitoring and data analysis from this trial are expected to be valuable and transferable to the trial of other innovative pavement technologies that promote sustainability in the circular economy.

Of particular relevance to this trial was the use of recycled plastic in asphalt mixes. Crumb rubber and recycled plastics are similar in chemical structure as they are both polymers. Waste plastic is a source of another environmental crisis Australia and the world are currently facing. Success in this trial of crumb rubber road can potentially expedite the investigation on the viability of recycled plastic modified roads under a range of traffic conditions.

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Long-term pavement performance (LTPP) study – an overview

Dr Tim Martin, Lith Choummanivong, ARRB

Introduction

The Austroads-funded long-term pavement performance (LTPP) study ran from 1994 to 2018. Its four primary objectives were to:

1. Enhance road asset management strategies by using improved pavement performance models.
2. Compare the performance of a range of Australian pavement sections with United States (US) sections established under the Strategic Highway Research Program Long Term Pavement Performance (SHRP-LTPP) Program.
3. Compare the performance of accelerated loading facility (ALF) test pavements with actual road pavement performance.
4. Investigate the quantitative influence of various maintenance surface treatments on long-term pavement performance, as determined by the long-term pavement performance maintenance (LTPPM) portion of the study.

These objectives were achieved using regular functional (roughness, rutting, cracking) and structural (deflection) observations on specific LTPP sites observations in conjunction with the long-term pavement performance maintenance (LTPPM) observational data. This observational data was collected from a range of in-service pavement LTPP and LTPPM sites set up for the study.

These objectives were also achieved in combination with the data obtained from the ALF experiments, under controlled environmental conditions and aimed at quantifying the effect of: (i) surface maintenance treatments and; (ii) increased axle loads (Martin 2010, 2011).

Findings – observational data

Estimation of deterioration rates

The deterioration rate of a pavement is a good indicator of pavement performance. Pavements are expected to deteriorate over time under traffic loading and climatic conditions. However, the deterioration process is often slowed due to the influence of surface maintenance and can be reversed due to the restorative impact of rehabilitation works.

The estimation of the deterioration rate, excluding the impact of either minor or major restorative works, was addressed by the ARRB in-house software tool that calculates the linear rate of progression (LRP) over part, or the whole, of the monitored pavement segment that is undergoing deterioration. The tool adopts a set of decision rules to validate each time-series data point for the calculation of the progression rate. The LRP software tool was written in an MS Excel macro and run on a spreadsheet with input data and output results worksheets attached to the file (Martin 2008).

The tool uses the maximum limit (ML), which is defined as the upper limit of consecutive deterioration change that can be acceptable, and the tolerance limit (TL), which is the maximum improved change condition allowed between two consecutive measurements, to tighten or relax the selection of input data. The ML and TL values set in the LRP interface for the calculation of progression rates for structural and functional distresses are given in Table 1.

Table 1: LRP tolerances

Performance parameter	Maximum limit (ML)	Tolerance limit (TL)
Deflection (µm)	100	50
Roughness (IRI)	0.80	0.25
Rutting (mm)	4	2
Cracking (%)	10	4

Source: Austroads 2019.

Results of LRP processing for individual LTPP sites, the estimated rates of deterioration, are summarised in Table 2 for the various road types. The deterioration rate calculation requires a minimum number of three sequential valid data points. In the case where this condition is not satisfied, no valid result is produced by the tool. Table 2 summarises the range of observed rates of annual deterioration of deflection, roughness, rutting and cracking on the LTPP sites.

Table 2: LTPP observed deterioration rates

State/Territory area	Road type	Deflection rate (µm/year)	Roughness rate (IRI/year)	Rut rate (mm/year)	Crack rate (%/year)
Queensland (rural/urban)	Highways & roads	10 – 49	0.02 – 0.42	0.01 – 0.35	0.00 – 3.49
New South Wales (rural/urban)	Freeways & highways	6 – 24	0.00 – 0.09	0.00 – 0.32	0.10 – 5.08
Victoria (rural/urban)	Freeways & highways	1 – 21	0.01 – 0.10	0.00 – 1.49	0.00 – 1.40
South Australia (rural/urban)	Freeways & highways	0.00 – 95	0.01 – 0.02	0.34 – 0.58	0.00 – 3.3
ACT (rural/urban)	Highway & roads	6 – 40	0.01 – 0.17	0.06 – 0.30	-0.05 – 3.15

Source: Austroads 2019.

Findings – comparisons of deterioration rates

Comparative analysis studies of the LTPP pavement data with ALF experimental data were undertaken at an early stage of the project. The studies concluded that the pavement performance predictions made from ALF were generally comparable with that of the LTPP pavements (Clayton 2002, Tepper et al. 2002).

A comparison of the LTPP asphalt pavement sites' performance with that of US SHRP-LTPP sites of similar loading and climate revealed that the sites from both groups experienced similar structural and functional deterioration, in terms of roughness and rutting (Austroads 2009). Cracking data was not available for the comparative analysis.

Findings – performance models

A number of road deterioration (RD) and works effects (WE) models were developed during the LTPP study. These included:

- The interim network-level functional and structural RD models for flexible pavements (Austroads 2010a, 2010b).
- The interim WE models for a wide range of surface treatments (Austroads 2007, 2017).
- The probabilistic RD model development, using the decision tool @Risk and a data condensation technique known as stochastic information packets (SIP) (Austroads 2016).
- The asphalt and seal life prediction models based on bitumen hardening Austroads 2010c).

Findings – impact of maintenance on performance

An investigation of the influence of surface maintenance treatments on pavement deterioration was based on the data collected from eight LTPPM sites from 2000 to 2018. This influence was assessed by treating each treatment as a variable while keeping all other factors – including pavement strength, traffic, climatic and topographic conditions – constant. Five different surface treatments were accommodated in any one LTPPM site.

The maintenance treatments were broadly classified into six groups as per Table 3. Routine maintenance, minimum maintenance, polymer modified binder (PMB) reseal and normal resealing occurred on every one of the eight LTPPM sites, whereas the geotextile reseal and a reseal with shape correction were only used on five and two sites respectively.

Table 3: Mean rate of deterioration by treatment group

Treatment group	Deflection		Roughness		Rutting		Cracking	
	Mean rate (µm/year)	Rank	Mean rate (IRI/year)	Rank.	Mean rate (mm/year)	Rank.	Mean rate (%/year)	Rank.
Routine maintenance	20	5	0.09	8	0.68	8	1.10	8
Minimum maintenance	23	6	0.09	7	0.69	8	1.39	5
Geotextile reseal	23	4	0.07	5	0.57	5	0.20	4
PMB reseal(1)	24	7	0.05	7	0.74	9	0.29	8
Normal reseal(2)	19	5	0.10	8	0.42	8	0.53	6
Reseal with s/correction	19	1	0.03	2	0.93	2	0.01	1

1 Also includes scrap rubber reseal and polymer modified binder reseal.
2 Including reseal Class 170 and reseal with Polyseal.
Source: Austroads 2019.

From Table 3 the following is observed:

- All six groups have a similar rate of structural deterioration as indicated by mean rate of deflection. These treatments, therefore and as expected, either had no influence or caused similar effects on the pavement structural performance.
- In terms of roughness progression, the impact of the geotextile reseal, PMB reseal and a reseal with shape correction on roughness was superior to the rest of the treatments (Austroads 2018).
- In terms of rutting progression, however, the results were slightly different to that of roughness progression, with the normal reseal and geotextile reseal giving the best performance while the remaining treatments had a similar effect on rutting performance.
- As expected, typical periodic maintenance treatments such as the geotextile reseal, PMB reseal, normal reseal and a reseal with shape correction, are the best treatments for long-term pavement protection. Routine and minimum maintenance treatments can initially be a quick and low-cost method of treatment and are only a short-term maintenance solution.

Monitoring – lessons

After nearly 24 years of continuous monitoring experience, lessons were learnt about certain aspects of fieldwork, from the site establishment to the management and execution of the fieldwork program, which are summarised as follows:

- The majority of the original SHRP and ALF-LTPP test sections were set up on long-life pavements with thick asphalt or a bound base overlying a bound subbase in Victoria, NSW and Queensland. These sections represent major highways on national road networks but do not represent most of Australia's roads, which are typically built on an unbound granular base with sprayed seal surfacing. These long-life pavement sites showed extremely slow functional and structural deterioration rates and required a longer period of monitoring to obtain useful data.
- All sites were annually monitored in the early stages of the study, which was later reduced for those sites with low rates of deterioration. Some long-life pavement LTPP sites were structurally monitored every five or six years, while those with conventional or weak pavements on a low volume traffic were tested for deflection on a yearly base. The annual monitoring frequency for functional performance remained for all sites.
- Both the survey method and equipment used for the study changed over the years in response to changes in road safety policy (which require lane closure) by participating road agencies in combination with the benefits of technological advancement – for example, the switch from the walking profilometer (WP) to the multi-laser profilometer (MLP) and the change from field-based visual crack assessment to manual visual rating from digital images. These necessary changes initially required further data processing efforts to ensure a smooth transition from one system to another.

Concluding remarks

The in-service pavement LTPP/LTPPM observational data was obtained through a rigorous monitoring approach that consumed a significant portion of the annual budget. The quality of this data is currently superior to that collected from a network survey.

The LTPP database and webpage will continue to exist as a valuable data source for research in pavement related areas. The data has been used by many researchers and is frequently used by academia inside and outside Australia. The LTPP database can be used to store additional data from other studies, such as the past local road deterioration study and any other future performance studies.

From the outset, the Australian LTPP study provided valuable pavement performance input to the US SHRP program. While the Australian sites were relatively limited in number, the initial intention was to use these as reference sites to 'calibrate' the performance of Australian pavements against the vastly numerically superior US SHRP study of approximately 1200 sites.

The LTPP study has fulfilled its original objectives. The study created an environment, or working platform, to facilitate the activities required to achieve the primary objectives of the study, such as tools for estimating the influence of climate on pavement distress and progression rates of pavement distress. In addition, technology and knowledge transfer activities involved establishing the LTPP/LTPPM database and webpage and the annual newsletter to promote further investigation and research. International activities involved the comparison of the performance of Australian LTPP sites with those of US-LTPP and a review of the 2002 AASHTO pavement design guide performance relationships to see if these were applicable to Australian LTPP sites.

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Aspects of evidence in incident investigation

Paul Hillier, Gavin Lennon, ARRB

Why do we investigate a road incident?

The answer will almost certainly differ depending on your background and the agency you work for – each of which having their own end goal.

Yes, through investigation, we can determine liability and seek punishment for those at fault, but the most important thing that comes from a proper investigation, is the opportunity to learn. In learning, we can develop strategies and practices that can prevent similar crashes from occurring.

In that, we have found the primary purpose for all road incident investigations – to prevent similar crashes from re-occurring.

In this article, some key aspects of evidence and incident investigation are set out as a source of information for those who have not had exposure to the field, but nonetheless, are interested in reducing the toll on our roads.

Why information gathered at the scene of a road incident can be so valuable

While there is no mandate in Australia to investigate road incidents, all severities of road incident deserve to be investigated. This is because the information secured provides enormous potential for learning and continual improvement in strategy, policy, designs, standards, guidelines and practices, across all elements of the Safe System. Similarly, road-related incidents can lead to criminal and/or civil proceedings (litigation) where the facts of the incident – in simple terms, what happened, the infrastructure provision and its condition, and decisions reached in managing and maintaining a road – are typically examined in detail.

This article explores the above position and highlights the need for pertinent information to be collected, secured and analysed as soon as practicable following an incident. In other words, there are two highly significant dimensions here: time and scope.

In simple terms, the more detailed and thorough the collection of information after an incident, the more thorough the subsequent investigation and reconstruction of that incident can be.

However, it is not about 'collecting everything' – the skill is in recognising and capturing the pertinent information.

Similarly, time is of the essence – some information is transient (it only exists for a short time) or ceases to be available over time.

This has led many practitioners in the field to declare that information secured at the scene of the incident – often referred to as contemporaneous – is absolute gold in preventing similar incidents reoccurring across the network. This should be the primary aim: to investigate and mitigate risk, not determine fault, appropriate blame or incriminate. This has led to the emergence of the term blameless (or root cause) investigations: to unravel the facts and solely the facts.

Notwithstanding, it is recognised that a thorough investigation can also help a road agency and their legal representative in determining their conduct of a legal proceeding where an allegation of defective infrastructure has been made by one of the parties involved in the incident. In such an instance, gaps in information can give rise to assumptions and uncertainty, which is far from desirable. Gathering information at the time of an incident and securing it can also safeguard against situations where the legal proceedings may be brought several years later.

But don't the police investigate incidents?

There is a popular misperception that the police and/or insurance companies investigate all road-related incidents. The reality is that only fatal and some serious and publicly sensitive incidents are investigated in sufficient detail to enable a formal forensic reconstruction. Police investigations have the primary objective of establishing fault and linked to that, the prospect of prosecution of one or more of the parties involved. The authors suggest this is very different to the needs of public and private sector road agencies. Indeed, the fact of a legal process being in play can delay the release and utilisation of critical learnings from an incident by a matter of years.

This misperception has also led many road agencies to not undertake their own investigations or, where they do undertake them, to look for a wider understanding or more generic safety outcome. The authors believe this to be misguided and a lost opportunity.

What information is typically collected?

The information collected, often referred to in lay terms as evidence or physical evidence, can be defined in simple terms as 'items that prove or disprove a fact in an incident'. By this definition, the suite of information (sometimes referred to as the bundle of evidence, the bundle, or the brief) can be wide ranging and must be determined on an incident-by-incident basis. While a general mantra of 'if in doubt, collect it' is wise, which can give rise to tools such as checklists, over time practitioners will develop a good practical understanding of core and other items ultimately required.

As a basic categorisation, information gathered can either be physical (e.g. the type and dimensions of skid marks, the position of a road sign, or the type and condition of line markings) or observational (e.g. witness accounts/statements), both of which are gathered at scene; or documentary (e.g. works records, Traffic Management Plans, Standard Operating Procedures), which is collated back in the office.

Good practice tips for investigating incidents

ARRB can be contacted to provide a range of support to road agencies and private sector clients on establishing an incident investigation strategy and increasing their capacity and capability in these fields or conducting independent blameless investigations of road-related incidents. It is vital that organisations establish policy and structured practices that are consistently and reliably enacted by a pool of investigators with requisite competency in terms of skills, experience, knowledge and attitude.

Notwithstanding, the following good practice tips will assist organisations in conducting investigations, securing and collating important information from an incident scene, and just as importantly, ensuring that the lessons to be learnt are identified and continual improvement effected:

Preparation

- Prepare for the investigation. Make sure you know the correct location and find out as much as you can about the incident before leaving the office, gathering any pertinent background, e.g. maps, plans and drawings. Ensure that all equipment needed is available and readily accessible – it is good practice to have an always-ready 'site kit' to hand that is checked and replenished upon return from each incident.

Conduct of the investigation

- Safety/WH&S is paramount. Ensure the safety of all parties involved can be achieved and maintained before even thinking about collecting information. If the location seems unsafe or safety cannot be secured, then the investigation must not commence or continue, as appropriate. Stay calm and safe.

  Working solo on investigations should be expressly avoided – a second practitioner, acting as an observer, is the desired arrangement.

- Furthermore, established site protocols and courtesies must be observed if an incident has just occurred and/or emergency services are in attendance. If the latter, the investigator must make themselves known to the site controller on arrival and observe their instructions and requests. Communication is essential, as the site controller can assist in securing any transient items before they are lost (e.g. if adverse weather is expected or an involved vehicle is about to be moved); provide essential information on what evidence is related and what may have been created post incident (e.g. scrape marks created by the salvage of vehicles, tyre marks left by first responders' vehicles, damage to vehicles caused in the extrication process); identify and bring to attention key witnesses to the incident.

- Do not just consider and record the outcome (e.g. the at-rest positions of vehicles involved and/or damage to infrastructure). While this is important, consider and identify the most pertinent underlying facts and root causes (e.g. where did the vehicle initially lose control and why? Was it a poorly maintained slippery road surface on the apex of a curve?). Always keep in mind, the reason for something happening can be more important than what happened.

- While on site, take copious photographs and video, including of drive-throughs of the site wherever possible, then review and collate the items later. Capture 'like/similar' environments on the same route too to help determine consistency of provision. Good practice exists in the photography

Figure 1: Photography of the damaged vehicle at the incident site

of damaged vehicles, incident sites and their immediate approaches, and should be promoted. This is not always done well and can affect or compromise the investigation and/or any later incident reconstruction. Recent technologies, such as laser scanners, have revolutionised site data capture and subsequent incident reconstructions.

- Time is of the essence as there is nearly always pressure on investigators to conclude their work, e.g. so that a road can be re-opened to traffic. Efficiency and experience are crucial in collecting the information before the risk of losing it, as is prioritising which items to collect. For example, evidence such as skid marks are transient in nature, having a short existence/'shelf-life' before disappearing naturally in the advent of adverse weather or the wear associated with heavy traffic volumes. Other items, conversely, can be collected in a timelier manner (e.g. a return visit in light traffic or at night-time to collect items such as lane widths, which can be assumed constant at a location).

After the site component

- Consult investigation checklists and proforma documents – collate and record details of the investigation and items gathered and not available.
- Clearly set out the facts within a formal investigation report and establish recommendations (including the actions required and who is responsible for them).
- Communicate the lessons learnt from the investigation and improvements needed to mitigate risk as widely as possible, i.e. both internally and externally, ideally for the good of the sector/industry.

General

- Wellbeing – the aftermath of a road incident is stressful for the person/s directly involved, first responders and investigators alike. At the scene, compassion and empathy are good qualities for an investigator, such as when taking witness statements. Similarly, the issues associated with Post Traumatic Stress cannot be over stressed.
- Future proofing – understanding the next generation of incidents. Embedding good practice in incident investigations will enable road designers, network managers, road safety engineers and maintenance practitioners to collect and analyse information as crash mechanisms and outcomes involving vulnerable road users, motorcycles and heavy vehicles evolve, as well as in future paradigms, e.g. where Connected Autonomous Vehicles (CAVs, or driverless vehicles) are involved.

Gaps, assumptions and what if the site has changed?

Gaps in the information secured from incident scenes will typically lead to assumptions being made, which can lead to either ill-informed site- or network-management decisions (internal usage), or in the case of legal proceedings (external usage), can prejudice the road agency's position. This further reinforces the desirability of timely and thorough site investigations, not least given that the procedural rules of civil litigation mean that a road agency may not become aware of an incident and/or that an allegation of defective infrastructure has been instigated until a few years after the incident. By that time, changes to the site and its infrastructure provision may well have occurred. So, what then? A site investigation can still provide value, confirming long-standing items or features that may not have changed or helping to establish why changes have been made. This information can then be used by the road agency and its legal representatives to determine their ongoing response. In short, it is better to know what gaps in information are present and how a site has changed, such that any assumptions made can be assessed and challenged where grounds exist.

Closing remarks

Traditional investigations follow the HVE (Human, Vehicle, Environment) approach. The Safe Systems approach acknowledges that humans are flawed, they will make errant judgements and decisions, take risks and be susceptible to oversight.

Thorough investigation of all incidents, as routinely conducted in the investigation of air and rail incidents, can foster in a new age of just culture in road incident investigation, shifting focus from blame to improvement. This shift in focus facilitates the Safe System approach and allows for the development of safer infrastructure to prevent similar incidents from occurring – which is the ultimate goal of any investigation. A question which should be troubling us all is why this is done for air and rail incidents, but not road?

By equipping investigators with a better understanding of what is important within an investigation of a road incident, and how to appropriately document and present this information, road agencies can not only highlight deficiencies within the current infrastructure, but also formulate plans to prevent the reoccurrence of similar deficiencies in the future.

Applying the concept of social license to road network asset management: a first cut

Emeritus Professor William (Bill) Young, Monash University
Dr Mike Shackleton, ARRB

Foreword

Social Media is empowering the community and enabling it to influence government policy. More and more communities are speaking out on particular issues and retrospectively influencing their implementation. Decision makers need tools to ascertain the attitude of the community before policies are implemented to direct them more in line with community attitude and needs.

This article is the first in a series aimed at outlining the concept of Social License as it pertains to operation and management of road networks. Social license is a term that is used colloquially as well as in its formal sense, so this paper starts with an exposition of social license and its relevance to another colloquially and formally used term – asset management.

During an earlier study funded by the Australian Research Council (ARC) and the National Transport Organisation (ARRB) as part of the ARC Nanocomm Hub, the authors explored perceptions of desirability and likelihood of various road management and related actions. This exploration is described in detail elsewhere (Young et al 2021).

At the time, social license as it pertained to particular private sector initiatives was a topic much in the public mind. Two questions arose as the exploration, mentioned above, continued:

- Was there a case to apply social license to compare a broad range of public sector or public interest initiatives and/or operations as well as at an individual level?
- If that were so, how could public perceptions of the desirability and likelihood of various policies, actions and trends be used to bring social license into consideration?

This paper is intended to stimulate discussion and debate, rather than present a proven validated method for measuring social license as it pertains to road network operation.

Introduction

Roads are a fundamental transport infrastructure. They carry the lion's share of today's people movement. They provide people with day-to-day access to work, education, play and retail activity. They facilitate the logistics chain through allowing movement of goods and resources from their extraction to manufacture and public outlets. They provide the framework for car, truck, bus, tram, light rail, motorbike, bicycle, e-scooters and pedestrian mobility. Identifying how different stakeholders and members of society currently use and view roads is an important step in determining how roads should be managed in the long term. Social license has a role in this.

This paper is part of a larger ARRB project looking at the future of roads. It focuses on the general public's view of roads' future through the exploration of the social licence to operate the road system (SLORS). A SLORS can be seen as means of continually gaining views of the community's view and/or acceptance of the operation of the entire road system, particularly regarding future operation and potential policy measures and characteristics. This is challenging to measure over time but needs formal quantification if decision makers are to increase the like between planning and implementation.

The intention of the work was to set in motion discussion, activity and progress towards understanding how to measure social license prior to the implementation of policies as it pertains to road network operations and determine quickly whether social license is just another trendy, short-lived buzzword, or a useful measure for road network operators and their stakeholders.

Key concepts

Asset management and its evolution

Road infrastructure operations require a co-ordinated, efficient and well-informed assessment process, to ensure that efficient, sustainable, safe and cost-effective transport outcomes are achieved. The views of the community about the future of roads are an essential input into each of these processes as they are the system end-users and the effective setter of community expectations.

Road asset management, broadly defined, refers to any system that monitors and maintains road operational value to an entity or group. Road asset management is a systematic process of developing, operating, maintaining, upgrading, and disposing of assets cost-effectively. As such, it can refer to shaping the future interfaces between the human, built, and natural environments through collaborative and evidence-based decision processes. Social license can improve and assist in making this process more sensitive to community expectations.

Early pavement and asset management systems were configured to optimise only total transport costs, with safety included as a cost, and environmental and social considerations being practically non-existent. Nowadays, road networks are expected by their custodians and users alike to be:

- Safe for all road users, regardless of the mode and means of transport;
- Sustainable in their impact on the environment;
- Optimised around community expectations and trends in travel aspirations; and
- Good value for taxpayer or ratepayer dollar.

Asset management success is therefore as much a matter of community and user expectations nowadays as it is the preserve of transport economists. Indeed, many transport economists routinely include, or seek to include, all these benefits in their calculations. It is this evolution that caused the authors to consider the concept of social license in a road asset management context.

Social licence and triple bottom line

For the purposes of this article and work, the definition proposed by Kenton (2019) provides a usable and relevant description of the concept of social license.

"The social license to operate (SLO), or simply social license, refers to the ongoing acceptance of a company or industry's standard business practices and operating procedures by its employees, stakeholders, and the general public." (Kenton, 2019)

The triple bottom line (TBL) is an important part of any evaluation of success nowadays. It is a framework or theory that recommends that companies commit to focus on social and environmental concerns just as they do on profits. The TBL posits that instead of one bottom line, there should be three: profit, people, and the planet.

Linking these concepts to managing and operating a road system:

A social licence in operating a road system (SLORS) would relate to the ability to gain and maintain the support of the people that live in a road system's area of influence for the manner in which or extent to which the road system meets their needs. A SLORS is granted by the community and is formulated by the beliefs, perceptions and opinions held by the local population and other stakeholders. It is dynamic and temporary because such beliefs, opinions and perceptions are subject to continual change. A SLORS needs to be measured, earned and maintained by those with custody of the road network as well as by those providing a service on the infrastructure, such as public transport providers and freight carriers from the micro level to bulk freight.

Initial applications of the SLO to transport projects have three levels of approval or licence (Coffey, 2020). These are

- Approval – Level 2 -approval/support: Seen as a good neighbour and the community have pride in the project and defend its legitimacy.
- Acceptance – Level 1 - acceptance/tolerance: Lingering and recurring issues and threats. The community is watchful and cautious in the interaction with the project.
- Licence withheld: Work stoppages, blockages, boycotts, legal challenges, and sabotage.

Examples of each level in a road context might be:

Level 2: local residents supporting traffic calming measures outside a school (noting some road users may not offer the same degree of license)

Level 1: speed-limit enforcement

Licence withheld: resorting to legal action over expropriations of land for projects, alternative routing of projects etc.

A Social model in Road Safety

A social model for road safety is being considered in Australia (Australian Government, 2020). It is thought that involvement of the public in improving road safety can be enhanced through the adoption of a social model. The social model is layered, with the individual at its heart. It expands from responsibility for an individual's own behaviour to their ability to influence other individuals and organisations, to organisations actively prioritising safety, community influence and advocacy, right through to systemic change at a macro societal level. The aim of using a social model approach is to build road safety into "business as usual" through various touchpoints and mechanisms across multiple sectors of society. The specific layers are:

- The individual
- The interpersonal function
- The organisational response
- The community approach'
- The system / public outcome approach: influence road safety outcomes,

The measure of performance on this approach is improved safety outcomes; in terms of loss of life and seriousness of injuries.

Rationale and approach

An objective measure of social license – or likely social license – granted would assist decision makers in formulating an implementation strategy for packages of measures they deem necessary.

As part of a broader project on the future of roads, regular surveys of road users – not just motorists – were undertaken over a period of five years. In these surveys, users were asked to express their views on a range of possible actions that road owners might take in terms of whether the measure should happen and whether it would happen.

This was a large data set, so the authors used it as a first step in investigating the notion of social license.

The rationale was that a user's view that something should or should not happen was at least a proxy indicator for whether they would grant or withhold social license. Furthermore, it was hypothesised that the degree of that sentiment – strongly agree, somewhat disagree etc. – might give an insight into degree of license.

The response to 'would happen' was hypothesised to be driven by more by external factors; trust or lack of trust in road owners to do the 'right' thing, or to do the 'wrong' thing. However, it was considered possible that strong feelings about the wrong things being done or the right things not being done could influence resistance or support for the measures, our efforts focused on using both 'will happen' and 'should happen' sentiments in looking at models for measuring social license.

Measures (statements) available for evaluation

The 18 measures (statements) listed below were those available for consideration in hypothesising a SLORS model. Because of the origins of the data, some were actions that a road owner might or might not implement, while others were characteristics of the network.

Responders were asked to rate from1 to 5 the likelihood of each statement being true in the future (5 being highest likelihood), and on a similar scale the desirability of it being true in the future. A subset of the data – a single annual survey's results – are shown in the following diagram (Figure 1) on a 'Should Happen' vs 'Will Happen' grid

The 18 are grouped below:

Change and policy

- Roads and their use should remain largely the same as they are today.
- Private companies should have a larger role in the planning and management of roads in the future
- People should pay a toll or road charge for each trip, with charges dependent on the time of day, route and distance

Infrastructure design and operations

- On major roads like highways, cars and trucks should be separated from cyclists and pedestrians.
- The physical quality of roads and their surfaces should improve in the future
- Underground road and rail tunnels should be more common in the future
- Parking on major roads should not be permitted.
- Local roads, and roads through shopping areas, should give priority to pedestrians and cyclists.
- Smart road infrastructure (e.g. variable signs informing travel time on freeways etc.) should become a necessary part of future roads
- The use of this technology should improve the level of service of roads in future

Demand and Usage

- increasing congestion on our roads in the future is likely
- increasing traffic on our roads in the future is likely
- Road travel should be more environmentally sustainable in the future
- Public transport should be a more common mode of travel in the future
- There should be an increase in the number and capacity of roads in the future

Drivers/users

- In the future, roads should be much safer for all users
- Driver behaviour should improve in the future
- Car, truck and bus travel should all be automated (e.g., driverless) in the future

Some points of interest from the diagram are:

- Highly desirable improvement of driver behaviour (labelled '1' on the diagram), is the least likely to occur, according to respondents.
- The most likely to occur events are increased traffic (18) and increased congestion (17) on our roads, a dystopian but not unexpected viewpoint.
- Beyond those two 'events', respondents felt that the two most likely changes will be parking restrictions on major roads (15) and the inevitability of smart infrastructure becoming necessary to improve conditions (16).
- Again unsurprisingly, 'user pays' pricing (10) is the policy that has least support, which explains why such changes can be talked about for decades with very little action.
- When compared to congestion (17), respondents imply that they would prefer to deal with congestion increases to having to pay to avoid those increases.

Concluding remarks

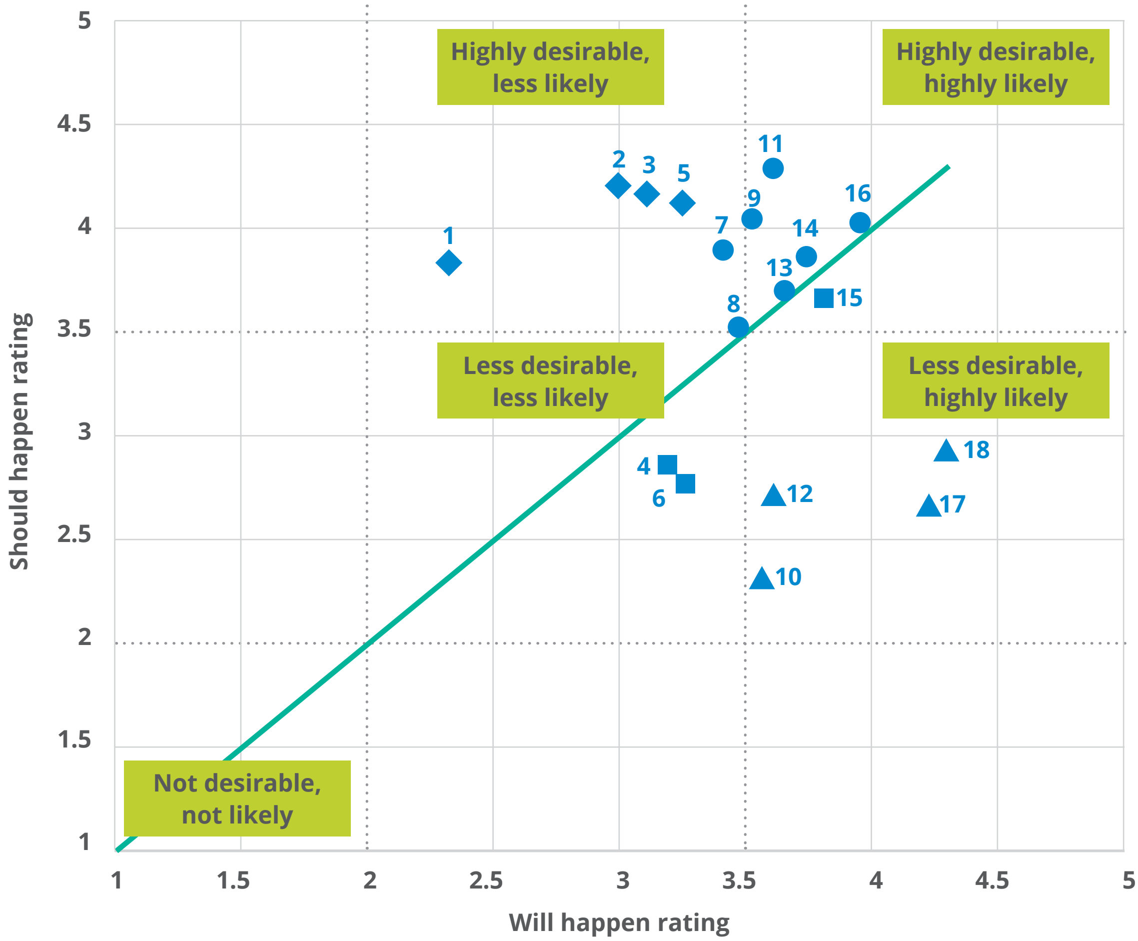
The community is likely to have more and more direct impact on the acceptance of policy as technology enables its views to be more widespread.

This article has outlined some key concepts and a possible approach to measuring social license as it pertains to management and governance of a road network. The approach is however equally applicable to rail, port and airport infrastructure, as it is user-focused.

The next paper will attempt to use the two indices to hypothesise a social license model and explore differences in an indicated social license parameter between different demographic groups.

In the meantime, constructive engagement and criticism of the ideas or an exchange of ideas on the same, would be welcomed by the authors.

Figure 1: Survey results and the relative desirability and likelihood ratings for each measure



Highly desirable, Highly likely

9 Technology improves level of service of roads
13 Increase in number & capacity of roads
15 Parking on major roads not permitted
11 Cars/ trucks separated from cyclists & pedestrians
14 Road and rail tunnels more common in the future
16 Smart road infrastructure become necessary

Highly desirable, less likely

1 Driver behaviour improves
3 Physical quality of roads improves
7 Public transport more common mode
2 Roads much safer for all users
5 Road travel more environmentally sustainable
8 Local roads priority to pedestrians/cyclists

Less desirable, less likely

4 Roads and their use remain the same
6 Car, truck and bus travel all driverless

Less desirable, highly likely

10 People pay a toll or road charge for each trip
17 Increasing congestion on our roads in the future
12 Private companies have a larger role
18 Increasing traffic on our roads in the future

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Advancement of pavement design for practical use incorporating climatic effects for unbound pavements with thin seals

9

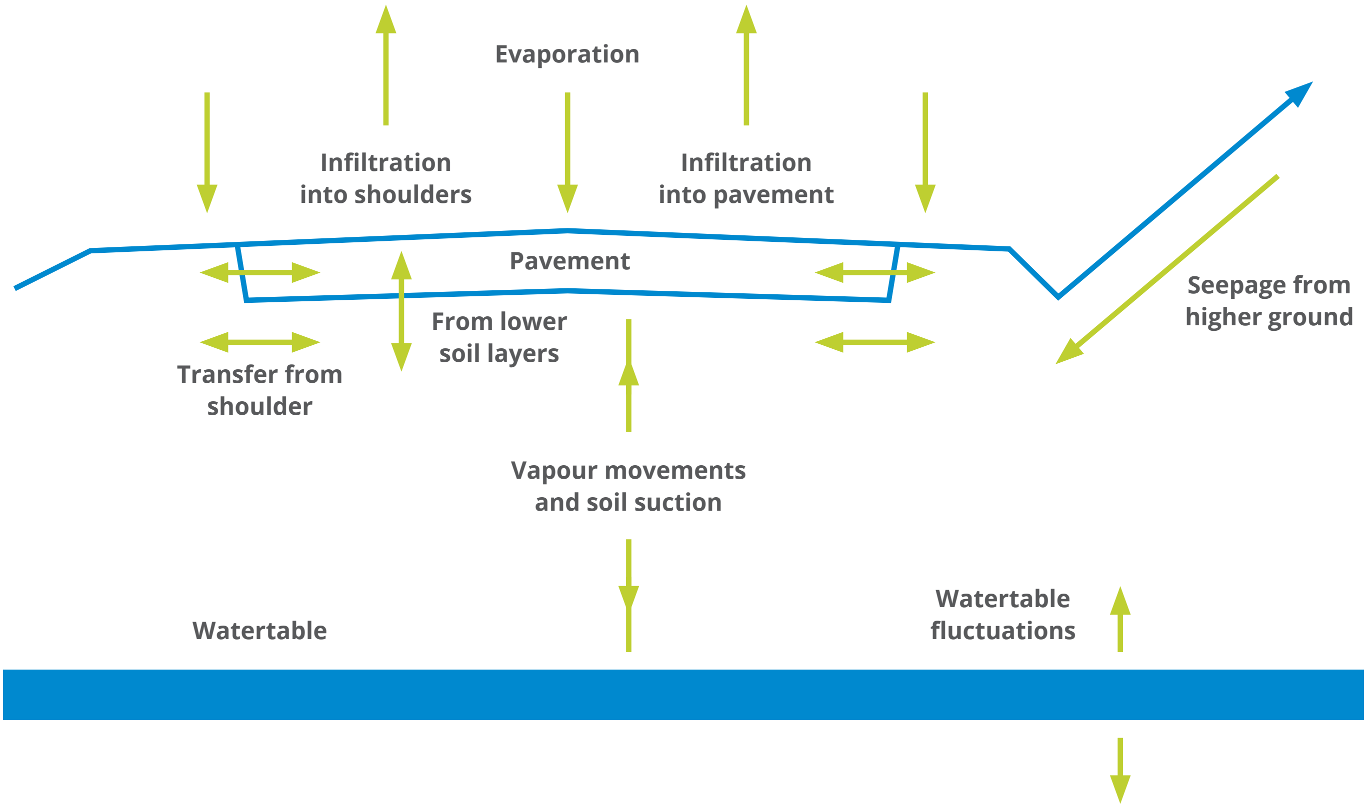
Chathuri Jayamali Maha Madakalapuge,
SPARC Hub, Monash University

Background

Every year, Federal and State governments spend billions on road pavement rehabilitation because of road failures happening worldwide. Environmental factors such as moisture and temperature are identified as the significant reasons for these road failures. Unbound pavements with thin sprayed seals, which amount to about 90% of the overall Australian road network, are more susceptible to environmentally driven deterioration coupled with the effects of traffic loads. Unbound granular materials (UGMs) used to construct the base, and subbase layers are severely vulnerable to performance losses due to moisture variations. Subgrade strength is also adversely affected by moisture changes.

Even though it is intended to construct and maintain 100% impermeable sprayed seals it is not practicable to achieve. Past experimental research studies have shown that the saturated permeability of a sprayed seal may vary from 10-5 m/s to 10-10 m/s and depends on several factors such as seal type, age, resealing conditions, etc. Because of the considerable permeability in seals, moisture exchanges between the surrounding environment and the pavement structure occur due to different physical phenomena, as shown in Figure 1. Thus, even after the construction of the pavement, the moisture conditions in each pavement layer vary depending on the prevailing climatic factors such as precipitation, evaporation, air temperature, relative humidity and the water table depth fluctuations during the service life. These temporal moisture variations, that occur due to climatic factor changes, significantly affect the strength properties in both UGMs and subgrades. Therefore, it is essential to account for those temporal moisture variations during the pavement design process.

Figure 1: Moisture exchange between surrounding environment and the pavement structure (Austroads 2017)



Different countries have adopted different approaches to incorporate temporal moisture variations into pavement design. The current method used in the United States of America embodies a specialist module known as the Enhanced Integrated Climatic Model (EICM) to predict the moisture variations that occur with time, in the pavement layers, considering detailed climatic input data for a given location. These predicted moisture variations are then considered in the structural design of pavements when determining the material strength properties.

The current Australian pavement design guide (Austroads 2017) has adopted a conservative approach by guiding the designer to evaluate the strength/stiffness parameters of the materials through testing at the highest moisture content likely to occur during the service life, based on annual rainfall and drainage conditions. Nonetheless, the design guide provides guidance on dealing with moisture and temperature related issues in pavements under Section 4 - Environment. In particular, it notes "The moisture conditions in unbound granular pavement materials can also have a major effect on performance. When the degree of saturation of unbound granular materials exceeds about 70%, the material can experience a significant loss of strength/modulus".

The current design is yet to advance to incorporate temporal variations of moisture due to climatic factor changes during the service life. Currently, a workable model is not available to accurately predict the moisture variations in pavements after construction for Australia. Thus, this research project attempts to address this drawback and advance the current pavement design for the Australian context.

Model development overview

Firstly, a 1D numerical model, which represents the middle 1/3 of the pavement where the rutting is significant, was developed by capturing essential physical processes of coupled moisture, vapour and heat flow through unsaturated media as depicted in Figure 1. Following the Austroads guidelines and state-of-the-art unsaturated soil mechanics principles, particular preference is given to the degree of saturation (DoS) evaluations during the lifetime of the pavement. The parameters for the model were calibrated from laboratory experiments and literature datasets such that it became usable for the field.

The developed model was validated using an experimental dataset obtained from an actual test pavement constructed in New South Wales, Australia. The analysis showed an excellent match with the simulated results, and more than 80% of spot measurements fit with the simulated results with a 0.1 margin. The developed model was then equipped to simulate, predict and evaluate the moisture variation in unbound granular pavements under different climatic conditions in Australia and used to analyse hydraulic pavement performance behaviours. The developed model was further simplified based on the climatic zones by evaluating relative significance of thermal liquid and vapour flow. Figure 2a shows a sample Degree of Saturation variation (Sr), obtained using the developed model under a typical North Melbourne climate for 10 years of operations. Refer to Figure 2b for the geometry of the selected pavement.

The effect of key factors such as water table depth, initial conditions, and UGM properties were evaluated, and certain trends of Sr variations were identified by a number of sensitivity analyses performed. The developed model was utilised to determine the equilibrium suction and the Sr under different climatic conditions, and investigate the equilibration behaviour of unbound pavement with thin seals. The developed framework will be further validated and improved for industry usage with confidence in the capability of advancing current designs to enhance the quality of construction, cost-savings and safety. This numerical model can also be equipped to evaluate the preference of new materials, such as mixtures of recycled materials in pavement layers, innovate new materials and pavement layer configurations and examine the effect of climate change effects on unbound pavements.

Figure 2a: Degree of saturation variation at middle of each layers under a typical North Melbourne climate

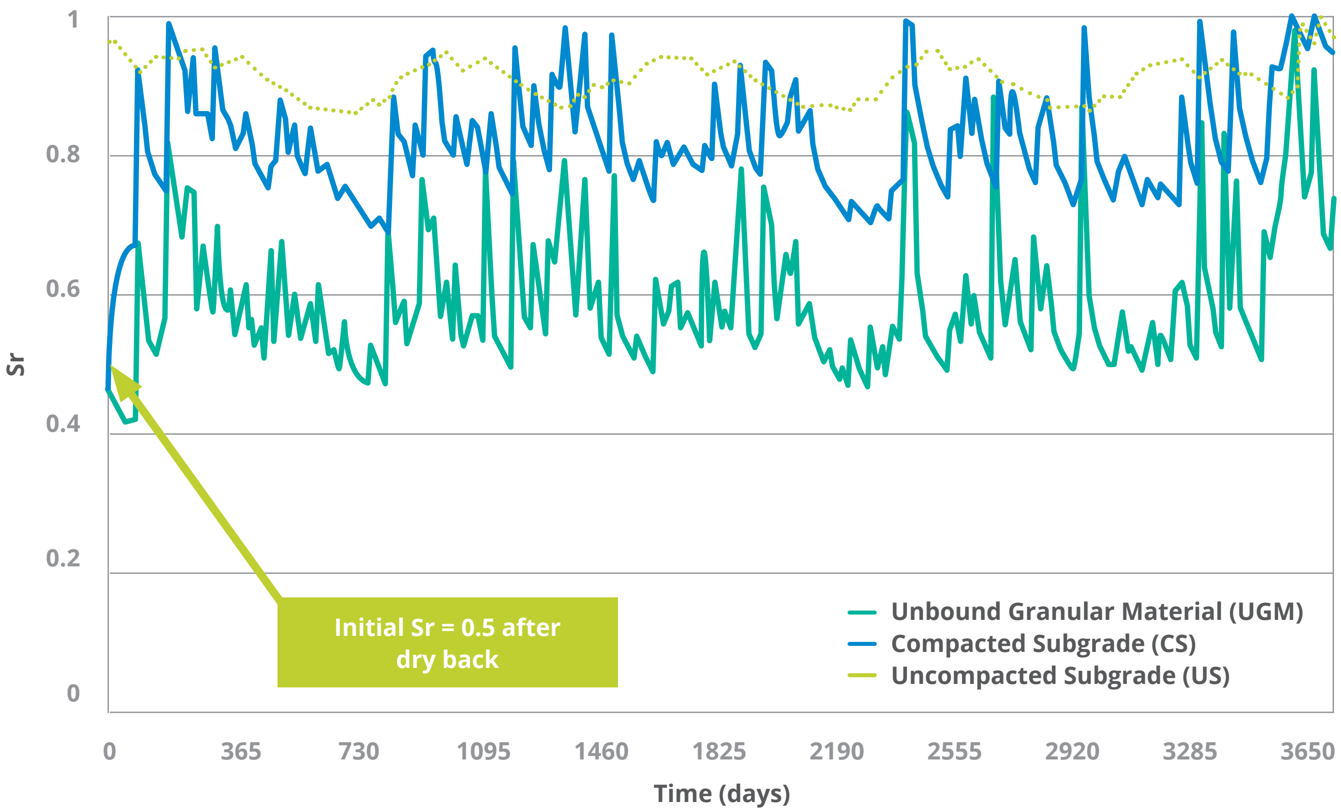
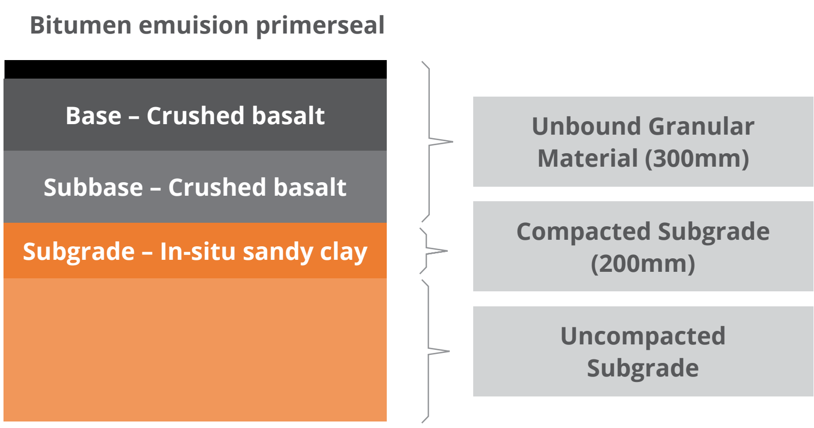


Figure 2b: Geometry of the pavement



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ORGANISATION

OFFICES IN:
BRISBANE, SYDNEY, ADELAIDE, PERTH, CANBERRA

NATIONAL TRANSPORT RESEARCH CENTRE AND HEAD OFFICE:
MELBOURNE, 80A TURNER STREET
PORT MELBOURNE, VIC 3207