THE FUTURE OF MOVEMENT

APRIL 2024

JOURNAL OF INTEGRATED MOBILITY

NTRO NATIONAL TRANSPORT RESEARCH ORGANISATION

CEO FOREWORD

The Transport sector continues to evolve as the new suite of challenges is understood and research is completed across the globe at the fastest pace in more than a generation. The NTRO teams across Australia and New Zealand continue to work closely with Local Governments and State and Territory Agencies to develop new knowledge across the transport sector to solve the challenges of today and tomorrow.

The decarbonisation agenda across the globe will have a profound impact on the way we design, build, maintain and use our transport infrastructure. Teams of NTRO staff are embedded in international work programs to establish the pathway for the development of new knowledge that will result in generational change in infrastructure development and use.

The rise in deaths and serious injuries on the road system across Australia and New Zealand, in particular, requires a laser-like focus on solutions and the creation of an innovation platform to step-change out of the current trajectory. The tragic loss of life and the associated impacts on families, workplaces and the community as a whole, is an horrendous toll to bear. The delivery of creative solutions, backed by sound research and a determination to embed impactful outcomes that change the course of safety on the road system, is pressing and urgent.

The NTRO Journal is a voice for the articulation of this new knowledge and will expand its reach to be a global reference point for researchers and practitioners alike to adopt new ideas and implement next-generation infrastructure development. The NTRO team will play our part in shaping the transport future; I ask you to join us on this journey.

Michael Caltabiano
Chief Executive Officer

IN THIS ISSUE

Users of the transport system the world over are becoming more mode agnostic, with an appetite to travel or move freight differently than in the past. This is creating increased pressure to ensure that all parts and modes of the system work efficiently, effectively, safely and sustainably under a range of conditions. While broadening our focus to the system, however, we should not take our collective eye off the basics, nor should we lose sight of the need to progress mature technologies to extract greater value from them.

This issue of our Journal reflects the complexity of this growing challenge. Papers are referred to by first author only for ease of reference.

NTRO's Executive Director of rail, Natalie Loughborough, outlines the challenges facing the rail sector's contribution to transport. One of NTRO's younger professionals, Donald Shackleton, effectively presents a challenge to the rail industry with a pen-picture of the rail ecosystem and services in Korea.

Jason Sprott has written a short outline of some of the challenges and opportunities facing the global maritime industry and relates those back to the Australian and New Zealand context.

Cassandra Simpson demonstrates the value of bringing existing road-based knowledge and technology to bear on new challenges in modes other than roads. She highlights some work that has been done in modernising runway assessments using world-leading iPAVe technology to deliver better technical and operational outcomes.

Safety of transport system users will always be a priority for responsible stewards and users of the system. Paul Hillier's note raises some ideas around competency sets in road safety. MacGregor Buckley and Sepehr Dehkordi describe an approach to using deep learning to identify hazardous locations on transport systems.

Sustainability of transport assets is as important to users and owners as safety. Georgia O'Connor's paper runs the sustainability lens over tunnels, while Dr Chrysoula Pandelidi outlines an approach to making road surface binders more sustainable in the longer term.

For those who enjoy the hardcore analysis of transport infrastructure, Dr Negin Zhalehjoo has collaborated with two pavement engineering legends to present the findings of some recent work on back calculation of pavement and subgrade moduli.

Mike Shackleton, PhD
Chief Research Officer

Danielle Garton
Leader, Research Office Programs

Issue #3

NTRO Journal ToC

Natalie Loughborough

Natalie is NTRO's Executive Director, Rail. Natalie has high level experience within the transport sector, both overseas and in Australia. She has worked for operators in the UK such as First Group, Serco and Abellio, in addition to local government bodies such as Transport for Greater Manchester. Natalie also brings more than 15 years of board director level experience to the role, working across heavy rail, light rail, ferries and buses, with a commitment in all roles to designing an exceptional customer experience for end users within the transport space.

Donald Shackleton

Donald holds both a BSc majoring in Pure Mathematics and minoring in Statistics and Computer Science, and a Diploma of Languages in Ukranian from Monash University. While studying for the Diploma, Donald joined the NTRO as an intern in January of 2020 as part of the Advanced Technology Lab, where he became a Research Assistant at the end of his internship. Donald is currently a professional in the NTRO's Data and Technology team, where his work centres around data processing and analysis.

Jason Sprott

Jason Sprott is a Senior Executive with substantial environmental planning, sustainability, master planning, major projects and corporate planning experience across 30 years. With experience in the port industry that spans two decades, Jason is the national lead for ports & airports with the National Transport Research Organisation.

Cassandra Simpson

Cassandra is a Principal Engineer at the NTRO within the Asset Performance team. At the NTRO, Cassandra is responsible for bid/tender preparation, coordination, project management and business development of pavement asset management projects and research, asset management modelling, service level determination of assets, specialist surfacing treatment selection and advice.

Dr Negin Zhalehjoo

Negin is a Senior Engineer at ARRB/NTRO with more than 11 years of combined industry, research, and teaching experience. Since she joined the ARRB pavement team in 2019, Negin has been technically leading several Austroads and National Asset Centre of Excellence (NACoE) projects dealing with pavement material characterisation, recycled materials, pavement performance and modelling, stabilised materials, and development of new material performance relationships for asphalt/pavement materials.

Dr Didier Bodin

Didier is a Principal Engineer within NTRO's Safer Smarter Infrastructure team. Since he joined the company back in 2010, Didier's research focus has been within the pavement's space, working on projects dealing with rut-resistance characterisation, modelling and prediction of unbound granular materials response. Prior to this, Dr Bodin spent ten years as a researcher at LCPC (Laboratoire Central des Ponts et Chaussées – France) in the Pavements Department, where he managed projects focused on asphalt fatigue characterisation and modelling.

Dr Geoff Jameson

Geoff Jameson is a Chief Engineer in NTRO's Safer Smarter Infrastructure team. Since joining the company in 1994, Geoff has worked in the pavement technology area on a veriety of projects addressing issues associated with pavement design and performance, specifications and materials characterisation. This work has also included accelerated loading facility trials of unbound granular materials, asphalt, cemented materials, recycled materials and rigid pavements.

Dr Chrysoula Pandelidi

Chrysoula is a Senior Engineer in the Sustainability and Material Performance team at ARRB/NTRO. Chrysoula has expertise in the field of materials processing following her PhD in polymer matrix composite material extrusion additive manufacturing. She has worked in a range of projects in the field of additive manufacturing and has a clear passion for materials processing and recyclability. During her time with ARRB, Chrysoula has worked in various projects relating to the incorporation of recycled materials in road pavements.

Dr Mike Shackleton

Mike is a Civil Engineer with 30+ years' experience in pavements, Assets and network planning, and holds a PhD in the field of research governance from Monash University. He is the Chief Research Officer at NTRO and Deputy Director (Industry) of the Monash University SPARC Hub. In the R&D and consulting roles he has held, Mike has developed a passion for access to mobility for rural and remote communities, and the importance of reliable, fit-for-purpose road infrastructure. Related to this is his passion for understanding how transport systems currently perform, and what will be required of them in the future.

Georgia O'Connor

Georgia O'Connor is a Senior Engineer in the Asset Management Portfolio of ARRB's Asset Performance Team. Georgia's background is in Environmental Engineering, Governance and Sustainability. Georgia's key focus areas and technical expertise include undertaking vulnerability assessments and developing risk management plans for the impact of climate change and natural hazards on transport infrastructure and developing sustainability strategies for major transport infrastructure projects.

Dr Richard Yeo

Dr Richard Yeo has 30+ years research and management experience in the roads sector. He is the Chief Operating Officer for the NTRO with oversight of national innovation programs. Richard has held key roles with Austroads and VicRoads as well as in commercial private sector consulting. He is an Adjunct Professor (Practice) with Monash University and maintains close involvement with initiatives such as Industrial Transformation Hubs and other academic research. Richard is involved in several national and international standards committees covering topics of asset management and digital engineering.

Michael Tziotis

Michael Tziotis has over 20 years' experience in the areas of program development and evaluation, research and investigation, transport planning, traffic engineering and design, road design, road safety (including road safety reviews/audits), and the development of road-based policy, standards and practices. Michael's expertise includes the management and undertaking of national strategic and technical research in road safety, road design and road tunnels. He also has been heavily involved in the development and periodic review of the national Austroads best practice guides in road tunnels, road design and road safety.

Les Louis

Les Louis is an independent consultant with over 50 years' experience in road engineering and management. His career included over 33 years in the Department of Main Roads (or its successors), more than three years as the National Director of Highways for Hyder Consulting in Australia and over twenty years as an independent consultant. His experience covers all aspects of road engineering with an emphasis on planning and design in recent years. He has a strong management record, occupying senior management positions in Main Roads (25 years) and Hyder Consulting.

Tony Peglas

Tony Peglas is a Technical Director at Aurecon with experience in the planning, design, contract documentation and construction supervision of tunnels, civil structures and major infrastructure transport projects. Tony's areas of expertise include design, contract documentation and construction supervision of tunnels and associated underground structures for road, rail, mass transit and utilities. Tony is experienced in the planning and procurement of multi-discipline major infrastructure transport projects.

Dr Simon Xue

Simon is an experienced transport economist and holds a PhD in economics from the University of Melbourne. In his career, Simon has successfully led and delivered both scoping studies and economic evaluations for a variety of transport assets including highways, airports and railways. He is an expert in extracting insights from data. Simon has also led the quantitative lifecycle assessment for innovative and sustainable pavement materials. Additionally, Simon has contributed to the preparation of evidence-based policy advice to help the South Australian government to achieve carbon emission reduction from road freight operations.

Nigel Lloyd

Nigel Lloyd is a Principal Structures Engineer at Waka Kotahi New Zealand Transport Agency. Nigel has 25+ years expereince in the design, evaluation and management of bridges and other highway structure in New Zealand and the United Kingdom.

Dr Sepehr Dehkordi

Sepehr is a Senior Engineer within the NTRO's mobility futures team. Sepehr has a background in Control and Automation Engineering, and he is currently researching Connected Automated Vehicles and Intelligence Transportation systems. He conducts interdisciplinary research in the areas of control theory, robotics, transportation, mobility & AI. He fuses sensory data such as radar, LiDAR, cameras, GPS, & V2X communication devices to assess safety and develop decision-making algorithms.

Dr Amolika Sinha

Amolika is a Senior Engineer at the NTRO within the mobility futures team. Her research interests are autonomous driving systems (ADS) and next-generation mobility. Her skills include data mining and big data analysis. In addition to this, she has extensive experience with statistics, machine learning, deep learning, transfer learning and advanced computer vision.

Trevor Wang

Trevor Wang is a Senior Engineer in NTRO's Mobility Futures team. After graduating from the University of Queensland with the qualification in Civil and Environmental engineering, his internship with ARRB/NTRO was directly related to the industry of traffic engineering. This work instilled experience in traffic management and planning, and showcased Trevor's ability to handle complex projects relating to road designs and traffic operations.

Dr Charles Karl

Dr Charles Karl is the National Discipline Leader in Transport Futures. He is a Member of Standards Australia IT-023 and an Australian delegate at ISO TC204 on ITS. Charles's doctoral thesis in 2003 investigated the response of drivers to a dynamic traveller information system which he had co-developed through a business he founded earlier.

Macgregor Buckley

Macgregor Buckley is a Data Scientist with a passion for applying AI and Machine Learning to solve real-world problems and create innovative solutions. He has a strong foundation in Data Science, having completed a Bachelor of Information Technology with a major in Data Science from Macquarie University in 2021. Currently, Macgregor is a data analyst at Toronto-Dominion Bank in Ontario, Canada. Prior to this, Macgregor worked at NTRO as a data scientist driving the development of computer vision programs for vehicle tracking an object detection and segmentation.

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.

National Transport Research Organisation (NTRO) Rail – Considering the challenges in the rail sector and the need for future progress

Natalie Loughborough (NTRO)

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Watch Interview »

Introduction

Australiasia's rail networks plays a significant role in keeping the country connected, supporting the movement of people, products and services both locally and nationally. As an industry, the rail sector contributes around $30 billion to the country's economy; provides employment for over 165,000 workers, enabling more than 960 million passenger trips; and transports close to 760 billion net tonne-kilometres of freight (Australasian Railway Association 2020a).

With $155 billion in the pipeline for investment in rail infrastructure across Australia and New Zealand for the next 15 years (Australasian Railway Association 2020b), and a large proportion of that funded by agencies and public sector organisations, there is a need to get it right first time. To achieve this, the sector needs to both attract people to the industry and to ensure the skill sets developed are cultivated across Australia and New Zealand. Complementing this, the sector must also have processes and systems that foster rather than hamper the much-needed innovation in the sector.

Current challenges

A major component in being able to make effective and well-informed decisions for the delivery of improvements in any sector is to have a consistency in function and approach across the industry. Part of this includes up-to-date and consistent industry methods and standards, which are both fundamental to ensuring that successful future progress can be achieved across the network.

While acknowledging that the complexity and fragmentation of the 29 networks across Australia – with its three gauges and 11 separate signaling systems – makes national alignment and integration across the industry difficult, it is still important to seek improvement. By focusing on the possible economic benefits of a more cost effective, efficient and sustainable rail system, this interoperability challenge can begin to be addressed.

However, in seeking to improve the integration and operation of the rail network, the skills shortage also needs to be tended to. Without ways to either attract skills into the industry, effectively train up current employees and/or foster a culture looking at different ways of doing things, the sector will continue to rely on disappearing skill sets. This will present an additional barrier to improvement and innovation in the rail sector.

Further to the above, rail must also consider, plan for and enact improvements for a best approach to achieving the net-zero emission target for the transport sector by 2050, as well as accommodating the predicted increase in the freight task by 35% between 2018 and 2040 (Transport and Infrastructure Council 2019). To remain the mode of choice, keeping up with these increasing societal and economic demands is essential.

NTRO Rail overview

Known as the source of independent, reliable and robust guidance for the delivery of next generation infrastructure for the transport sector, NTRO is a for-purpose organisation and registered research provider, collaborating with all levels of government, transport agencies, consultants, academia and private sector organisations in the transport and mobility space.

With a core focus of the business on integrated mobility, seeking to provide innovative and impactful mobility solutions to all Australians and New Zealanders, the NTRO pulls together multi-modal transport expertise and solutions to facilitate the adoption of new technologies and materials, and ensure meaningful progress across road, rail, ports and airports.

In mid-2022, NTRO combined the expertise of both the Australian Road Research Board (ARRB) and the Australian Centre for Rail Innovation (ACRI) to form NTRO Rail. This combination provides Australia and New Zealand with its first dedicated innovation and solutions hub focused on addressing current and future challenges in the rail sector, including those of recognised national importance mentioned earlier in the article.

In August 2023, I joined NTRO as the Executive Director, Rail, seeking to step up and consider what the challenges are in rail and what is needed for future progress, to help solve the challenges of tomorrow, today.

I bring an extensive background in public transport delivery to this role, having worked in heavy rail, light rail, ferries and buses, across both national and international contexts. As in all roles I have held, I am committed to designing an exceptional customer experience for end users within the transport space. As the Executive Director, Rail, I will be focused on delivering an innovation pathway for the rail sector by drawing on the wealth of knowledge and expertise held by NTRO across asset performance, sustainability and material performance, next-generation transport systems, and data analytics and infrastructure measurement (NTRO n.d.).

Addressing the challenges – a starting point

For the challenges the rail industry faces, any decision-making process needs to be informed by robust, up-to-date data. Systematic processes to continuously collect data on the rail network, applied to rail using the rich, sixty years of experience employed by the NTRO in road mapping, will enable a deep and well-informed understanding of any network issues. Subsequently, this knowledge can drive effective solutions and outcomes through evidence-based decision making. Further to this, it is especially important to consider how new methods and technologies – such as AI and digital twins that can provide more advanced, real-time feedback/data – can be utilised to benefit current and future operations.

The flow-on effect of ensuring decisions are based on sound and consistent data will be delivery of a long-lasting, sustainable and more cost-effective network. However, for these decisions to be implemented effectively, it is crucial that there is consistency within the applicable standards and approaches.

Alongside addressing consistency across the sector, developments and changes in standards and approaches should also be considered through a lens of innovation and opportunity to progress the industry. Consider, for example, the developments now coming to fruition from the Hansford Review that Network Rail (UK) commissioned in 2017 (Network Rail 2017). Within this review, encouraging innovation balanced with improving cost efficiency, through the development of partnerships with commercial suppliers and manufacturers, were key principles. The review has really tested the industry in moving away from a stagnating approach, opening up and allowing greater competition in the UK rail market. This review, in conjunction with the Network Rail Standards Challenge (Network Rail 2023), encourages innovation and broader industry involvement whilst protecting the integrity and ability to trace any changes to scope and standards.

In a much earlier stage, Australia's National Rail Action Plan (NRAP) from the National Transport Commission (NTC) affords Australia's rail industry much opportunity for encouraging innovation in the sector as it seeks to improve efficiency and sustainability through national alignment of new technologies, standards and skills training (NTC n.d.). With the NRAP, and the

previously mentioned $155 billion investment in rail, this is an opportune time to prioritise and work on the interoperability challenge of Australiasia's rail networks.

Further, as the plan also seeks to address the rail skills shortage, it is crucial this is supported by ensuring that effective training and resources are available for shortage areas, as well as investigating new or different ways of doing things. To achieve this, educators and broader rail industry representatives and bodies need to work together to determine the existing training gaps and opportunities, and formulate a plan for the best way forward. In this area, an independent organisation and training provider such as NTRO would be well-placed to take a step back, work with agencies who already have been formally given a remit in this space (such as the Australasian Railway Association), and consider the industry training needs from an objective point of view.

Finally, in keeping rail the mode of choice, the industry must keep up with the requirements and demands placed on it from both environmental and economic perspectives.

From the sustainability viewpoint, the carbon footprint of rail must be reduced in accordance with the net zero by 2050 emissions target for the transport sector. This will require all network assets, materials and energy uses to be scientifically assessed and considered from a whole-of-life perspective. These assessments are ones NTRO has extensive experience in for both the road and rail sectors. For testing, the NTRO's world-class laboratory in Port Melbourne provides a full range of engineering and performance testing services for surfaces and materials, and the organisation's Accelerated Loading Facility (ALF) can carry out true commercial-scale research testing and modelling. As for sustainability and whole-of-life assessments, NTRO has developed a sustainability overlay model for the materials used in the road and rail sectors. This model is a cloud-based tool for comparing material profiles and greenhouse gas contributions, and for calculating benefit-cost ratio outcomes from the selections made.

Meanwhile, to meet the significant and growing freight task, particularly following the impact of the pandemic and significant severe weather events, it is clear that Australia needs a resilient, reliable and efficient national rail freight network. The national freight and supply chain strategy five-year review commissioned in 2023 considers the requirements and opportunities for improvement to achieve meeting this demand. The outcomes of this review will produce a revitalised position for the industry and one that NTRO will respond to.

Summing up

This is the perfect time in the transport sector for putting rail at the forefront of getting it right first time, with truly evidence-based decisions. Never has there been a more exciting time to be part of the future of a multi-modal approach to the strategic direction for transport, alongside the opportunity to take rail forwards with the breadth already applied in the road, ports and airports spaces.

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NTRO rail outreach experience in South Korea

Donald Shackleton

Watch Interview »

Introduction

With ARRB's transition to the NTRO, an emphasis has been placed on outreach beyond Australia and New Zealand, alongside an expansion of focus across the transport sector; beyond roads and into rail, ports and airports. To represent NTRO Rail internationally, Donald Shackleton from NTRO's Asset Performance team ventured to South Korea in early 2023. Following his travels, Donald recounted the trip and the insights he gained from the experience via a recorded interview (view the interview here). This article provides a written account of this interview.

Purpose of the trip

I had the opportunity to travel to South Korea on behalf of NTRO to attend the International Union of Railways' (UIC) April training session for the Asia-Pacific region. The Korean Railway Corporation (KoRail) is one of their key partners and is responsible for organising this series of training sessions. As someone with a background in the more abstract field of mathematics, I was eager to learn more about the practical elements of the rail industry, as I have done with roads through my work at NTRO. This trip provided the perfect opportunity for me to do so.

Insights

During my visit to KoRail, I was fascinated by the extensive research and development work KoRail carries out. The speakers from KoRail shared with us information about various R&D projects they have been working on, and some of them stood out for me. For instance, they have developed a semi-automated system that enables railway maintenance workers to make their presence known to trains. This system is integrated into the wider signalling system and when workers are on the track ahead, the train driver gets alerted to slow down. It is centred around geolocation of a tablet or other handheld device with a specialised software package installed. Another impressive project is the drone bridge inspection system that they have developed. They use a van to deploy the drones, which then fly out a predefined circuit and return with detailed visual and GPS information. This method is more efficient and effective than using human inspectors, as the drones can detect minute changes in the bridge structure that are not visible to the human eye. For example, the bridge may have shifted by half a centimetre since the previous inspection, which a comparison of drone surveys can easily detect but a human inspector cannot. Overall, I was impressed by the level of innovation at the Korean Railway Corporation.

As for my personal experience of the South Korean public transport system, I found it fast, clean and easy to navigate, even though I don't speak any Korean. I was able to catch a train to and from the airport without any trouble. I also got to see the transport system from two perspectives: the customer-facing side and the operational side. The control rooms at the stations emphasised the importance of both train and human safety. One such control room had cameras that could detect if anyone was on or too close to the tracks. In such cases, an alert would be sent and a warning would be played over the nearby speakers, asking people to clear the tracks. During our visit, we were given a tour of the country's control room, which was truly impressive. The room takes up most of the building it is in and resembles a major Area Control Centre, such as that for the Melbourne Flight Information Region. A large monitor wraps around the room, displaying the signalling status for every track in Korea. It's amazing to see so much information centralised in one place in real time.

Furthermore, the Railway Federation's Asia Pacific region covers a wide range of countries, extending from the Caucasus through to Australia. Representatives from various countries such as Georgia, Kazakhstan, Azerbaijan, Malaysia and Australia attended the event, with most attendees being from railway regulators or operators. The representation was comprehensive, providing an excellent opportunity to meet people from different countries. It was especially insightful to meet representatives from Kazakhstan and Mongolia, who mentioned facing similar challenges to ours in Australia, due to their countries' sparse populations. In their countries, as in ours, it can be very challenging to justify building railway infrastructure where the population density is low. This was interesting because it wasn't something that would immediately come to my mind when thinking about railways in these countries.

Overall experience

In addition to the training, the overall trip was enjoyable. The organizers from KoRail were very helpful in guiding us throughout the trip and making sure we had things to do after the conference. On one such outing, they arranged for us to visit Gyeongbokgung palace complex and suggested that we rent hanbok for the occasion, which is the traditional Korean dress. As a result, there is a photograph of all of the attendees in Korean traditional dress standing alongside the KoRail staff in standard business attire in the palace courtyard. It was a fantastic experience.

Attending UIC training sessions such as this one on rail safety is something I highly recommended, especially to colleagues, as NTRO expands its presence in the rail industry. These sessions provide the opportunity to discuss the challenges faced in the railway space in our country and in other countries across the Asia-Pacific region. The focus of this particular session was safety, which prompted us to delve into the safety concerns specific to rail transportation and in future may lead to identifying ways to improve. By attending such sessions, we can explore ways to enhance safety measures and find solutions to the problems faced by the railway industry.

Challenges and Opportunities in the Port Sector

Jason Sprott Executive Director (Ports & Airports)

email: jason.sprott@ntro.org.au

Keywords: decarbonisation, sustainability, challenges and opportunities.

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Watch Interview »

Introduction

The launch of the National Transport Research Organisation (NTRO) in December 2022 signalled the emergence of the only national entity undertaking applied research and project/policy based advisory work across all modes of transport – road, rail, ports and airports – throughout Australia and New Zealand.

The NTRO Ports division focuses on not only the here and now – applying the incredible research and technical project-based skills gathered over 60 years to the port sector – but also on the emerging horizon issues, both challenges and opportunities.

There is no doubt that the maritime sector faces unprecedented challenges, with accelerating expectations from a range of stakeholders including neighbouring communities, shipping lines, regulators, shareholders, investors and of course, the actual users of port infrastructure – stevedores, transport companies, freight managers and so on.

What must be achieved throughout the port sector, and more broadly through our economy, is a higher level of certainty in policy, regulation and strategic direction. Through certainty comes investment confidence, which brings job creation, increased well-being and economic strength. Strength that helps ensure the resources for rigorous environmental, social and cultural heritage protection.

This short article highlights two of the challenges – and in my view, opportunities – facing the sector.

Challenges … and Opportunities

Decarbonisation

International shipping plays a central role in global trade, carrying more than 80% of trade by volume (ie. more than 80% of the world merchandise trade by volume is transported by sea). However, shipping is also a significant source of greenhouse gas (GHG) emissions, accounting for around 3% of global emissions. And critically, emissions are increasing in this sector – for example, between 2020 and 2021, total emissions from the world fleet increased by 4.7% (UNCTAD 2022), with most of the increase coming from container vessels or the dry bulk and general cargo fleets. Alarmingly, the industry's greenhouse gas emissions have increased by 20% over the last decade. Without action, emissions could reach 130% of their 2008 levels by 2050 (UNCTAD 2023).

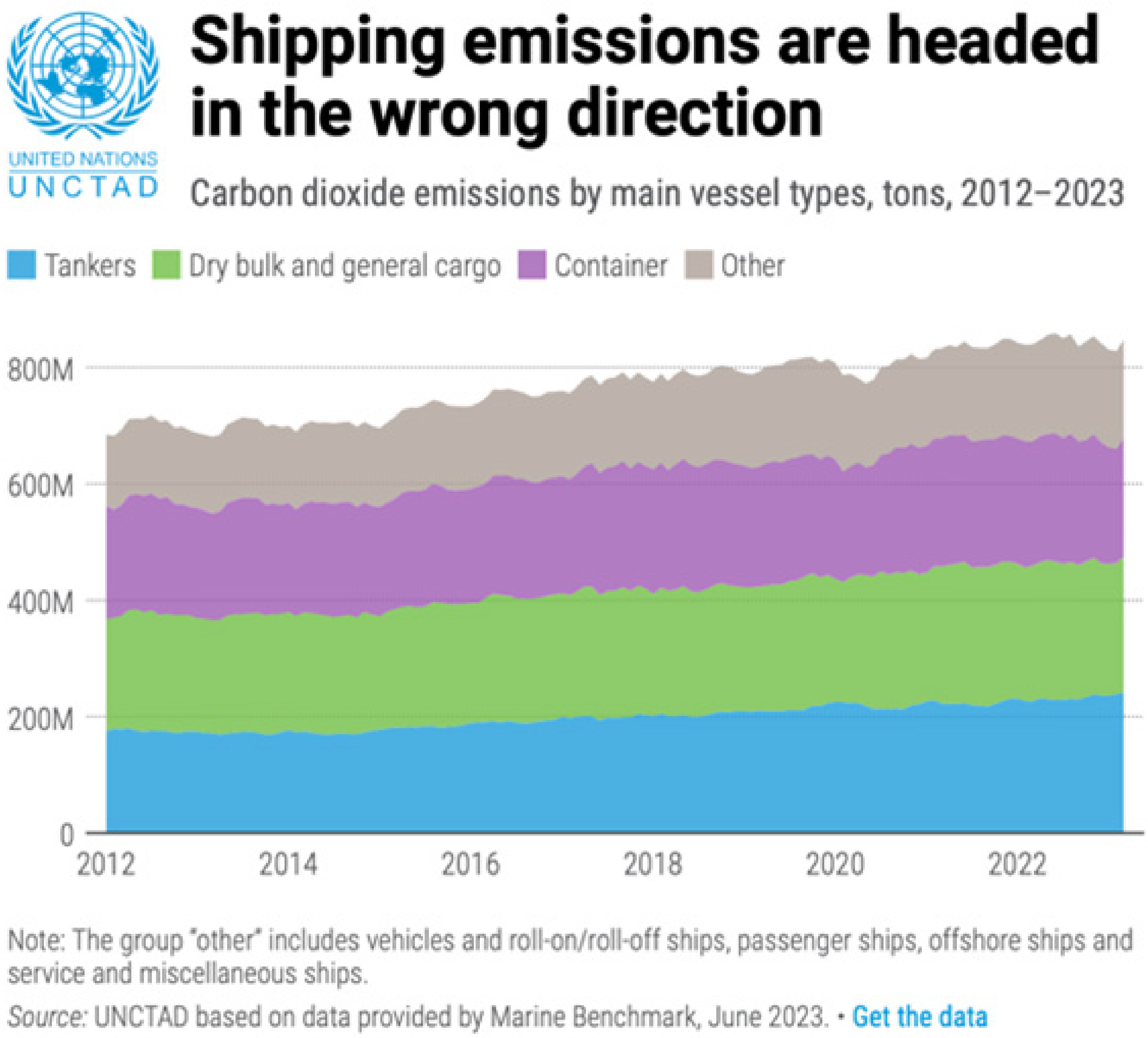

Figure 1. World fleet's CO2 emissions (UNCTAD, 2023)

The International Maritime Organisation (IMO) is the United Nations agency that focuses on the safety and security of maritime transportation, with a particular lens on preventing pollution from international shipping activities. The IMO has adopted mandatory measures to reduce GHG emissions from international shipping under the pollution prevention treaty (MARPOL) – the Energy Efficiency Design Index (EEDI), which is mandatory for new ships, and the Ship Energy Efficiency Management Plan (SEEMP). Building on these and other energy efficiency measures, the IMO formally released its Greenhouse Gas (GHG) Strategy. This called for a reduction in the carbon intensity of international shipping to reduce CO2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050 compared to 2008; and to reduce the total annual GHG emissions from international shipping at least 50% by 2050 compared to 2008.

To further efforts in decarbonising and reducing emissions from the sector, additional IMO regulations came into effect in January 2023 relating to efficiency indicators: the Energy Efficiency Existing Ship Index (EEXI); and the Carbon Intensity Indicator (CII), both requiring shipping lines to accelerate their efforts in assessing ship performance and to allocate more resources to fleet renewal and new fuel technologies to comply with the regulations. Consequential impacts may include slower steaming times; increased freight rates; and the faster retirement of older vessels currently servicing the sector.

Significantly, in July 2023, the IMO released its revised GHG Strategy. In a landmark moment for the sector, IMO member states agreed to:

- reach net-zero GHG emissions by or around 2050; and
- ‘indicative checkpoints’ that call for reducing total GHG emissions by 20% and striving for 30% by 2030 and 70% and striving for 80% by 2040, both relative to 2008.

A comparison of accelerating GHG ambitions, prepared by the International Council on Clean Transport (ICCT), is seen in Figure 2.

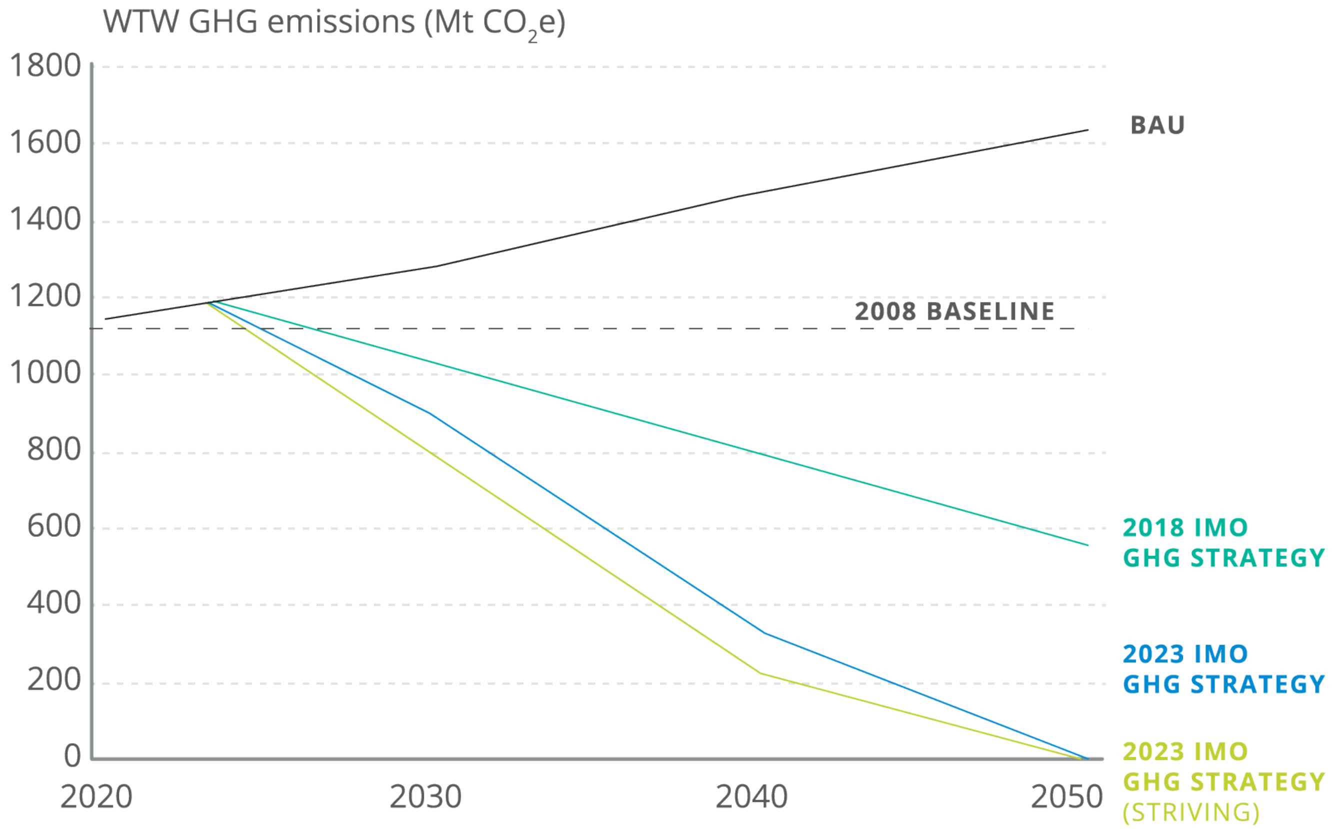

Figure 2. Comparison of IMO GHG Strategy’s (ICCT, 2023)

The revised IMO strategy has provided greater clarity and confidence for future technological developments; for the most viable, available and cost-efficient fuels; for regulatory measures, particularly around carbon pricing; and finally, for incentives to encourage more 'first movers' in the decarbonised fuel space (ie. hydrogen, methanol and/or ammonia fuels).

NTRO is participating in the Australia–New Zealand Green Shipping Corridor Project managed by the Maersk McKinney Moller Centre for Zero Carbon Shipping. This is an incredibly exciting opportunity to be at the forefront of research and insight into the complicated task of determining how best to define, secure and advance green corridors. As an Advisory Board Member to the study, we are engaged with several global partners, including energy producers, ports, ship owners, exporters, terminal operators, government entities, regulators, and global technology and logistics service providers. However, from recent workshops with stakeholders in Australia and New Zealand, it is clear that increased data integrity and more inclusive consideration of the entire port network is necessary.

The opportunity for regional production of green marine fuels of the future must also be pursued – ie. hydrogen (as a feedstock fuel), green ammonia, green methanol and a range of biofuel options. The production of these fuels could stimulate regional development and serve a critical part in global decarbonisation of the maritime sector if they are produced in export-potential volumes for global hubs, such as Singapore. Critically though, we must create the correct policy settings and incentives to ensure these potential energy hubs also face 'inwards' (or domestically) to help decarbonise our hard to abate sectors such as the heavy vehicle transport sector.

Decarbonisation of the sector must, however, extend beyond waterside operations. Landside decarbonisation must also receive elevated attention if we are to truly achieve decarbonised (or green) supply chains. The opportunities within landside operations – at and around ports and along road and rail corridors – are significant and are available right now. This is where the NTRO offering is so special and exactly where we can focus our efforts through targeted research and strategic advice to port entities, port users and regulators at State and Commonwealth levels.

Our Sustainability and Materials Performance teams, in conjunction with our National Materials Laboratory in Melbourne, are at the forefront of research to upscale the use of recycled materials in transport infrastructure, offering significant decarbonisation benefits.

Over and above this technical and exploratory work, we must remember the first principles of increasing the energy and resource efficiency of current operations through all available means. All actors in the supply chain can reduce the carbon intensity of operations. The first step is of course, to clearly understand existing emission profiles (baselining), enabling the development of a targeted strategy to reduce emissions.

Ensuring Sustainable Outcomes

Sustainability within the port sector is not a new concept, having been taken-up with varying degrees of intent by Australian and New Zealand ports. Some, such as the Port of Brisbane and NSWPorts (via the former Sydney Ports Corporation), have been active in this space since the early 2000s. Both entities released sustainability development/green port guidelines around 20 years ago, in addition to pursuing other sustainability endeavors such as seeking a deeper understanding of landside and waterside emission surveys during that era.

Nowadays, most Australian port entities, whether private or government-owned, have port sustainability frameworks and/or positions. Some are more advanced than others and have the benefit of a rigorously developed strategy/plan, whilst others are approaching sustainability from a project/initiative point of view.

As heightened stakeholder and investor interest in the port sector accelerated, more attention on port sustainability was required. Above and beyond this need, port entities understood the value in adopting and communicating a solid approach to sustainability. From Cairns in the north to Hobart in the south, from Western Australia to the Great Barrier Reef World Heritage coastline of Queensland, the port sector is increasingly focused on how to facilitate trade in a safe, viable and sustainable way.

Over the last 10 years, international and domestic port sustainability policy endeavours have advanced significantly. At the international scale, the World Port Sustainability Program (WPSP) was launched in 2018 by the International Association of Ports and Harbors (IAPH). As an Associate Member of IAPH, the NTRO is a proud supporter of the WPSP program. With central themes of Digitialization, Infrastructure, Health, Safety and Security, Environmental Care, Community Building, and Climate and Energy, WPSP is now the globally accepted platform and sustainability reference point for the port industry. Critically, this global initiative is consistent with the United Nations' sustainability platform Sustainable Development Goals (SDGs).

Figure 3. Figure 3: United Nations SDGs (UN Global Compact, 2023)

At the domestic level, Ports Australia released the Port Sustainability Strategy Development Guide in mid-2020, which is now used nationally (and across the global industry) to ensure the development of robust and stakeholder-informed sustainability strategies. As one of the key authors of this document, it has been rewarding to see the industry benefit from following a robust, evidenced-based four-stage methodology. Many port entities and private sector operators have now used the Ports Australia Guide to shape their sustainability work.

Central to this process is the undertaking of a detailed internal and external stakeholder-inclusive 'Materiality Assessment' to better understand the most important issues facing an organisation. A clear understanding of these issues (from both the internal and external perspectives) is fundamental to successful policy development and strategy execution.

Key to success, and the challenges going forward, is ensuring that sustainability strategies are value-adding to businesses and stakeholders. Sustainability is about people, the environment, efficient/viable business operations and partnerships (critically including indigenous, industry, academic and surrounding communities). If these critical sustainability themes can be understood and enhanced through smarter, safer and more resilient policy, then significant value will be created.

It is my view that sustainability within the port sector is an ongoing but incredibly exciting challenge. Central to success will be landside and waterside decarbonisation (including clarity around emission scopes); safety; indigenous relationships; operational efficiency endeavors; enduring stakeholder partnerships; and a strong focus on the diversity, education and well-being of the people within our businesses and, more broadly, through our sector.

As new technology emerges, as our environments become more fragile, as business viability changes with fluctuating economic circumstances, and as communities' and stakeholders' expectations accelerate, leading organisations will respond, adapt and strive to continuously improve. This is the cycle of continuous sustainability.

Since joining NTRO I have been amazed by the skills and talent within our organisation and I look forward to applying those skills and talents to the port sector – as we work in partnership towards a safe, resilient, sustainable and smarter future.

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Translating road survey technology to airports

Cassandra Simpson

Introduction

The National Transport Research Organisation (NTRO) recently pioneered the application of road survey technology to airports. ARRB's established expertise in road survey technology has a long history of innovation and improvement to provide a repeatable assessment of the condition of roads. ARRB's fleet of over ten dedicated survey vehicles, including national survey vehicles, unsealed road survey vehicles and now three flagship iPAVE vehicles, regularly measures the condition of roads across Australia, with thousands of kilometres covered in the last year. The specialised laser equipment, gyroscopic measurement and high-quality images are the backbone of many road agency asset management systems and provide valuable insights to network management.

Airport asset management includes a condition assessment of the runway and taxiways and in 2022 ARRB worked with Airport Consultancy Group and Essendon Airport to bring road technology advantages to airports (Simpson & Shackleton 2022). Condition assessments at airports rely on manual measurements made by experienced surveyors. Conventional airport assessment requires a team of surveyors to inspect the runway and taxiway using a grid pattern and taking measurements in each grid. This means the runway or taxiway must be shut down for all air traffic while the survey team is working in the area. And the shut-down must occur during daylight to enable visual survey for the team – which is the busiest time for airport traffic.

As part of the work conducted in 2022, ARRB provided both a conventional specialist visual assessment and an automated survey using iPAVE. The iPAVE survey provided the following additional benefits:

- Improved repeatability of the survey results
- Reduced time for the survey, reducing the impact on airport traffic
- Continuous measurement and reporting of the condition throughout the survey
- Better records of the condition, using high-quality images
- Repeatable assessments
- Location of the condition assessment every 5 m using GPS.

ARRB completed both the visual manual survey and the automated road survey of parts of the airport within the following timescales. The manual survey, of about 10% of a runway, required a half-day shut-down of the area. The iPAVE survey, of 100% of a runway, was also completed in a half-day, with no pedestrian workers and with the capacity to quickly move on and off the runway to allow priority air traffic to use the area, clearly showing the benefits of the iPAVE technology.

Conventional survey

The conventional survey includes a visual and manual measurement of parts of the runway. Depending on the condition of the area, 10% to 25% of the area is surveyed. The survey uses a standard to rate 17 different conditions:

- Alligator Cracking
- Bleeding
- Block Cracking
- Corrugation
- Depression
- Jet-Blast Erosion
- Joint Reflection Cracking
- Longitudinal and Transverse Cracking
- Oil Spillage
- Patching and Utility Cut Patching
- Polished Aggregate
- Ravelling
- Rutting
- Shoving
- Slippage Cracking
- Swell
- Weathering.

Although the rating system is specific, it's time consuming and not necessarily repeatable because some of the assessments are subjective. The measurement of depressions requires a 3 m straightedge and measurement of the area of the loss of shape. Even setting out the grid pattern for the survey is time-consuming when runways are over 1000 m long and often over 20 m wide.

The survey results in 17 rated conditions and then requires a series of calculations using 19 different adjustment graphs to provide a condition result for each surveyed area, and then an overall condition rating using two optional systems, for the runway.

The conventional survey is detailed and can be considered subjective, time intensive for the surveyors, requires significant closure time for the active runways and taxiways, and provides measured results for only part of the surveyed area. The conventional survey method has been in use for many years and was developed when automated survey equipment was not available.

NTRO's road survey technology

NTRO's iPAVE (Figure 1) road survey technology measures roughness, rutting, cracking, surface texture and deflection. NTRO's survey fleet measures road condition all over Australia. The vehicles are fitted with digital laser profilers and digital imaging systems, which allow the vehicles to automatically capture road condition data at normal highway speeds.

Figure 1. ARRB iPAVE

The vehicle is equipped with seven cameras, all calibrated to measure road inventory and defect lengths and/or areas. The camera views include front centre, front left, front right, left side, right side, rear and pavement-facing ones. All images are captured at 5 or 10 m intervals. The vehicle also uses laser scanners and point lasers capable of covering a 4 m transverse profile of the road to measure pavement rutting over the full width of the lane.

Condition Attributes Used for Assessments

Rutting (mm)

Rutting is a measurement of the transverse profile of a road. A rut is a depression usually occurring in one or both wheel paths. Rutting is a defect that affects road safety and is used as an indicator of the structural strength of pavement. Rutting can lead to ponding in the wheel paths, which in turn could cause a safety hazard and/or damage the underlaying pavement layers once water finds a way to seep through. It is a permanent, traffic-associated defect that usually increases with increases in heavy vehicle traffic loading.

Roughness (IRI)

Roughness, also known as ride quality, rideability or smoothness, is a common objective measure of the general condition of the road. It relates to how comfortable the road is to drive on. Roughness is commonly measured as the longitudinal profile in both wheel paths in a selected lane.

Cracking Extent (%area)

Cracking is a pavement defect signified by splitting of the pavement material due to the action of traffic loading, environmental stress or flaw in material characteristics. It is usually identified as visible discontinuities at the surface, not necessarily extending through the entire thickness of a member or pavement. There are three main types of cracks: transverse, longitudinal and crocodile. A longitudinal crack is parallel to the road centrelines. A transverse crack is a crack at right angles to the road centreline. Crocodile cracking is interconnected cracks forming a series of small blocks resembling a crocodile's skin or chicken wire, normally caused by excessive deflection of the surface over unstable/weak subgrade or lower courses of the pavement (Austroads 2015).

Surface Texture

Texture depth refers to the amplitude of deviations from the surface plane of the road and is influenced by the size, shape and spacing of the aggregate of the surfacing material (Austroads 2009).

Applying new technology to airport survey

The road survey technology provides a different set of information:

- A set of five high-quality images to the front, sides and rear of the iPAVE every 5 m
- Roughness results available in a variety of national and international formats
- Rutting results available for left and right wheelpath
- Cracking results available in a variety of modes
- Surface texture results for the left and right wheelpath, and the centre of the survey area.

The runway was surveyed using several individual runs to ensure the entire width of the area was covered.

Comparing two methods

The two sets of results for the areas showed similar condition, although comparing results is not straightforward. As an example, the manual results reported:

- No areas of depressions
- Some areas of low-severity rutting where the rut was considered a surface depression with uplift adjacent to the rut
- No areas of shoving.

Meanwhile, the automated survey results for the same areas as the manual survey reported:

- Roughness ranging from 0.5 to over 5 IRI that shows movement in the longitudinal profile
- Rutting ranging from 1.5 to 8.0 mm.

Each of the automated data points can be pinpointed to the location using the geographic co-ordinates recorded with the data. This allows mapping of the results to identify any areas of concern.

A better way

The ARRB project allows a comparison of the conventional manual survey of airports with automated surveys using newer technology. The automated survey provides a much greater depth of information, repeatable and measurable results and panoramic images at every 5 m. The automated survey provides a safer working environment for the survey staff to remain in vehicles, rather than be pedestrian workers, and requires far less shut-down time for the airport.

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The development of an algorithm for pavement and subgrade modulus back-calculation

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Introduction

One of the most advantageous applications of non-destructive pavement deflection testing is to determine the modulus of pavement layers and subgrade using back-calculation. The back-calculation of modulus can be achieved using an iterative process. This process requires an initially assumed layers' moduli that will be continuously adjusted during the iterations until the best match is obtained between the measured and predicted surface deflection values (Austroads 2019a).

Several methods have been developed for the back-calculation of pavement layers' moduli over the last few decades. ARRB developed one known as EfromD1 (Elastic modulus from Deflections) model (Potter 1989), which adopted the linear elastic model CIRCLY for the pavement deflections calculations. The implemented iterative procedure in Efromd1 continues until the desired agreement between the predicted and measured deflections is achieved or until no better match to the measured deflections can be obtained (Vuong 1989). However, a notable limitation of the EfromD1 model was that if the initial layers' moduli to commence the iterative procedure were not selected appropriately, the predicted moduli could be related to a local minimum that were not necessarily the best match with the measured ones.

To address this limitation, ARRB developed EfromD2 model (Vuong 1989). Similar to EfromD1 model, EfromD2 also used CIRCLY during the iterative process. However, a different iterative method to back-calculate the pavement layers' moduli was employed in EfromD2.

In 2003, Transport South Australia commissioned ARRB to improve the back-calculation method. Hence, ARRB developed the EfromD3 model that combines the EfromD2 and EfromD1 iterative techniques. This resulted in a more robust prediction of pavement responses while having a reduced computing time compared to the EfromD1 model. EfromD2 and EfromD3 have been used by several Australian road agencies for over a decade, which showed them to be satisfactory.

Objective

This article provides an overview of a part of a study conducted by ARRB for the Austroads project TT2044 entitled Improved Methods of Using Pavement Deflection Data in the Design of Rehabilitation Treatments (Austroads 2019a). One of its objectives was to develop an algorithm for the back-calculation of pavement layers and subgrade moduli for future use in the mechanistic-empirical procedure of pavement rehabilitation design, as presented in the Guide to Pavement Technology Part 5: Pavement Evaluation and Treatment Design (Austroads 2011).

AustBack back-calculation algorithm

For this project, an improved back-calculation algorithm was developed. Developing an algorithm was considered a critical and effective step for the possible future development of new back-calculation software. The algorithm was entitled the 'Austroads back-calculation algorithm' or 'AustBack'. In this algorithm, a detailed step-by-step procedure demonstrating the mathematical expressions and the iterative techniques used in the back-calculation method was presented.

The AustBack back-calculation algorithm employed the EfromD3 principles, which basically incorporated the mathematical equations and steps in EfromD1 into the iterative techniques in the EfromD2 model.The required steps and sequences were therefore derived from the EfromD1 and EfromD2 source codes. As a result, the algorithm consisted of two main stages representing the iterative techniques for back-calculation based on these two models. The EfromD1 model implemented the Rosenbrock function minimisation algorithm (Machura & Mulawa 1973) to generate new values for material properties throughout the iterations. The Gram-Schmidt orthogonalisation procedure (Arfken, Weber & Harris 2012) is used in the algorithm. The weighted sum of the squares error function is used in the EfromD1 model to quantify the agreement between the predicted and measured deflection values. On the other hand, a different iterative method using the modulus correction factors was used in EFROMD2. The correction factor was used to adjust the moduli for each layer at each iteration and was calculated from a relationship between the measured and predicted deflections.

Additionally, the algorithm was further improved by adding the following two optional features:

- moduli constraints for subgrade sublayers
- sub-layering of the granular layers and the moduli constraints for the granular sublayers.

The AustBack back-calculation algorithm is not presented in this article. However, the comprehensive and detailed algorithm can be found in the Austroads project report (Austroads 2019a).

Moduli constraints for subgrade layers

This study developed an approach for modelling the subgrade layer for the back-calculation process in order to improve the algorithm. The properties of the in-situ subgrade material may change with depth, which needs to be taken into account in the back-calculation model.

In the proposed algorithm, the subgrade is sublayered into three sublayers, including the top subgrade (0 to 300 mm depth below the top of the subgrade); the intermediate subgrade (300 to 800 mm depth); and the bottom subgrade sublayer (below 800 mm, semi-infinite). This sublayering method is consistent with the approach used in Austroads (2019b).

Additionally, using the evaluations conducted to assess the likely variation of modulus with depth, moduli constraints for subgrade sublayers were applied in the algorithm. The evaluation was based on the surface modulus, or 'composite modulus', calculated from the Boussinesq equations (Ullidtz 1987) using pavement surface deflections. Horak (2007) discussed that the composite modulus, at a reasonably large distance from the edge of the FWD loading plate, can be used as an indicator of the subgrade material behaviour. The slope of the composite modulus can also represent the expected changes (increase or decrease with depth) in the subgrade sublayers moduli. The details of the composite modulus and the associated assessments carried out in this project can be found in Austroads (2019a).

Finally, the moduli constraints for the subgrade layer were added in the algorithm by applying a gradual change of modulus with depth between the three sublayers using a linear relationship. This avoided having the unrealistic back-calculated moduli for the three sublayers or a significantly higher/lower modulus in the intermediate subgrade sublayer compared to the bottom or top sublayers 'sandwich effect'.

Moduli Constraints for Granular Sublayers

In the mechanistic-empirical design of new flexible pavements, the total thickness of the granular base and subbase layers is divided into five sublayers of equal thicknesses (Austroads 2018). The modulus for each sublayer can be determined using a modulus ratio. The ratio of moduli for adjacent sublayers can be obtained from a relationship between the modulus of the top granular sublayer and the modulus of the underlying subgrade. It should be noted that a similar procedure is used to calculate the design moduli of granular materials in the mechanistic-empirical design of rehabilitation treatments.

To further improve the back-calculation algorithm, the total thickness of granular layers was divided into five sublayers to be consistent with the approach for the design moduli determination. The model had a maximum modulus assigned to the top granular sublayer so that it was capped not more than double for every 100 mm of the granular layer. It should be mentioned that this optional feature may not be used when the modulus value of the top subgrade layer is higher than the granular layer moduli.

Case Studies

The developed improved algorithm was subsequently tested and verified using two selected case studies. The first case was related to 'asphalt surfaced granular pavement' control section as part of the research related to the performance of foamed bitumen stabilised pavements in Calder Freeway, Victoria. The second case study was a 'thick asphalt on cemented subbase pavement' that used the available FWD data (Austroads 2011). The objective was to assess the AustBack algorithm and to evaluate the benefits of its associated optional features to assist the back-calculation analysis.

It should be noted that the AustBack algorithm is independent of the response to load model. However, CIRCLY (Mincad Systems 2004) was used in the verification step for the adopted case studies in this project.

Input parameters

The back-calculation analysis from the FWD testing data and using the AustBack algorithm requires the user to select or input the following parameters:

- FWD loading configuration including the radius of the FWD loading plate and the load magnitude
- FWD measured deflection data including the number of measured deflections, the offsets, and vertical pavement surface deflection values
- Pavement configuration
- Number of layers in the pavement and subgrade
- The thickness of each layer
- Poisson's ratio of each layer
- Degree of anisotropy of each layer
- The first estimation of modulus for each layer, 'seed values'
- Back-calculation parameters including the acceptable error function, maximum number of iterations, maximum and minimum modulus for each layer, and deflection weighting factor (deflection weighting factor is assumed as 1.0 as the default value).

The initial moduli (seed values) are used to commence the iteration procedure. Appropriate estimations of the seed values, as well as selecting a good modulus range (the minimum and maximum moduli), can improve the quality of the back-calculation analysis. The local knowledge of the pavement condition and the available laboratory characterisation data, as well as a proper engineering judgment, can be used to select appropriate input parameters for the analysis.

The project proposed a method to define the seed moduli for the subgrade sublayers using the composite modulus data. The mathematical equations to determine the initial subgrade values using the slope of the composite modulus for deflection offsets greater than the total pavement thickness were presented in this study (Austroads 2019a).

The iterative procedure of a back-calculation analysis will be completed once the predicted deflection values match the measured ones (error function below the inputted acceptable error function), or when the inputted maximum number of iterations is reached. The error function provides an estimation of the quality of the fit between the measured and predicted deflections.

Back-calculated moduli and discussion

The back-calculation analysis was conducted using the AustBack algorithm with and without the optional features of the 'constraint for subgrade sublayers' and 'granular sublayering'. Figure 1 shows the back-calculated moduli of the three subgrade sublayers related to the first case study of 'asphalt surfaced granular pavement structure' with granular base and subbase. Figure 1.a shows the obtained moduli while no constraints to subgrade or granular layers were applied. Figure 1.b, on the other hand, illustrates the moduli while both granular sublayering and subgrade constraints were considered in the analysis. In this figure, top, intermediate and bottom represent the three subgrade sublayers.

The result showed that applying the two constraint options (Figure 1.b) affected the back-calculated moduli obtained for each sublayer. The modulus at chainage 140 m was clearly improved and a higher modulus for the intermediate sublayer compared to the bottom and top was not observed in that case. However, the study showed that although the subgrade constraint resulted in more realistic subgrade sublayers moduli, the error function generally increased with this option. Therefore, it is suggested to employ this optional feature when a significantly higher/lower modulus in the subgrade intermediate layer is observed compared to the other adjacent layers.

Figure 1a

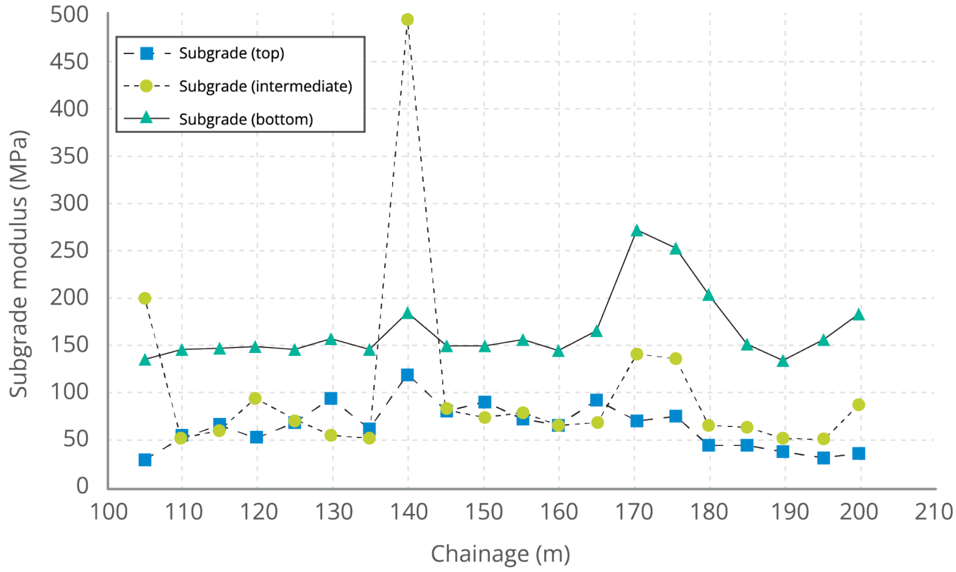

Figure 1b

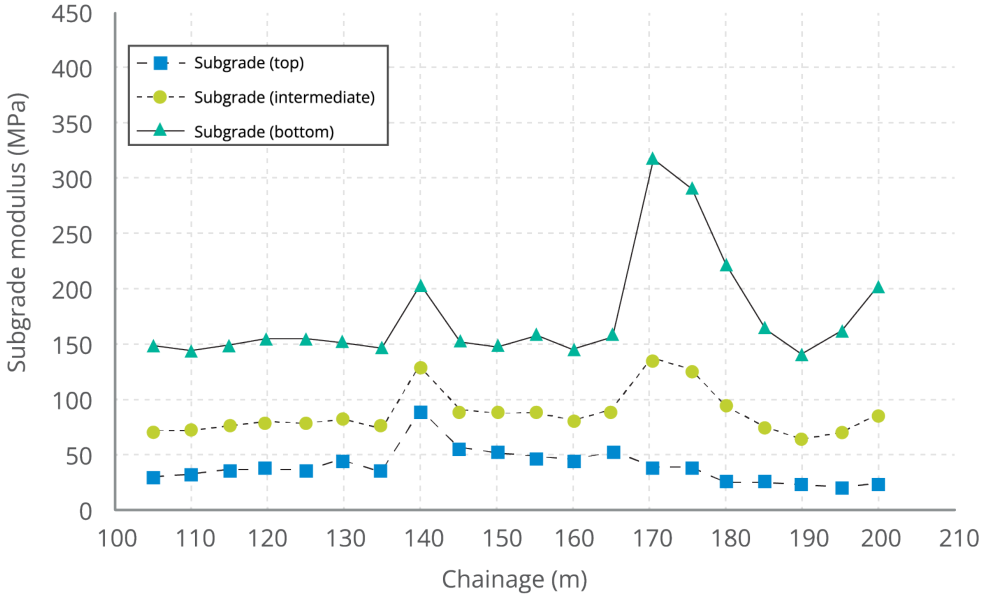

Figure 1. back-calculated moduli of the three subgrade sublayers: (a) analysis with no constraints; (b) analysis using the subgrade constraints and granular sublayering rules. Source: Austroads (2019a)

Figure 2 shows another example related to the first case study. This figure demonstrates the back-calculated moduli of granular base and subbase layer while the subgrade constraints and granular sublayering were separately applied in the analysis. In this figure, sublayering represents back-calculation analysis using the option of granular sublayering.

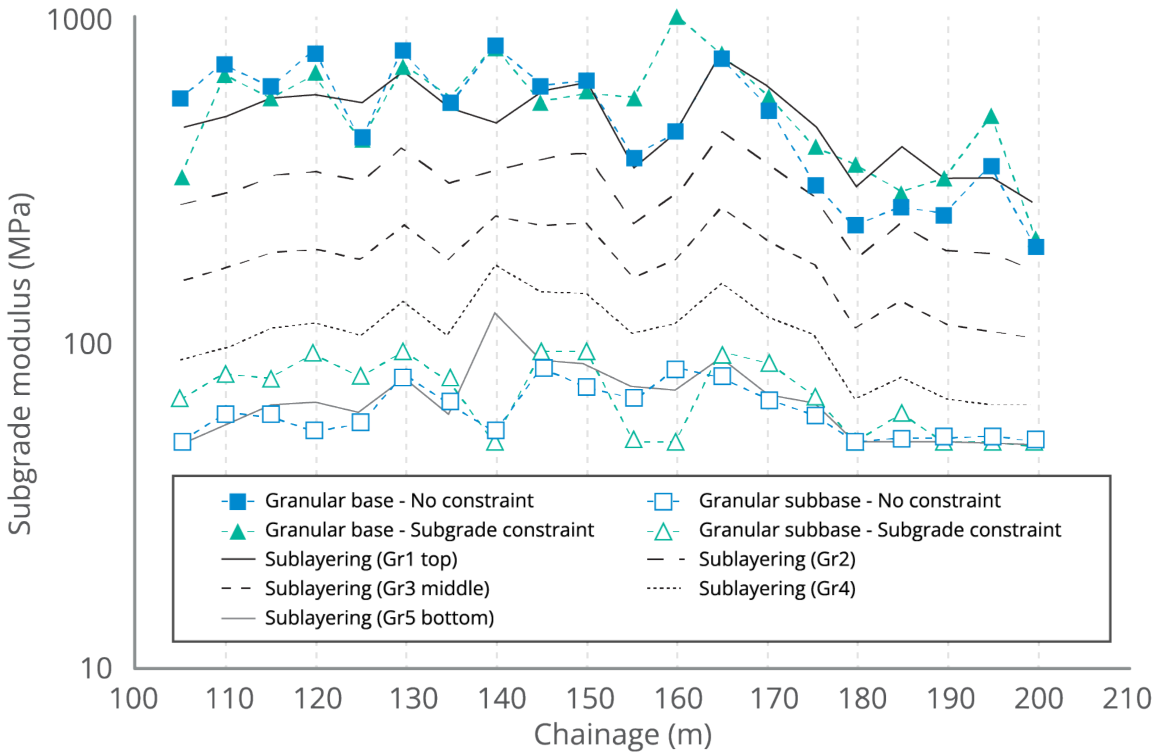

Figure 2. back-calculated moduli of the granular layer with and without the constraints. Source: Austroads (2019a)

The results showed that the subgrade constraints did not have a significant influence on the final moduli obtained for the granular base and granular subbase layers. As shown in Figure 2, these two layers generally exhibited similar moduli with and without subgrade constraint.

When the granular sublayering constraint was employed, the moduli of the granular sublayers (Gr1 to Gr5) were gradually decreasing from the top (Gr1) to the bottom (Gr5). In this case, Gr1 to Gr5 generally exhibited the moduli within a similar range to the ones from the base and subbase without the constraints (see Figure 2).

Also, the analysis conducted based on the two case studies in this project showed that applying the constraints options did not generally affect the back-calculated modulus of asphalt layers.

Conclusion

This project developed the AustBack algorithm for the determination of pavement layer and subgrade moduli using the measured pavement surface deflections. Detailed and comprehensive step-by-step sequences of the iterative procedures, in addition to the required mathematical expressions used in the back-calculation model, were developed and presented and can be found in Austroads (2019a).

The optional treatment features of the moduli constraints for granular sublayers and the moduli constraints for subgrade sublayers were also embedded in the model to improve the algorithm. The subgrade constraint enabled the gradual change of subgrade modulus with depth using a linear relationship. The proposed granular multilayering approach was consistent with the design pavement model (Austroads 2018).

In addition, a method to determine the seed values for the subgrade sublayers was developed using the composite modulus concept, which enables the users to define appropriate input parameters for the back-calculation analysis.

Finally, the algorithm with and without the two options was tested and validated using the FWD measured deflection data from actual case studies, and the benefits of the optional features were demonstrated.

Acknowledgement

The authors wish to acknowledge the original project work that informs this article, which was undertaken for, and is detailed in, Austroads (2019a).

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Research and Development Update – Development of Bio-binders for a Post-bituminous World

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Watch Interview »

Introduction

Addressing the impact of human activity on the environment has been increasingly at the forefront of academic and industry research activities. Although many industries are developing means to tackle this, few have the capacity to affect it at such a scale as infrastructure.

As non-renewable fossil fuel deposits start depleting, a relative increase in the price of bitumen will be noticed (Austroads, 2012). For countries like Australia, which have extensive road networks requiring yearly maintenance, this may significantly impact infrastructure quality and development. The annual requirement for bitumen in Australia exceeds 800,000 metric tonnes (Asphalt Institute, 2022). This short research update introduces one of the R&D projects NTRO is undertaking aiming to investigate the development of bio-binders to fully or partially replace bitumen in flexible pavements. It summarises the theoretical background for the research and outlines the approach the project is to follow. It is one of five projects aiming to solve challenges Australia is yet to face.

Main Drivers for the Research

Bituminous materials find a variety of applications in road infrastructure and with more than 800,000 km of road network in Australia (ARRB, 2022), they are always a topic of interest. Bituminous materials primarily derive from fossil fuel, but with petroleum oil reserves becoming depleted there is a desire to investigate adhesives from renewable resources (Metwally and Williams, 2010). Recent fluctuations in the price of petroleum have also created uncertainty that has shifted the focus towards alternative solutions such as bio-binders. Even though the topic has previously been investigated, with applications on flexible pavements dating back to 2007 (Al-Sabaeei et al., 2020), bio-binders commonly accepted by local councils and contractors alike are yet to be developed (Bao et al., 2020). Regardless, it is expected that bio-binders still have potential, as they have been found to have similar components as these of conventional bitumen – namely asphaltenes, aromatic, resina and saturates (Chen et al., 2018, Dhasmana et al., 2015). At the same time, there is great potential in Australia to establish farms growing native flora that thrive in the Australian climate, as well as solid organic waste that needs to be diverted from landfill (ARRB, 2022).

Theoretical Background

Bitumen has an integral role in road construction. It is a non-crystalline material comprising mainly heavy hydrocarbons and has complex rheological characteristics (Ahmad et al., 2017). Bitumen functions as the adhesive in flexible pavements and provides water-proofing characteristics, protecting the subgrade layers (Aziz et al., 2015). Bitumen, however, is produced using fossil fuels and so alternatives to this scarce resource warrant investigation (Metwally and Williams, 2010).

Bio-binders are a potential alternative. To produce bio-binders, an appropriate source of biomass needs to be defined that, with the right processing, will produce bio-oils. Bio-oils are further processed to then produce bio-binders. Bio-binders can be incorporated through various formulations in road pavements. They may be incorporated as replacement for bitumen (100 %); as bitumen extenders (part bitumen replacement 25 – 75 %); bitumen fluxes (part bitumen replacement 7 – 15 %); or as bitumen modifiers (< 10 %); all depending on their properties (Airey et al., 2008).

The properties of bio-binders depend not only on the production process but also the selected biomass (Cai et al., 2018). To successfully substitute or replace bitumen with a bio-binder, the latter should demonstrate certain performance characteristics vital to its suitability for application in flexible pavement construction. They require viscoelastic behaviour that indicates adequate relaxation and creep characteristics, as well as resistance to thermal-oxidative aging and low water susceptibility (Fini et al., 2011).

Biomass

Biomass derives from plants and other organic waste and is used to generate fuels and/or energy (Wang et al., 2020). There are multiple sources of biomass, including wood and agricultural residues, as well as biowaste from households, farms and industry (ARRB, 2022). The great variability in biomass sources will understandably result in bio-oils and bio-binders with different chemical and, as a result, performance characteristics (Dong et al., 2019). It has been previously found that bio-binders produced from corn stover, switch grass and oak wood demonstrate properties similar to those of bituminous binders (Peralta et al., 2012).

Biomass comprises hydrogen, oxygen, nitrogen, sulphur and primarily elemental carbon. Typically, herbaceous biomass yields lower carbon, lower hydrogen, greater nitrogen and greater sulphur contents when compared to woody biomass. Woody biomass primarily consists of three polymers, namely hemicellulose, cellulose and lignin. Hemicellulose is a branched amorphous heteropolymer with relatively weak intermolecular bonds. Cellulose, on the other hand, is a high molecular weight polyssacharide formed by strong intra- and intermolecular hydrogen bonds. Lastly, lignin is an aromatic compound often treated as a natural polymer, which has some binding capacity and a hydrophobic nature (Gollakota et al., 2018). The phenolic groups in lignin provide some antioxidant effects by capturing and reacting with oxygen containing free radicals (Peralta et al., 2012).

Production Methods for Bio-oils

Bio-oils can be derived through liquefaction or more commonly through pyrolysis (Alper et al., 2015).

Pyrolysis is the process of burning biomass under an inert atmosphere, yielding biochar, gaseous products and bio-oils (Alper et al., 2015, Alvarez et al., 2018). Biomass is degraded through a series of complex thermal reactions in the absence of oxidizing agents (Fini et al., 2011). The distribution of the process's three products depends on the heating rate and temperature, among other factors (Ingram et al., 2008). Typically, fast pyrolysis produces 10 – 20 wt.% gases; 15 – 25 wt.% bio-char; and 60 – 75 wt.% bio-oils (Peralta et al., 2012). Slow pyrolysis introduces heat in the system at a rate between 5 and 80 °C/min, which results in the material having residency times up to 30 min; while fast pyrolysis is related to short residency times, between 10 and 20 s, as a result of a heating rate of 1000 °C/min (Jena and Das, 2011). Vacuum pyrolysis has also been investigated for the production of notable amounts of bio-oils. The process involves the pyrolysis of biomass at 450 °C under pressure of no more than 20 kPa (Mohan et al., 2006).

Parameters that can be controlled and will affect the outcomes of fast pyrolysis include particle size, heating rates, char separation, liquid collection, ash separation, moisture content, reactor configuration, reaction temperature, vapour residency time, heat supply and transfer, and secondary cracking (Peralta et al., 2012). For successful fast pyrolysis, the temperature needs to be carefully controlled; the heat transfer rates need to be very high; the char needs to be quickly removed from the environment; while the vapor residency times need to be kept low and the vapours rapidly cooled (Alvarez et al., 2014). The parameters used during the process will affect the concentration of each of the products as well as their quality (Alper et al., 2015). Optimum for bio-oil production is a moderate temperature during processing and a short vapour residence time (Bridgwater, 2004). The process is also simple and requires a relatively low initial investment (Alvarez et al., 2018).

Hydrothermal liquefaction is a direct liquefaction process that takes place at temperatures between 200 and 400 °C and 10 – 25 MPa of pressure. When compared to thermochemical liquefaction and fast pyrolysis, hydrothermal liquefaction has a lower bio-oil yield capacity. Hydrothermal liquefaction produces bio-oils of superior quality when compared to pyrolysis, with greater heating values and low moisture content (Goncalves et al., 2021). During the process, the biomass is broken down through hydrolysis and then further decomposed through dehydration, dehydrogenation, deoxygenation and decarboxylation, while subsequent polymerisation may lead to the formation of complex chemicals (Gollakota et al., 2018). It has previously been discussed that bio-oil yield is greater at higher temperatures during processing, although an upper limit has been agreed to exist beyond which the oil yield starts decreasing again. Similar findings have been discussed for the residency time, where a duration threshold also appears to exist. Although there does not seem to be agreement as to what that optimum residency time is, literature agrees that greater residency times result in lower char yield, again with a threshold for optimum duration (Mahssin et al., 2021).

Production of Bio-binders

The produced bio-oil needs to further be treated to become a bio-binder suitable for road applications (Wang et al., 2020). Typically, crude oil is refined to produce usable components such as fuels and bitumen. The crude oil goes through a process called fractional distillation, involving an atmospheric and then a vacuum distillation step. Following the atmospheric distillation step, the long residue, comprising lubricating oil, paraffin wax and bitumen, remains in a liquid state. This is then further processed through vacuum distillation to produce distillates, gas oil and short residue. Bitumen is then manufactured from the short residue (Morgan and Mulder, 1995). The process is schematically illustrated in Figure 1.

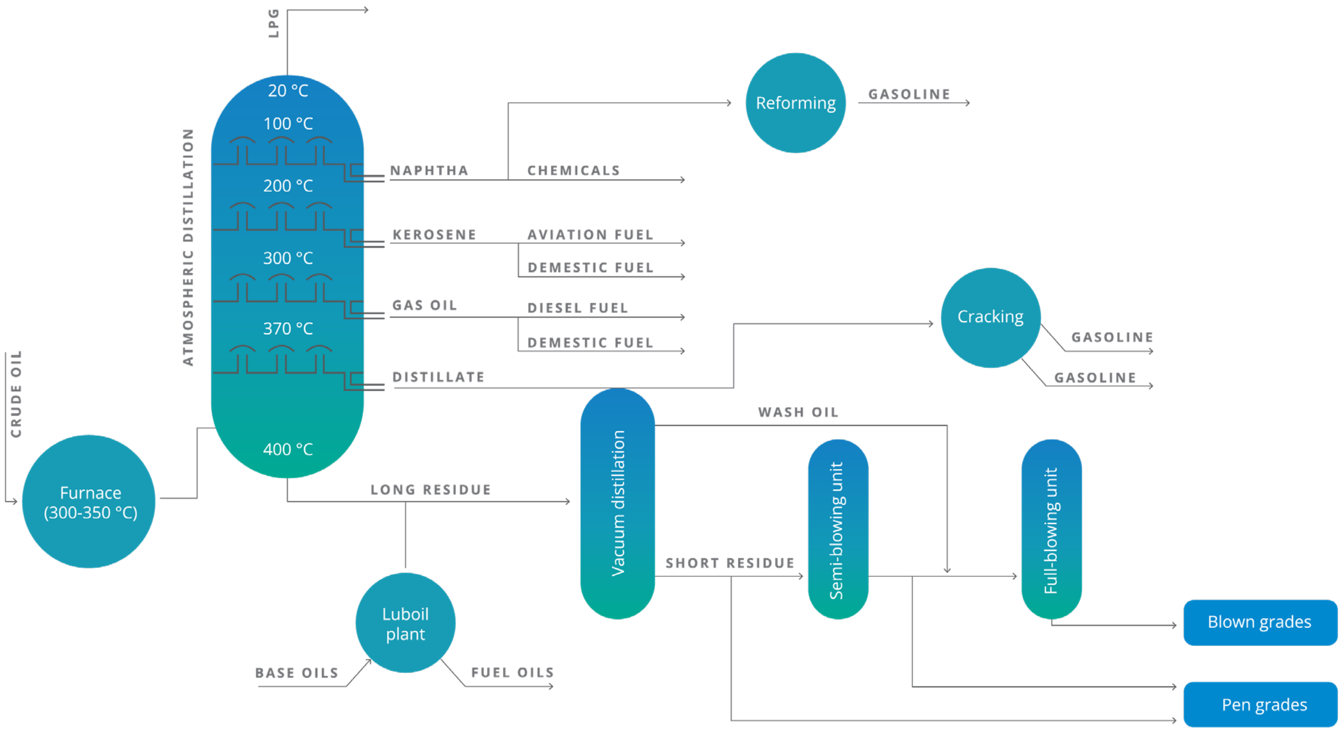
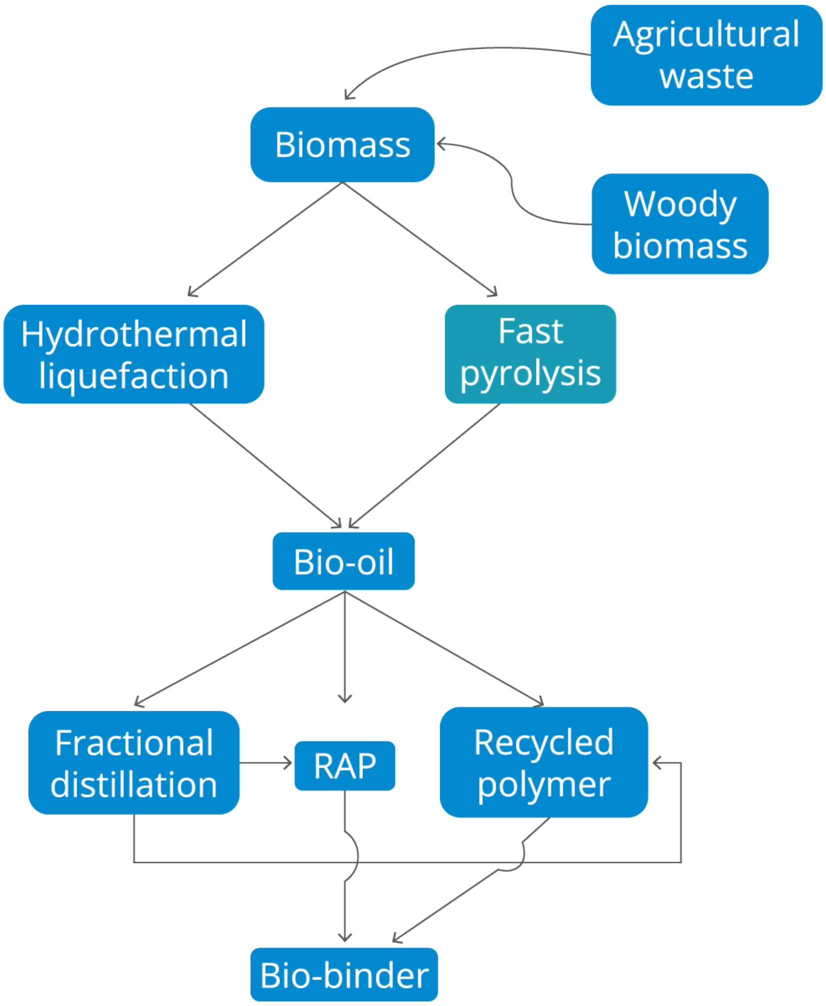


Figure 1. Schematic illustration of crude oil refining process. Adapted from Morgan and Mulder (1995).

In the case of biomass-derived bio-oil, further processing can include processes such as harmonic and oxidation processes, as well as distillation, similar to the processing crude oils undergo, and further polymer modification. Distillation may also be used along with the other three processes (Su et al., 2018).

Research Approach



Future of the Research

Two sources of biomass are to be investigated for producing bio-binders: one woody biomass that can naturally thrive in the Australian climate; and one from agricultural waste. The former is necessary to understand when the latter cannot meet demand; while investigating the potential of agricultural waste not only allows for its diversion from landfill but also ensures that production does not compete with that of food.

It was understood early on that critical collaborations need to be formed to transition from the biomass to the bio-oil as the processes most suitable, namely hydrothermal liquefaction and fast pyrolysis, are not available at NTRO's state-of-the-art laboratory. Following the production of the bio-oil, various formulations are to be investigated to assess the suitability of the products for use in flexible pavement applications. Specific challenges that need to be overcome include:

- the rapid oxidation of bio-binders
- the relatively low viscosity of bio-binders
- compatibility with existing bituminous materials.

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Towards More Sustainable Road Tunnels in Australia and New Zealand: Recommendations for Practitioners

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7







Introduction

Sustainability is important for many reasons but fundamentally it is not about what we should do for the environment, it is something we must do to preserve our quality of life and of all life on the planet. It is particularly important for road tunnels because compared to a road at grade, a road tunnel has a substantially larger carbon footprint due to the significant efforts required to build it and the nonstop operation of its systems through its life cycle. In Australia and New Zealand, governments have committed to achieving net zero emissions by 2050. Organisations responsible for delivering and operating road tunnel infrastructure will have an obligation to reduce embodied and operational emissions as far as practicable, as the tunnels will exist beyond 2050.

This article is based on a research project commissioned by Austroads, the collective of transport and road agencies in Australia and New Zealand. The research presented in this article was undertaken as the basis for updating the Austroads Guide to Road Tunnels on the topic of sustainability (Austroads 2022a, b, c, d, & e). This research is publicly available here: austroads.com.au/publications/tunnels/ap-t364-22

In addition, this research was presented as part of the 2nd International PIARC Conference on Road Tunnel Operations and Safety & VIII Spanish Tunnel Symposium. Further information on this conference can be accessed here: https://www.piarc-tunnels-spain2022.org/

This article summarises this research by providing a definition for sustainability in the context of road tunnels; how sustainability fits within the lifecycle of a road tunnel; and case studies of sustainability initiatives for energy efficiency, lighting, ventilation and portal emissions.

Defining Sustainability in Road Tunnel Developments

At the heart of this research was the concept of sustainability. It can be a complex and evolving subject whose definition may vary from country to country, industry to industry and from time to time. Therefore, defining sustainability appropriately in the context of our research ensured that the solutions developed would be fit-for-purpose for tunnels in Australia and New Zealand.

The research identified three related concepts that contribute to sustainability in road tunnel development: sustainability; infrastructure sustainability; and road tunnel sustainability.

According to the United Nations, achieving sustainability is meeting "the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). This is known as an outcome-based understanding of sustainability and is adopted by Infrastructure Australia (IA) (Infrastructure Australia, 2021).

According to the Infrastructure Sustainability Council (Infrastructure Sustainability Council, 2021) infrastructure sustainability can be defined as "infrastructure that is designed, constructed and operated to optimise environmental, social and economic outcomes of the long term". This version highlights the need to undertake a life-cycle approach to achieve desirable sustainability outcomes.

PIARC (2017) highlights the social, economic and environmental principles as the three pillars that will support the development of sustainable road tunnels. However, the sustainability pillars are not independent; they interact with each other. PIARC (2017) describes the interaction between the pillars such that if the:

- economic and social pillars are both addressed, then the process is equitable
- economic and environmental pillars are both addressed, then the process is viable
- environmental and social pillars are both addressed, then the process is bearable.

One measure, or set of measures, for a road tunnel project to be considered truly sustainable is if all three sustainability pillars are supported. However, this is hardly ever the case in practice. For example, construction of a new tunnel may benefit the economy and have social benefits but may not be positive for the environment. The choices made for sustainability are therefore the result of compromise, balancing the pillars using methods including multi-criteria analysis or a societal cost-benefit analysis to quantify and/or weigh the economic, social and environmental effects.

The Importance of Considering Sustainability in the Context of Road Tunnels

Road tunnels are energy-intensive elements of infrastructure. Their construction demands a large amount of natural resources and material such as cement, aggregate and steel. In use they require continual operation and maintenance and periodic major refurbishments and upgrades. They generate a large amount of carbon during their operation and maintenance phases. Typically, more than 60% of the total embodied carbon and operational carbon of a project is produced during its operational lifetime (Duarte, Cooke and Thomas, 2013). As road tunnels have a lifespan of around 100 years, any investment in sustainability will therefore have a long-lasting effect.

Compared to a road at grade, the energy used to build a tunnel is greater; but it is still small compared to the life-cycle energy requirements for its operations, as depicted in Figure 1.

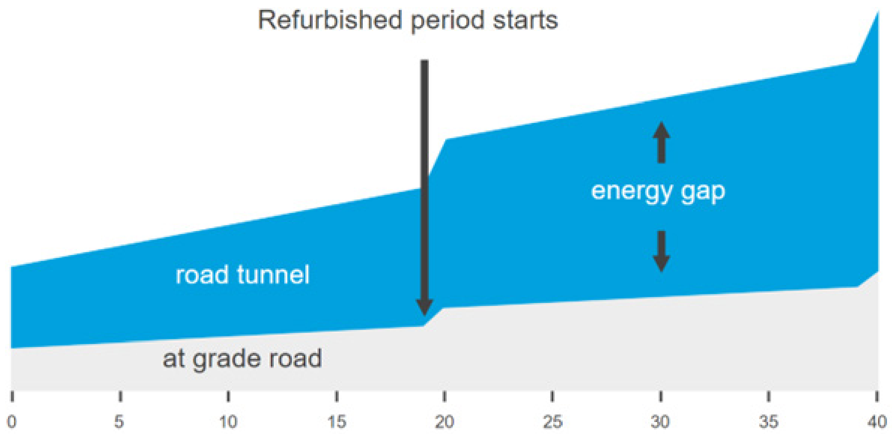

Figure 1. Comparative energy use of a road in tunnel and at grade © Duarte, Cooke and Thomas (2013)

How Sustainability Fits within the Life Cycle of a Road Tunnel

The scope to change the sustainability performance of a road tunnel depends on its developmental stage, with options to address sustainability issues becoming increasingly limited as the tunnel approaches further advanced stages of its development.

The earlier a sustainability initiative is considered during the life cycle of a project, the better the chance it has to be fully coordinated and incorporated into its lifetime. It will also be less costly to implement. The influence on sustainability outcomes for the life-cycle phases of a road tunnel project are:

- Procurement – whether procurement occurs before or after the planning and design phase, the procurement structure can have significant impact on sustainability. The priority for sustainability compared to other requirements such as time, cost and risk, will influence the sustainability outcomes for the full project life cycle.
- Planning and design – playing the most critical role in tunnel sustainability is the planning and design phase. The impact of this phase on the operation costs, and therefore maintenance, is significant (60 to 80%); this illustrates the significant influence this phase has when applied to the concept of sustainable development (Infrastructure Sustainability Council, 2021). The relative importance of individual life-cycle phases on the cost of tunnel maintenance is illustrated in Figure 2.
- Construction – during construction, the focus typically shifts to minimising energy consumption and waste and limiting impacts on the environment and community (PIARC, 2017). Many sustainability measures implemented during the construction phase still need to be identified early in the planning and design phase to be successful.
- Commissioning – during commissioning, there is generally less opportunity to improve the planned sustainability measures, as the purpose of commissioning is to validate that the tunnel is operating as designed. At this stage there is limited historical data available to evaluate potential efficiency improvements.
- Operations – the operation of a road tunnel is highly dependent on the design and construction phases that precede its commissioning (PIARC, 2017). Sustainability can still be supported in the operations phase by improving the measures planned and implemented from the design, based on the evaluation of effectiveness in practice (e.g. energy consumption and air quality). Consideration is often given to routine tunnel maintenance, reactive tunnel maintenance, life-cycle maintenance and tunnel services (e.g. electricity and water). Operations is also the stage where retrofitting is extremely difficult and expensive.

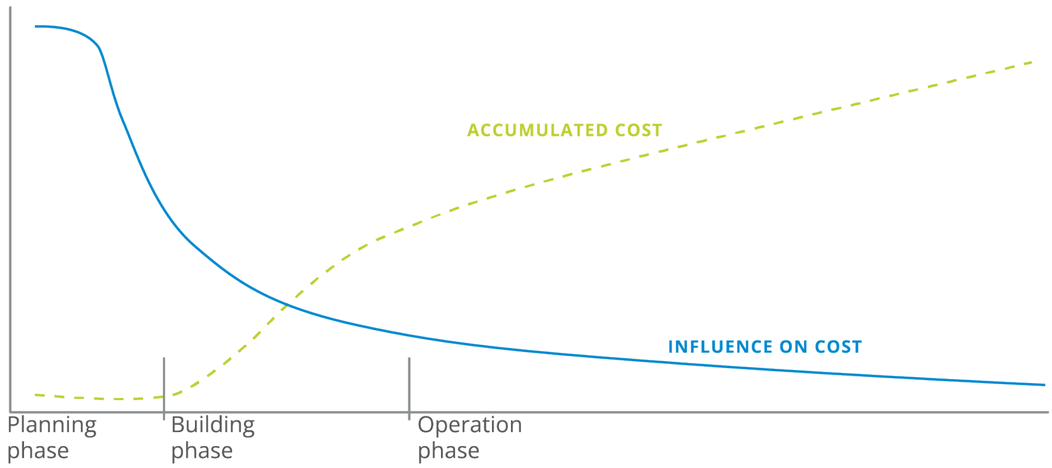

Figure 2. Relationship between the cost of maintenance and the level of influence on the costs © PIARC (2017)

Energy Efficiency in Road Tunnel Operations

As just noted, options to further improve sustainability performance are significantly reduced at the operation and maintenance stages. One exception is during tunnel operation, where there are ongoing training opportunities to raise employees' awareness of sustainable practices. Opportunities to improve sustainability performance are also present when a tunnel undergoes refurbishment. The extent of the impact will depend on the scale of refurbishment or upgrade. To capitalise on these opportunities, new sustainable technologies may be retrofitted to the existing tunnel. These technologies may include new systems (e.g. lighting and ventilation) that are more energy efficient and/or technologies for mitigating pollution from tunnel operations.

In terms of energy efficiency, major contributions to sustainability can be achieved through improvements to lighting and ventilation systems.

For example, the introduction of LEDs allows the lighting level to be tailored to the ambient lighting conditions of the time of year, time of day and weather conditions outside the tunnel. Further savings can be achieved by shade structures at the portals and by appropriate landscaping at the portals. These methods reduce the difference between the external and internal light level, with a consequent lowering of the artificial light required in the tunnel. Renewable sources of power, such as solar, can supplement energy demands.

Most road tunnels in Australia do not allow portal emissions, representing a significant constraint on the design of the ventilation system at the design and planning stages of a tunnel project (Conway, 2017). Outside Australia however, almost all road tunnels have portal emissions. To achieve zero portal emissions, all tunnel air is discharged through tunnel ventilation outlets to achieve ambient air quality environmental standards, which requires pulling air at the tunnel exit portal against the natural direction of traffic flow (piston effect). This requires operation of the tunnel ventilation system 24 hours a day and does not account for the likely reduction of emissions from vehicles built in the future (O'Kelly, 2020) nor the varying use of the tunnel through a given day and week.

Both the Eastlink Tunnel in Melbourne, Australia, and the Waterview Tunnel in Auckland, New Zealand, have implemented innovative approaches to ventilation such as managed portal emissions, to improve sustainability.

EastLink Tunnel (Melbourne, Australia) Ventilation Improvements

By introducing a more energy-efficient ventilation system, the EastLink Tunnel in Melbourne had its air emission licence amended in 2018 to allow for daytime portal emissions in addition to night-time emissions (EastLink n.d.). Two energy-conserving upgrades were supported by the extended emission hours. Shepherd and Monson (Shepherd and Monson, 2021) found that these upgrades reduced the energy used by the ventilation system by 68%, saving approximately 6.2 GWh or 9000 tonnes of CO2-e per annum. In addition, this halved audible fan noise. The upgrades applied were: (1) variable speed drives on fans, allowing the fans to operate at a more efficient lower speed; (2) an automatic control system, allowing monitoring of the output of the existing air quality and control of the operation and speed of each exhaust fan.

Waterview Tunnel (Auckland, New Zealand) Portal Emissions

The Waterview Tunnel in Auckland, New Zealand allows portal emissions. The conditions of consent for Waterview effectively require performance-based air quality criteria to be achieved at the nearest sensitive receivers to each portal. This enables the effects of dispersion and dilution to be taken in account while still requiring a clearly defined air quality outcome to be achieved (Hannaby and Wright, 2013).

Barriers to Sustainability

Through an extensive literature review and stakeholder consultation, this research identified some of the potential barriers to achieving good sustainability outcomes on tunnel projects. A few examples of these are:

- a lack of political will and policy-driven solutions towards sustainability.
- a requirement to permit new material usage but no incentives or rewards to do so, meaning suppliers are disinclined to create more sustainable products and contractors can't be expected to adopt them in competitive bids, particularly if – even if more sustainable – they are more costly.
- sustainability expressed in contract documents as one of many requirements but typically not given significant priority.
- rating systems that can be taken advantage of by adopting unrealistic business-as-usual standards against which to compare sustainability initiatives. To counter this, some jurisdictions have started to specify the business-as-usual standards in their tender processes.

Achieving Sustainability Success

To conclude, this following discussion provides an example of a typical sustainability approach and considerations for a road tunnel project.

The success of a project in achieving meaningful sustainability outcomes requires:

- clear commitment and leadership to deliver sustainability outcomes
- identification of minimum, feasible and effective sustainability requirements; and the embedding of accountability in these requirements
- contract requirements structured in such a way that the project team and client prioritise sustainability
- projects managed so that design and construction decisions consider sustainability outcomes, suitable prioritisation to be applied, and sustainability to be integrated across all disciplines and phases of the project
- a sustainability plan to be prepared and supporting investigations and activities to be undertaken.

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Hazardous location identification for head-on collisions with roadside assets and objects: A deep learning approach

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Introduction

In road safety, the "killer tree" problem refers to a head-on collision with a pole/tree and contributes to 30-50% of Australian road fatalities (Morris et al. 2001). As such, hazardous trees are a component of the International Road Assessment Programme (iRAP) star rating process for road safety inspections, impact assessments and designs. However, repeat iRAP ratings of a specific road segment are performed less frequently than the rate at which vegetation can grow from a non-hazardous size to a hazardous one (e.g. possible in 3-12 months). Additionally, the iRAP rating process is applied manually, which is time consuming and costly.

Developing a lower-cost, more innovative and faster network monitoring system is considered highly desirable. A promising approach to achieve this, and better monitor gradually changing assets, is to enable automated and semi-automated network monitoring with artificial intelligence (AI) and machine learning (ML). As such, the Australian Road Research Board (ARRB) was commissioned by the Queensland Department of Transport and Main Roads' (TMR) Spatial Labs to develop an end-to-end model for detecting and classifying road assets and vegetation that detects and maps killer tree hazards.

By implementing state-of-the-art deep-learning algorithms for an efficient classification and detection system, and noting that the identification of killer tree hazards is a three-level process (Figure 1), the methodology proposed by ARRB will help identify killer trees and flag the geo-locations in a Geographic Information System (GIS). This will facilitate infrastructure management agencies to act against noted hazards and carry out necessary treatments.

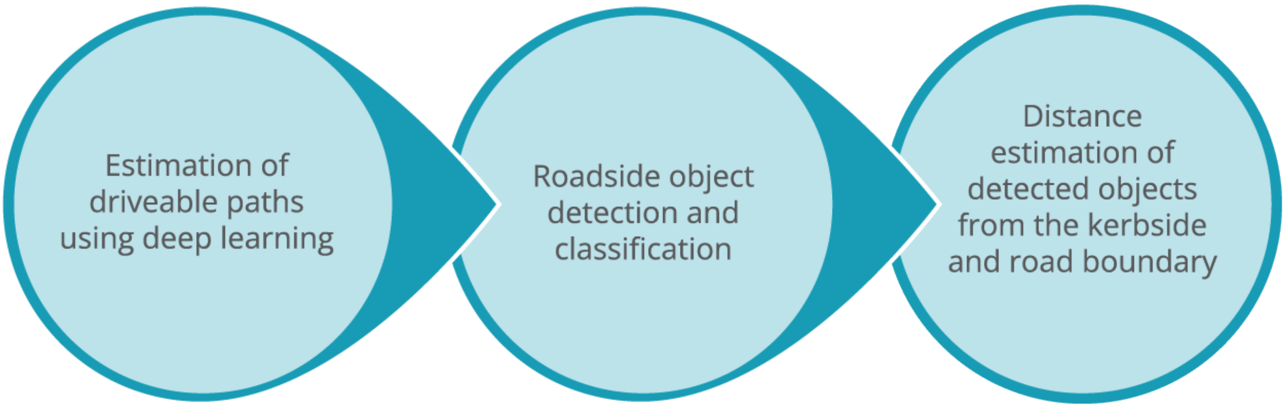

Figure 1. Three-level process to identifying killer tree hazards using AI/ML

The challenges in existing data collection and processing methodologies used for road safety and asset management were also considered (Table 1). To overcome the challenges to detecting hazardous locations with the presence of roadside objects (e.g., killer trees), this project pursued the development and evaluation of an AI tool.

Challenge	Description
Cost	Raw data collection, annotation and post-processing for ratings require intensive, manual, human monitoring (e.g., for identifying defects and/or road network changes) of thousands of kilometres of footage and are thus costly.
Time	Surveys are performed less frequently than required to account for significant vegetative growth. Increasing survey frequency for more up-to-date information would be, timewise, almost impossible to process manually.
Data	Advanced automated technologies collect large amounts of raw data, which is costly to ingest and process on the backend.
Automation	Detection and classification of hazards: most road ratings are assessed manually and not all the safety attributes can be captured automatically.

Table 1. Data collection challenges/gaps

Data description

Digital Video Road (DVR) is a type of video data created from the road data annually collected by ARRB for all state-controlled roads in Queensland. The DVR data consists of two sets of data files:

- Spatial video - image footage of recorded locations at 10 m intervals, and
- Navigational (NVG) - calibration metadata and the GIS information associated with each video frame.

Spatial video data comprises frames taken at 10 m intervals from 7 different directions - forward, left, right, rear, left side, right side, and the road surface (generated at 5 m intervals). Depending on the surveyed road section's length, multiple files are generated for each camera. Figure 2 shows an example of all captured directions when viewing files in a DVR viewer.

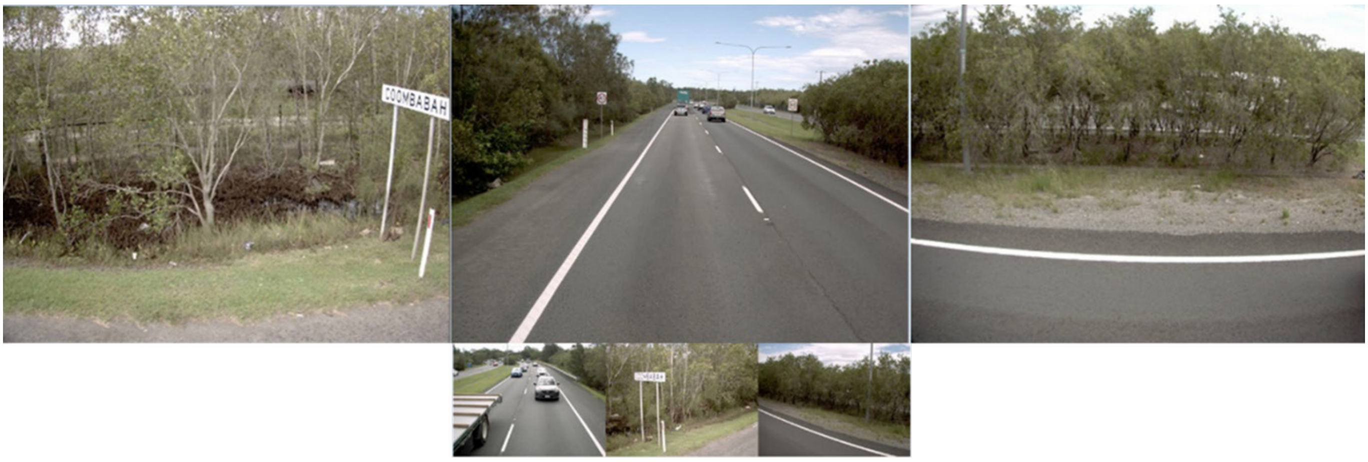

Figure 2. Example of video data when opened in a DVR viewer

NVG files store the metadata and attributes listed in Table 2, including those used for each DVR (e.g., road name, lane number, etc...). NVG file data, including for road chainages, GPS coordinates, altitude and frame numbers, are collected at 10 m intervals and at 5 m intervals for the NVGX file (i.e. NVG file with additional information from extra cameras and the road surface video).

NVG file attributes and metadata			
Survey vehicle type	Codec	Calibration plane type	Flip image
Survey date	Compression level	Calibration point type	Chainage
Survey time	Offset forward	Pixel X	Section ID
Road name	Offset right	Pixel Y	Sectional chainage
Carriageway number	Height	Distance X	Latitude
Lane	Pan	Pan	Longitude
Direction	Tilt	Distance Z	Altitude
Description	Resolution	Calibration point	Frame number for each camera
Comment	Field of view	Calibration plane	
Camera name (direction)	Calibration	Filenames (AVI files)	

Table 2. List of NVG file attributes and metadata

Methodology

The project proposed that by using the front view camera's DVR image data, training of a custom model could be undertaken for detecting killer trees and reporting the geographical location. An overview of the development process is described in this article, with Figure 3 below depicting the block diagram for the proposed methodology.

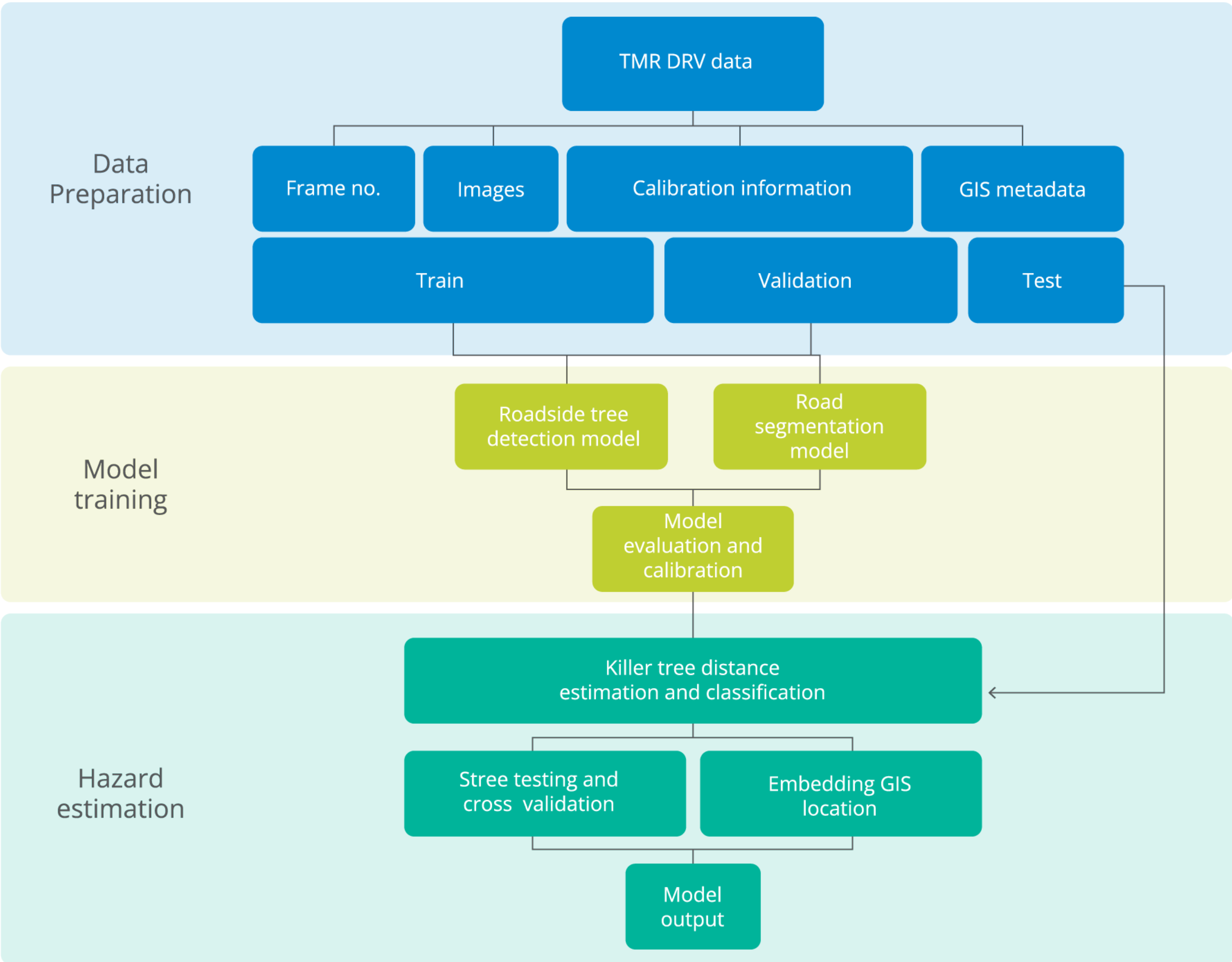

Figure 3. Proposed methodology

For data preparation, data is divided into training and testing. The latter includes annotating tree trunks and driveable paths using annotation tools such as OpenVINO's CVAT1 (utilised in this project). For ease of use and precision, tree trunks were detected utilising polygon coordinates/polygon masks, which allowed detection to the pixel and thus more precise distance estimations. Figure 4(a) shows an example of data annotated in this way. Upon annotating a few images, the data is exported with the polygon coordinates.

To determine the distance of a given object to the road, the boundaries of the road must be identified. While different approaches can be used for this road segmentation, it was decided to use the same object detection pipeline developed for tree trunk detection. Figure 4(b) shows an example of a labelled road used to train the model.

(a)

(b)

Figure 4. Example of annotated (a) tree trunks, and (b) road segmentation using CVAT

Detection model, algorithms and architectures

Transfer learning

Training a model from scratch requires extensive training data and resources. To reduce time and resources in developing a custom model, the project made use of transfer learning. This process is "the improvement of learning in a new task through the transfer of knowledge from a related task that has already been learned." (Soria et al. 2009).

The most vital task for this project is detecting tree trunks along the road corridor. To do this, an open-source project mask regional-based convolutional neural network (R-CNN)2 was utilised, which employed in its method feature pyramid networks, along with a ResNet101 backbone, to identify features. Then, a pre-trained model on the Microsoft Common Objects in Context (MS COCO) dataset (Lin et al. 2015) was utilised to identify anchors within images. The last layer of the model was then trained on the project data to identify tree trunks from these anchors.

Using this transfer learning process, the tree trunk and road segmentation model was trained by annotating 180 images, a relatively small data set, saving much time.

Tree trunk detection

Training data was exported with the polygon coordinates and the final layer of the model was then trained on the small tree trunk dataset. Figure 6 shows tree trunk detection results when bounding boxes or polygons were used for data annotation. The result shows that the trunks' edge detection using polygons outperforms the bounding boxes, so the project progressed with polygon annotation.

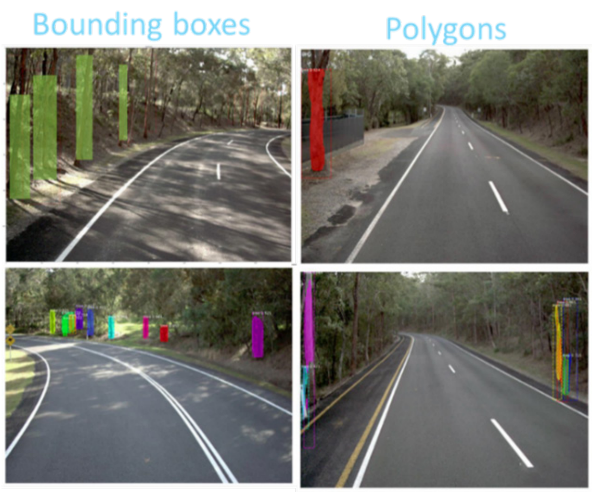

Figure 5. The impact of bounding boxes and polygons annotation on the trunk detection

Road segmentation

For road segmentation, an off-the-shelf MobileNet (Howard et al. 2017) model trained on the CityScapes dataset (Cityscapes Dataset 2022) was identified for use in the project. However, the available model wasn't deemed precise enough due to the inclusion of the road shoulder and gravel paths in its mask (Figure 7).

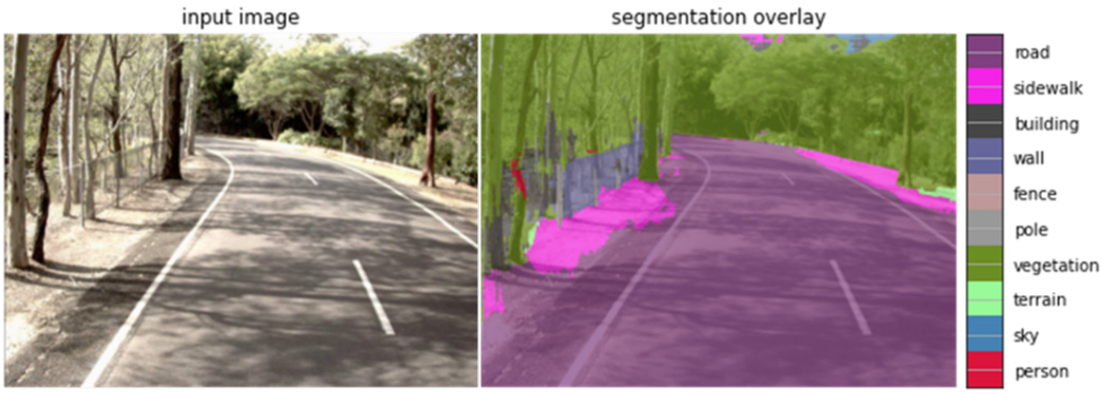

Figure 6. An example of using the shelf semantic segmentation on the DVR data using MobileNet

Source: (Howard et al. 2017)

To overcome this, a small data set was labelled and used to train the available model based on polygons with outside road lines in the labelling. This allowed the model to identify the drivable path of the road without including the shoulder. This was theorised to have better precision in road width estimation, allowing the width of any given road segment to be assumed as 7 m, based upon an average 2-lane road. Figure 8 shows the successful road segmentation and tree trunk detection using the proposed model.

Figure 7. Successful road segmentation and tree trunk detection using proposed transfer learning

Hazard distance estimation model

To estimate the distance of an object to the road, a pixel-distance ratio is used. As a typical road lane is 3.5 m, and the roads used as training inputs had two lanes, a driveable width of 7 m was assumed. Figure 9 shows points P and Q indicating the edges of the tree, and points T and U indicating the edges of the road. The difference in X-coordinate pixels was used to determine the distance of the tree, and its width, by calculating the pixel-driveable width ratio at that distance.

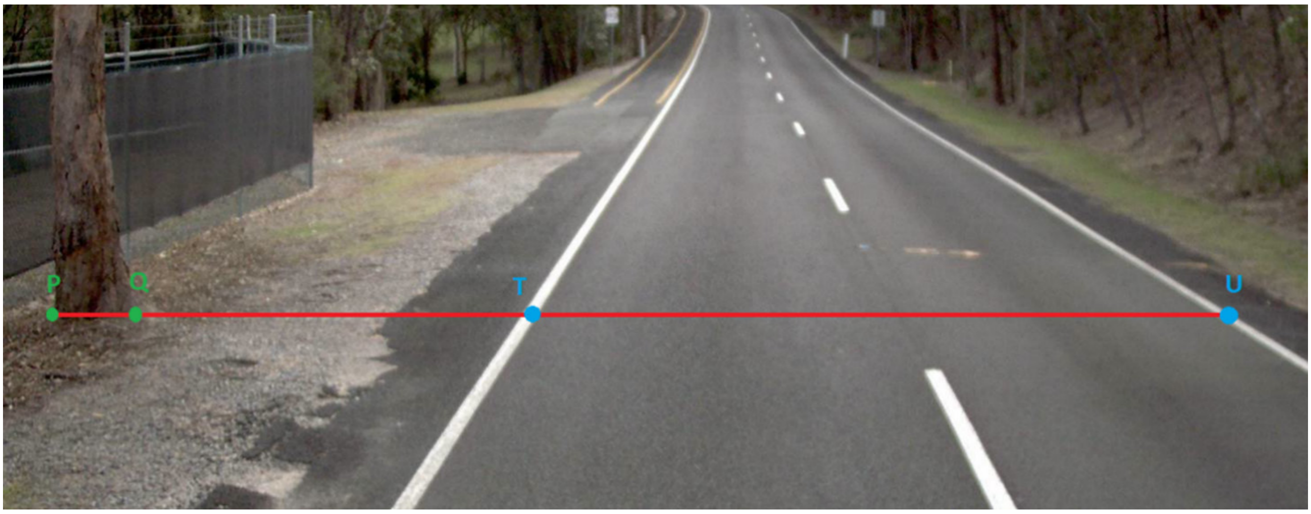

Figure 8. Image showing the distance estimation procedure.

To determine whether a tree is dangerous, iRAP ratings (IRAP 2021) are applied. These ratings provide three categories of the hazardous trees, all with trunks greater than 10 cm in diameter. In decreasing order of danger:

i. Trunks closer than 1 m to the road

ii. Trunks 1 to 5 m from the road

iii. Trunks 5 to 10 m from the road.

Detected trees are categorised based on calculated widths and distances, then multiplied by an extra 15% to account for any errors from the road to determine the danger category. These are then reported by the program along with real-world location coordinates and a survey date. Table 3 provides a program output example for both a location with, and one without, an identified killer tree based on iRAP rating for trunks greater than 10 cm in diameter and closer than 1 m to the road.

Date	Diameter (m)	Distance from road (m)	ID	Latitude	Longitude	Hazard category
11/06/2021	0.2894	0.7165	104	-27.6499	153.2307	i
11/06/2021	0.1568	6.2048	105	-27.6500	153.2306	iii

Table 3. Sample trunk detection GIS report and associated attribute

Evaluation result and discussion

The evaluation of the end-to-end performance of the proposed model (Figure 3) was undertaken by computer vision and pattern recognitions to compare the predicted vs actual condition outcomes of the model. Accuracy of the model, determined by the ratio of the total number of correctly identified samples to the total number of samples, was calculated using a confusion matrix (Table 4).

		Predicted condition	
	Total population = P + N	Positive (PP)	Negative (PN)
Actual condition	Positive (P)	**True positive (TP),** hit	**False negative (FN),** type II error, miss, underestimation
	Negative (N)	**False positive (FP),** type I error, false alarm, overestimation	**True negative (TN),** correct rejection

Table 4. Binary classification confusion matrix

Where:

TP = correctly labelled as accepted *TN = correctly labelled as rejected*

FP = incorrectly labelled as accepted *FN = incorrectly labelled as rejected*

The matrix provides insight into the system's overall performance, including the model sensitivity, specificity, miss rates and fall-out rates (Table 5). These metrics are reported on a range of 0 to 1 (respectively low to high). In general, a high sensitivity and specificity rate show that the system is good in killer tree detection and correctly rejects objects that are not killer trees.

Performance Measure	Description	Calculation
Sensitivity	True positive rate (TPR): how well true positives can be identified. High outcome = Model is good at detecting killer trees.	$TPR = \frac{TP}{TP + FN}$
Specificity	True negative rate (TNR): how well true negatives can be identified. High outcome = Model is good at identifying when there are no killer trees.	$TNR = \frac{TN}{TN + FP}$
Miss rate	FP ratio: how often the model is missing object identification. High outcome = Model is incorrectly classifying non-killer trees as killer trees.	$FPR = 1 - TNR$
Fall-out rate	FN ratio: how often the model is incorrectly identifying objects. High outcome = Model is missing out on identifying a lot of killer trees.	$FNR = 1 - TPR$

Table 5. System performance measures

Evaluation results for selected use cases

To evaluate the proposed algorithm, reported crash data from TMR3 and ARRB's road survey repository were leveraged to identify locations with prevalent trees and a type of crash identified as "off carriageway hit object". From this, Mt Cotton was selected as a control site and route No. 414_1 was selected as a "hazardous tree in driving scene" use case.

To avoid biasing outcomes, the evaluation data had not been seen before by the model. A total of 135 scenes were manually annotated using visual observation and binary decision making to find a trunk and decide on the killer tree potential of the object in each image.

Figure 10 shows the qualitative results of the proposed detection model on sequential images of a test road. The result indicates a consistent detection from one frame to the next. It is also observable that signs, bars or pillars are sometimes detected as a tree trunk. These false detections do not pose significant issue for the proposed end-to-end model due to size, height and dimension. The manual annotation shows that TP= 89 and FP = 7 for the selected samples shows the 96% accuracy of tree trunk detection using Mask-RCNN.

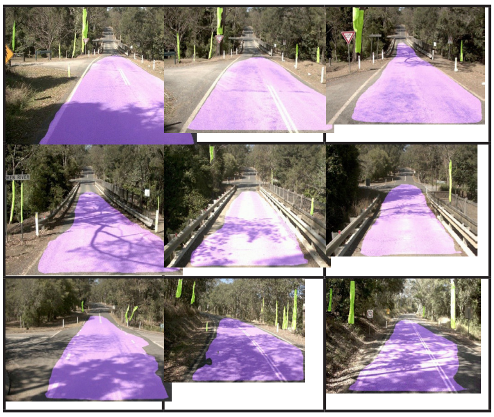

Figure 9. qualitative result on road segmentation (purple) and tree trunk detection (green) while driving. (a) to (i) are sequential video frames

The overall performance of the proposed method on the control and use case sites was evaluated to give an accuracy of 86% and 72% respectively, both acceptable performance levels. Overall, the proposed system was noted to have a high sensitivity and specificity, justifying the proposed model approach in detecting killer trees. The evaluation results for the selected use cases are provided in Table 6.

(a)		**Predicted condition**	
	Total population = P+N = 62+34	**Positive**	**Negative**
Actual condition	**Positive (P)**	**TP = 52**	**FN = 10**
	Negative (N)	**FP = 3**	**TN = 31**

Sensitivity = 0.84, model performance is good in detecting killer trees
Specificity = 0.91, model is good in identifying there is no killer trees
FNR = 0.1613
FPR = 0.0882
Accuracy = 86%

(b)		**Predicted condition**	
	Total population = P+N = 19+20	**Positive**	**Negative**
Actual condition	**Positive (P)**	**TP = 13**	**FN = 6**
	Negative (N)	**FP = 5**	**TN = 15**

Sensitivity = 0.68, model performance is good in detecting killer trees
Specificity = 0.75, model is good in identifying there is no killer trees
FNR = 0.3157
FPR = 0.25
Accuracy = 72%

Table 6. Performance evaluation of the proposed model for (a) Mt Cotton and (b) Route No. 414_1 use cases

Concluding remarks

By utilising deep-learning algorithms, a proof-of-concept, end-to-end model for the detection and classification of killer trees was developed with promising evaluation results. To scale up the proposed model to cover entire road networks, and maintain quality datasets on killer trees, further evaluation is required. The system would also need training through more meaningful/larger datasets.

Future research relies on more efficient data annotation. Although only 180 samples were used and achieved acceptable results (96% in detecting tree trunks), data annotation is still an extensive task. Aggregation of reported incident data with DVR is a complex task and proper data ingestion is required to integrate the proposed model into current safety datasets. As such, generating a data ingestion framework to undertake data annotation in a semi-automated way would be more appropriate for large-scale deployment. Additionally, the proposed data engine could be used to detect other assets such as signs, barriers, lane markings and traffic signs, to generate an inventory system.

Acknowledgment

This work was funded by Queensland Transport and Main Roads (TMR) as part of TMR Spatial Labs program 2022. The authors would like to thank FrontierSI for their inputs on this project.

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A better way of expressing and assessing competency requirements in the fields of road safety and traffic engineering

Paul Hillier

Competency is an essential determinant in whether a task or activity is completed successfully and efficiently, and can be defined as a combination of skills, job attitude and knowledge that is reflected in behaviour that can be observed, measured, and evaluated.

The author is encouraged that historical ranking ('next in line') and/or time-serving ('length of service') led prerequisites in appointing practitioners to key/senior technical positions or identifying practitioners to enter a development pathway are increasingly becoming superseded by more sophisticated, competency-based requirements inspired by the positive experiences of learning professionals. This evolution in thinking has also led to greater clarity, objectivity and equity.

This does not mean unnecessary complexity, as the learning profession has identified a number of useful models in existence that can be adopted in setting out and assessing the competency required of prospective and existing practitioners.

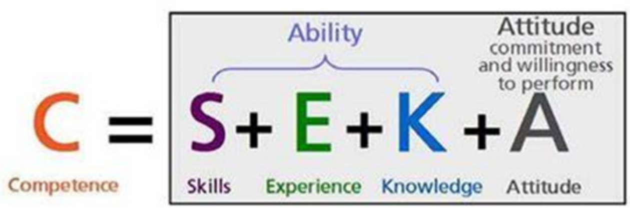
These range from a more basic coverage of:

KSE - Knowledge, Skills and Experience – where one scenario of usage is to qualify an expert witness in a courtroom

KSA - Knowledge, Skills and Attitude – widely used within the public health sector; and

KASH - Knowledge, Attitude, Skills and Habits

To the author's favoured SEKA Model as shown:



Source: thepeakperformancecenter.com

The SEKA Model shows that competence should be seen as a sum of a number of attributes (listed and defined here in alphabetical order):

- ability – possession of the means or skill to fulfil a task or role, or alternatively, talent, skill or proficiency in a particular area.
- attitude – a settled and consistent way of thinking or feeling about a task or role.
- experience – practical contact with, and observation of, facts or events.
- knowledge – a body of facts or information acquired through experience or education that gives the theoretical or practical understanding of a subject or task, so allowing its performance. It is stressed that studying technical/scientific articles and texts alone does not constitute competency.

Attitude is highly significant in influencing performance and is widely held as the most important factor in learning, to build upon the potential provided by knowledge and skills. Unfortunately, attitude is one of the more difficult attributes to accurately and reliably assess!

- skill – the capabilities or proficiencies developed through specific training or hands-on experience to enable a task to be performed successfully, i.e. skills are accrued by practically applying knowledge.

The SEKA Model has been adopted very successfully as a framework to then set out the specific competencies required by road safety or traffic engineering practitioners in a role or through a career path, e.g. job applications; or to qualify to fulfil a specific task, e.g. road safety auditor or road safety audit team leader.

The standard Australian Qualifications Framework (AQF) approach promotes the development of predefined Units of Competency, which are then further categorised into Elements of Competency, and the requisite skills, experience, knowledge, and attitude matched and then assessed against. Units and Elements of Competency can range those deemed 'essential' or 'core' (i.e. a defining capability or advantage that distinguishes that person or role) to 'secondary', 'tertiary' and 'other'.

The assessment process is detailed to ensure both consistency and objectivity, and nearly always involves the preparation of a formal submission (sometimes called a portfolio of evidence) by the applicant seeking the position or role. A degree of self-assessment will typically be required as a pre-requisite, before moving to a peer consideration as to whether the applicant has satisfied competency against the Units and Elements within that framework.

A range of assessment methods/tasks is typically specified, including, for example; face-to-face interviews using a standard set of questions; consideration of testimonials and references; provision of past project reports, a work journal and/or professional CV/resume tailored to the pertinent role or task; and records of Continued Professional Development (CPD) and/or Recognition of Prior Learning (RPL).

As new technology continues to emerge and develop, a portfolio of evidence will increasingly include emails, data sets, program/application outputs, e-based learning, e-workshops etc.

Closing summary

Utilising the experiences of the learning profession by adopting a competency model and framework has considerable advantages, as identified in this article. Such an approach has been successfully applied by the author in the fields of road safety and traffic engineering and can break any historical dependency on rank ('next in line') and/or time serving ('length or service'). The latter has been identified as an issue in the industry, with too much expectation (or perceived right) that a person will be promoted to fill a senior role, enter a development pathway or gain permission to fulfil a specific task such as road safety auditing or leading post incident investigations, just because they have met a time-based criterion and/or been doing a similar job for a certain length of time. Such practice is only valid and not subject to question where a robust, objective assessment of competency also typically takes place.

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