Collaborative Rail R&D –
Successes, Challenges and Future Opportunities

A Rail Manufacturing CRC Perspective

SUMMARY

Funded jointly by participating Australian and international rail organisations and the Commonwealth Government's Cooperative Research Centres Program, the Rail Manufacturing CRC began operations in 2014 for a term of six years, with a focus of driving the development of new products, technologies and supply chain networks to enhance the competitiveness of Australia's rail manufacturing industry.

By supporting and sponsoring collaborative research between industry and publicly-funded research agencies, the Rail Manufacturing CRC aided the development of technologies that will lead to new opportunities for Australian manufacturers.

With the Rail Manufacturing CRC's closure in June 2020, this report focuses on sharing the recent innovation successes and provides insight into future opportunities and challenges facing the rail sector over the coming decade.

Australian Government
Department of Industry, Science, Energy and Resources

Business
Cooperative Research Centres Program

The Rail Manufacturing CRC's PhD students - January 2019

1
INTRODUCTION

From its formation in 2014, the Rail Manufacturing Cooperative Research Centre (CRC) worked closely with leading proponents of the Australian rail industry to increase research and development (R&D) and innovation in the rail sector.

Over its six years of operation, the Rail Manufacturing CRC developed projects with organisations including Downer, Knorr-Bremse, CRRC, Bombardier Transportation Australia, Sydney Trains, Queensland Rail, Aurizon, HEC Group, Australasian Railway Association, TrackSAFE Foundation, Global Synthetics, Foundation QA, Airlinx, OneSteel and the Victorian Government's Department of Transport.

As projects were identified, industry organisations were matched with world-class researchers across Australia's research institutions, including CSIRO, CQUniversity, Deakin University, University of Technology Sydney, Monash University, RMIT University, University of Queensland, Queensland University of Technology, University of Wollongong, Swinburne University of Technology and Victoria University.

The Rail Manufacturing CRC's project portfolio included work in research areas such as battery and supercapacitor development, new braking technologies, bearing maintenance optimisation, the use of new materials for rail manufacturing, integrated passenger information systems, condition-based monitoring systems, more efficient analysis of rail infrastructure, train operations diagnostics, and improvements to train cabin ventilation.

This report provides a broad overview of several of the Centre's key projects. Furthermore, the background to the establishment of the CRC will be provided along with key learnings from the last six years. Finally, the report will provide a synopsis of future challenges and opportunities that the rail sector will need to face in the coming decade.

More details on the Centre's projects can be found at www.rmcrc.com.au.

2
RESEARCH FOCUS AREAS

The strategic direction for the Australian rail supply chain was last captured in the 2012 *On Track to 2040 – Preparing the Australian Rail Supply Industry for Challenges and Growth* roadmap (reference 1).

The roadmap was developed following intensive engagement and collaboration with over 210 industry participants, who identified three priority research areas that should be pursued: Power and Propulsion, Materials and Manufacturing, and Monitoring and Management.

The roadmap also defined the need for a collaborative research entity dedicated to innovation in rail supply, which subsequently supported the establishment of the Rail Manufacturing CRC in 2014.

Given the extensive work undertaken in the *On Track to 2040* roadmap, the Rail Manufacturing CRC used its findings to help define the Centre's own three key research programs for delivery;

» Power and Propulsion;

» Materials and Manufacturing; and

» Design, Modelling and Simulation.

2.1 Power and Propulsion

This research program area focused on energy, cost efficiency and improved competitive performance in advanced rail manufacturing through research, development and commercialisation in energy regeneration and storage, and advanced braking systems.

Within this program, industry projects were conducted in supercapacitor power applications and energy management systems, lithium-ion battery development, advanced braking control systems, and new composite disc brakes.

2.2 Materials and Manufacturing

This second research program area focused on the development of new materials, component monitoring, and manufacturing processes in rail.

A wide range of projects were conducted within this program, including condition-based monitoring systems for rail components and optimised maintenance regimes, robotic assembly and maintenance of rollingstock, low fume MIG welding, axle bearing maintenance optimisation, laser repair of rail components, and the manufacture of lightweight train panels.

2.3 Design, Modelling and Simulation

The third research area aimed to enhance industry competitiveness through research, development and commercialisation in advanced design and simulation, automated health monitoring, advanced data analysis and information systems, and advanced operations management systems.

Projects within this program included new technologies for congestion monitoring and station management, virtual and augmented reality technologies for rail staff training, data management for predictive maintenance, Internet of Things (IoT) and big data analysis, and the use of robots and drones for infrastructure inspection.

2.4 Long term and short term research

The projects developed within the Centre's programs were based on industry need, with the rail sector defining the research challenges. In the Centre's inaugural years of operation, several long-term exploration research projects were initiated. Towards the final years of the Centre's operations, projects were shorter term and more applied in nature. Primarily, this was in reaction to two independent factors, firstly a number of major global mergers and acquisitions occurred in the rail sector in the second and third years of the Centre's operation which resulted in decreased R&D activity in Australia during this period. Secondly, the six-year lifetime of the Centre limited the timeline available for midterm research projects, which resulted in shorter, more applied research projects being commissioned.

3
INDUSTRY PROJECT OUTCOMES

With over 30 industry projects undertaken by the Rail Manufacturing CRC, there were multiple projects with commercialisation opportunities both in Australia and internationally. A small selection of these projects is detailed below.

3.1 Energy Storage: Supercapacitor and battery technologies and control systems

The Rail Manufacturing CRC's largest research activity was in the field of energy storage, where the Centre funded a number of projects with several industry partners. The individual projects in this activity can be classified into three research topics:

1. new supercapacitor materials;
2. new rechargeable battery chemistries; and
3. new energy storage control systems.

3.1.1 Supercapacitors and control systems

Research conducted by CSIRO and CRRC focused on catenary free light-rail. In most scenarios, it is common for light rail to utilise a catenary to supply power, but this has three main disadvantages, namely cost, grid stability, and aesthetics. On-board energy storage using supercapacitors that utilise periodic charging locations have many desirable features. However, there are three key challenges to using supercapacitors that need to be overcome:

1. High cost of storing energy;
2. Low volumetric energy density; and
3. Low gravimetric energy density.

An alternate to supercapacitors is to use rechargeable batteries. However, current commercial batteries (eg. lithium-ion chemistry), are not optimal due to slower change rates, limited battery discharge times and expected lifetimes (only 1,000 cycles).

Although cell manufactures do list fast charge, fast discharge and long lifecycles, they are typically mutually exclusive. So generally, if the charge or discharge rate is increased, the lifetime goes down (the figures given above are typical in that a cell can often do 1C charge, 1C discharge, and 1,000 cycles).

Figure 1: Prototype supercapacitor storage and control system.

Recent breakthroughs in electrical storage have enabled new types of cells, where the two leading candidates for light rail are Lithium Titanate (LTO) battery chemistries and Lithium Graphite battery/super-capacitor hybrids (hybrid). These have much higher charge and discharge rates and lifetimes compared to conventional batteries, and much higher energy densities than supercapacitors (though still much less than a traditional lithium chemistry).

Researchers at CSIRO have shown that the hybrid cell has a reasonable energy density and it has advantages in terms of cost when compared to other similar technologies. This makes the hybrid cell a candidate for on-board light rail energy storage, where it is possible to put a large supercapacitor pack on board and charge the system at periodic stations rather than at every station.

In conjunction with the new cells, new semiconductors, particularly high-powered insulated-gate bipolar transistors, have driven the cost of these systems down below that of a catenary, making replacement of a traditional catenary feasible. The system developed at CSIRO is now being tested on a production-size system (refer to figure 1).

3.1.2 Rechargeable battery technologies

The Rail Manufacturing CRC also conducted battery development work at the University of Technology Sydney (UTS) with industry partner HEC Group. These projects focused on new cell chemistries with the aim of producing lithium-ion batteries and hybrid supercapacitors with improved energy density and cycle life for auxiliary and emergency applications in rail.

Lithium-rich oxides have been a candidate for next-generation lithium-ion batteries due to their high energy density and high discharge voltage. However, they have low rate capability and poor cycle life. In the work conducted by UTS and HEC, a $LiAlF_4$ coating was used to overcome those obstacles (reference 2).

The as-developed lithium-rich cathode material showed outstanding performance including an ultralong cycling stability (3,000 cycles) with energy (246 mA h g^{-1}) densities exceeding the well-developed commercial Nickel-Cobalt-Manganese cathode materials (190 mA h g^{-1}) (reference 2). The lithium-rich cathode materials normally demonstrate poor rate performance. The $LiAlF_4$ coating improved the rate capacity by a factor of 3 compared with the uncoated material, displaying a capacity of 133 mA h g^{-1} at 5C (reference 2). This work provides a new strategy to develop high-performance lithium-rich cathode materials for high-energy-density lithium-ion batteries.

As well as cathode materials, work also involved the development of anode materials including optimised synthesis routes for the large-scale preparation of materials. Carbon coated Lithium Titanate anode materials were prepared by solid state reaction and spray drying methods. Initial outcomes from this work have been encouraging and work is continuing to optimise and scale up the materials synthesis processes.

3.2 Condition-based monitoring

Within the Australian rail sector, a great deal of focus in the last six years has been devoted to the development of condition-based monitoring systems and applications.

Condition-based monitoring is the process of understanding the lifecycle or maintenance cycle of rail assets using sensors, models and data mining to establish trends, optimise maintenance cycles, identify imminent failure, and predict the remaining life of an asset. The area has attracted a great deal of interest from several Rail Manufacturing CRC participant organisations, with an overview of some of the projects provided as follows.

3.2.1 Predicting bearing wear

The wear and degradation of rail axle bearings poses a great cost to the rail industry. Rail companies must keep their rollingstock in a serviceable condition as excessively worn bearings can contribute to safety issues such as vibrations, excessive clearances and possibly even derailments.

However, with the sheer number of rollingstock and the physical demands needed to overhaul a single bearing, replacing the axle bearings is a big task, and costs rail operators millions of dollars to service a single fleet of trains.

For operators and maintainers, effectively balancing maintenance requirements with operational availability and cost is an important aspect of equipment management. Tuning bearing parameters through bearing and lubricant selection and maintenance practices can have considerable impact on these decisions. It was Bombardier's interest in better understanding the condition of its rail fleet's axle bearings coupled with the expertise of the University of Queensland, that provided the impetus for this research.

Figure 2: Researchers at the University of Queensland assessing lubrication regimes on in-service axle bearings.

In this project, a model and tool were created to optimise bearing wear by selecting lubricant and maintenance parameters, with a goal to extend the life of bearings operating well below their fatigue threshold (reference 3). By analysing the bearing materials and studying the real effects of bearing wear, an accurate predictive model was developed for the axle bearings of interest.

The outcome of this study resulted in two key findings. Firstly, the model was able to compare the wear characteristics of different manufacturer's axle bearings. It was concluded that the current maintenance cycles for two specific axle bearings studied could be extended under certain conditions including optimal re-greasing. This was due to effects of the roller-race contacts within the bearing which, depending on the geometry of an individual bearing and the running conditions, could be demonstrated to have an effect on the amount of lubricant maintained within the bearing. Hence those geometries that maintained larger quantities of lubricant volumes subsequently resulted in less bearing wear.

The second major outcome demonstrated that specific lubrication regimes would increase both the time between maintenance cycles and the overall lifecycle of the bearings, and a number of recommendations have been provided to Bombardier.

A key takeout from this study is that predicating the behaviour of rail components through fundamental analyses provides greater capacity for operators, maintainers and manufacturers to understand the individual parameters that determine the maintenance and lifecycles of component parts. Combining this knowledge with evolving real-time sensor monitoring and ongoing advances in algorithm development is likely to provide users with more accurate prediction models for maintenance and failure, resulting in maintenance savings and fewer in-service breakdowns.

3.2.2 Predictive monitoring of rail infrastructure

In collaboration with Sydney Trains and UTS, the Rail Manufacturing CRC initiated projects to study two areas of infrastructure assessment and predictive analysis. The first related to developing models to assess predictive maintenance of rail switches/points on the Sydney Trains network, and the second used vision systems to identify maintenance needs on overhead wires and associated infrastructure.

3.2.3 Smart axle transducer transmitter for freight wagons

In general freight and heavy haul, condition-based maintenance techniques use vehicles to inspect the track and instrumented track sections to diagnose the trains in operation – but not in real-time. Reduced costs, miniaturisation of electronics and the IoT revolution opens the possibility of implementing real-time on-board condition monitoring for general freight and heavy haul wagons.

Given the lack of power and communication in wagons, and the scalability challenges of performing fleet wide on-board conditioned based monitoring, CQUniversity, in collaboration with the Rail Manufacturing CRC, developed an ultra-low power on-board device to monitor wagon faults in real-time (smart sensor node), with an optimised sensor node hardware architecture using analogue signal processing methods to reduce the computational power demands and hardware cost.

The project implemented the first prototype of an overheated bearing detection smart sensor node and studied the power savings. The team has also completed comprehensive simulations to study the dynamic behaviour of a railway wagon operating with a wheel flat fault, which enabled them to put together a second prototype of the smart sensor node.

Figure 3: CQUniversity PhD student Esteban Bernal Arango undertaking simulation experiments with prototype electronics.

3.2.4 Intelligent Data Fusion and Analytics Framework

Downer developed a system to monitor its train fleets called TrainDNA. With the academic support of Deakin University, the Rail Manufacturing CRC sponsored research to develop new data models and predictive algorithms that analyse and provide exception-based reporting to Downer staff.

The complexity of these challenges cannot be understated. Modern rail rollingstock is highly sophisticated and produces considerable data. For example, the Waratah fleet in NSW produces over 30,000 signals every 10 minutes from its fleet which are captured and analysed (reference 4).

With such volumes of data being processed across the rail network, there is significant benefit to utilising artificial intelligence to interpret data, reducing the need for human intervention.

The collaboration between Downer, Deakin University and the Rail Manufacturing CRC has enabled the development of algorithms to monitor and assess components within rollingstock to identify and predict more accurate maintenance regimes and identify potential future systems failures prior to them occurring.

The data analytics work conducted through this project has been implemented into the TrainDNA system and will assist Downer and its customers to reduce downtime and optimise rollingstock maintenance.

3.3 Passenger information systems

Developed by UTS, Downer and the Rail Manufacturing CRC, Dwell Track™ is a technology solution which anonymously monitors passenger numbers and behaviour in real-time on rail station platforms.

Chronic congestion on platforms can lead to extended dwell times when trains stop to drop off and pick up passengers. This in turn affects passenger comfort, train path capacity, service delivery and reliability. Dwell Track™ enables station staff to make effective decisions when guiding passengers in real-time and provides longer term insights into enhanced platform operations around dwell management.

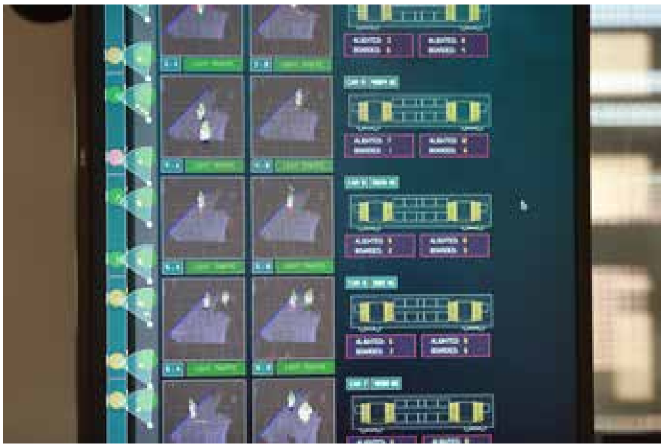

Figure 4: Dwell Track™ technology showing real time tracking of passengers

The system utilises infrared sensors and algorithms to detect and track human movement on train platforms. The difficulty of this task is increased in crowded environments due to frequent visual occlusions, and the sheer number of people in close proximity.

In response, Dwell Track™ leverages advances in 3D camera technology to extract relevant spatial and temporal information from the rail platform in real-time. The 3D cameras work by firing an irregular pattern of dots from an infrared projector and sending it to a processor to determine depth from the displacement of the dots.

Using depth data, several algorithms identify the head and shoulders, and use this detail with a tracking framework incorporating social norms to track individual movements (reference 5).

Dwell Track™ determines train door positions, door status, platform occupancy, passenger counts, and the direction passengers are moving.

Having this information not only supports the more efficient scheduling of trains, it also provides rail operators with the ability to try different ways to influence passenger behaviour on the train platform in real-time, whether through overhead announcements, colour coded lighting systems of where to stand, platform signage, educational initiatives or changes to platform layout.

The project was supported by Queensland Rail and Sydney Trains, with both rail operators providing facilities to trial the technology over the last six years.

3.4 Future Roadmapping

During the course of the Rail Manufacturing CRC's lifetime, the Centre participated in a number of forums aimed at developing knowledge that will assist the rail sector in future years.

3.4.1 Smart Rail

The *Smart Rail Route Map* (reference 6) was developed in collaboration with the Australasian Railway Association (ARA) and Deakin University, and focused on emerging digital and communications technologies.

The development of digital technology throughout the world has led to a rapid rise in the number of emerging technologies and new products being offered to the rail sector. With the last major Australian industry review of emerging technologies being conducted in 2012 (reference 1), the Rail Manufacturing CRC and the ARA co-commissioned a study in 2018 to review recent developments in the digital and communications areas and to work with industry to look at future industry needs.

In developing the route map, over 250 interactions with rail industry representatives occurred through workshops, videoconferences, group and individual discussions, with the goal to develop a technology roadmap to assess new and emerging technologies in the digital and communications area.

While the *Smart Rail Route Map* project produced a report with recommendations, the outcomes of this work focused on a small subset of the initial research priorities identified in the *On Track to 2040* roadmap (reference 1). Therefore, the Rail Manufacturing CRC views this work as complementary to the original outcomes of that roadmap and not a replacement.

Within the *Smart Rail Route Map*, the key rail areas considered to be most impacted by the introduction of new digital and communications technologies were:

» Passenger Customer Experience;

» Freight Customer Experience;

» Traffic & Network Management; and

» High Performing Railways (HPR).

From the four identified areas, several short-term priorities were identified for further investigation and research:

» Disruption management for passenger rail;
» Customised information services for passenger rail;
» Predictive journey planning techniques for passenger rail;
» Real-time information for freight customers;
» Data sharing platform across the supply chain;
» Identify key data requirements for Traffic and Network Management;
» AI and automation for system management;
» Management of technology legacy systems;
» Up-skilling the rail industry; and
» Improving safety through advanced technology.

A Smart Rail Executive Committee was formed, comprising of key representatives from the rail sector, to develop strategies for implementing the priorities. The Rail Manufacturing CRC looks forward to seeing the ARA and its members implement the findings of this route map throughout the coming months.

Further details of the program and a copy of the report can be found at www.smartrail.net.au.

3.4.2 Future workforce

In 2019, the Rail Manufacturing CRC, Department of Transport (Victoria) and Victoria University undertook a comprehensive study on future workforce in the transport sector. The results are detailed in seven reports that can be found at https://bit.ly/31Bj9Qp.

The *Reimagining the workforce: building smart, sustainable, safe public transport* collaborative research project commenced in July 2019, with extensive input from the rail industry via face-to-face workshops, in-depth organisational reviews and individual interviews. The entire rail supply chain network was represented by Tier 1, 2 and 3 organisations, rail operator businesses, and transport and industry peak bodies.

The project undertook an independent systemic study by Victoria University of the Victorian public transport sector with seven reports produced;

» a background review of the current industry context;
» an organisational review that focused on the development of the inclusive and innovative culture needed to retain and build the future workforce;
» an organisational review and economic analysis that focused on training and the economics associated with apprenticeships;
» a community report detailing the extent to which young people in Australia view careers in rollingstock and the extent to which demographic changes among young job seekers, and changes in social and cultural values in relation to work, have changed the landscape for securing the future workforce in rollingstock; and
» an economic study discussing the rail, tram and bus rollingstock manufacturing, maintenance and operations sector nationally, with particular reference to how procurement contributes to Victoria's economy and workforce.
» A workshop document which summarised the above five reports for workshop participants; and
» An interim action plan which identified three priority focus areas, and associated key tasks, for implementation over the short and long term:
    » Develop a clear image of the public transport sector to appeal to young people;
    » Optimise local content, and maximise social and economic benefits; and
    » Develop a ten-year strategic plan for training to support workforce development and workforce profiles for Victoria.

The reports developed during this study will inform the recently formed National Rail Action Plan Committee which has been tasked by the National Transport Commission to develop the committee's plan.

The outcomes of the reports will also be implemented in Victoria through the Rail Industry Development Advisory Committee, chaired by the Victorian Rail Advocate (reference 8).

3.4.3 Reflections of '*On Track to 2040*'

During the course of the Rail Manufacturing CRC's tenure, two reviews of the *On Track to 2040* roadmap were conducted. The first review was conducted internally by the Rail Manufacturing CRC in 2018 and concluded the plan was still highly relevant, however the original vision for implementing the plan had not been fully enacted.

The original recommendations of *On Track to 2040* described six strategic opportunities:

Governance

- Establish a Steering Committee
- Appoint an industry champion
- Promote roadmap and outcomes

Regulation & Standardisation

- Define and catalogue national standards
- Establish a single safety and standards body
- Target funding toward standardisation

Funding

- Map available funding sources
- Consolidate funding
- Prioritise funding toward roadmap

Collaboration

- Develop business case for change
- Establish test and development facility
- Facilitate data access
- Open software architecture

Research

- Establish manufactures research body
- Align research funding to roadmap
- Investigate technologies in allied industries
- Benchmark rail against similar industries

Policy

- Define national rail policy agenda
- Establish rail development agency
- Provide incentive for strategic rail R&D
- Prioritise relevant rail engineering education
- Define and establish efficiency targets

In reviewing progress by the rail sector against the original recommendations of *On Track to 2040,* the major developments have been in the Research and Policy areas.

The formation of the Rail Manufacturing CRC and the implementation of a number of industry-led projects has resulted in coordinated and collaborative research being undertaken. It should also be noted that research continues to be undertaken by universities and national laboratories.

In the area of policy, there have also been gains with the Australian Senate conducting an inquiry into the Australian Rail industry in 2017 (reference 7) and the recent agreement to develop a National Rail Action Plan under the auspices of the National Transport Commission (reference 8). The Rail Manufacturing CRC has supported both these initiatives.

However, activity to support the other four recommended strategic areas has not progressed as the plan envisaged, so essentially many of the issues identified still remain valid challenges for the broader rail sector.

The Rail Manufacturing CRC also participated in a second forum in 2019 organised by the ARA. This review also found that the *On Track to 2040* roadmap was still valid although it noted with the conclusion of the Rail Manufacturing CRC, that maintaining the successes achieved in the research and policy areas would be harder to maintain with the loss of significant Government co-funding.

4
PHD STUDENT PROGRAM

With the rail industry likely to face severe skills shortages in the coming decades (reference 9), particularly in data focused roles, it is essential to attract the next generation of employees to join the industry.

In support, the Rail Manufacturing CRC worked to identify and support a cohort of 51 PhD students working on rail-related research across leading Australian universities.

To encourage the Centre's PhD students to consider a career in rail after graduation, a variety of initiatives were delivered to promote information sharing, relationship building and induction into Australia's rail industry, including:

» guest presentations from senior rail representatives from Bombardier, Downer, Australasian Railway Association, and Sydney Trains;

» annual PhD student forums to deliver professional development rail training;

» targeted career readiness and power pitch training courses;

» tours of headquarters and key depots in Melbourne, Sydney and Brisbane;

» a paid internship program, trialled in conjunction with TrackSAFE Foundation, at Queensland Rail, Department of Transport and Main Roads (TMR) and Aurizon;

» a mentoring program, matching students with senior rail industry representatives; and

» financial support for students to attend key rail conferences.

With impending skills shortages throughout numerous Australian industry sectors due to grow from 2020 onwards (reference 9), coupled with the rail sector's need to attract increasingly cross disciplinary workers to address the sector's uptake of new and emerging digital technologies, the capacity to attract and support post graduate students for the rail sector is critically important.

Furthermore, the need for the rail industry to attract, employ and retain these individuals in an increasingly competitive market, is a key ongoing challenge for the rail sector.

5
FUTURE CHALLENGES FOR RAIL R&D

The rail sector within Australia has experienced significant change over the last six years. This has included the plateauing of mine site developments, accompanied by a lower growth in demand for new rollingstock in heavy haul rail, the increase in passenger rail rollingstock and passenger rail infrastructure projects, and the announcement of the Inland rail project.

One of the key achievements of the Rail Manufacturing CRC was its contribution to building a research culture within the domestic supply chain, particularly with the manufacturing organisations. This has resulted in the development of key relationships between R&D organisations and the rail manufacturing sector, something which has not existed previously to the same extent prior to the Centre's establishment.

Despite this, there are a number of key challenges that have the potential to impact the successful implementation of rail innovation in the future:

5.1 Need for national harmonisation

The Australian rail industry is highly dependent on Government policy and funding across both state and Federal levels for rail projects. Government policy, regulation, standards, and training certification for rail are set by individual states and organisations and while there is cooperation, there is a lack of a national agenda for rail (both passenger and heavy haul). One of the key challenges for the sector is to work towards a national harmonisation of standards and regulations, which would assist the rail industry to increase economies of scale and likely lead to more domestic R&D opportunities. Furthermore, developing rail sector precincts for workforce development and innovation, while seeking to address the fragmentation and lack of skills portability that exists in the rail training sector, would be of significant benefit.

5.2 Need for industry co-investment in R&D

Over the last six years, the rail sector has witnessed significant changes in global corporate structures, with an array of merger and acquisition activities, administration events and corporate restructures within both the global and Australian rail sectors.

These market pressures have undoubtedly influenced the Australian domestic research strategy and the capacity of industry to commit to research and development during times of corporate change.

Notwithstanding the loss of participants and revenue due to corporate restructures, the Rail Manufacturing CRC has witnessed steady growth in rail sector research and development activity, particularly in the last two years, with increased funding being made available for specific project areas, as detailed in section two of this paper.

Much of this growth has been as a direct result of Government co-investment and the role that research centres like the Rail Manufacturing CRC play in building trusted relationships between industry and the research sector.

The rail industry can also assist in funding future innovation. While a number of Tier 1 manufacturers and maintainers are increasing investment in domestic R&D, an equal number of Tier 1 companies and to a lesser extent operators are not, and this is clearly a choice by the latter to limit or reduce their investment in domestic R&D and local supply chain development.

With State and Federal Governments scheduled to invest over $100B in rail projects over the coming three decades, there exist opportunities for Australia to build new high-tech industries, grow its supply chains, and to train and educate its workforce. Linking long term local R&D investment and local supply chain development to the future outcomes of rail tenders would assist in providing impetus to all companies to invest in local innovation. However, as evidenced by recent examples in the defence sector, any policy and contractual requirements for local content will benefit from ongoing monitoring and auditing.

5.3 Supporting a culture of innovation

While the Commonwealth Government's investment in the rail sector has been positive, there still exists a future need for further support to assist the rail sector to continue to grow its investment in R&D and innovation, while also supporting programs that facilitate ongoing cultural change that is more supportive of R&D, technology trials, and the implementation of new technologies.

When it comes to the rail sector, both Government and industry tend to be conservative in relation to implementing innovation in rail. This has ultimately meant that R&D projects in the rail sector require much longer lead times than other sectors, which essentially creates hurdles for SME's who are trying to introduce new products to market.

With the number of science and research qualified employees in the rail manufacturing and maintenance sector totalling less than 0.3 per cent (reference 10), this may explain some of the conservatism to innovation and new product adoption within the rail sector, a further barrier to innovation which stifles domestic R&D. This is where organisations like CRC's and other intermediaries play an important role in being able to provide project management expertise, co-funding and an intermediary support between industry and research organisations.

5.4 Securing future funding for rail R&D

The Rail Manufacturing CRC has supported the rail sector to develop new technologies by co-funding projects, assisting companies to build a culture of innovation, training the next generation of highly skilled postgraduates, and providing an intermediary that can identify new technologies and assist companies develop relationships with research providers. With the closure of the Centre in 2020, the rail sector has lost this capacity and will need to look at other initiatives to support its future innovation needs.

The rail sector clearly needs ongoing support to assist companies preparing to tackle the massive pipeline of rail related projects over the next three decades. There exist significant opportunities for the sector to increase local manufacturing, develop supply chains and to train and educate a highly skilled workforce, however Government intervention and support will be required.

At present, future avenues for the rail sector to access R&D funding are limited and will be primarily contained within small grant programs like the Australian Research Council Linkage Program and the Cooperative Research Centre Projects program (a co-funded program for single projects). While these programs have merit, they are typically aimed at single, short-term applied research projects rather than long-term applied or disruptive research. The benefit that large collaborative programs like the CRC Centres bring to sectors like rail is the capacity to have an independent team that can develop long term relationships with both academia and industry. This ultimately builds momentum, innovation culture, and supports both disruptive and applied research projects. While short-term applied research projects support the short-term needs of industry, it is the incremental and disruptive technologies developed through the CRC Centres that will create the greatest long-term benefits and returns.

Investment in R&D is a long-term endeavour in future economic growth. Research not only provides the promise of new technologies, it can lead to new industries, create new jobs and develop new intellectual property. Government investment in rail R&D should be considered in the same way that capital investment is assessed, with the same appetite for risk and to create future employment opportunities.

In fact, linking R&D to rail tenders and Government capital expenditure would likely increase innovation. This can promote the creation of new domestic industries and potential export opportunities. Without this, domestic R&D will be limited and Australia's access to innovation will be provided through multinational organisations developing solutions offshore that may not necessarily be optimally suited for Australian needs and requirements.

Australia's research sector is world class and in terms of the rail sector, underutilised. The abovementioned projects the Rail Manufacturing CRC has undertaken demonstrate the benefits the rail sector has gained from the CRC program. With the closure of the Centre in 2020, there will be a need for both Government and industry to consider new models to support ongoing innovation. Left too long, the expertise and momentum built over the last six years may be lost.

6
INDUSTRY ENAGEMENT

In terms of Australia's capacity to deliver innovation, the Rail Manufacturing CRC was encouraged that several global manufacturers were working with Australian researchers due to their research expertise and reputation. The outcomes from such studies will not only result in technologies for a global market, but also assist Australia to maintain its key research facilities and expertise, while producing intellectual property that research institutions can utilise in predefined markets or alternate industry sectors.

One of the Rail Manufacturing CRC's goals was to work with rail suppliers across Tiers 1 to 3. While the Centre has worked with an array of SME's, only a small number had the financial capacity to commit directly to projects with the Centre.

Reflecting on the Centre's SME engagement, it quickly became evident that the Australian rail supply chain is still highly fragmented. The ACIL Tasman 2012 report *Railway Manufacturing Industry, A Profile of the Railway Manufacturing Industry in Australia*, prepared for the Department of Innovation, Industry, Science and Research (reference 10) outlined that while small to medium firms make up 90 per cent of the rail manufacturing supply chain, a small number of large Tier 1 manufacturers dominate, taking 87.5 per cent of overall revenue. This trend does not appear to have changed markedly since 2012, judging from the ongoing lack of appetite for SME's to invest in innovation and R&D. Therefore, future investment in small to medium enterprises is required if Australia is to increase its capacity to both manufacture locally and support local innovation.

Subsequently, programs that better provide opportunities for SME's to grow and invest in R&D will bring opportunities to both the rail and research sectors. Encouragingly, Australia still has significant research capability to accommodate future manufacturing research investment, so anything that Governments can do to provide incentive for SME's to either grow, merge or collaborate with other SME's, will provide a setting for encouraging future innovation.

7
FUTURE OPPORTUNITIES

The Rail Manufacturing CRC has fostered strong working relationships between industry participants and publicly-funded research agencies, contributing to the continued development of a domestic rail research culture. In terms of future opportunities, the Centre's experience would suggest the rail sector needs to keep progressing and innovating to meet the above-mentioned challenges. It is recommended that Australia's rail industry works to:

» engage with Governments towards the harmonisation of regulations and standards;

» embrace innovation and forge new alliances and collaborations with research organisations to increase the rate of domestic innovation;

» change the perceptions of the rail industry harboured by the next generation of graduates and postgraduates to one that reflects a more modern mode of transport that is innovation-centric in nature;

» upskill the rail sector to include managers and staff that have a broad understanding of the current Science, Technology, Engineering and Mathematics (STEM) landscape;

» actively work to attract a younger and more diverse workforce to the sector; and

» collaborate with a broader cross section of the transport and research sectors to gain a more holistic view of future innovation and economic opportunities worldwide.

7.1 Future research themes

In terms of future research areas based on the Rail Manufacturing CRC's interaction with the rail sector, the key areas of ongoing research are likely to include:

» energy storage systems for light rail, hybrid rail and auxiliary power applications;

» high temperature batteries for outback rail applications;

» rollingstock-based sensors and applications for real-time condition-based monitoring above and below rail;

» coatings and laser repair treatments of rail components, including cold spray coatings for anti-corrosion and surface repair, and laser repair of rail components;

» weld modelling for ensuring the quality and reproducibility of fabricated rail parts;

» condition-based modelling and predictive maintenance models for rollingstock and rail infrastructure;

» passenger congestion systems that alleviate crowding, reduce train dwell times and improve customer service;

» passenger information systems that provide passengers with information to create a better customer experience;

» automated use of drones and robots to monitor track, culverts and rollingstock reducing corridor access times and reducing risk to staff;

» virtual and augmented reality applications for training;

» new lightweight materials for rollingstock;

» video analytics for fault detection; and

» the use of low-cost robotics in rail manufacturing and maintenance facilities.

8 CONCLUSIONS

With the Rail Manufacturing CRC's funding concluding in June 2020, the Centre has played a key role in fostering a greater R&D culture with its participants and the broader Australian rail sector over its six years in operation.

While the Centre has been successful in developing a number of new technologies, the six-year time frame it was afforded has meant that it has terminated at a critical time for the rail sector.

With growing investment in rail rollingstock and infrastructure and a desire to increase the levels of local manufacturing, the rail sector will need organisations like the Rail Manufacturing CRC to assist both Government and industry to support innovation, develop a rail innovation culture, develop new technologies, and to assist SME's in the supply chain to grow through the development and adoption of new technologies.

The Centre remains optimistic that its projects, along with the rail industry's renewed enthusiasm to invest in local R&D, will provide the basis for continued partnerships between Australian rail businesses and universities in the future. However, there is a strong argument for continued and prolonged Government funding to support ongoing innovation in an important and rapidly growing sector.

With substantial investment comes immense opportunities for Australia to build its blue and white-collar workforce by seeking to utilise future investment to support the creation and adoption of new domestic rail technologies, build new supply chains based on emerging technologies, fund domestic innovation initiatives and attract and retain a new and emerging workforce of highly skilled engineers and science professionals that will support the industry in future decades.

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