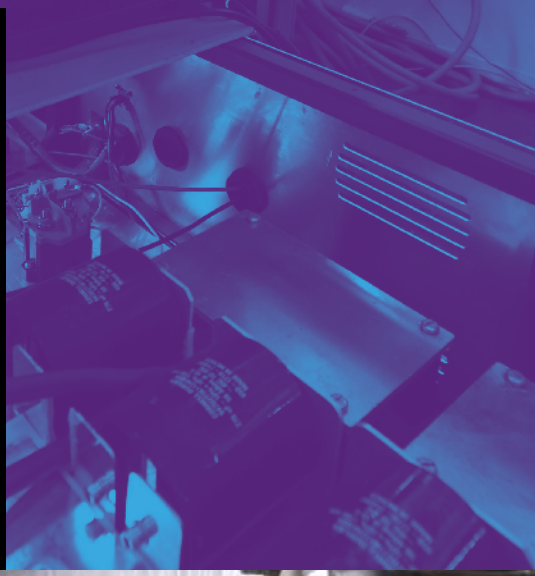
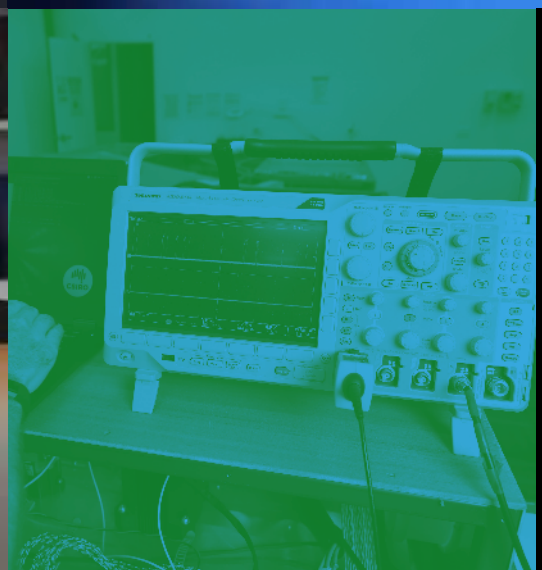
Annual Report 2019—20

Rail Manufacturing CRC

Vision

To transform and support the rail sector through industry-focused research, collaboration and technology implementation





Mission

To improve the capacity and competitiveness of the Australian rail manufacturing industry and to support its continued integration into global supply chains through the use of new technologies and innovation.

Strategy

To promote innovation and create impact in the rail manufacturing industry through cutting-edge research and the commercialisation and implementation of new technologies.

Contents

Australian Government
Department of Industry, Science, Energy and Resources

Business Cooperative Research Centres Program

Cover image: Maintenance works underway on rail fleet at Bombardier's Wulkaraka depot

Message from the Chair and MD

With the Rail Manufacturing CRC ceasing operations on 30 June 2020, this final report takes a look back at the Centre's achievements and challenges over the past six years, and a look forward towards future opportunities for Australia's rail sector.

The start-up phase: new challenges, new opportunities

The Rail Manufacturing CRC was established as a collaboration between the rail industry, Government and academia to build a more agile, globally competitive and resilient local industry, with a core focus on innovative research and development.

With an emphasis on driving the local development of new products and technologies and by improving the competitiveness of Australia's rail manufacturing industry, the Rail Manufacturing CRC's programs were selected to make substantial contribution to developing and sustaining increased levels of local work. The focus on creating jobs of high technological content was also expected to contribute to attracting the best and brightest university students into the rail industry.

The pre-start-up planning and early start-up phase showed a market with a strong emphasis on heavy haul and freight research in response to the mining boom that had continued many years previously. At this time, there was a belief that the heavy haul focus would continue for several years. However, the subsequent plateauing in the resources demand and the resulting impacts on businesses in the mining sector caused a decrease in the demand for R&D in rail-related mining and heavy haul activities.

A further challenge for the Rail Manufacturing CRC was a substantial industry-consolidation and restructuring within Tier 1 and Tier 2 organisations, resulting in multiple mergers and acquisitions of the participants during the first three years of the Centre's life. This manifested in several project proposals being delayed, pending resolution of new ownership, or substantially modified due to new corporate needs.

Fortunately at the same time, a number of significant passenger rail projects were initiated, and further projects announced. This created new opportunities for the Rail Manufacturing CRC and consequently, these events were to have a substantial impact on the Centre's project portfolio and technological drivers that were to define our legacy.

Changing focus and adjusting programs

This change in focus towards passenger rail R&D resulted in new industry participants joining the Rail Manufacturing CRC – with the Centre's research participants responding by adjusting their focus and quickly adapting to the proposed changes in activities.

Despite the early challenges, many significant outcomes were achieved during the Rail Manufacturing CRC's six-year tenure. In terms of project successes, our collaborations and partnerships with industry and the research sector have resulted in several commercially ready or near ready products, including:

- the Dwell Track™ platform monitoring technology trialled in late 2019 in collaboration with Sydney Trains at the operator's Wynyard station,
- CSIRO's development of new aluminium matrix composite brake discs for high speed rail by CRRC,
- battery packs for backup battery rail applications,
- a model to predict axle bearing wear by the University of Queensland,
- control systems for energy storage devices on rail vehicles, and
- new algorithms for predictive maintenance in Downer's TrainDNA solution.

As a result of the strong collaborative model that the CRC program provides, there has been growing support for local research and development and a growing culture of innovation and collaboration building in the rail sector.

Moreover, as the Rail Manufacturing CRC's programs have grown, we have successfully encouraged Australian businesses to invest time and resources into working with creative minds and collaborating to find new ways of innovating. A focus on innovation enables these businesses, small and large, to be world-class organisations. Innovation will provide resilience and sustainability that will underpin growth and an ability to address the scale issues that restrict many small to medium companies in Australia.


Paul Johnson MBE, Chair

Dr Stuart Thomson, CEO

Identifying the next generation of rail leaders

The Rail Manufacturing CRC's PhD scholarship program was initiated midway through the Centre's six-year term, with our team working with the universities to identify those students working on predominately "blue-sky" R&D projects, that if successful, had the potential for disruptive outcomes.

Some of these projects have included the development of video algorithms to detect defects in rail catenary systems, data analysis devices and techniques for condition monitoring, the development of small autonomous crawling robots for maintenance applications, the use of unmanned autonomous vehicles for railway infrastructure monitoring, the development of lightweight sandwich panels for rail applications, and the identification of new technologies for rail suicide prevention.

Combining the scholarship students with the CRC's industry project PhD students, 51 PhD students have commenced their PhD research with financial support from the Rail Manufacturing CRC. This program has introduced the rail industry to a cohort of enthusiastic students working on topics of great relevance to some of industry's most persistent challenges. It is encouraging to note that some of the PhD research projects have led to additional industry collaborations, which further demonstrates the emerging culture of collaboration between our industry participants and the university sector. For the rail industry, this also means that our PhD students will, upon graduation, be available to work in the rail industry, a highly beneficial outcome for the sector.

For our students, working in a highly supportive environment for three years with Australia's leading universities and research institutions has been a welcome experience. The capacity for our students to conduct their projects has enabled them to gain key technical skills and understand the innovation challenges being faced. In many ways, a number of these projects would not normally have been conducted in Australia due to the technical and commercial risks of the projects. Instead, we feel that supporting this blue-sky research has been complementary to our industry funded research and development programs.

Government commitment critical for future success

Over the course of the Centre's six-year lifetime, the Rail Manufacturing CRC has achieved a notable success rate in the projects undertaken and the deliverables to our stakeholders. None of this success would have been achievable without the consistent support of the Commonwealth's CRC Program within the Department of Industry, Science, Energy and Resources.

Post-wind-up of the Centre, our key stakeholders still believe that there is a need to see continued Government investment to support future rail R&D programs and initiatives. While considerable progress has been made to date, the rail sector still needs to keep investing in a range of new technology areas, including energy storage, real-time condition-based monitoring, industry 4.0 implementation programs, and an array of digital technologies.

Furthermore, the next ten years will likely see even more emphasis on technologies like 3D-printing, virtual and augmented reality devices and software, the internet of things (IoT), and predictive maintenance condition monitoring systems. The adoption of these technologies and the development of new technologies no doubt would benefit from ongoing Government support.

With rail investment likely to hit $150 billion in the coming decades, there should be greater opportunities to leverage such investment, in an aggregated way, to grow and enhance our national rail industry of the future. To achieve this, new models of cooperation between industry and researchers, individual state Governments, and the Commonwealth Government will need to be explored. A national strategy for rail and rail innovation would be a great impetus for ensuring a future innovative rail sector.

Message from the Chair and MD, continued

Thanks to our team

Our core leadership team and administrative staff have been key to the success of the Rail Manufacturing CRC. The team has worked incredibly hard to establish and run the Centre and its collaborative environment for industry, academia and Government.

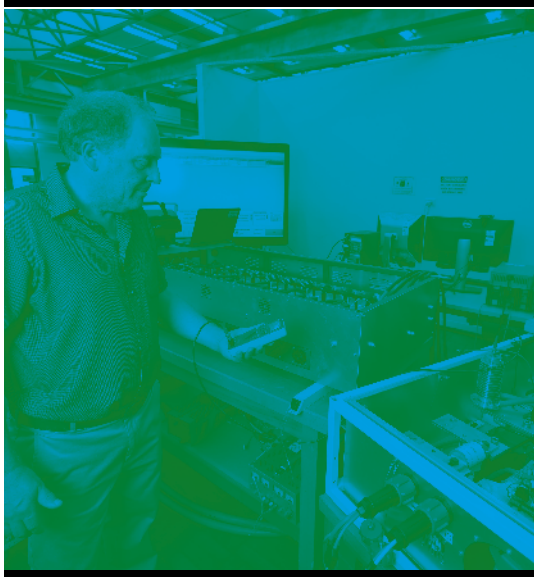
The team steered the programs through a new growth phase and implemented one of the crowning successes of the Centre, the PhD scholarship program. Most importantly, the team has remained to oversee the orderly closure of the Centre and the transfer of the successful project outcomes to industry, as a legacy for those to follow.

Thank you to all Board members, past and present, for their guidance, support and direction over the last six years.

And finally, thanks to the academic and industry partners who've participated in projects, attended events, mentored students and shared their expertise. This support was critical to our Centre providing a meaningful program of work for Australia's rail industry.

Moving forward, we hope that the legacy of the Rail Manufacturing CRC is a culture of collaboration and innovation that will persist well past the Centre's lifetime – shown through the relationships built, the PhD students trained and the organisations that participated.

51
PhD students
supported



65
industry projects
conducted

Paul Johnson MBE
Chair – Rail Manufacturing CRC

Dr Stuart Thomson
CEO – Rail Manufacturing CRC

35

participating
organisations

About the Rail Manufacturing CRC

The Rail Manufacturing Cooperative Research Centre (CRC) was established in 2014 to build a collaborative research and development program between Australia's rail manufacturing industry and world-leading Australian education institutions.

Funded by participating rail organisations and the Cooperative Research Centres Program of the Federal Government's Department of Industry, Science, Energy and Resources, the Rail Manufacturing CRC has concluded its six-year lifespan, closing on 30 June 2020.

The Rail Manufacturing CRC managed partnerships between key stakeholders, including rail manufacturing multinationals, Australian small-to-medium enterprises, research and development providers, industry peak bodies, and Australian State and Federal Governments.

Research completed in:

01 Power and Propulsion

- Battery development and manufacture
- Supercapacitor technologies
- Rail-wheel-interface
- Composite braking
- Energy management systems

02 Materials and Manufacturing

- Component durability testing
- Maintenance optimisation
- Composite materials design
- Automated assembly
- Advanced welding and cladding

03 Design, Modelling and Simulation

- Passenger information systems and dwell time management
- Cabin airflow modelling
- Data transfer and analytics
- Virtual and augmented reality rail training

Maintenance of rail assets in the workshop

Australian Government
Department of Industry, Science, Energy and Resources

Business Cooperative Research Centres Program

From 2014–20...


Annual Report
2014-2015


ANNUAL REPORT 2015–16
RAIL MANUFACTURING CRC

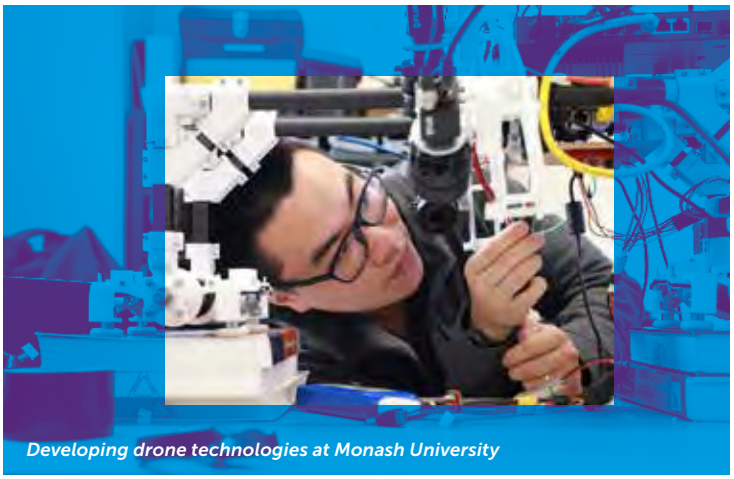

ANNUAL REPORT 2016–17
RAIL MANUFACTURING CRC

Visit www.rmcrc.com.au for past reports, project summaries and student profiles.

Southern Cross Station, Melbourne

Executive summary

Achievements



Developing drone technologies at Monash University

Research and collaboration

In its sixth and final year of operation, the Rail Manufacturing CRC's research program has witnessed a surge in outputs due to 22 projects completing during this year. Even more importantly, project outputs are now beginning to be commercialised and implemented by the rail sector.

One key example is Downer's partnership with Deakin University and the University of Queensland via two key projects – Project R3.1.4 - ***Intelligent data fusion and analytics framework*** (Downer / Deakin University) and Project R3.1.5 - ***Wheel and bearing wear prediction*** (Downer / University of Queensland).

Downer has developed a new software system called TrainDNA, which uses complex analytics and machine learning to perform data collection, monitoring and alerts, which the Rail Manufacturing CRC projects have extended into a focus on predictive maintenance. Currently deployed on its Sydney-based fleet of Waratah trains, TrainDNA will be rolled out across other train fleets that Downer maintain to monitor systems including batteries, airbag pressure, and HVAC performance. TrainDNA was presented to the rail industry at AusRAIL Plus in October 2019 in Sydney, where delegates were shown a live version of technology, alongside presentations delivered by Downer engineers about the underlying work that went into developing the data analytics capability.

Battery and energy storage projects have also been a prominent feature of the Rail Manufacturing CRC's R&D program. Research ranged from battery material advancement to the development of battery back-up systems for specific rail applications. Through a series of projects between HEC Group and the University of Technology Sydney, lithium-rich cathode materials developed showed outstanding performance with an ultralong cycling stability and energy densities exceeding commercial cathode materials.

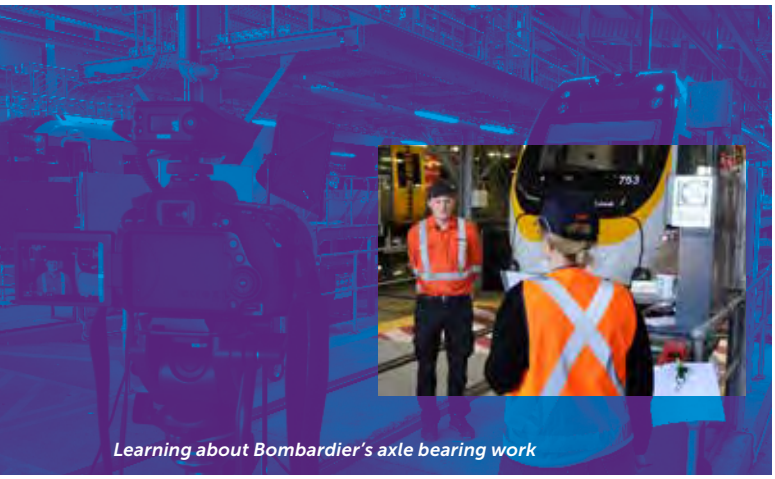
Other projects focused on energy storage and battery back-up work using commercially available batteries or supercapacitors, which resulted in prototype systems being assessed and trialed by organisations including CRRC, Knorr-Bremse and Downer.

Another key research focus has been data modelling and algorithms to improve operations. A long-running example during the Centre's lifetime has been the development of a responsive passenger information system via Project R3.1.2 - ***Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system*** (Downer / University of Technology Sydney). This project resulted in the creation of Dwell Track™, which anonymously monitors passenger numbers and behaviour in real-time on rail station platforms, determining train door positions, door status, platform occupancy, passenger counts and the direction passengers are moving.

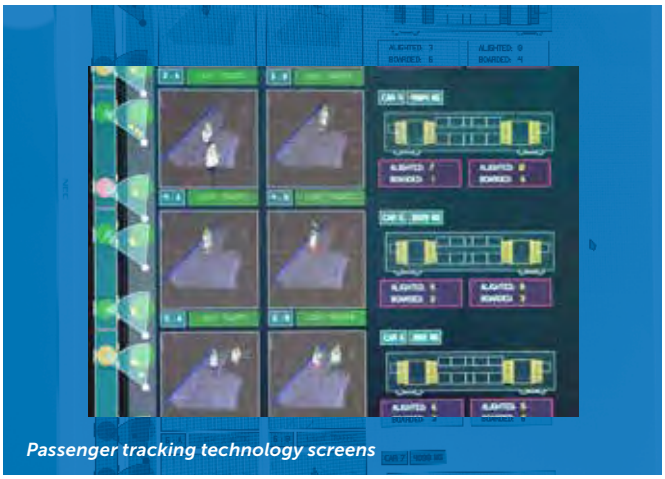
Having this information not only supports the more efficient scheduling of trains, it also provides rail operators with the ability to try different ways to influence passenger behaviour on the train platform in real-time. This can be managed through overhead announcements, colour coded lighting systems of where to stand, platform signage, educational initiatives or changes to platform layout. The project has been supported by rail network operators Queensland Rail and Sydney Trains, with both providing facilities to trial the technology over the last five years.

Additionally, two new project agreements were executed in 2019–20:

- Project R2.1.4 - ***Low fume high productivity MIG welding*** (CRRC / CSIRO)
- Project R3.1.5 - ***Wheel and bearing wear prediction*** (Downer / University of Queensland)



Learning about Bombardier's axle bearing work



Passenger tracking technology screens

Commercialisation and utilisation

The Rail Manufacturing CRC's model for commercialisation and utilisation was developed in close consultation with its industry and research participants, with an overarching principle to support and facilitate industry-led research outcomes.

Twenty-two Rail Manufacturing CRC projects were completed during 2019–20 (more detail on each project is included in this report's Performance against activities section on pages 18–33):

- Project R1.1.1 - ***New generation lithium-ion batteries with high energy and long service life for rail industry applications*** (HEC Group / University of Technology Sydney)
- Project R1.1.2 - ***Hybrid supercapacitors with high energy and power densities for rail industry applications*** (HEC Group / University of Technology Sydney)
- Project R1.3.4 - ***Supercapacitor energy management system stage 2*** (CRRC / CSIRO)
- Project R1.3.5 - ***Lighting and control battery backup*** (Downer / CSIRO)
- Project R1.3.6 - ***Battery pack durability*** (Knorr-Bremse / CSIRO)
- Project R1.5.1 - ***Aluminium matrix composite brake discs*** (CRRC / CSIRO)
- Project R2.1.1 - ***Platform gap*** (Downer / Monash University)
- Project R2.1.2 - ***Protection of cast steel coupler from corrosion by cold spray*** (CRRC / CSIRO)
- Project R2.1.3 - ***Laser repair of railway cast components*** (CRRC / CSIRO)
- Project R2.1.4 - ***Low fume high productivity MIG welding*** (CRRC / CSIRO)
- Project R2.3.1 - ***Accelerated life testing and characterisation of critical components*** (Knorr-Bremse / CSIRO)
- Project R2.3.4 - ***Monitoring and control of false brinelling*** (Bombardier / University of Queensland)
- Project R2.5.1 - ***Performance of recycled rubber inclusions for improved stability of railways*** (Tyre Stewardship / Australasian Centre for Rail Innovation / University of Wollongong)
- Project R2.5.2 - ***Application of geogrids for minimising track deformation and degradation under high frequency cyclic and heavy haul loading*** (Global Synthetics / Foundation QA / University of Wollongong)
- Project R3.1.2 - ***Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system*** (Downer / University of Technology Sydney)
- Project R3.1.3 - ***Predictive maintenance models for Sydney Trains*** (Sydney Trains / University of Technology Sydney)
- Project R3.1.4 - ***Intelligent data fusion and analytics framework*** (Downer / Deakin University)
- Project R3.1.5 - ***Wheel and bearing wear prediction*** (Downer / University of Queensland)
- Project R3.2.2 - ***Development of a responsive passenger information system for the Sydney Trains network (stage 2)*** (Sydney Trains / University of Technology Sydney)
- Project R3.3.3 - ***Reimagining the workforce: building smart, sustainable and safe public transport*** (Department of Transport / Victoria University)
- Project R3.4.1 - ***Arc welding modelling*** (CRRC / CSIRO)
- Project R3.6.1 - ***Experimental and computational study on the key ventilation issues affecting air quality and thermal comfort in train cabins*** (Airlinx / RMIT University)

All utilisation milestones were achieved during the reporting period – see page 35 for more information.

Executive summary, continued.

Education and training

The need for the Australian rail industry to attract, employ and retain a new generation of employees is a key challenge for the sector.

In support, the Rail Manufacturing CRC has worked to identify and support a cohort of 51 PhD students working on rail-related research across leading Australian universities. This final number of students is well above the original target to support 30 students.

There are currently 10 students actively working on industry projects, 29 students receiving PhD scholarships and two students who received a 12-week internship opportunity at Queensland Rail, Aurizon and the Queensland Government's Department of Transport and Main Roads in past financial years.

Five PhD students completed their PhDs in 2019–20, which is in addition to the two students who submitted their theses in the 2018–19 Financial Year.

The Rail Manufacturing CRC has continued to support and provide guidance to its students, with the completion of the Grow Your Career program which launched in March 2019, and the hosting of the final PhD Students' Forum in March 2020, which was focused on the importance of building networks and identifying career opportunities following graduation.

There are seven active education-related milestones, two of which have been Achieved in 2019–20 and five that are In Progress and will be completed post 30 June 2020 – see page 37 for more information.

Sydney train station

Risks and impediments

Since commencing in 2014, the risks that the Centre has sought to mitigate over its six-year lifetime have included:

- the global economic environment which has resulted in significant merger and acquisition activity in the rail sector,
- domestic and international demand for manufactured products,
- the nature of competitive global supply,
- the general level of confidence within the sector, and
- the capacity of domestic manufacturers to invest in research, innovation, capital equipment, and human resources.

The Centre's Board and Management team have continued to engage with Participant organisations to ensure current projects are completed, project intellectual property is identified, recorded and assigned, and all project financial accounts are finalised during 2019–20.

The Centre will achieve the majority of its Commonwealth Milestones, delivering on its undertaking to create relevant, cutting-edge and innovative products and services for its participant organisations and the broader rail sector.

The two milestones not achieved relate to Project R1.2.1 - ***Intelligent magnetic levitated railway track-vehicle*** (Simplex / Deakin University), which was terminated by the Centre in 2017. Milestones relating to postgraduate completions will be met, but post 30 June 2020.

Sydney train station

Performance against activities

01 Power and Propulsion

Energy and cost efficiency, and improved competitive performance in advanced rail manufacturing through research, development and commercialisation in:

- Energy Regeneration and Storage
- Advanced Braking Systems
- Electronic Motors and Systems

02 Materials and Manufacturing

Competitive cost, durability and performance in advanced rail manufacturing through research, development and commercialisation in:

- High Performance Materials For Heavy Haul
- Advanced Manufacturing
- Advanced Lightweight Materials
- Low Cost Manufacturing Systems

03 Design, Modelling and Simulation

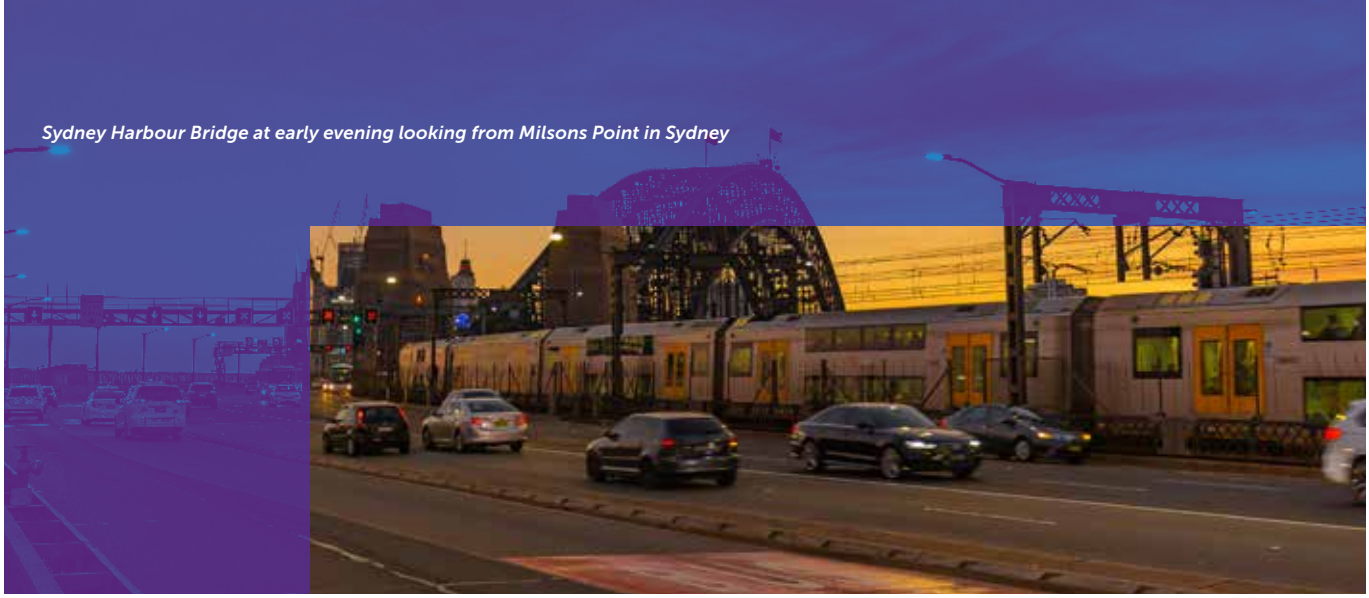
Safety and efficiency in advanced rail manufacturing to enhance industry competitiveness through research, development and commercialisation in:

- Advanced Design and Simulation
- Automated Health Monitoring
- Advanced Data Analysis and Information Systems
- Advanced Operations Management Systems
- Energy Use Management Tools

Project commencements

In 2019–20, the Rail Manufacturing CRC commenced two final projects:

- Project R2.1.4 - ***Low fume high productivity MIG welding*** (CRRC / CSIRO):
  The development of MIG welding tips and modelling new rail welding parameters to reduce weld fume.
- Project R3.1.5 - ***Wheel and bearing wear prediction*** (Downer / University of Queensland):
  Identifying the most critical axle bearing and wheel wear parameters to monitor as best predictors of bearing degradation to enter into predictive models.



Sydney Harbour Bridge at early evening looking from Milsons Point in Sydney

Twenty-two projects were completed during the last 12 months:

01
Power and Propulsion

Within Program area 1 – Power and Propulsion

Project R1.1.1 - ***New generation lithium-ion batteries with high energy and long service life for rail industry applications*** (HEC Group / University of Technology Sydney):

This research focused on the development of new anode and cathode materials for lithium-ion batteries, with the potential to enable higher energy density and a longer cycle life. This could be used for propulsion and enabling regenerative braking of the train, signaling systems and auxiliary applications such as the train's air conditioning and back-up power needs.

Project R1.1.2 - ***Hybrid supercapacitors with high energy and power densities for rail industry applications*** (HEC Group / University of Technology Sydney):

This research aimed to develop a hybrid supercapacitor with high energy and power densities and advanced supercapacitor management systems for rail. The implementation of this new supercapacitor technology could effectively provide voltage stabilisation for rail systems and improve the performance of propulsion for light rail vehicles.

Project R1.3.4 - ***Supercapacitor energy management system stage 2*** (CRRC / CSIRO):

This project developed a prototype energy management system using commercially available supercapacitors to enable the application of catenary-free trams. This approach would eliminate overhead wires to power the trams, instead requiring an onboard energy storage system with high enough energy density to support travel between stations and high enough power density for rapid charging and discharging.

Project R1.3.5 - ***Lighting and control battery backup*** (Downer / CSIRO):

Downer's Waratah train fleet in Sydney has 78 sets with four control and eight lighting battery banks per set. These battery banks are made up of lead acid battery packs. This project investigated the use of a longer lasting lithium battery pack solution.

Project R1.3.6 - ***Battery pack durability*** (Knorr-Bremse / CSIRO):

This project focused on prototyping and manufacturing a new battery configuration. The first step of this project was to see which battery configurations were possible, prior to prototyping the preferred option and conducting field testing.

Project R1.5.1 - ***Aluminium matrix composite brake discs*** (CRRC / CSIRO):

This project manufactured and tested a new material for brake discs, made of ceramic and metal composite. More wear resistant and a better conductor of heat, the material was developed in a lab environment and then scaled up for manufacture.

02
Materials and Manufacturing

Within Program area 2 – Materials and Manufacturing

Project R2.1.1 - ***Platform gap*** (Downer / Monash University):

This research investigated the potential for a deformable plastic filler to bridge the gap between the train and platform at rail stations. After commencing, the loading and deformation required to bridge the platform gap were not able to be demonstrated, so the project's deliverables were shortened to complete the project early.

Project R2.1.2 - ***Protection of cast steel coupler from corrosion by cold spray*** (CRRC / CSIRO):

This project investigated the use of cold spray to mitigate the cracking of couplers, which is the linkage between rail cars. Corrosion fatigue is a common failure mechanism due to the gross weight and length of freight trains. Cold spray coating was used to develop improved anti-corrosion coatings for rail couplers.

Project R2.1.3 - ***Laser repair of railway cast components*** (CRRC / CSIRO):

When casting steel components, defects can occur which can be a significant problem to fix or replace. In response, this project investigated the potential for defects to be repaired by a high power (4 kW) industrial system using a high-power laser beam as a heat source to melt compatible metal powder blown into the laser beam.

Project R2.1.4 - ***Low fume high productivity MIG welding*** (CRRC / CSIRO):

Due to health and safety requirements and productivity considerations, it is important to control weld fume. With any potential hazard, the most effective means of control is to limit generation at the source, with CSIRO's high deposition MIG tip invention providing improved control. This enables welding under more stable operating conditions and reduces weld fume generation.

Project R2.3.1 - ***Accelerated life testing and characterisation of critical components*** (Knorr-Bremse / CSIRO):

Knorr-Bremse worked with CSIRO to test the performance of air conditioning units in different atmospheric conditions, specifically focused on the motor that controls the cooling fan on the unit. The project looked to determine which factors cause failure of the motor, subsequently developing a predictive test to see if the motors from potential suppliers will stand up to likely conditions.

Project R2.3.4 - ***Monitoring and control of false brinelling*** (Bombardier / University of Queensland):

As the rail industry becomes increasingly global, the requirement to understand the effects of transport-related movement and forces on rail components is critical. Currently when bearings are transported, a form of wear called false brinelling can occur. This project involved developing wear models and assessing bearings during transportation to understand the cause of false brinelling, so that future transportation conditions can be adjusted to ensure the bearings arrive in prime condition.

Project R2.5.1 - ***Performance of recycled rubber inclusions for improved stability of railways*** (Tyre Stewardship / Australasian Centre for Rail Innovation / University of Wollongong):

The use of recycled rubber mats under the track's ballast was investigated to test the potential for reducing ballast degradation. Work conducted indicated that railway bridge decks were the application where rubber inclusions could have the most benefit.

Project R2.5.2 - ***Application of geogrids for minimising track deformation and degradation under high frequency cyclic and heavy haul loading*** (Global Synthetics / Foundation QA / University of Wollongong):

This project investigated the benefit of geogrid materials underneath the rail ballast. The ballast can subside and degrade through constant use, so adding geogrids underneath may provide for stabilisation that requires less maintenance. This laboratory research involved testing the performance of the geogrid by simulating rail loading and vibration.

Melbourne's tram network

Dwell Track™ camera hardware developed by the University of Technology Sydney

03
Design, Modelling and Simulation

Within Program area 3 – Design, Modelling and Simulation

Project R3.1.2 - ***Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system*** (Downer / University of Technology Sydney):

This project created a dwell-time diagnostics tool called Dwell Track™ that uses 3D Infrared cameras and algorithms to anonymously monitor passenger numbers and movement at train station platforms. The technology can quantify passenger congestion on platforms and near train doors that lead to extended dwell times. Data from Dwell Track™ will enable train operators to improve platform management procedures and communications to passengers.

Project R3.1.3 - ***Predictive maintenance models for Sydney Trains*** (Sydney Trains / University of Technology Sydney):

The advent of cutting-edge machine learning and analytics provides rail operators with an opportunity to reposition asset maintenance interventions. This project incorporated research and development work to highlight the benefits and potential for leveraging the immense volume of data collected by Sydney Trains for asset condition monitoring and maintenance optimisation.

Project R3.1.4 - ***Intelligent data fusion and analytics framework*** (Downer / Deakin University):

Downer has built a digital platform called TrainDNA, which seeks to digitalise data taken from both internal and external train monitoring systems. This platform uses cognitive computing tools to display current status on train location and performance. Building upon this platform, the data science capability was augmented using Deakin University research methodology to develop algorithms for predicting maintenance needs

Project R3.1.5 - ***Wheel and bearing wear prediction*** (Downer / University of Queensland):

This project supported Project R3.1.4, providing the most critical axle bearing and wheel wear parameters to monitor as best indicators/predictors of bearing degradation to enter into predictive models used by Downer's TrainDNA platform.

Project R3.2.2 - ***Development of a responsive passenger information system for the Sydney Trains network*** (stage 2) (Sydney Trains / University of Technology Sydney):

The project investigated methods of automatically monitoring passenger numbers, installing a demonstration passenger information system at Sydney's Town Hall station using existing CCTV, Dwell Track™ and Wi-Fi in real-time.

Project R3.3.3 - ***Reimagining the workforce: building smart, sustainable and safe public transport*** (Department of Transport / Victoria University):

This research aimed to address the current knowledge gaps to support the development of a sustainable workforce, while strengthening the employment and training pipeline for the transport industry. It also aimed to examine how organisations can work with their current workforce to ensure alignment and adjustment to technological and social changes faced in Australia.

Project R3.4.1 - ***Arc welding modelling*** (CRRC / CSIRO):

Metal welding is important in the manufacture of rollingstock, with the use of software that reliably predicts weld properties having the ability to save significant time and expense. CSIRO has developed modelling software that can provide information on a weld, including speed, gas flow and rate.

Project R3.6.1 - ***Experimental and computational study on the key ventilation issues affecting air quality and thermal comfort in train cabins*** (Airlinx / RMIT University):

This project involved modelling airflow from the air vents within a train environment to determine optimum airflow based on different passenger numbers. Achieving an optimal temperature ensures passenger comfort is high, while also reducing the impact of contaminants in the airflow.

Performance against activities, continued.

Rail Manufacturing CRC Projects current during reporting period

	Number	Project	Participants
Program 1 – Power and Propulsion			
1	R1.1.1	New generation lithium-ion batteries with high energy and long service life for rail industry applications	HEC Group / University of Technology Sydney
2	R1.1.2	Hybrid supercapacitors with high energy and power densities for rail industry applications	HEC Group / University of Technology Sydney
3	R1.3.4	Supercapacitor energy management system stage 2	CRRC / CSIRO
4	R1.3.5	Lighting and control battery backup	Downer / CSIRO
5	R1.3.6	Battery pack durability	Knorr-Bremse / CSIRO
6	R1.5.1	Aluminium matrix composite brake discs	CRRC / CSIRO
Program 2 – Materials and Manufacturing			
7	R2.1.1	Platform gap	Downer / Monash University
8	R2.1.2	Protection of cast steel coupler from corrosion by cold spray	CRRC / CSIRO
9	R2.1.3	Laser repair of railway cast components	CRRC / CSIRO
10	R2.1.4	Low fume high productivity MIG welding	CRRC / CSIRO
11	R2.3.1	Accelerated life testing and characterisation of critical components	Knorr-Bremse / CSIRO
12	R2.3.4	Monitoring and control of false brinelling	Bombardier / University of Queensland
13	R2.5.1	Performance of recycled rubber inclusions for improved stability of railways	Tyre Stewardship Australia / Australasian Centre for Rail Innovation / University of Wollongong
14	R2.5.2	Application of geogrids for minimising track deformation and degradation under high frequency cyclic and heavy haul loading	Global Synthetics / Foundation QA / University of Wollongong
Program 3 – Design, Modelling and Simulation			
15	R3.1.2	Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system	Downer / University of Technology Sydney
16	R3.1.3	Predictive maintenance models for Sydney Trains	Sydney Trains / UTS
17	R3.1.4	Intelligent data fusion and analytics framework	Downer / Deakin University
18	R3.1.5	Wheel and bearing wear prediction	Downer / UQ
19	R3.2.2	Development of a responsive passenger information system for the Sydney Trains network (stage 2)	Sydney Trains / UTS
20	R3.3.3	Reimagining the workforce: building smart, sustainable and safe public transport	Department of Transport / Victoria University
21	R3.4.1	Arc welding modelling	CRRC / CSIRO
22	R3.6.1	Experimental and computational study on the key ventilation issues affecting air quality and thermal comfort in train cabins	Airlinx / RMIT University

Commonwealth Milestone status as at 30 June 2020

Milestone number	Milestone	Due date	Status
Program 1 – Power and Propulsion			
R1.1.4	Report approved for evaluation and validation of Demonstrator.	30 Dec 2019	Completed
R1.3.6	Design and development of manufacturing process completed.	30 Jun 2020	Completed
R1.3.7	Final report approved and release IPR for utilisation/commercialisation approved. Start of Production.	30 Jun 2020	Completed
R1.4.5	Report approved for scale up and commercialisation. Field Trials completed.	31 Dec 2019	Completed
R1.4.6	Design and development of manufacturing process completed.	31 Mar 2020	Completed
R1.4.7	Final report approved and releases IPR for utilisation/commercialisation. Start of Production.	31 Mar 2020	Completed
R1.5.4	Completion of 1 PhD student.	30 Jun 2019	Completed
R1.5.5	Completion of 4 PhD students.	30 Jun 2020	In Progress
R1.5.6	Strategy in place to manage transition and support the completion of any unfinished PhD students following the closure of the CRC.	30 Jun 2020	Completed
Program 2 – Materials and Manufacturing			
R2.2.4	Validated model for physical and predicted data.	31 Dec 2019	Completed
R2.2.5	Design, develop component and manufacturing process completed.	30 Jun 2020	Completed
R2.2.6	Test and evaluate component and report on optimal process completed.	30 Jun 2020	Completed
R2.2.7	Final report approved and release IPR for utilisation/commercialisation. Start of Production.	30 Jun 2020	Completed
R2.3.6	Test and evaluate component and manufacturing process field trials completed.	31 Dec 2019	Completed
R2.3.7	Final report approved and release IPR for utilisation/commercialisation. Start of Production.	30 Jun 2020	Completed
R2.5.5	Completion of 3 PhD students.	30 Jun 2019	In Progress
R2.5.6	Completion of 6 PhD students.	30 Jun 2020	In Progress
R2.5.7	Strategy in place to manage transition and support the completion of any unfinished PhD students following the closure of the CRC.	30 Jun 2020	Completed
Program 3 – Design, Modelling and Simulation			
R3.1.2	Further development and scale up of Automated on-line health monitoring system.	30 Dec 2019	Completed
R3.1.7	Final report approved and release IPR for utilisation/commercialisation. Start of Production.	31 Dec 2019	Completed
R3.4.4	Validated model for physical and predicted data.	31 Dec 2019	Completed
R3.4.5	Design and develop component and manufacturing process completed	31 Dec 2019	Completed
R3.4.6	Test and evaluation completed.	31 Dec 2019	Completed
R3.4.7	Final report approved and release IPR for utilisation/commercialisation.	30 Jun 2020	Completed
R3.5.5	Design and develop component and manufacturing process completed.	31 Dec 2019	Completed
R3.5.6	Test and evaluate component and manufacturing process field trials completed	31 Mar 2020	Completed
R3.5.7	Final report approved and release IPR for utilisation/commercialisation. Start of Production.	30 Jun 2020	Completed
R3.6.7	Final report approved and release IPR for utilisation/commercialisation. Start of implementation in company.	31 Dec 2019	Completed
R3.7.4	Completion of 1 PhD student.	30 Jun 2018	Completed
R3.7.5	Completion of 3 PhD students.	30 Jun 2019	In Progress
R3.7.6	Completion of 8 PhD students.	30 Jun 2020	In Progress
R3.7.7	Strategy in place to manage transition and support the completion of any unfinished PhD students following the closure of the CRC.	30 Jun 2020	Completed

Performance against activities, continued.

Research

Developing supercapacitor technologies at CSIRO

01
Power and Propulsion

Program 1 – Power and Propulsion

The development and application of lithium battery technology has been the key focus of Program 1 over the last six years, with the rapid uptake of lithium battery developments in automotive and renewable energy fields stimulating interest from the rail sector.

Based on industry needs, the research has focused on developing batteries and supercapacitors specifically for rail applications, plus using commercial batteries for propulsion and power backup. Key in this space has been the working relationship between HEC Group and the University of Technology Sydney in battery and supercapacitor development.

Within Project R1.1.1 - ***New generation lithium-ion batteries with high energy and long service life for rail industry applications*** (HEC Group / University of Technology Sydney), the research group developed lithium battery electrode materials which showed improvements compared with typical commercial batteries with a cycle life of over 3,000 cycles achieved at lab scale.

Pure graphite materials normally used for lithium batteries were replaced with either silicon/graphite or lithium titanate, which showed benefits of higher energy density for silicon/graphite and higher cycle life for lithium titanate. Importantly, the processing route for producing the materials was compatible with the industrial scale processing equipment currently used for battery materials.

For Project R1.1.2 - ***Hybrid supercapacitors with high energy and power densities for rail industry applications*** (HEC Group / University of Technology Sydney), the development of lithium titanate composite materials, trialed through a number of production routes, demonstrated the ability to increase the performance of lithium titanate anode materials for supercapacitors, making them more conductive. Extensive testing of the powders produced, enabled optimisation of the lithium titanate to produce the best performing materials.

Another key partnership has been between CRRC and CSIRO with the range of projects focused on developing supercapacitors to power catenary-free rail.

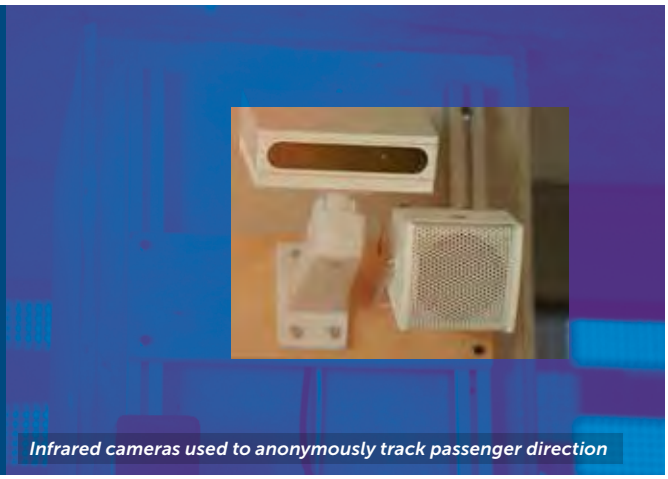
In Project R1.3.4 - ***Supercapacitor energy management system stage 2*** (CRRC / CSIRO), this project involved the development of control systems by CSIRO to manage supercapacitor cell charging, discharging and battery balancing. In conjunction with the hybrid cells, new semiconductors with particularly high-powered insulated-gate bipolar transistors made replacement of a traditional catenary system feasible. The integration of near field communications into the control system enabled the state of the system to be communicated as the train approaches the platform for charging purposes.

CSIRO has worked with CRRC, Downer and Knorr-Bremse on separate industry projects in the development of rail battery applications, resulting in prototype systems based on commercially available batteries. Whist COVID-19 restrictions slowed this work and restricted the ability to conduct onsite trials, the battery prototypes were developed to a stage that enables the companies to conduct the trials in due course.

Within the area of propulsion, braking was a focus, delivering improved materials for use on high speed trains.

For Project R1.5.1 - ***Aluminium matrix composite brake discs*** (CRRC / CSIRO), the team at CSIRO successfully developed and produced full size brake discs made from aluminium ceramic composite materials. The brake discs met requirements for mechanical strength, wear rate and heat dissipation, enabling the composite brake disc to be certified and undergo trialing at CRRC prior to full production commencing.

Testing ballast stability at the University of Wollongong



Infrared cameras used to anonymously track passenger direction

02
Materials and Manufacturing

Program 2 – Materials and Manufacturing

With the prevalence of build and maintain contracts in Australia, Program 2 has seen a focus on maintenance and durability projects that aim to either increase the durability of rollingstock components or understand the durability expectations to optimise maintenance and overhaul programs.

Project R2.3.4 - ***Monitoring and control of false brinelling*** (Bombardier / University of Queensland) aimed to develop an accurate predictive model for axle bearing wear by studying the real effects of bearing wear during transportation.

Project R2.5.2 - ***Application of geogrids for minimising track deformation and degradation under high frequency cyclic and heavy haul loading*** Global Synthetics, Foundation QA / University of Wollongong) involved a series of large-scale rail ballast tests, with and without geogrid reinforcement under cyclic loading conditions, providing track engineers with the data on geogrid performance in relation to track maintenance requirements.

New materials were not as significant a part of Program 2 as expected, however the use of cold spray and laser cladding processes at CSIRO were used to improve the performance of rollingstock components.

With Project R2.1.2 - ***Protection of cast steel coupler from corrosion by cold spray*** (CRRC / CSIRO), the coating of zinc onto steel substrates using could spray achieved all of the required parameters of speed of application, coating thickness, density, bond strength and corrosion performance. A key achievement of the project was the significant improvement in adhesion of the coating that was addressed as a variation to the project.

Another new materials project between CRRC and CSIRO was Project R2.1.3 - ***Laser repair of railway cast components*** (CRRC / CSIRO). For this work, several metal powder compositions were assessed to determine the composition and laser parameters to repair defects resulting in a crack free repair. These studies have provided enough confidence for the laser technology to be applied in industrial applications.

From a combined safety and improved performance perspective, Project R2.1.4 - ***Low fume high productivity MIG welding*** (CRRC / CSIRO) developed new weld tip designs which, combined with optimal weld parameters for the specific designs, demonstrated potential for a reduction in weld fume by around 50 per cent. The potential benefits of the project are not only in productivity improvements, but also the health and safety benefits in the reduction of the welders' exposure to fumes.

There has not been many projects focused on the use of lightweight materials as expected at the start of the CRC, however a number of PhD projects are looking at materials and designs to reduce weight. The benefits of weight reduction including the ability to transport higher loads of freight and energy savings in passenger networks hopefully make weight reduction something for future implementation.

03
Design, Modelling and Simulation

Program 3 – Design, Modelling and Simulation

Expertise in algorithm development and the emergence of low cost computing power to handle large amounts of data have generated interest in data analytics and machine vision for rail applications.

Through the development of the Dwell Track™ technology solution, Project R3.1.2 - ***Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system*** (Downer / University of Technology Sydney) achieved the automatic detection of the position, direction and number of up to 50 passengers per camera on a railway platform. Sixteen ethernet-connected depth cameras were installed along the length of Wynyard's platform three in a trial of the technology with Sydney Trains.

A related project was Project R3.2.2 - ***Development of a responsive passenger information system for the Sydney Trains network*** (stage 2) (Sydney Trains / University of Technology Sydney). An experimental system was built at UTS to develop electronics, software and graphical user interfaces for passenger information systems. This work led to a demonstrable passenger information system installed at Town Hall station, allowing the collection of insights into customer movements from existing CCTV, Dwell Track™ and Wi-Fi in real-time.

In the predictive maintenance space, two projects were conducted on behalf of Downer in support of the organisation's TrainDNA system – Project R3.1.4 - ***Intelligent data fusion and analytics framework*** (Downer / Deakin University) and Project R3.1.5 - ***Wheel and Bearing Wear Prediction*** (Downer / University of Queensland).

The Deakin University research team developed algorithms to assess train components to predict more accurate maintenance regimes and identify potential failures. The data analytics was implemented into Downer's TrainDNA system, providing engineers with real-time access to data analytics. Furthermore, the University of Queensland provided the most critical axle bearing and wheel wear parameters to monitor as best indicators/predictors of bearing degradation to enter into TrainDNA's predictive models.

Project R3.4.1 - ***Arc welding modelling*** (CRRC / CSIRO) involved the development of a software module to predict welding parameters that give optimised quality and speed of welds in rail components. Validated models of arc welds for aluminium, magnesium and steel joints for butt, lap, T and corner joints were developed and incorporated into the software module. Validated models for arc welding of steels with Ar/O_2 and Ar/CO_2 shielding gas were also developed and incorporated into the module.

Another modelling project has been the long-term partnership between Melbourne-based SME Airlinx and RMIT University, on Project R3.6.1 - ***Experimental and computational study on the key ventilation issues affecting air quality and thermal comfort in train cabins*** (Airlinx / RMIT University). The project team developed a comprehensive model for air flow in train carriages enabling different designs to be considered for optimised passenger comfort. Various designs of airconditioning diffusors were modelled and tested, supporting the proposal of new diffusor designs.

Planning for future workforce needs is of clear importance to Australia's rail industry. In response, Project R3.3.3 - ***Reimagining the workforce: building smart, sustainable and safe public transport*** (Department of Transport / Victoria University) conducted detailed organisational and economic reviews across a diverse range of roles including engineers, drivers, manufacturers and maintenance workers to assess how to retain staff and promote the industry to the next generation of workers.

Melbourne city tram stop

Publications list in 2019–20

In the past 12 months, a total of 55 publications were produced across the Centre's industry-led and PhD scholarship projects – publication details are listed below:

Articles in scholarly refereed journals

Bernal, E., Spiryagin, M. and Cole, C. Wheel flat detectability for Y25 railway freight wagon using vehicle component acceleration signals. Vehicle System Dynamics (2019): 1-21. (Project R1.7.2)

Brinji, O., Fallahnezhad, K. and Meehan, P. (2019). Analytical model for predicting false brinelling in bearings. Wear, p.203135. (Project R2.3.4)

Chen, F., Xiang, J., Thomas, D. and Murphy, A. Model-based parameter optimization for arc welding process simulation, Appl. Math. Modell. 81 386–400 (2020). (Project R3.4.1)

Dong, L., Wang, W., Wang, W., Wang, C., Li, Y., Xu, C., Wan, S., He, F., Kang, F. and Wang, G. High-Power and Ultralong-Life Aqueous Zinc-Ion Hybrid Capacitors Based on Pseudocapacitive Charge Storage, Nano-Micro Letters 2019, 11, 94. (Project 1.1.2)

Fallahnezhad, K., Brinji, O., Desai, A. and Meehan, P. (2019). The influence of different types of loading on false brinelling. Wear, 440(441), p.203097. (Project R2.3.4)

Gong, Y., Li, Z., Zhang, J., Liu, W. and Zheng, Y. Online Spatio-temporal Crowd Flow Distribution Prediction for Complex Metro System, IEEE Transactions on Knowledge and Data Engineering, 2020. (Project R3.7.2)

Jaumaux, P., Liu, Q., Zhou, D., Xu, X., Wang, T., Wang, Y., Kang, F., Li, B. and Wang, G. Deep-Eutectic-Solvent-Based Self-Healing Polymer Electrolyte for Safe and Long-Life Lithium-Metal Batteries, Angew. Chem. Int. Ed. 2020, DOI: 10.1002/anie.202001793. (Project 1.1.2)

Lee, Y. F., Lu, Y., and Guan, R. (2020). Nonlinear guided waves for fatigue crack evaluation in steel joints with digital image correlation validation. Smart Materials and Structures, 29(3), 035031. (Project R3.7.5)

Li, Z., Zhang, J., Wu, Q., and Kirsch, C. Field-Regularised Factorization Machines for Mining the Maintenance Logs of Equipment. In: Mitrovic T., Xue B., Li X. (eds) AI 2018: Advances in Artificial Intelligence. AI 2018. Lecture Notes in Computer Science, pp. 172-183 vol 11320. Springer, Cham. (Project R3.7.2)

Mojumder, S., Su, H., Qiu, C., Mutton, P., Singh, A. & Yan, W. (2020). The role of bending stress on the initiation of reverse transverse defects. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 0954409720904329. (Project R2.7.6)

Pang, Y., Chen, B. K., and Liu, W. (2019). An investigation of plastic behavior in cold-rolled aluminum alloy AA2024-T3 using laser speckle imaging sensor. Int. J. Adv. Manuf. Tech., 103, 2707–2724. (Project R3.7.7)

Pang, Y., Chen, B. K., Liu, W., Yu, S. F., and Lingamanaik, S. N. (2020). Development of a non-contact and non-destructive laser speckle imaging system for remote sensing of anisotropic deformation around fastener holes. NDT & E International, 102219. (Project R3.7.7)

Pang, Y., Chen, B. K., Yu, S. F. and Lingamanaik, S. N. (2020). Enhanced laser speckle optical sensor for in situ strain sensing and structural health monitoring, Opt. Lett. 45, 2331-2334. (Project R3.7.7)

Pang, Y., Lingamanaik, S. N., Chen, B. K., and Yu, S. F. (2020). Measurement of deformation of the concrete sleepers under different support conditions using non-contact laser speckle imaging sensor. Engineering Structures, 205, 110054. (Project R3.7.7)

Pozzebon M., Lin, C. and Meehan, P. On the Modeling of Wear in Grease-Lubricated Spherical Roller Bearings. Tribology Transactions. 2020:1-14. (Project R2.3.2)

Roy, T., Abrahams, R., Paradowska, A., Lai, Q., Mutton, P., Soodi, M., Fasihi, P. and Yan, W. Evaluation of the mechanical properties of laser cladded hypereutectoid steel rails. Wear 432 (2019): 202930. (Project R2.7.13)

Saki, M., Abolhasan, M., & Lipman, J. (2020) A Novel Approach for Big Data Classification and Transportation in Rail Networks. In IEEE Transactions on Intelligent Transportation Systems, vol. 21, no. 3, pp. 1239-1249, March 2020. (Project R3.7.1)

Shrestha, S., Spiryagin, M., and Wu, Q. Friction condition characterization for rail vehicle advanced braking system. Mechanical Systems and Signal Processing, vol. 134, p. 106324, Dec. 2019, doi: 10.1016/j.ymssp.2019.106324. (Project R1.7.1)

Shrestha, S., Spiryagin, M. and Wu, Q. Real-time multibody modeling and simulation of a scaled bogie test rig, Railway Engineering Science, pp. 1–14, 2020, doi: 10.1007/s40534-020-00213-y. (Project R1.7.1)

Su, H., Li, J., Lai, Q., Lun Pun, C., Mutton, P., Kan, Q., Kang, G. and Yan, W. (2020). Ratcheting behaviour of flash butt welds in heat-treated hypereutectoid steel rails under uniaxial and biaxial cyclic loadings. International Journal of Mechanical Sciences. Volume 176 (Project R2.7.6)

Su, H., Lun Pun, C., Mutton, P., Kan, Q. and Yan, W. (2019). Numerical study on the ratcheting performance of heavy haul rails in curved tracks. Wear - An International Journal on the Science and Technology of Friction, Lubrication and Wear (Volumes: 436-437, 15 October 2019, 203026) (Project R2.7.6)

Wang, S., Xiong, P., Guo, X., Zhang, J., Gao, X., Zhang, F., Tang, X., Notten, P. H. L. and Wang, G. A Stable Conversion and Alloying Anode for Potassium-Ion Batteries: A Combined Strategy of Encapsulation and Confinement. Adv. Funct. Mater. 2020, 2001588. (Project R1.1.1)

Xia, F., Durandet, Y., Yu, T. X., and Ruan, D. (2020). Large deformation of corrugated sandwich panels under three-point bending. Journal of Sandwich Structures & Materials. (Project R2.7.4)

Yu, X., Yu, Z.-Y., Zhang, X.-L., Li, P., Sun, B., Gao, X., Yan, K., Liu, H., Duan, Y. and Gao, M.-R. Highly Disordered Cobalt Oxide Nanostructure Induced by Sulfur Incorporation for Efficient Overall Water Splitting. Nano Energy 2020, 104652. (Project R1.1.1)

Zhang, F., Guo, X., Xiong, P., Zhang, J., Song, J., Yan, K., Gao, X., Liu, H. and Wang, G. Interface Engineering of MXene Composite Separator for High-Performance Li–Se and Na–Se Batteries. Adv. Energy Mater. 2020, 2000446. (Project R1.1.1)

Zhang, Y., Alarco, J., Nerkar, J., Best, A., Snook, G. and Talbot, P. (2019). Improving the rate capability of LiFePO4 electrode by controlling particle size distribution. Journal of the Electrochemical Society 166, A4128-A4135. (Project R1.3.3)

Zhang, Y., Alarco, J., Nerkar, J., Best, A., Snook, G. and Talbot, P. (2020). Nanoscale characteristics of practical LiFePO4 materials - Effects on electrical, magnetic and electrochemical properties. Materials Characterization 162, 110171. (Project R1.3.3)

Zhang, Y., Alarco, J., Nerkar, J., Best, A., Snook, G., Talbot, P. and Cowie, B. (2020). Spectroscopic Evidence of Surface Li-Depletion of Lithium Transition-Metal Phosphates. ACS Applied Energy Materials 3, 2856-2866. (Project R1.3.3)

Zhao, S., Yan, K., Zhang, J., Sun, B. and Wang, G. Reviving Reaction Mechanism of Layered Lithium-Rich Cathode Materials for High-Energy Lithium-Ion Battery. Angewandte Chemie International Edition n/a (n/a). DOI: 10.1002/anie.202000262. (R1.1.1)

Full written conference paper – refereed proceedings

Chen, F., Xiang, J., Thomas, D. and Murphy, A. MIG welding software benchmarking, IIW Document 212-1636-19, Annual Meeting of International Institute of Welding Study Group 212, Bratislava, Slovakia, 2019 (2019). (Project R3.4.1)

Chen, J., Jindal, H., Philpot, D., Khan, S., Lim, C. and Creighton, D. Can I Trust Machine Learning Analytics? Downer's Approach to Predictive Maintenance, AusRAIL PLUS 2019, 3-5 December 2019, Sydney Australia. (Project R3.1.4)

Gabrys, B. Automated composition, optimisation and adaptation of complex predictive systems. An invited keynote talk presented in November 2019 at the Workshop on Learning and Mining with Industrial Data, 2019 IEEE International Conference on Data Mining (ICDM), Beijing, China, 2019. (Project R3.1.3)

Gong, Y., Li, Z., Zhang, J., Liu, W., Chen, B. and Dong, X. A Spatial Missing Value Imputation Method for Multi-view Urban Statistical Data. 29th International Joint Conference on Artificial Intelligence. 2020. (Project R3.7.2)

Gong, Y., Li, Z., Zhang, J., Liu, W., & Kirsch, C. Network-wide crowd flow prediction of Sydney trains via customized online non-negative matrix factorization. In Proceedings of the 27th ACM International Conference on Information and Knowledge Management, pages 1243–1252, 2018. (Project R3.7.2)

Gong, Y., Li, Z., Zhang, J., Liu, W. and Yi, J. Potential passenger flow prediction: A novel study for urban transportation development. Proceedings of the 34th AAAI Conference on Artificial Intelligence, pages 4020–4027, 2020. (Project R3.7.2)

Indraratna, B., Ngo, N. Qi, Y, and Rujikiatkamjorn, C. (2020). Track Geomechanics for Future Railways: Use of Artificial Inclusions. ICTG2020 - 4th International Conference on Transportation Geotechnics. Chicago, USA. (Project R2.5.2)

Indraratna, B., Ngo, N. and Rujikiatkamjom, C. (2019). Advancement of Rail Ballast Testing Methodologies and Design Implications. Geo-Congress 2020 (Project R2.5.2)

Indraratna, B., Qi, Y., Jayasuriya C., Heitor A. and Navaratnarajah, S. Use of rubber tyre elements in track stabilization. Invited keynote paper for 15th International Conference on Geotechnical Engineering, 2019. Lahore, Pakistan. (Project R2.5.1)

Indraratna, B., Qi, Y, and Ngo, T. (2020). Sustainable Transport Infrastructure Adopting Energy-absorbing Waste Materials. The 1st International Symposium on Construction Resources for Environmentally Sustainable Techniologies (CREST 2020), Kyushu, Japan. (Project R2.5.1)

Jayasuriya, C., Indraratna, B. and Ferreira, F. The Use of Under Sleeper Pads to Improve the Performance of Rail Tracks 2020. Indian Geotechnical Journal, DOI: 10.1007/s40098-020-00418-2. (Project R2.5.2)

Jayasuriya, C., Indraratna, B., Rujikiatkamjom, C. and Navaratnaraja, S. (2019). Application of elastic inclusions to improve ballasted track performances. Geo-Congress 2020 (Project R2.5.2)

Kocbek, S. and Gabrys, B. Automated Machine Learning Techniques in Prognostics of Railway Track Defects. 2019 International Conference on Data Mining Workshops (ICDMW), Beijing, China, 2019, pp. 777-784, doi: 10.1109/ICDMW.2019.00115. (Project R3.1.3)

Performance against activities, continued.

Lee, Y. F., Lu, Y., Chiu, W.K. and Iman, S. 2019. Nonlinear guided waves detection for fatigue crack detection in a steel joint, in the Proceedings of the 12th International Workshop on Structural Health Monitoring, 10-12, September 2019, Stanford University, Stanford, CA, USA (Project R3.7.5)

Murphy, A., Chen, F., Xiang, J., Thomas, D and Feng, Y. Modelling the mushy zone in MIG welding, IIW Document 212-1634-19, Annual Meeting of International Institute of Welding Study Group 212, Bratislava, Slovakia, 2019 (2019). (Project R3.4.1)

Murphy, A., Xiang, J., Park, H., Chen, F., Thomas, D., Feng, Y., Tanaka, K., Shigeta, M. and Tanaka, M. Metal vapour in arc welding, Proc. 5th International Symposium on Visualization in Joining & Welding Science through Advanced Measurements and Simulation & 8th International Conference of Welding Science and Engineering, Osaka, Japan, 2019, vol. 1, pp. 1–2 (2019). (Project R3.4.1)

Murphy, A., Xiang, J., Park, H., Chen, F., Thomas, D., Feng, Y., Tanaka, K., Shigeta, M., and Tanaka, M. Metal vapour in arc welding. Book of Abstracts, 21st Gaseous Electronics Meeting, Canberra, 2020. (Project R3.4.1)

Pang, Y., Chen, B. K., Lingamanaik, S. N., and Yu, S. F. (2019). Development of a non-contact and non-destructive laser-speckle imaging system for sensing railway conditions. In Proceedings ICCIVIL 2019 – 4th International Conference on Civil Engineering (ICCIVIL), Hangzhou. (Project R3.7.7)

Shrestha, S., Spiryagin, M., and Wu, Q. Variable control setting to enhance rail vehicle braking safety. In Joint Rail Conference JRC2020, 2020, [online access] pp. 1–6. (Project R1.7.1)

Shrestha, S., Koirala, A., Spiryagin, M., and Wu, Q. Wheel-rail interface condition estimation via acoustic sensors. In Joint Rail Conference JRC2020, 2020, [online access] pp. 1–6. (Project R1.7.1)

Thomas, D., Murphy, A., Chen, F., Xiang. J. and Feng, Y. ArcWeld: A case study of the extensibility of software applications built using Workspace architecture, Proc. 23rd International Congress on Modelling and Simulation, Canberra, Australia, 2019, pp. 470–476 (2019). (Project R3.4.1)

Wang, M., Zhang, J. and Lu, G. Numerical Analysis of Energy Absorption Performance of Voronoi core and Origami core sandwich panels. The 7th International Conference on Design and Analysis of Protective Structures (HIS-DAPS2019), 04-06 December 2019, Seoul, Korea. (Project R2.7.3)

Wenhua, J., Zhenliang, M., Inhi, K., Seonha, L. Revealing Mobility Regularities in Urban Rail Systems. 11th International Conference on Ambient Systems, Networks and Technologies, Warsaw, Poland, April 2020. (Project R3.7.11)

Yang, J., Shiwakoti, N. and Tay, R., Train dwell time models–development in the past forty years. In 41st Australasian Transport Research Forum (ATRF), October 2019, Canberra, ACT, Australia. (Project R3.7.13)

Yang, L., Li, X. and Tu, J. (2019). Thermal comfort analysis of a high-speed train cabin considering the solar radiation effects. Indoor and Built Environment 0(0): 1420326X198760 (Project R3.6.1)

Zhang, L, Zhang, J., Li, Z. and Xu, J. Towards Better Graph Representation: Two-branch Collaborative Graph Neural Networks for Multimodal Marketing Intention Detection. 21st IEEE International Conference on Multimedia & Expo. 2020. (Project R3.7.2)

An engineer working on a tramline during the night

Commercialisation

The Rail Manufacturing CRC's model for commercialisation and utilisation was developed in close consultation with its industry and research participants, with an overarching principle to support and facilitate industry-led research outcomes in an independent manner.

This model is tailored to each project and is dependent on factors, including the:

- capacity of the participants to use and commercialise project outcomes,
- research and commercial inputs to the project,
- benefit to Australia,
- contributions of parties to intellectual property, and
- commercial viability of the research outcomes.

With the Centre playing an independent role in project decision making, the commercialisation model limits the number of organisations seeking input into commercial decisions, which ensures that Industry and Research Participants investing in the project will receive benefit from any commercial returns.

Before projects commence, all commercial outcomes and Intellectual Property (IP) terms and conditions are determined through transparent contractual negotiations upfront, which limits any potential IP legacy issues in future years.

Projects completed

As of June 2020, twenty-two Rail Manufacturing CRC projects were completed during the year:

- Project R1.1.1 - ***New generation lithium-ion batteries with high energy and long service life for rail industry applications*** (HEC Group / University of Technology Sydney)
- Project R1.1.2 - ***Hybrid supercapacitors with high energy and power densities for rail industry applications*** (HEC Group / University of Technology Sydney)
- Project R1.3.4 - ***Supercapacitor energy management system stage 2*** (CRRC / CSIRO)
- Project R1.3.5 - ***Lighting and control battery backup*** (Downer / CSIRO)
- Project R1.3.6 - ***Battery pack durability*** (Knorr-Bremse / CSIRO)
- Project R1.5.1 - ***Aluminium matrix composite brake discs*** (CRRC / CSIRO)
- Project R2.1.1 - ***Platform gap*** (Downer / Monash University)
- Project R2.1.2 - ***Protection of cast steel coupler from corrosion by cold spray*** (CRRC / CSIRO)
- Project R2.1.3 - ***Laser repair of railway cast components*** (CRRC / CSIRO)
- Project R2.1.4 - ***Low fume high productivity MIG welding*** (CRRC / CSIRO)
- Project R2.3.1 - ***Accelerated life testing and characterisation of critical components*** (Knorr-Bremse / CSIRO)
- Project R2.3.4 - ***Monitoring and control of false brinelling*** (Bombardier / University of Queensland)
- Project R2.5.1 - ***Performance of recycled rubber inclusions for improved stability of railways*** (Tyre Stewardship / ACRI / University of Wollongong)
- Project R2.5.2 - ***Application of geogrids for minimising track deformation and degradation under high frequency cyclic and heavy haul loading*** (Global Synthetics / Foundation QA / University of Wollongong)
- Project R3.1.2 - ***Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system*** (Downer / University of Technology Sydney)
- Project R3.1.3 - ***Predictive maintenance models for Sydney Trains*** (Sydney Trains / University of Technology Sydney)
- Project R3.1.4 - ***Intelligent data fusion and analytics framework*** (Downer / Deakin University)
- Project R3.1.5 - ***Wheel and bearing wear prediction*** (Downer / University of Queensland)
- Project R3.2.2 - ***Development of a responsive passenger information system for the Sydney Trains network (stage 2)*** (Sydney Trains / University of Technology Sydney)
- Project R3.3.3 - ***Reimagining the workforce: building smart, sustainable and safe public transport*** (Department of Transport / Victoria University)
- Project R3.4.1 - ***Arc welding modelling*** (CRRC / CSIRO)
- Project R3.6.1 - ***Experimental and computational study on the key ventilation issues affecting air quality and thermal comfort in train cabins*** (Airlinx / RMIT University)

For more detail on project deliverables, go to pages 18 to 33.

Utilisation milestones

All utilisation milestones were achieved during the reporting period:

Milestone number	Milestone	Due date	Status
Program 1 – Power and Propulsion			
U1.1.2	Grant of Utilisation rights to R&D Participant	30 Jun 2020	Completed
U1.1.3	Assignment of Project IP	30 Jun 2020	Completed
U1.3.3	Grant of Utilisation rights to R&D Participant	30 Sep 2019	Completed
U1.3.4	Assignment of Project IP	30 Sep 2019	Completed
U1.3.5	Decision whether or not to proceed with production	30 Apr 2020	Completed
U1.4.2	Evaluation of advanced braking system in the field by an end user	30 Jun 2020	Completed
U1.4.3	Grant of Utilisation rights to R&D Participant	30 Jun 2020	Completed
U1.4.4	Assignment of Project IP	30 Jun 2020	Completed
Program 2 – Materials and Manufacturing			
U2.1.6	Production of improved durability components	30 Jun 2020	Completed
U2.2.5	Production of rolling stock maintenance cost reduction technology	30 Jun 2020	Completed
U2.3.2	Evaluation of Steel for Rail sleepers in the field	30 Dec 2019	Completed
U2.3.5	Production of Steel Rail sleepers	30 Jun 2020	Completed
U2.4.5	Start of Production of substructures for reduced vibration and enhanced stability	30 Jun 2020	Completed
Program 3 – Design, Modelling and Simulation			
U3.1.5	Production of Automated on-line health monitoring system	30 Jun 2020	Completed
U3.2.5	Start of Production of advanced detection technologies	30 Jun 2020	Completed
U3.3.3	Grant of Utilisation rights to R&D Participant	30 Jun 2020	Completed
U3.3.4	Assignment of Project IP	30 Jun 2020	Completed
U3.3.5	Up take by Industry of software and hardware incorporating the algorithms	30 Jun 2020	Completed
U3.4.2	Validation of Advanced tool for evaluating rail infrastructure condition completed	30 Dec 2019	Completed
U3.4.5	Deployment of Advanced software tool for evaluating rail infrastructure condition	30 Jun 2020	Completed
U3.5.2	Validation of Advanced software tool for energy management and optimisation in the field	30 Dec 2019	Completed
U3.5.3	Grant of Utilisation rights to R&D Participant	30 Jun 2020	Completed
U3.5.4	Assignment of Project IP	30 Jun 2020	Completed
U3.5.5	Start of Production of Advanced software tool for energy management and optimisation	30 Jun 2020	Completed
U3.6.4	Assignment of Project IP	30 Jun 2020	Completed
U3.6.5	Start of use of airflow simulation for light rail passenger vehicles	30 Jun 2020	Completed

Education and training

Student workshopping underway

With impending skills shortages throughout the Australian rail industry sector due to grow from 2020 onwards[1], the need for rail to attract, employ and retain a new generation of employees is a key challenge that needs addressing.

In support, the Rail Manufacturing CRC has worked to identify and support a cohort of 51 PhD students working on rail-related research across leading Australian universities – well above the original target set to support 30 students.

Industry projects

As of 30 June 2020, there are 10 students actively working on industry projects:

- Tianyi Wang and Shuoqing Zhao, both working on Project R1.1.1 - ***New generation lithium-ion batteries with high energy and long service life for rail industry applications*** (HEC Group / University of Technology Sydney)
- Pauline Jaumaux, working on Project R1.1.2 - ***Hybrid supercapacitors with high energy and power densities for rail industry applications*** (HEC Group / University of Technology Sydney)
- Matthew Pozzebon and Abdul Mannan, both working on Project R2.3.2 - ***Axle bearing maintenance optimisation*** (Bombardier / University of Queensland)
- Osama Brinji and Vijayaragavan Raju, both working on Project R2.3.4 - ***Monitoring and control of false brinelling*** (Bombardier / University of Queensland)
- Alexander Virgona, working on Project R3.1.2 - ***Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system*** (Downer / University of Technology Sydney)
- Rehan Mohammad and Yit Hong Choo (Kelvin), both working on Project R3.1.4 - ***Intelligent data fusion and analytics framework*** (Downer / Deakin University)

PhD scholarships

As of 30 June 2020, 29 PhD Scholarship students were currently working on a wide variety of industry-leading rail research projects, including real-time condition monitoring, using drones for assessment, laser cladding technologies, augmented and virtual reality for training, big data analytics and automated assembly of rollingstock fabrications.

During 2019–20, the process for those PhD students eligible to apply for a co-funded six-month paid extension occurred, with 21 extensions granted.

Encouraging the next generation of rail employees

With an ever-increasing number of students supported by the Centre, the Rail Manufacturing CRC has continued to deliver ongoing learning opportunities to its students.

In March 2019, the Grow Your Career program was launched, a combined face-to-face and webinar training program delivered across 2018–19 and 2019–20 to upskill students to understand their personality preferences, career goals and drivers, and to develop strong LinkedIn profiles, resumes and interview techniques.

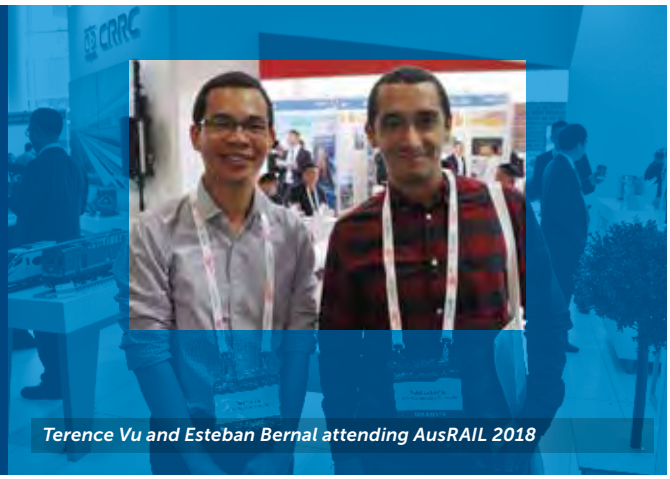
The third and final PhD Students' Forum was hosted in Sydney in March 2020, with students in attendance from University of Technology Sydney, University of Wollongong, Deakin University, Monash University, Swinburne University, RMIT University, CQUniversity and the University of Queensland.

The focus for the forum was the importance of building professional networks. Each student was also asked to develop a poster about their research to be shared during the event. The students took part in a keynote session about best practice networking. This was followed with an evening industry networking session represented by Downer, Transport for NSW, Deakin University and UTS Rapido.

A team of judges – made up of Research Director Larry Jordan, Chair Paul Johnson and Knorr-Bremse's Josh Pitcher – reviewed all poster submissions and selected Esteban Bernal of CQUniversity as developing the poster that best presented his PhD's focus, challenges and opportunities.

[1] Australasian Railway Assocation & BIS Oxford Economics, "ARA Skills Capability Study: Skills Crisis – A Call to Action"

Student tour at Downer Newport depot



Terence Vu and Esteban Bernal attending AusRAIL 2018

PhD completions

Milestones for PhD students now focus on the number of PhD completions, which the Rail Manufacturing CRC defines as the PhD thesis being submitted for assessment.

In 2019–20, five students completed their PhDs:

- Zhang Yin of Queensland University of Technology submitted her thesis in January 2020 for Industry Project R1.3.3 - ***High energy supercapacitor development*** (CRRC / CSIRO)
- Julien Collart of University of Technology Sydney submitted his thesis in January 2020 for Industry Project R3.1.2 - ***Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system*** (Downer / University of Technology Sydney)
- Xiaochun Gao and Yi Chen, both of University of Technology Sydney submitted their theses in February 2020 for Industry Project R1.1.2 - ***Hybrid supercapacitors with high energy and power densities for rail industry applications*** (HEC Group / University of Technology Sydney)
- Mahdi Saki of University of Technology Sydney submitted his thesis in May 2020 for PhD Scholarship Project R3.7.1 - ***Ultra-reliable and cost-effective communication infrastructure for future IoT-based railway applications***

This is in addition to two PhD students who submitted their theses in 2018-19 - Chamindi Jayasuriya from University of Wollongong and Zheshuo Zhang from Queensland University of Technology.

PhD withdrawals

Of the 51 PhD students supported, the following student withdrawals occured over the Centre's lifetime:

- one student working on an industry project
- three students who received a scholarship
- one student who participated in the internship program

Status against milestones

There are seven active education-related milestones, two of which have been Achieved in 2019–20 and five that are In Progress.

The delay in achieving PhD completion milestones was due to the establishment of a comprehensive PhD scholarship program mid-way through the Rail Manufacturing CRC's lifetime. The scholarship program was established after a smaller than expected number of initial industry projects with PhD involvement opportunities was identified.

With the establishment of the PhD Scholarship Program, the bulk of PhD students commenced in 2016–17 and 2017–18. This will result in an expected mass number of completions in the 2020–21 and 2021–22 Financial Years, post the Centre's closure.

Milestone number	Milestone	Due date	Status
Program 1 – Power and Propulsion			
R1.5.4	Completion of 1 PhD student	30 Jun 2019	Achieved
R1.5.5	Completion of 4 PhD students	30 Jun 2020	In Progress
Program 2 – Materials and Manufacturing			
R2.5.5	Completion of 3 PhD students	30 Jun 2019	In Progress
R2.5.6	Completion of 6 PhD students	30 Jun 2020	In Progress
Program 3 – Design, Modelling and Simulation			
R3.7.4	Completion of 1 PhD student	30 Jun 2018	Achieved
R3.7.5	Completion of 3 PhD students	30 Jun 2019	In Progress
R3.7.6	Completion of 8 PhD students	30 Jun 2020	In Progress

Current list of commenced PhD students – as of 30 June 2019

#	Student name	Degree	Start date	Expected completion date	Project title	Research institute	Student's country of origin
Program 1 – Power and Propulsion							
1	Tianyi Wang	PhD	25/08/2017	August 2021	New generation lithium-ion batteries with high energy and long service life	University of Technology Sydney	China
2	Shuoqing Zhao	PhD	22/08/2017	August 2021	New generation lithium-ion batteries with high energy and long service life	University of Technology Sydney	China
3	Pauline Jaumaux	PhD	20/08/2018	August 2021	Hybrid supercapacitors with high energy and power densities for rail industry applications	University of Technology Sydney	Belgium
4	Xiaochun Gao	PhD	26/08/2016	Completed	Hybrid supercapacitors with high energy and power densities for rail industry applications	University of Technology Sydney	China
5	Yi Chen	PhD	26/08/2016	Completed	Hybrid supercapacitors with high energy and power densities for rail industry applications	University of Technology Sydney	China
6	Zhang Yin	PhD	2/05/2016	Completed	High energy supercapacitor development	Queensland University of Technology	China
7	Sundar Shrestha	PhD	03/07/2017	January 2021	Estimation of adhesion conditions between wheels and rails for the development of advanced braking control systems	Central Queensland University	Nepal
8	Esteban Bernal Arango	PhD	03/07/2017	January 2021	Smart axle transducer transmitter for freight wagon condition monitoring systems	Central Queensland University	Colombia
9	Minoo Oveisi	PhD	24/10/2018	April 2022	A static and dynamic loading assessment of structural-critical composite material rolling stock carbody shells	RMIT University	Iran
Program 2 – Materials and Manufacturing							
10	Cameron Milne	PhD	12/01/2015	N/A[3]	Axle-bearing maintenance optimisation	University of Queensland	Australia
11	Matthew Pozzebon	PhD	28/04/2016	October 2020	Axle-bearing maintenance optimisation	University of Queensland	Australia
12	Abdul Mannan (Mannan)	PhD	01/07/2018	July 2022	Axle-bearing maintenance optimisation	University of Queensland	Bangladesh
13	Osama Brinji	PhD	13/04/2017	December 2020	Monitoring and control of false brinelling	University of Queensland	Saudi Arabia
14	Vijayaragavan Raju (Vijay)	PhD	01/07/2018	July 2022	Monitoring and control of false brinelling	University of Queensland	India
15	Chamindi Jayasuriya	PhD	22/08/2014	Completed	Performance of recycled rubber inclusions for improved stability of railways	University of Wollongong	Sri Lanka
16	Chuhao Liu	PhD	18/04/2017	October 2020	The performance of stabilised ballast in rail tracks	University of Wollongong	China
17	Mahsa Taherimandarjani	PhD	30/04/2018	October 2021	Laboratory evaluation of laser cladding on rail wheel steels	Swinburne University of Technology	Iran
18	Meng Wang	PhD	25/01/2018	July 2021	Manufacturing of lightweight panels	Swinburne University of Technology	China
19	Fukun Xia	PhD	15/12/2017	July 2021	Evaluation of hybrid structures for impact performance in rail applications	Swinburne University of Technology	China
20	Vu Trong Thien (Terence)	PhD	27/02/2017	December 2020	Automated assembly for rolling stock fabrication in rail industry	University of Wollongong	Vietnam
21	Hang Su	PhD	27/02/2017	October 2020	Optimisation of rail welding process parameters to mitigate rolling contact damage	Monash University	China
22	Pravin Urudra	PhD	01/03/2017	N/A[4]	Evaluating the suitability of laser cladded rail steel in heavy haul application	Monash University	Malaysia
23	Simon Wagner	PhD	14/05/2018	May 2022	Heavy haul train force control product	Central Queensland University	Australia
24	Elias Salloum	PhD	01/03/2018	September 2021	Optimising friction-stir welding and alloy design to ensure the durability of light weight carriages in the rail fleet	RMIT University	Australia
25	Mohammad Adinehrand	PhD	14/11/2018	March 2022	Miniature crawling robots for rolling stock manufacture and maintenance	RMIT University	Iran
26	Anthony Micheletto	PhD	04/01/2018	April 2021	Improvement of flashbutt welds in premium rails	Monash University	Australia

[3, 4] This student withdrew from his PhD

#	Student name	Degree	Start date	Expected completion date	Project title	Research institute	Student's country of origin
Program 2 – Materials and Manufacturing							
27	Tommy Huynh	PhD	10/12/2018	December 2022	Fire-retardant and lightweight composite materials for rolling stock carriages	RMIT University	Australia
28	Panahsadat Fasihi	PhD	14/08/2018	February 2022	Full-scale implementation of a new wheel-rail maintenance technology by using laser cladding	Monash University	Iran
29	Don Kushlani Ranmal Ranasinghe	PhD	27/06/2016	N/A[5]	Optimal design of raised rail - road crossing structure	Queensland University of Technology	Sri Lanka
30	Zheshuo Zhang	PhD	17/11/2015	Completed	Effect of raised rail - road crossing to the safety of road vehicles	Queensland University of Technology	China
Program 3 – Design, Modelling and Simulation							
31	Alexander Virgona	PhD	29/08/2014	September 2020	Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system	University of Technology Sydney	Australia
32	Julien Collart	PhD	05/02/2015	Completed	Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system	University of Technology Sydney	France
33	Rehan Mohammad	PhD	21/08/2019	August 2023	Intelligent data fusion and analytics framework	Deakin University	India
34	Yit Hong Choo (Kelvin)	PhD	15/01/2020	January 2023	Intelligent data fusion and analytics framework	Deakin University	Malaysia
35	Mahdi Saki	PhD	02/02/2016	Completed	Ultra-reliable and cost effective communication infrastructure for future IoT-based railway applications	University of Technology Sydney	Iran
36	Zhibin Li	PhD	02/03/2017	September 2020	Big data analytics for condition based monitoring and maintenance	University of Technology Sydney	China
37	Huaxi Huang	PhD	03/04/2018	November 2021	Rail infrastructure defect detection through video analytics	University of Technology Sydney	China
38	Amir Eslami	PhD	05/06/2017	N/A[6]	Drive-by bridge inspection: the use of instrumented revenue wagons for structural health monitoring of rail bridges	Monash University	Iran
39	Yu Fung Lee (Joseph)	PhD	27/02/2017	August 2020	Nonlinear vibro-acousto-ultrasonic waves for fatigue cracking detection in key rail components	Monash University	China
40	Chi Hei Vong (Calvin)	PhD	27/02/2017	August 2020	Control and navigation of micro UAV in small railway culverts and tunnels	Monash University	Portugal
41	Yong Pang	PhD	30/05/2017	February 2021	System for real-time monitoring and sensing railway conditions by laser light	Monash University	China
42	Dongyu Zhang	PhD	01/03/2017	December 2020	Hybrid unmanned aerial system for railway inspection	Monash University	China
43	Nalin Randeniya	PhD	15/06/2017	December 2020	Train maintenance training enhancements with transformative technologies for productivity and quality measures	Swinburne University	Sri Lanka
44	Andrew Danylec	PhD	15/06/2017	December 2020	Develop and establish augmented reality tools in High Capacity Metro Train for productivity and quality enhancements	Swinburne University	Australia
45	Wenhua Jiang	PhD	17/10/2017	April 2021	Short-term rail passenger flow forecasting application	Monash University	China
46	Don Skerman	PhD	22/10/2018	October 2022	Efficient daily track monitoring system	CQUniversity	Australia
47	Jie Yang (Joanne)	PhD	22/06/2018	December 2021	Optimising railway carriage design for improved dispersion, capacity and safety	RMIT University	Australia
48	Bibek Baral	PhD	09/10/2018	N/A[7]	FEM modelling of vacuum consolidation to alleviate visco-plastic strains in soft subgrade soils	University of Wollongong	Nepal
49	Peter Allen	PhD	31/08/2018	March 2022	Impeding train suicide using safety by design principles – a conceptual solution	Swinburne University	Australia
50	Krutika Shahabadkar	PhD	30/04/2020	April 2024	Implementation of virtual reality learning tools for improvements in hazard identification and safety enhancements	Swinburne University	India
51	Alejandro Tamani	PhD	22/11/2018	November 2022	Development of evacuation management tool for rail transport	RMIT University	Australia

[5] This student withdrew from her PhD
[6] This student withdrew from his PhD and reverted to Masters
[7] This student withdrew from his PhD

Intellectual property management

The Rail Manufacturing CRC focuses on ensuring maximum benefit and impact are derived from intellectual property derived from its projects.

The Rail Manufacturing CRC does not seek to own intellectual property nor seek royalties from the technology it develops. Instead, the Centre seeks to ensure that the technologies its projects deliver will provide the maximum benefit to the project partners.

Ownership and use of the project intellectual property is defined during the development of individual project agreements between the respective project participants, which ensures that the process is transparent and beneficial to all parties.

Patent applications to-date

Application number	Title	Priority data	Applicants
Provisional Patent 2019901155	Smart sensor node device and method for detecting faults and abnormal operating conditions on-board railway vehicles	2019-04-04	Central Queensland University
Provisional Patent 2020900085	Smart sensor node device and method for detecting faults and abnormal conditions on-board vehicles and distributed networks	2020-01-13	Central Queensland University
PCT/AU20 18/05 1303	Monitoring systems, and computer implemented methods for processing data in monitoring systems, programmed to enable identification and tracking of human targets in crowded environments	2017904919 6 December 2017 AU	University of Technology Sydney Downer EDI Rail Pty Ltd

Melbourne's train network

Collaboration

During 2019–20, the Rail Manufacturing CRC has continued to promote, engage and participate in multiple initiatives aimed at growing engagement and collaboration.

The Centre has worked to foster links between its postgraduate cohort and its industry participants. Several industry participants and third party organisations are currently providing support to the PhD students through access to expertise, data and materials, all of which strengthens the quality of the students' research work.

The Rail Manufacturing CRC's current suite of projects provided considerable benefit to its Participants, with 22 projects completing in 2019–20, in addition to 39 PhD students currently engaged on industry projects and via PhD scholarships.

By participating in numerous rail industry forums, this has enabled the Rail Manufacturing CRC to develop relationships with worldwide rail manufacturers, rail operators and Government organisations across its six years in operation.

As part of these activities, the Centre has participated in a range of industry briefings, conferences, forums and peak body advisory groups, and continued to work closely with rail peak bodies including the Rail Industry Safety and Standards Board (RISSB) and the Australasian Railway Association (ARA).

Collaborative projects with commercial potential or industry impact

Several of the Rail Manufacturing CRC's current projects are providing considerable benefit to their participants, with multiple projects close to realising commercial outcomes – including:

» Project R1.1.1 - ***New generation lithium-ion batteries with high energy and long service life for rail industry application*** (HEC Group / University of Technology Sydney):
This project has developed new high-performance battery technologies for rail and other applications. HEC Group are currently scaling up production of the new technologies in their production facilities to gauge technical feasibilities and cost

» Project R1.3.3 - ***High energy supercapacitor development*** (CSIRO / CRRC):
This project has resulted in several advances being made in the development of supercapacitors that can be used for rail applications. The technology developed during this project has generated interest from domestic companies and CSIRO will continue to develop this technology post the Rail Manufacturing CRC.

» Project R1.3.4 - ***Supercapacitor energy management system stage 2*** (CRRC / CSIRO):
Energy storage control systems being developed jointly by CRRC and CSIRO hold significant opportunities for the domestic and global rail sector. This work has involved the prototyping of an energy management system which will undergo full scale testing once COVID-19 restrictions are lifted, with the potential to be produced and used in the field in future.

» Project R1.5.1 - ***Aluminium matrix composite brake discs*** (CRRC / CSIRO):
The development of new processes and materials for high speed rail disc brakes has been prototyped by the CSIRO. The initial performance of protypes has been good and there is potential for this technology to be adopted for high speed rail applications (following type testing and the meeting of all regulatory requirements).

» Project R2.1.2 - ***Protection of cast steel coupler from corrosion by cold spray*** (CRRC / CSIRO):
A chief advantage of cold spray is that it does not use a large amount of heat, which would otherwise alter the substrate microstructure. Since metallic bonds form between particles, cold spray coatings exhibit high strength and adhesion compared with mechanical plating methods. Following successful demonstration of the technology, it is understood that CRRC will seek to implement the use of cold spray in its manufacturing facilities.

» Project R2.3.2 - ***Axle bearing maintenance optimisation*** (Bombardier / University of Queensland):
This project demonstrated the potential to reduce maintenance and overhaul requirements for rollingstock by examining methods to model and predict lubrication needs for the maintenance of the axle bearings. The implementation of modelling outcomes is expected to provide substantial savings.

Light rail in Newcastle CBD

» Project R2.3.4 - ***Monitoring and control of false brinelling*** (Bombardier / University of Queensland):
During the transport of bearings, one potential issue that can affect the performance of these bearings is the creation of bearing component wear. This wear can occur due to small oscillations or vibration during transport and can significantly reduce the performance and lifetime of bearings operating on the field. This project has monitored and attempted to understand the factors that lead to false brinelling in the transport of rollingstock components. The study successfully developed sensors and instrumentation for recording conditions during transport and has identified base requirements needed to transport these rail components.

» Project R3.1.2 - ***Integrated passenger behaviour, train operations diagnostics and vehicle condition monitoring system*** (Downer / University of Technology Sydney):
This project developed Dwell Track™, a passenger tracking technology which was trialed in the Sydney Trains network in August 2019 onwards. Sixteen cameras were installed at Wynyard station to use algorithms that 'sensed' crowd movement. The data provided staff with information to help reduce platform congestion and direct passengers more efficiently and effectively, while also providing long term insights into platform operations around dwell management. Algorithms developed in this project are the subject of a patent (see page 40) and Downer is currently looking at commercialisation options for the technology.

» Project R3.1.4 - ***Intelligent data fusion and analytics framework*** (Downer / Deakin University):
Downer has recently implemented a monitoring system called TrainDNA to monitor its recently manufactured rollingstock. This project has provided added capability to TrainDNA by providing data analytic tools and algorithms that improve the prediction capabilities of the technology system. Several components have been studied and the data tools refined, which will provide greater capability for Downer to assess and review potential performance issues in real-time. The potential for this technology to improve reliability and decrease network outages could result in significant savings and decreases in rail network delays.

» Project R1.3.6 - ***Battery packs for trains*** (Knorr-Bremse / CSIRO):
The project is currently developing a specialised battery pack and control system for use in rail applications. A prototype system has been built and is being assessed. Field trials are expected to be undertaken in late 2020.

» Project R3.3.2 - ***Development of a smart rail route map*** (Australasian Railway Association / Deakin University):
The delivery of a study to identify and prioritise technology initiatives for the rail sector in the digital and communications technology area. The work consulted with a cross section of participants from the rail industry sector resulting in a list of key priorities that the ARA have agreed to implement, via a specially convened Smart Rail committee.

» Project R3.3.3 - ***Reimagining the workforce: building smart, sustainable, safe public transport*** (Department of Transport Vic / Victoria University):
This research aimed to understand what practical steps might be taken to address critical skills shortages currently facing the sector. The project provided a systemic assessment case study of the Victorian public transport rollingstock sector from three perspectives: economic, organisational and community in the broader context of the public transport system. The final report is an interim action plan that lists three priorities identified by industry representatives. The study will inform and assist the National Transport Commission, through the Transport and Infrastructure Committee of the Council of Australian Governments, to develop a National Rail Action Plan.

» Project R3.6.1 - ***Experimental and computational study on the key ventilation issues affecting air quality and thermal comfort in train cabins*** (Airlinx / RMIT University):
This project developed a 3D model to predict thermal airflow and contaminant dispersion in train cabins. The project outputs have been used to design ventilation systems for passenger train cabins, but also have applicability for other industry uses such as commercial buildings.

SME engagement

Small-to-medium enterprises (SMEs) comprise a large majority of Australia's rail manufacturing and maintenance sector, so are an important element of the rail industry. Not all SMEs have had the capacity to become participants in the Rail Manufacturing CRC, however, the Centre seeks to ensure it continues to provide opportunities for SMEs to engage where possible.

The Centre's SME engagement included the following activities in 2019–20:

- Delivery of two Rail Manufacturing CRC Participants Forums during the year,
- Direct engagement with the Centre's CEO and key staff through participation in rail industry events and forums – including key rail conferences, rail peak body events and Federal and State Government forums,
- Regular communication about the Centre's activities and progress through the Rail Manufacturing CRC's email newsletters, website and social media updates, and face-to-face meetings, and
- The inclusion of 58 SMEs participating[8] in Project R3.3.3 - Reimagining the workforce: Building smart, sustainable and safe public transport (Department of Transport Vic / Victoria University).

Current projects with SMEs

During the reporting period, the Rail Manufacturing CRC had seven SMEs participants, with three SMEs actively participating with the Centre via two projects:

Project R2.5.2 - ***Application of geogrids for minimising track deformation and degradation under high frequency cyclic and heavy haul loading*** (Global Synthetics / Foundation QA / University of Wollongong):

Global Synthetics and Foundation QA were involved in the implementation of technologies to solve unique challenges involving rail ballast infrastructure. A series of large-scale tests investigated the behaviour of the rail ballast with and without geogrid reinforcement under cyclic loading conditions. Simulation results showed that the geogrid can significantly reduce the deformations of ballast under these loading conditions.

Project R3.6.1 - ***Experimental and computational study on the key ventilation issues affecting air quality and thermal comfort in train cabins*** (Airlinx / RMIT University):

Airlinx derived a greater understanding of its ventilation products through long-term modelling and simulation research being undertaken in collaboration with RMIT University. In this project, commercial software was used to develop a computational fluid dynamics model for assisting ventilation designs.

[8] 55 SME organisations and three bodies representing SMEs were directly involved in the project throughout Project R3.3.3 through participation in interviews, surveys, focus groups or roundtables, and participation in the planning workshop.

Onsite track maintenance underway

Communications

Communications is key to the successful operations of the Rail Manufacturing CRC. Throughout the past six years, the Communications program has worked to:

» provide internal and external stakeholders with timely, consistent and informative communications about the Rail Manufacturing CRC's direction and activities,

» maintain strong and collaborative relationships with the Centre's industry and research institute participants and key external stakeholders, and

» regularly evaluate the communication channels used via surveys, feedback, website analytics, social media engagement and newsletter readership.

Within 2019–20, the Rail Manufacturing CRC:

» hosted one face-to-face Sydney Participants Forum in November and one Zoom-based online Forum in June 2020

» ran its third and final PhD students' forum and wrapped up a six-month long webinar career readiness training program in August 2019

» held regular project meeting and strategy planning sessions with Participant organisations

» participated in a wide number of rail-focused sessions, including AusRAIL 2019, Australia China Young Scientist exchange program, the Metro Rail Stations and Terminal conference, CeBIT, numerous Victorian Rollingstock Research Sector meetings, the International Symposium on Frontier Materials, the Rail Suppliers Technology Roadmap 2040 Review, and industry engagements sessions for Project R3.3.3 - ***Reimagining the workforce: building smart, sustainable, safe public transport*** (Department of Transport Vic / Victoria University).

Unfortunately due to the COVID-19 pandemic, the majority of final external presentations and sessions scheduled for March 2020 onwards were postponed to late 2020 or cancelled outright – and given the Rail Manufacturing CRC's wind-up on 30 June 2020, the Centre will be unable to participate.

While these restrictions have impacted on the Centre's engagement strategy, most engagement and communication activities have continued through video conferencing, newsletters, and social media.

Developing a suite of project videos to promote the Centre's legacy

Alignment to CRC Program Branding

As required, all communications activities adhere to proper use of CRC Program Branding, as specified in the Funding Agreement. This has included the appropriate promotion of logos and inclusion of content used in presentations delivered, on printed communications collateral and online via the Centre's website and social media channels.

Partners and third parties

Essential Participants

Participant name	Participant type	ABN	Organisation type
Bombardier Transportation Australia Pty Ltd	Essential	73 010 699 804	Large Industry
Central Queensland University	Essential	39 181 103 288	University
China Railway Rolling Stock Corporation (CRRC)	Essential	Not applicable	Large Industry
CSIRO	Essential	41 687 119 230	Australian Government
Deakin University	Essential	56 721 584 203	University
Downer EDI Rail Pty Ltd	Essential	92 000 002 031	Large Industry
Monash University	Essential	12 377 614 012	University
OneSteel Manufacturing Pty Ltd *	Essential	42 004 651 325	Large Industry
Queensland University of Technology	Essential	83 791 724 622	University
Swinburne University of Technology	Essential	13 628 586 699	University
The University of Queensland	Essential	63 942 912 684	University
University of Technology Sydney	Essential	77 257 686 961	University
University of Wollongong	Essential	61 060 567 686	University

* As per the original terms and conditions of its Participants Agreement, OneSteel ceased as an Essential Participant as of November 2019.

Asset inspection underway at Bombardier's Wulkaraka depot

Other Participants

Participant name	Participant type	ABN	Organisation type
Airlinx Heating and Cooling Pty Ltd	Other	28 094 691 791	Individual SME
Australasian Centre for Rail Innovation (ACRI) Ltd	Other	52 164 764 167	Other
Australasian Railway Association	Other	64 217 302 489	Other
Department of Transport (Victoria)	Other	69 981 208 782	State Government
Foundation QA	Other	78 090 519 289	Individual SME
Global Synthetics	Other	71 120 519 520	Individual SME
HEC Group	Other	18 165 129 260	Large Industry
Knorr-Bremse Australia Pty Ltd	Other	31 092 562 671	Large Industry
Royal Melbourne Institute of Technology	Other	49 781 030 034	University
Sydney Trains	Other	38 284 779 682	State Government
TrackSAFE Foundation	Other	98 155 604 872	Individual SME
Tyre Stewardship Australia Ltd	Other	44 164 971 939	Individual SME
UGL Rail Services Pty Ltd	Other	58 000 003 136	Large Industry
Victoria University	Other	83 776 954 731	University

Third Party Participants

Participant name	Participant type	ABN	Organisation type
Austrade	Third Party	11 764 698 227	Government
Queensland Rail Ltd	Third Party	71 132 181 090	Large Industry

Governance

The Rail Manufacturing CRC Limited ("RMCRC"; "Company"; "Centre") is an unlisted public company limited by guarantee, incorporated and domiciled in Australia. Rail Manufacturing CRC Ltd is registered as a charity with the Australian Charities and Not-for-profits Commission.

As a registered charity, the Australian Taxation Office granted income tax exemption, a Fringe Benefits Tax rebate on capped employee fringe benefits and certain GST concessions to the Centre. As a result, no provision for income tax has been made in the Centre's financial accounts.

Directors' Meetings

The Rail Manufacturing CRC Board met five times during 2019–20:

29 August 2019, 28 November 2019, 27 February 2020, 26 March 2020 and 11 June 2020.

During the year ended 30 June 2020, the number of Board meetings held while each Director was in office and the number attended by each Director was as follows:

Name	Role	Key skills	Independent / Organisation	Appointed (Resigned)	A[9]	B[10]
Current Directors						
Paul Johnson	Chair	Executive management, R&D, engineering, business administration, transport industry expertise, experience as a non-executive director	Independent	31/10/2014	5	5
Bronwyn Constance	Independent Director	Financial management, business administration, manufacturing industry administration, experience as a non-executive director	Independent	31/10/2014	5	5
Stuart Thomson	Executive Director (CEO)	Business administration, executive management, IP, commercialisation, R&D, experience as an executive director	Rail Manufacturing CRC	20/03/2015	5	5
Michael Miller	Industry Nominee	Financial management, business administration, manufacturing industry administration, IT, experience as non-executive director	Downer EDI Rail	14/10/2015	5	5
Grant Stanley	Research Nominee	R&D, commercialisation, higher education expertise, experience as a non-executive director	Central Queensland University	14/04/2016	5	3
Michael McLellan	Industry Nominee	Manufacturing industry administration, commercialisation, M&A, experience as a non-executive director	Knorr-Bremse Australia	26/09/2016	5	5
Jasbir Tumber	Industry Nominee	Rail industry administration, maintenance and operations; engineering, business administration	Sydney Trains	21/11/2019	5	2

[9] A = Number of meetings held while the Director held office

[10] B = Number of meetings attended

Chair Paul Johnson being interviewed for Centre legacy videos

The Board is responsible to its members and Participants for the company's performance. The Board's election, composition, function and responsibilities are set out in the company's Constitution and in the Participants Agreement.

The filling of casual director vacancies is the responsibility of the Remuneration and Nominations Board Committee as follows:

» Nominee directors - nominations are sought from the relevant industry or research Essential Participants (EP's), such that only industry EP's may nominate candidates to replace industry nominee directors and only research EP's may nominate candidates to replace research nominee directors. Likewise, voting is by nominee type EP only.

» Independent directors - nominations are sought from suitable candidates, always keeping in mind the need to ensure that, collectively, the directors have skills and experience across a constitutionally established minimum set of fields.

The Board sets the Rail Manufacturing CRC company strategy and performance targets, it reviews and approves all company policies and it oversees the implementation of procedures to ensure that the Management team meets the Board's objectives. The Board meets at least quarterly for scheduled meetings.

The Chair is an independent director, and the Company's Constitution requires that the Board include:

» up to four persons elected by a vote of the Industry Essential Participants,

» up to one person elected by a vote of the Research Essential Participants,

» up to three independent non-executive directors elected by a vote of Essential Participants, and

» the CEO.

At the Annual General Meeting ("AGM") held 28 November 2019, three serving Directors retired by rotation as required under the constitution. All retiring Directors were re-elected, namely Paul Johnson, Michael McLellan and Grant Stanley.

The Board for the year to 30 June 2020 consisted of seven (7) Directors, with two Independent Directors, three Industry Nominee Directors, one Research and Development Nominee Director and the CEO. On 30 June 2020, the three Industry Directors and the Research and Development Nominee Director resigned from the Board, leaving the two Independent Directors and the CEO to govern the Board from 1 July 2020 through the wind up period.

Board

CHAIR - PAUL JOHNSON MBE

DIPAIRCRAFT DESIGN, MSC(AIRCRAFT DESIGN), MAICD.

INDEPENDENT DIRECTOR AND BOARD CHAIR SINCE 31 OCTOBER 2014.

CHAIR OF RESEARCH & DEVELOPMENT AND REMUNERATION & NOMINATIONS BOARD COMMITTEES.

EXPERIENCE AND EXPERTISE:

After 22 years in the Royal Australian Navy, Paul joined General Electric (USA) as the Australian Manager of Business Development. He was later assigned to Singapore as the ASEAN countries Regional Director for Business Development and was promoted to regional President for South Asia and Australasia, with responsibility for business activities in 17 countries. In 2003 Paul was appointed as Managing Director and CEO of Lockheed Martin Australia, while also acting as Chairman of the Australian Industry Group's Defence Industry Executive Council.

Since retiring from Lockheed Martin in 2011, Paul has been involved as a director on the Boards of a number of institutions, currently including Director of Aerospace, Maritime and Defence and Security Foundation of Australia Limited (AMDSFA) and formerly a member of the Air Force Board and the Co-Chair Centre for Defence Industry Capability Advisory Board. Paul presently serves as an Independent Ministerial Advisor on Defence Innovation. He was awarded the MBE in 1980 in recognition of his contribution to the advancement of Naval Aircraft Engineering and is a Member of the Australian Institute of Company Directors.

BRONWYN CONSTANCE

FCPA, FAICD.

INDEPENDENT DIRECTOR SINCE 31 OCTOBER 2014.

CHAIR OF AUDIT & RISK BOARD COMMITTEE.

EXPERIENCE AND EXPERTISE:

Bronwyn has held many senior executive positions including Finance Director of Kraft Foods Limited Australia and New Zealand, Vice President Finance of Kraft Foods Asia, Executive General Manager Finance and Administration of Pasminco Limited and Finance Director of Nylex Limited. She spent her early career with the ACI Group of companies. Bronwyn is a former independent director of the Melbourne Market Authority, Plantic Technologies Limited, The Just Group Limited, Colorpak Ltd, DMTC Ltd and the CRC for Advanced Automotive Technology.

CEO - DR STUART THOMSON

BSC, BSC(HONS), PHD, GCTMLP, MRACI, GAICD.

EXECUTIVE DIRECTOR SINCE 20 MARCH 2015.
CHIEF EXECUTIVE OFFICER SINCE 1 APRIL 2015.

MEMBER OF RESEARCH & DEVELOPMENT BOARD COMMITTEE.

EXPERIENCE AND EXPERTISE:

Stuart received his PhD from the University of New South Wales (UNSW), and subsequently worked in various research roles at UNSW, the Max-Planck-Institut für Kohlenforschung and the Australian Nuclear Science and Technology Organisations (ANSTO). He has held numerous management roles in the manufacturing, mining, and agricultural sectors, including roles as Chief Operating Officer at CRC Mining and Executive Director and Board member of the Grape and Wine Research and Development Corporation. In 2015, he was appointed to the role of CEO and Managing Director of Rail Manufacturing CRC. He holds formal qualifications in Science, Trademark Law and Practice, and is a graduate of the Australian Institute of Company Directors.

MICHAEL MILLER

BEC, CA.

DIRECTOR SINCE 14 OCTOBER 2015 (INDUSTRY NOMINEE).

MEMBER OF AUDIT & RISK AND REMUNERATION & NOMINATIONS BOARD COMMITTEES.

RESIGNED 30 JUNE 2020.

EXPERIENCE AND EXPERTISE:

Michael joined Downer EDI Limited in 2011 and was appointed Group Head – Customer & Government Partnerships in January 2019. Prior to his current role, Michael has previously held the position of CEO Downer Rail and the CFO position for both Downer Rail and the Waratah Train Project. Prior to joining Downer, Michael held executive positions within the IT and Telecommunications industry, including Hewlett Packard and Nortel Networks. Michael is a Director of Downer EDI Rail and associated entities and a Director of the Australasian Railway Association.

PROF GRANT STANLEY

BENG(CHEM), PHD.

DIRECTOR SINCE 14 APRIL 2016 (RESEARCH & DEVELOPMENT NOMINEE).

MEMBER OF AUDIT & RISK, REMUNERATION & NOMINATIONS AND RESEARCH & DEVELOPMENT BOARD COMMITTEES.

RESIGNED 30 JUNE 2020.

EXPERIENCE AND EXPERTISE:

Grant Stanley holds undergraduate and postgraduate degrees from the University of Melbourne and has a background in Applied Microbiology/Biochemical Engineering, with ongoing research interests in biofuel production. He has experience in research and teaching and has published over 110 scientific papers, an international patent, has received a number of Commonwealth and Industry funding grants and supervised 15 PhD students. Grant was the Head of Molecular Sciences at Victoria University, he then joined Central Queensland University Australia (CQUniversity) as the Dean of Medical and Applied Sciences. In 2013 he became the Pro Vice-Chancellor (Research) and is currently the Deputy Vice-Chancellor (Research) at CQUniversity. Grant has sat on a number of Boards including the SmartWater Research Board and Queensland Cyber Infrastructure Board, and is currently a member of the Advance Queensland Expert Panel.

MICHAEL MCLELLAN

BENG, POSTGRADDIP

DIRECTOR SINCE 26 SEPTEMBER 2016 (INDUSTRY NOMINEE).

RESIGNED 30 JUNE 2020.

EXPERIENCE AND EXPERTISE:

Michael has been Managing Director of Knorr-Bremse Australia Pty Ltd since 2004. He is also a member of the Australasian Railway Association (ARA) board representing the Rail Industry Supplier group. Prior to joining Knorr-Bremse, Michael worked in a variety of management positions across organisations such as GUD Manufacturing, Honeywell and Caterpillar. He holds a Bachelor of Engineering, a Post Graduate Diploma in Marketing and is a Graduate member of the Australian Institute of Company Directors.

JASBIR TUMBER

BENG (HONS)

DIRECTOR SINCE 21 NOVEMBER 2018 (INDUSTRY NOMINEE).

RESIGNED 30 JUNE 2020.

EXPERIENCE AND EXPERTISE:

Jasbir was appointed Deputy Executive Director of Sydney Trains' Fleet Maintenance Division in July 2014, leading over 1,000 employees in the maintenance and presentation of 12 fleet types across Sydney and NSW Trains. He has over 20 years of experience in delivering customer services within transportation across both the public and private sectors, from engineering, operations and maintenance through to engaging and influencing executive stakeholders to deliver business transformations.

Committees

The **Audit and Risk Board Committee (ARBC)** is a subcommittee which reviews and provides recommendations to the Board on financial reporting, statutory audit functions, internal control functions, risk management, compliance and governance. The ARBC is chaired by an independent non-executive director and its membership during the past financial year included two industry representative directors and a research provider representative director.

The Committee met on four occasions in 2019-20. Membership of the committee was as follows:

- Bronwyn Constance (Chair),
- Grant Stanley (Research representative member),
- Michael Miller (Industry representative member), and
- Jasbir Tumber (Industry representative member).

The **Research and Development Board Committee (RDBC)** is a subcommittee which reviews and provides recommendations to the Board on project proposals, project progress and expenditure. Membership of the RDBC consists of an independent, non-executive director as Chair and a research representative director.

The Committee met on three occasions in 2019-20. Membership of the committee was as follows:

- Paul Johnson (Chair),
- Stuart Thomson (Managing Director), and
- Grant Stanley (Research representative).

The **Remuneration and Nominations Board Committee (RNBC)** assesses nominations for the Board and reviews remuneration of the Centre's Management and Independent Directors. The committee is chaired by an independent non-executive director and its membership includes an industry representative director and a research representative director.

The Committee met on two occasions in 2019-20. Membership of the committee was as follows:

- Paul Johnson (Chair),
- Grant Stanley (Research representative), and
- Michael Miller (Industry representative).

The **Research and Development Management Committee (RDMC)** provides advice to the CEO on technical research areas and meets quarterly to discuss the Rail Manufacturing CRC's project portfolio with the appropriate research and industry participant representatives.

The Committee met on four occasions in 2019-20. Membership of the committee was as follows:

- Larry Jordan (Chair, RMCRC Research Director),
- Colin Cole (CQU, RMCRC Program Leader),
- Paul Meehan (UQ, RMCRC Program Leader), and
- Stuart Thomson (RMCRC CEO).

Following the ending of Commonwealth funding at 30 June 2020, the three industry and the research representative directors resigned and the committees were disbanded.

Interviewing PhD student Joanne Jie Yang about her research

Management team

CEO - DR STUART THOMSON

BSC, BSC(HONS), PHD, GCTMLP, MRACI, GAICD.

CHIEF EXECUTIVE OFFICER SINCE APRIL 2015.

EXPERIENCE AND EXPERTISE:

Stuart has extensive experience in leading strategic research and development programs in both Government and commercial organisations, having held senior management positions in the private and public sectors. His past roles have included technical development roles in the manufacturing sector, Chief Operating Officer and Director of Research roles at CRCMining, and the Executive Director of the Grape and Wine Research and Development Corporation.

DR LARRY JORDAN

BSC, MSC, PHD.

RESEARCH DIRECTOR SINCE AUGUST 2015.

EXPERIENCE AND EXPERTISE:

Larry manages the delivery of the Rail Manufacturing CRC's research program to ensure high quality collaborative research is provided to the rail industry. With a background in materials science and experience in research, including electrochemical sensors, fuel cells and materials durability, Larry has worked in building construction, nanotechnology and automotive industries. Larry's past roles include Research Manager at the Advanced Manufacturing CRC and Chief Scientist at General Motors Holden.

SHARON SALPIGHIDIS

BCOM, DIPED, CPA, GAICD.

FINANCIAL CONTROLLER AND COMPANY SECRETARY SINCE SEPTEMBER 2016.

EXPERIENCE AND EXPERTISE:

Sharon provides strategic and operational management of the Rail Manufacturing CRC's financial activities and ensures the Centre complies with its statutory obligations. Sharon has previously held senior management positions across both listed public companies and fast-growing private start-up enterprises, facilitating multiple mergers, acquisitions and divestments. She has previously worked both locally and overseas in diverse industries including healthcare, construction, education and most recently in telecommunications and has a strong background in building efficient and robust processes for growing operations and organisations. She is a graduate member of the Australian Institute of Company Directors.

KATIE RIZZO

BARTS, GRADCERT.

COMMUNICATIONS MANAGER SINCE JUNE 2016.

EXPERIENCE AND EXPERTISE:

Katie is responsible for managing the communications function for the Rail Manufacturing CRC, which includes marketing, media engagement, event management and internal communications activities. Prior to joining the Centre, she worked in corporate communications, marketing and online communications roles across several sectors, including manufacturing, telecommunications, banking, energy and water.

HEIDI KRASULAK

ASSOCIATE DIPLOMA IN ADMINISTRATION, CERT IV BOOKKEEPING.

FINANCE AND RECORDS OFFICER SINCE JANUARY 2019.

EXPERIENCE AND EXPERTISE:

Heidi has extensive experience in business administration, bookkeeping, payroll and records management. Heidi's professional background includes general law including commercial contracts and settlements. Heidi assists with the financial and contract management for the Centre, including reporting and the annual audit process.

PROF COLIN COLE

BENG, MENG, PHD.

PROGRAM LEADER FROM APRIL 2015 UNTIL 30 JUNE 2020.

EXPERIENCE AND EXPERTISE:

Colin is the Director of the Centre for Railway Engineering (CRE) and also currently serves as a Program Leader in the Rail Manufacturing CRC. He's spent the past 26 years working specifically in railway research, completing more than 20 rail research projects related to train dynamics, simulation and development of on-board intelligent systems and devices. He has published over 148 technical papers, three books, two book chapters and three patents.

PROF PAUL MEEHAN

BENG(HON1), PHD.

PROGRAM LEADER FROM MARCH 2017. UNTIL 30 JUNE 2020.

EXPERIENCE AND EXPERTISE:

Paul is an expert in railway mechanics and noise, leading the University of Queensland research in rail mechanics as part of the Centre for Advanced Materials Performance and Manufacturing (AMPAM). He has led many successful large industry collaborative R&D projects totaling more than $14 million in competitive research funding. He also teaches several intermediate and advanced level courses in mechanics. He has authored over 140 internationally refereed publications and three international patents.

Name*	Organisation	Position title	Time committed
Stuart Thomson	Rail Manufacturing CRC	Managing Director and CEO	100%
Larry Jordan	Rail Manufacturing CRC	Research Director	100%
Heidi Krasulak	Rail Manufacturing CRC	Finance and Records Officer	80%
Sharon Salpighidis	Rail Manufacturing CRC	Financial Controller and Company Secretary	60%
Katie Rizzo	Rail Manufacturing CRC	Communications Manager	60%
Colin Cole	Rail Manufacturing CRC / CQUniversity	Program Leader	51%
Paul Meehan	Rail Manufacturing CRC / University of Queensland	Program Leader	51%

Financial management

For the year ended 30 June 2020, the Rail Manufacturing CRC expended its financial resources on contracting new research projects, managing and supporting existing research projects to their completion, and awarding and managing student PhD scholarships.

Financial performance

For the year ended 30 June 2020, the Rail Manufacturing CRC earned revenue of $8.91 million and other income of $0.17 million, and incurred expenses of $9.08 million, resulting in a $nil operating profit. Revenue of $8.91 million comprised $5.03 million of CRC Program Funding from the Department of Industry, Science, Energy and Resources and $3.88 million from Participants. Expenditure of $9.08 million included $7.61 million of research costs, $1.08 million of employee benefits costs and $0.39 million of administration and depreciation expenses.

Research expenditure has increased by $2.2 million or more than 40 per cent compared to last year. This result is $1.05 million lower than budgeted, due partly to unmet contributions from existing Participants and a number of projects coming in under budget.

Cash flows

During the year, the Rail Manufacturing CRC received $4.75 million of operating cash inflows (inclusive of GST), consisting of $0.96 million from the Commonwealth CRC Program, $3.6 million from Participants and $0.19 million in interest and other receipts. Operating cash outflows totalled $12.38 million (inclusive of GST), consisting of $11.22 million of research payments and $1.16 million of administration payments.

In-kind contributions

Total in-kind contributions of $19.06 million for the year ended 30 June 2020 comprised $13.44 million of staff in-kind and $5.62 million of non-staff in-kind contributions, being non-cash contributions to the Rail Manufacturing CRC's research programs by Research and Industry Participants, representing contributions of people, equipment and facilities.

Financial position

At 30 June 2020, total assets were $7.54 million and total liabilities were $7.54 million. Total assets are comprised predominantly of cash and cash equivalents of $6.85 million, and trade and other receivables of $0.66 million. Total liabilities are comprised predominantly of trade and other payables of $6.69 million, deferred revenue of $0.67 million and provisions of $0.17 million.

Financial issues

To meet the Rail Manufacturing CRC's current obligations to the Commonwealth, the key financial challenges are to deliver financial outcomes in line with the wind-up plan for the conclusion of the Centre.

Tram moving through Melbourne's Bourke Street Mall

Other activities

During the year, the Rail Manufacturing CRC participated in multiple industry forums to progress collaboration within the rail sector, including:

- the Reimagining the Workforce industry engagements sessions for Project R3.3.3 - ***Reimagining the workforce: building smart, sustainable and safe public transport*** (Department of Transport / Victoria University),
- the Sydney Trains trial of the Dwell Track™ technology,
- Australia China Young Scientist exchange program,
- the Metro Rail Stations and Terminal conference,
- CeBIT,
- AusRAIL 2019,
- numerous Victorian Rollingstock Research Sector meetings,
- the International Symposium on Frontier Materials,
- Rail Suppliers Technology Roadmap 2040 Review,
- the Rail Manufacturing CRC PhD Students' Forum, and
- two Rail Manufacturing CRC Participant Forums.

Activities within the second half of 2019–20 have been impacted due to COVID-19 restrictions.

While these restrictions have had an effect on the Centre's engagement strategy (see page 46), most engagement and communications have continued through video conferencing, newsletters, and social media.

Melbourne's Flinders Street station

Rail travel underway

CRC future plans and transition arrangements

The Rail Manufacturing CRC began in 2014, with a mandate to operate for six years. The Centre will not be transitioning to an alternate entity, and concluded its operations in June 2020.

In preparation for closing, the Rail Manufacturing CRC developed a wind-up plan, provided to the CRC Program in June 2019. As part of these arrangements, the Centre worked with its participants to ensure outcomes from current projects will be utilised or continued through alternate research endeavours.

More on the Centre's wind-up activities has been provided in detail in the 'End of CRC Funding Report' document submitted to the Federal Government in October 2020.

Activities not covered by the Grant Agreement

The Rail Manufacturing CRC also has a memorandum of understanding (MoU) in place with the Advanced Manufacturing Growth Centre.

Glossary.

ACRI	Australasian Centre for Rail Innovation
ACNC	Australian Charities and Not-for-profits Commission
AMGC	Advanced Manufacturing Growth Centre
ARA	Australasian Railway Association
ARBC	Audit and Risk Board Committee
ASIC	Australian Securities and Investments Commission
CFD	Computational Fluid Dynamics
CQU	Central Queensland University
CRC	Cooperative Research Centre
CRRC	China Railway Rolling Stock Corporation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Essential Participant (or 'EP')	Those persons, bodies and organisations who provide essential support (including cash or in-kind contributions) for the activities of the CRC
HVAC	Heating, ventilation and air conditioning
ICN	Industry Capability Network
IP	Intellectual Property
Other Participant	A participant who is not an Essential Participant who has signed an agreement with the CRC
QUT	Queensland University of Technology
R&D	Research and Development
RDBC	Research and Development Board Committee
RDMC	Research and Development Management Committee
RISSB	Rail Industry Safety and Standards Board
RMCRC (or 'the Centre')	Rail Manufacturing CRC
RNBC	Remuneration and Nominations Board Committee
SMEs	Small-to-medium enterprises
TSA	Tyre Stewardship Australia
UQ	University of Queensland
UTS	University of Technology Sydney
UoW	University of Wollongong

Bombardier's Next Generation rollingstock operating in Queensland

Rail Manufacturing CRC Ltd.

ABN – 14 600 249 518

PO Box 273
Flemington Victoria 3031
Australia

www.rmcrc.com.au