Landmark transport project takes collaboration to a new level

2015 Australian Construction Achievement Award (ACAA) Technical Paper

Australian Government

www.regionalraillink.vic.gov.au

State Government Victoria

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1 AUTHOR

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2 ABSTRACT

Regional Rail Link (RRL) was one of the most significant and complex infrastructure projects in Victoria's history, and the largest public transport development in Australia during its construction.

The $4.8 billion project, jointly funded by the Australian and Victorian governments, took approximately six years from commencement in 2009 to completion in 2015.

RRL has removed major bottlenecks in Melbourne's rail network, expanded the regional network and created significant extra capacity for metropolitan and regional services. It has delivered 90 kilometres of new rail track, including dedicated regional tracks from the suburbs of West Werribee Junction to Deer Park and along the existing rail corridor from Sunshine to Southern Cross Station in Melbourne's CBD.

New railway stations were built at suburban Wyndham Vale and Tarneit and three existing stations were rebuilt. The project also removed two level crossings and completed 13 road and rail grade separations.

RRL was delivered through six work packages, consisting of three alliances, two design and construct (D&C) contracts and one franchisee-managed scope of works. In total, there were 16 organisations engaged directly through these agreements.

In a complex stakeholder and delivery environment, the project proved to be highly successful, being delivered eight months ahead of schedule and $900 million under budget thanks to a bold procurement strategy, meticulously planned rail occupations, a collaborative performance culture and a highly successful communications program.

3 KEY WORDS

RRL, RRLA, work packages, eight months ahead of schedule, $900 million under budget, occupations, interfaces, Coordination and Interface Deed, Joint Coordination Committee, rail operators, stakeholders, track, stations, platforms, bridges, signalling.

4 INTRODUCTION

RRL is a landmark, award-winning, infrastructure project that has removed major bottlenecks in Victoria's rail network.

As a result of the project, Ballarat and Bendigo trains now use new dedicated tracks from Sunshine to Southern Cross Station, separating them from metropolitan services. Geelong trains will begin using the new track through Wyndham Vale and Tarneit from April 2015.

RRL increased the size of Victoria's rail network by laying 90 kilometres of new track connecting Melbourne's growing west to Geelong and the CBD by train for the first time. The project also included:

- two new stations at Wyndham Vale and Tarneit,
- reconstruction of west Footscray, Footscray and Sunshine stations
- two new platforms (15 & 16) at Southern Cross Station
- removal of two level crossings at Anderson Road in Sunshine

RRL creates capacity for an extra 23 metropolitan and 10 regional services during each morning and evening peak period. This means capacity for an additional 54,000 passenger trips each day.

As well as improving existing services, RRL lays the foundations for future expansion of the rail network to meet the needs of Victoria's growing population.

5 PROJECT SCOPE

RRL was a highly complex project that delivered $3.9 billion of rail infrastructure over three years of construction, within limited working windows on one of the most heavily trafficked rail corridors in Australia.

During construction, RRL added approximately $1 billion annually to the Victorian economy, peaking at $1.4 billion in 2013, and provided employment for more than 6,000 people.

In order to achieve its ambitious target program, the project spent an average of $1 billion per year for three years – with a typical monthly spend of $100 million per month for 31 months.

The major features of the project's scope included:

- 90 kilometres of dedicated regional tracks
- two new stations at Wyndham Vale and Tarneit, a rebuilt West Footscray station, significant upgrades of Footscray and Sunshine stations, and an upgrade of Tottenham station (see Figure 1)
- 23 road/rail grade separations, four rail/rail grade separations and 13 bridges (including 5 over waterways)
- 29,121m2 of retaining walls
- 1.3 million m3 of cut and 1.2 million m3 of fill
- 7,000 piles and 8,458m of noise barriers installed
- 27 kilometres of overhead line equipment
- Seven signal equipment rooms and eight communication equipment rooms
- 225,000 kilometres of signalling and communications cabling
- a new train control system and modification of existing train control systems (refer to Figure 2).

Figure 1: The upgraded Footscray station (left), new station at Tarneit in Melbourne's west (top right) and the upgraded Tottenham station (bottom right).

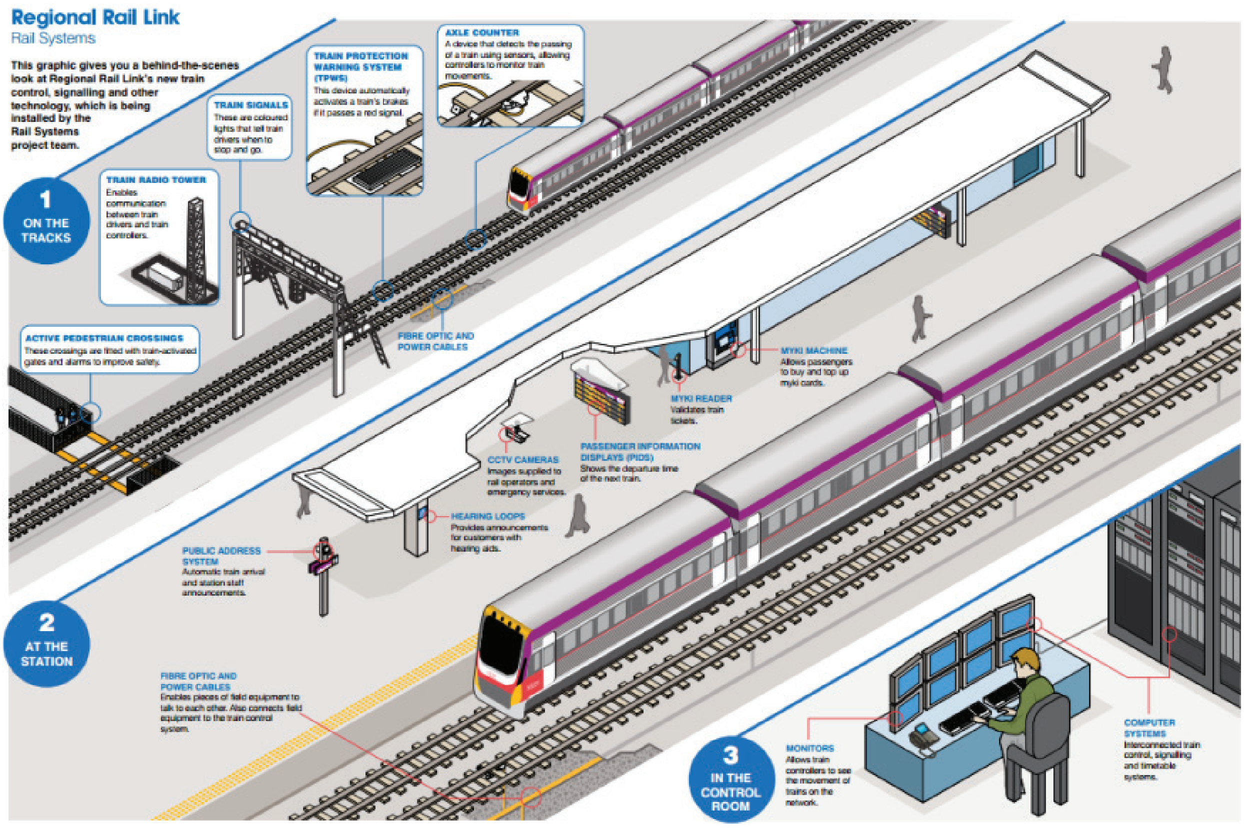


Figure 2: This graphic shows a behind-the-scenes look at RRL's new train control, signalling and other technology, which was installed by the Rail Systems project team.

6 CONTRACT

Due to the sheer size, complexity and varied scope of the project, the decision was taken to deliver RRL through six work packages, consisting of three alliances, two design and construct (D&C) contracts and one rail franchisee-managed scope of works.

Governance model

An Administrative Office model was opted for as the best option to manage the delivery of this major infrastructure project, with regular reporting to both the Secretary and the Minister for Public Transport.

A Coordination and Interface Deed was incorporated into the contact documentation for each of the work packages enabling the formation of a Joint Coordination Committee to oversee interface coordination and ensure all parties participated in the oversight of the delivery of RRL.

Packaging the works

The brownfield and greenfield sections of RRL provided a clear distinction for packaging and delivery model selection. The D&C delivery model was considered most suitable for the greenfield work packages and the alliance delivery model best suited to brownfield work packages.

The alliance delivery model provided commercial alignment between the constructor participants, Metro Trains Melbourne (Metro), V/Line and RRLA. Having the rail operators commercially aligned was crucial for the brownfield work packages where there was a high level of dependency to provide access, approve designs, coordinate occupations and accept rail infrastructure into service.

The timing of when to release work packages to market was also critical to ensure industry and unions actively addressed project industrial agreements in unison. This helped achieve a consistent outcome and reduced the likelihood of industrial disputation over wages and conditions.

The use of multiple work packages created some complex probity issues. However, clear rules were established for bidding to manage potential collusion and ensure the same resources were not proposed for different packages.

7 OUTCOMES ACHIEVED AGAINST PLANNED TARGETS

During construction, RRL added approximately $1 billion annually to the Victorian economy, peaking at $1.4 billion in 2013, and provided employment for more than 6,000 people directly and indirectly.

RRL successfully delivered against all set targets and met or exceeded all key result areas.

Safety

RRLA's Safety Management System was developed as a unique stand-alone system that still enabled compatibility and compliance with all safety management requirements of the Victorian Department of Transport, Planning and Local Infrastructure (DTPLI). This arrangement was necessary due to the complexity and size of the project.

The early vision established by RRLA was to be recognised for outstanding safety performance. It was acknowledged that in order to achieve this goal, the project required committed leadership, advanced collaboration and consultation processes, and unified commitment to this vision by all stakeholders.

Trust and transparency were also critical elements for achieving outstanding safety performance.

As 'leaders' on the project, it was essential for RRLA to ensure a consistent approach to safety culture, demonstrate commitment to continual improvement, lead by example and ensure RRLA provided the same safety standards for its employees as expected from other project participants.

Some of the key initiatives that contributed to these outcomes are summarised below:

- **Safety Risk Registers** were created by RRLA for each specific work package prior to the tender period to ensure that safety-related risks were understood and adequately addressed prior to contract award
- **Safety risk workshops** were required from the successful work package contractors to enable the creation of specific Work Package Safety Risk Registers. Participants also included all relevant project stakeholders
- **Common induction module** combining the requirements of RRLA, Metro, V/Line, VicTrack, and the Australian Rail Track Corporation (ARTC)
- **Quarterly safety forums** to share learnings and innovations
- **Confidential 24/7 phone line** for workers and the public to report safety issues
- **Incident hot spot publications** highlighting trends and improvement opportunities and a rail safeworking publication showcasing the innovative processes tested and used
- **Whole-of-project collection, analysis and trending** of RRL incident data, which supported program development and enabled real-time date sharing.

The project achieved an **impressive TRIFR of 10.4** against a formal target TRIFR of below 30 for 14.4 million man hours worked and a **lost time injury frequency rate (LTIFR) of 0.6** against a formal target LTIFR of 2.0. Both results set new benchmarks for a project of this nature.

Time and cost

RRL was the culmination of six years of intense planning, development, design and construction to deliver the most significant change to the Victorian rail network since the City Loop tunnels were constructed in the 1980s. The partnership style approach to stakeholder management and construction, combined with the creation of a high performance culture, resulted in the early delivery of $3.9 billion of infrastructure in which people from all stakeholder organisations had a sense of satisfaction and pride.

The early delivery of the expected benefits within the approved budget should go some way to providing confidence that Victoria can deliver very significant infrastructure projects that maximise value for taxpayer money.

This was achieved by:

- Recognising significant opportunities regarding the construction program, whereby if the works were completed early, all parties would benefit from fixed cost savings and maximising the KPI reward associated with early delivery. Based on this opportunity, the JCC set an overall target completion date for the project of December 2014 compared with the contractual requirement of June 2015
- Having all work packages collectively examine existing construction staging, look for opportunities to re-sequence works and cut time from the critical path. Six separate programs were merged to form a single, integrated program that supported early completion. For the Rail Systems work package, which supported the delivery of all the other packages and whose program was in turn dependent on all other work packages, the re-sequencing of works involved extensive negotiation and collaboration.
- During project development and procurement, RRLA investigated opportunities for some early benefits (platforms 15 & 16 completion). However, following the program optimisation led by the JCC, and in particular by the CMR work package, it was realised that by restaging the works via a staged benefits process even greater benefits could be realised (early commissioning of the line from Sunshine to Southern Cross). This helped when managing the disruption required delivering the project. In some instances, work packages were incentivised to deliver specific elements of scope earlier in the program.

Benefits that were realised early included:

- Dedicated V/Line tracks between South Kensington and new platforms at Southern Cross Station completed in December 2013 to give Geelong passengers a more streamlined journey to and from Melbourne
- A new railway station at West Footscray opened nine months ahead of schedule in October 2013
- A rebuilt concourse at Sunshine Station and a major upgrade to Footscray Station completed in January 2014
- Two level crossings removed at Anderson Road, Sunshine in January 2014 and June 2014.
- The Ballarat and Bendigo services were commissioned on to the new V/Line corridor from Sunshine to Southern Cross in July 14, one year earlier than originally planned.

Originally planned for completion in June 2015, RRL infrastructure was delivered **eight months ahead of schedule in October 2014.**

Thanks to an aggressive construction program and a meticulously planned occupation schedule, the project was completed early and **$900 million under budget for $3.9 billion,** with an average spend of $100 million per month for 31 months. Some of these savings have already been allocated to other critical transport projects in Victoria, including the removal of the Main Road level crossing in St Albans.

Quality and functionality

RRL met or exceeded all of the Scope and Technical Requirements inclusive of design, community amenity and whole-of-life considerations. Close working relationships with key stakeholders, particularly rail operators, ensured they were fully satisfied with the quality of the infrastructure delivered. Whole-of-life savings initiatives that delivered greater value than expected were:

- Improved durability and residual fatigue life of the North Melbourne Flyover
- Implementation of lockout protection utilising the signalling system
- Innovative gate design at stations
- Innovative design and implementation of new technology for train radio
- Procurement standardisation for points and crossings across the project

Comprehensive reviews were undertaken to identify all internal and external statutory obligations, and checklists developed to ensure compliance and demonstrate how it was achieved.

Environment and heritage

RRL intentionally set out to achieve sustainability outcomes that were better than industry practice. The commitment to these outcomes was driven by the passion of the RRLA team, supported by the RRLA Board and the individual work packages.

The intention was to deliver a major project that left a positive legacy for local communities and generated innovative practices that could be used on other infrastructure projects nationwide.

In 2010, at the commencement of concept design, a Sustainability Framework was developed for RRL. The framework defined a series of environmental, social, economic and technical principles, with supporting objectives and criteria that aligned with the relevant Victorian Government policy documents.

With the formation of RRLA, the sustainability approach to the project was reviewed and a series of workshops held to identify opportunities that existed across the project. This process coincided with an increased focus on the requirement for transport agencies to consider triple bottom line outcomes in their operations and in planning for new developments, following commencement of the *Transport Integration Act 2010* (Vic.). During the same year the *Climate Change Act 2010* (Vic.) also commenced, which resulted in a stronger focus by government agencies on sustainability and climate change in particular.

In an Australian first for a major rail infrastructure project, RRLA incorporated a comprehensive Sustainability Policy within the contractual framework for its six major construction contracts. Aimed at delivering the project to a standard that exceeded the 'business as usual' approach, the Sustainability Policy included 22 targets across environmental, social and economic themes. As a result, the policy and its targets were core influences on design, procurement and construction decisions throughout the project.

Financial incentives were also in place for contractors to develop and achieve additional sustainability targets. This initiative generated a number of innovations, including:

- Reduction in construction-phase energy and carbon by more than 20% giving an energy saving equivalent to the annual electricity consumption of 44,000 average Melbourne homes
- Reduction in operational-phase energy and carbon by 20% giving an energy saving equivalent to the annual electricity consumption of 6,000 average Melbourne homes
- 230 million litres of potable water saved which is the equivalent of the annual consumption of 1,000 four-person households
- 94.5% recycling/re-use of construction and demolition waste
- Five stations on the Victorian rail network now have a Green Star 4 star rating from the Green Building Council of Australia
- Collaboration between competitors within the project, and between the project and the wider industry
- Innovative use of materials and consequent changes to railway standards for future projects.

The RRL work packages developed a number of additional initiatives in collaboration with RRLA. The ability of the work packages to do this was incentivised through the contracts. These initiatives and the outcomes achieved are detailed below:

- Development of a Green Star Custom rating tool for above-ground railway stations (in Victoria). This tool is now available to industry to adopt for future rail projects across Australia
- Changes to standards and regulations to enable the installation of LED car park lighting within rail land (Victorian industry first). This paves the way for future rail projects to implement LED car park lighting
- Development of community engagement programs including engaging local traders, which has led to the creation of initiatives such as a food tour through Footscray in inner west Melbourne. This program has led to awareness raising about the local tourism potential of suburbs such as Footscray
- Use of potable water from alternative water sources including stormwater drained from the iconic Bolte Bridge and saline water from the Maribyrnong River. This demonstrates the use of large quantities of non-potable water is feasible on construction projects
- Preparation of a Construction Site Office Guide that documents environmental initiatives on the RRL project and will enable substantial improvements in the environmental performance of site offices on future infrastructure projects
- Delivery of Water Sensitive Urban Design measures and landscaping to enhance and protect the Newells Paddock in Footscray, protect local public and private property from flooding and protect the health of downstream natural environments
- Use of reclaimed brick rubble from a local source, in place of a quarried product, to construct a stabilised working platform for use during the excavation of the ARTC tracks at the North Melbourne Flyover
- Use of approximately 700 to 1,400 tonnes of recycled ballast in landscaping to create bands of spall rock in between planting rows
- Preservation of historically significant glass bottles uncovered during excavation works, including engagement of an archaeologist during early excavation to provide advice on the significance of the bottles. These bottles were gifted to the Victoria Bottles and Collectables Association

- Facilitation of stormwater harvested from CityLink, a major operating freeway, for use as construction water on the City to Maribyrnong River section of the project and provision of ongoing access to this alternative water source for other users beyond the construction phase of the project
- Incremental improvement on Sustainability Policy Target 10 on the City to Maribyrnong River and Footscray to Deer Park sections of the project – over 90% of all demolition and construction waste being reused or recycled (increase from 80%)
- Research and testing to demonstrate the suitability of a low-emission concrete product 'E-Crete', attainment of relevant approvals, and use in constructing a structural reinforced soil structure wall at Dudley Street, West Melbourne
- Incremental improvement on Sustainability Policy Target 17 on the City to Maribyrnong River section of the project – 100% reinstatement or revegetation using indigenous provenance (increase from 90%)
- Obtain approvals for, and use of, an alternative and more sustainable asphalt pavement mix (i.e. Warm-Mix Asphalt and/or Reclaimed Asphalt Pavement) in the construction of vehicle access tracks and/or a car park. These innovations needed to have sustainability credentials (relating to environmental or social criteria) and be novel to the Victorian rail industry
- Documented case studies delivered to RRLA in a form ready to be publicly distributed. The documents needed to cover improvements in sustainability performance as a result of early supplier engagement, sustainability questionnaires and sustainability requirements in tender documents.

8 TECHNICAL CHALLENGES AND INNOVATION

This section focuses on some of the most complex and difficult design and construction challenges the project faced, and the innovative techniques used to overcome those challenges and deliver best-for-project outcomes.

1. Dudley Street rail bridge (City – Maribyrnong River work package)

One of the most challenging pieces of infrastructure on RRL involved the construction of a new twin track rail bridge over Dudley Street, West Melbourne, to carry the additional tracks to separate V/Line and Metro services.

The new Dudley Street Bridge is a 74m long structure supporting the Up and Down RRL lines, providing access to Southern Cross Station platforms 1-8. The bridge spans across Dudley Street to the east of existing rail bridges and continues to span across Railway Place before returning to the existing rail corridor.

The bridge itself is supported on sections of the existing Melbourne Underground Rail Loop (MURL) tunnel and is made up of seven simply supported spans varying from 7.5m to 12m.

The major constraints affecting the construction of the bridge were the:

- Close proximity to the East Suburban tracks
- Requirement to not affect traffic on Dudley Street
- Brownfields environment that involved working in close proximity to a transmission gas main, a HV overhead power line
- Close proximity to one of Melbourne's oldest and most iconic live music venues, Festival Hall, without disrupting their business operations
- Requirement to maintain pedestrian access.

A number of design changes and innovative construction techniques were required in order to ensure the bridge could be safely built, on time, while addressing the above constraints.

Figure 3: The new bridge over Dudley Street sits just 300mm from the south-west corner of Festival Hall, one of Melbourne's oldest and most iconic live music venues.

Prefabricated segmental bridge design

In order to ensure minimal delays on site and to ensure no disruption to Dudley Street peak hour traffic, the majority of the bridge was prefabricated off site and lifted in position during a combination of rail occupations and weekend closures to Dudley Street.

Each prefabricated item was bespoke due to the space constraints, and needed to meet extremely tight tolerances to ensure that the next item would fit perfectly in position. Having each item bespoke made achieving the tight tolerances much more difficult as no two elements shared formwork or templates.

Conventional multi-span structures would use standard templates for ease of construction. The difficulties involved in having unique, bespoke elements made achieving the tight tolerances challenging. To ensure that each item would meet the required tolerances, significant off site surveillance was adopted to closely inspect and identify any issues prior to delivery.

Each of the bespoke six precast headstocks, two precast abutments, four precast pier segments and 10 prefabricated composite steel and concrete deck units were all installed during the programmed weekend with no delays or tolerance issues.

Figure 4: In situ column construction on Railway Place, directly behind Festival Hall.

Melbourne Underground Rail Link (MURL) tunnel strengthening works

The City to Maribyrnong River team identified that construction of the Dudley Street Bridge foundations over the existing MURL tunnel would increase strain on the already failing tunnel segments. To prevent differential settlement, the tunnel needed to be strengthened. In an attempt to prevent works being done inside the tunnel, design proposals to conduct all strengthening works above the tunnel were investigated, however the constraint of not being able to close Dudley Street for longer than a weekend made it impossible. The challenge to complete the strengthening works inside the tunnel needed to be met. After careful consideration of many designs for the tunnel strengthening, it was decided that the best design would include 24 individually bespoke 2m x 2m x 40mm thick 1.5 tonne steel plates to be fixed to the tunnel walls at the tunnel segment joints locations.

The installation of the plates required an innovative custom designed and built attachment to a hi-rail excavator that allowed the plates to be lifted, rotated and then attached to the tunnel walls. The custom attachment was nominated for a National Comcare Safety Innovation Award as the lifter provided a safe and quick method of lifting the plates given the limited space constraints in the tunnel.

To ensure that the plates would transfer all the bridge loads to adjoining tunnel segments, the plates were fixed with 50 M36 threaded bars epoxied into the tunnel walls. A custom collet design was developed that required extreme tolerances less than 1mm in order to ensure that all 50 bars in each plate were engaged equally. Each of the 1200mm collets were machine cut and painted to ensure the collet sat snugly with absolutely no play around the threaded bars.

To provide confirmation that the installed plates were successful in transferring the bridge loads to the adjoining tunnel segments, state-of-the-art wireless monitoring equipment was installed between the tunnel segments. This internationally sourced equipment was able to send instantaneous three dimensional movement information prior to the Dudley Street Bridge being constructed, after construction and during train movement to confirm that the tunnel settlement was in tolerance.

Completing construction works inside a small 4.8m wide x 5.2m high tunnel with one single access and egress point and over 400m to the entrance of the tunnel proved a significant logistical challenge. With only one access point all materials, tools, equipment and plant had to travel 400m on a single track, which made sequencing extremely critical. Once a trolley, vehicle or hi rail excavator of plant entered the tunnel there was no option to leap frog the item in front. Extremely detailed planning and sequencing was required to ensure that all required works could be achieved simultaneously with no delays.

In addition to the limited access, a huge volume of work was required to be completed in only five weekend occupations which called for a full closure of the City Loop tunnel system. In a total of 250 hours the following scope of works were completed:

- Relocation of clashing existing services in the tunnel
- Ultrasonic scanning of the tunnel walls to identify the reinforcement in the tunnel walls
- Templating of the reinforcement that was used to manufacture each of the 24 steel plates
- Installation of 24, 1.5 tonne steel plates onto the tunnel walls using an innovative custom built attachment to a hi-rail excavator
- Coring 1,200 46mm holes 500mm deep into the tunnel walls
- Epoxying 1200 M36 threaded bar with the machined collet and nuts
- Mixing over 250 bags of high strength epoxy grout and pour behind plates
- Installing the wireless three-dimensional fissure meter monitoring equipment.

All works were successfully completed during the planned five weekend occupations. The strengthening works to the MURL tunnel were essential to provide adequate foundations for the new Dudley Street bridge.

Figure 5: MURL tunnel completed strengthening works.

Installation of retaining wall

Due to the close proximity of the East Suburban rail lines and the constraints around closing the rail lines, a significant challenge to retain the tracks while providing sufficient room to construct the new bridge needed to be overcome. The four day Easter long weekend in 2013 was identified as an opportunity to provide a 70 hour window to remove 60m of the existing track, excavate over 500 tonnes of material, install 10 10-tonne precast panels, backfill behind the panels and then install new track and commission for trains to run prior to peak hour trains.

The extremely tight program had very little contingency and carried significant risk. Not completing the works on time would result in delayed track hand back and cancellation of peak hour trains. Added to the tight program was the extremely tight construction space behind Festival Hall as well as ensuring adequate back-up resources were available during the construction union's fixed no-works long weekend.

Extremely detailed planning and innovation was instrumental in ensuring a successful outcome, including transporting a large truck-mounted conveyor belt from Queensland to place 300m3 of no fines backfill in four hours. As a result, all works were completed on time with the rail line handed back to the rail operators for peak hour services, and the rest of the Dudley Street bridge able to be constructed.

Dudley Street bridge footings and piers

Proposed initial designs for a bridge that spanned over Dudley Street were rejected due to the load constraints on the MURL tunnel, therefore the challenge of constructing two piers on Dudley Street while not affecting peak hour traffic was faced. The approved design called for four in situ footings with post tensioned precast piers and headstocks.

Apart from the usual challenges faced with constructing post tensioned precast piers and the inherent tight tolerances required, the added challenge of needing to excavate 2m to expose the tunnel roof while impeding up to 600mm into the running lanes of Dudley Street without effecting peak hour traffic needed a solution. To reduce the risk of not achieving the scope of works within the seven VicRoads approved weekend closures, the excavation works were completed during 15 lane closures of Dudley Street at night. During these night shifts the excavations were completed by hand held tools so as to not cause damage to the MURL tunnel. The excavation was then propped and covered with recessed steel road plates in the lanes prior to opening the lanes to traffic for peak hour traffic.

Even though the night shifts only provided four hours of productive works per night, de-scoping the works from the seven weekend closures was pivotal to complete the bridge without any delays, as the steel road plates provided a safety net in handing back the lanes on time.

Following the excavation works, the footings and piers were then completed in three weekend road closures that involved the following:

- Scanning the tunnel roof
- Coring 103 vertical holes in the tunnel roof
- Installing the footing starter bars
- Installing a prefabricated cage
- Casting the footings with the required post tension starter bars within 5mm tolerances
- Installing the precast piers and headstocks
- Tensioning of the post tensioned bars.

The total scope of works required very detailed planning and was completed in full during the three planned weekend occupations with no delays to Dudley Street peak hour traffic and within the very tight tolerances required.

2. Maribyrnong River viaduct (City to Maribyrnong River work package)

The Maribyrnong River Viaduct is a $26 million, 15 span, 435m long elevated structure carrying the new RRL tracks from east of Kensington Road across to the west of the Maribyrnong River and was constructed in a 12 month period from late October 2012 through until early November 2013.

The structure consists of 14 piers and two abutments supporting 15 spans of Tee-Roff beams with the largest length of 35m and a weight of 90 tonnes each and a cast in situ deck containing two ballasted tracks and cantilevered structural steel access walkways along both sides. Architectural and urban design features include textured precast concrete panels at both sides of Kensington Road, both sides of the Maribyrnong River and at the western abutment where the panels are tied in with the construction of the embankment walls. Perforated cladding panels were installed throughout the southern side of the bridge with the span across the Maribyrnong River having backing panels to allow for the bridge to be lit up at night.

Significant challenges were encountered in the design and construction of the bridge, including soft ground, constrained access, adjacent structures, live road and rail, a flood plain and the Maribyrnong River.

The viaduct presented several challenges for the design and construction teams over and above the normal challenges of working in a live rail corridor and working around existing utility services, including:

Maribyrnong River

Home to the Australian Grayling (a listed vulnerable fish species, protected by State and Federal legislation), whose breeding habits required works in the river to be scheduled around spawning and migration, the need to maintain flood levels upstream to present day limits and access across the floodplain.

The river itself, at approximately 55m between banks and 5m deep, posed a significant constraint and challenge to construction of the bridge. Afflux on the Maribyrnong River must be avoided, hence the waterway pier had to be minimised.

The river pier works were required to be completed outside the period of May to July due to the spawning of the Australian Grayling, and outside the period of October to December, due to the migration of the Australian Grayling.

The pile cap on the eastern bank of the Maribyrnong river had a total of 42 driven piles and due to its proximity to the river, sheet piling was required to ensure construction of the 2m deep pile cap was completed.

During construction of the pile cap, large boulders approximately 2m in width were located along the bank. A design change was required for the excavation of the boulders and stabilised sand was used to hold up the bank to ensure it didn’t cave into the river during construction.

Scalzo Foods Industry

The viaduct is sandwiched between the existing Werribee lines and the Scalzo Foods Industry factory, containing highly vibration-sensitive equipment. The width of the new rail bridge and proximity to an established commercial building created issues including narrow access, vibration from piling and construction activities, support to the existing embankment and railway line and the need to maintain parking for Scalzo staff. The bridge pile caps were purposely designed to allow enough distance for a semitrailer to pass through the middle of pile caps.

The distance of the soil nail wall holding up the embankment was also purposely designed to allow for the 350 tonne Metcalf mobile crane to be able to install the precast crossheads. The overall clearance between the soil nail wall and the Scalzo building allowed for the crane to have a total clearance of 50mm to swing around. Once the crossheads were installed, no plant could access the previous location. As a result, all works had to be completed in the previous section as there was no access for cranes below the crossheads.

Heavenly Queen Temple

The temple adjacent to the site on the west of the river is a Buddhist temple, which shares the only access road to the site.

Existing Maribyrnong bridge

Spanning the river immediately upstream of the new bridge is the heritage listed single span Parker Truss Bridge on bluestone abutments which had to be protected during construction and not obscured post construction.

Shared use path

Popular shared use paths run along both banks of the river. At all times one side of the shared user path had to remain open. A floating pontoon was installed on the eastern side of the river which allowed cyclists/pedestrians to proceed around the worksite.

Lynch’s flood plains

Lynch’s flood plain was flooded approximately 1m in depth and large pumps were required to remove the water and discharge it into the Maribyrnong River. A robust water testing regime was followed during this process and pumps were set up throughout the duration of the piling/construction of the pier works.

Temporary soil nail walls were installed at piers 1, 2, 12 and abutment B. The abutment B soil nail walls failed due to the amount of water and the unsuitable backfill material behind the existing bridge west of the Lynch’s culverts wingwalls. As a result, a large pile cap was constructed to retain the failed soil nail wall allowing the construction of the abutment to continue.

This caused long delays to the program and the methodology of driving the river beams to the top of spans 15 through to 12 had to change. A semi-trailer with a jinker was lifted onto the constructed spans 14 through to 12 and with the use of a 350 tonne and 200 tonne crane the beams were erected onto the semitrailer and floated back into the launching truss which was spanned over the Maribyrnong River.

Ground conditions

The site is the current and former floodplain of the river and consists of up to 14m (depth) of Coode Island silt. The ground conditions typically include a variable depth layer of fill overlying Coode Island Silt, Fisherman's Bend Silt, Alluvial sands and clays, Moray Street Gravels and finally Siltstone.

Construction of bridge at Kensington Road

Due to the pier 1 pile cap having a depth of 2m and the requirement for it to be below finished ground level, sheet piling was installed in order to construct the pile cap. The sheet piles were incorporated to the soil nail wall design with a waler beam throughout the perimeter to hold back the ground.

A supervisory cable was 500mm away and was required to be located throughout its route to ensure that no damage was done to the cable. The installation of beams from the Scalzo building to abutment A were required to be completed in sequence as the crane had to be located within the previous span location. The final crane lift location to install span 1 had to be completed in a dual lift from the Melbourne Seafood Centre car park and Kensington Road. Extensive planning with the land owners was required due to the number of services running in the crane location and with the fish market running six days a week.

Proximity to operating rail network

The Maribyrnong River Viaduct runs parallel to the existing operational suburban lines. The lateral offset between the nearest existing track centre and the northern edge of the viaduct is nominally 8m to the edge of walkway and 9.5m to the concrete and precast beams.

Launching truss

Due to constrained access, the original plan was to transport the tee-roff beams to the eastern end of the viaduct and move them into position using a launching truss. The sequencing of these works was altered during construction so that beams were delivered to both ends of the bridge, as piling alongside the Scalzo factory took longer than anticipated due to the poor ground conditions. Use of the launching truss reduced the requirements for working at heights and eliminated the need to crane the beams over the factory or over the river. Using the truss also reduced the number of track occupations required in construction of the viaduct.

As the launching truss could only span over 3 spans, it had a specific method to installing all the beams from span 9 through to span 4. The launching truss had to pick up beams which were delivered on semitrailers with jinkers behind abutment A and place them in specific spans. At a later stage it had to be moved forward to pick up the beams it had positioned in the original location and carry them to the final position. A period of three weeks was used to deliver all the beams from span 4 to span 9. All the beams were required to be stacked up on top of each other to allow the launching truss to travel on the opposite side.

Construction of the river beams was originally meant to be completed by delivering them from abutment B although due to the challenges faced in the construction of the soil nail wall at abutment B, a 350 tonne crane and a 200 tonne crane dual lift was used to lift the beams to the constructed spans at piers 14 to 12 where a semitrailer and jinker was erected to reverse the beams to the launching truss.

Working platform/jetty

To facilitate working in the river, a temporary construction jetty was built to allow correct positioning of the jack up barge used to install the piles, provide a stable platform for a construction crane to place the headstock and to allow stable access for construction personnel. This technique allowed one half of the river to remain open at all times to river traffic.

Choice of piles

Foundations adjacent Scalzo Food Industries

Driven precast concrete piles were pre-bored through the stiffer upper fill layer into the CIS to minimise vibrations and surface displacements. Above ground pile caps for Piers 4 to 8 adjacent the Scalzo warehouse were adopted to avoid the need to temporarily excavate below the building founding level and interaction with groundwater.

Steel piles in river

A crawler crane was used to position the steel piles in the required position. A vibrating hammer was then used to drive the piles down to the required depth. A new steel pile was positioned over the top and welded to the pre-driven pile in the ground. The vibrating hammer then drove the pile to its final position. This process was completed for all the pile driving. Once this was completed the unwanted material was sucked out from the steel pile and the internal part of the steel piles was poured with concrete.

Precast headstocks

Precast headstocks were adopted to reduce the need to work at heights and work over the river and to reduce construction time on site. The overall design was completed to ensure that Metcalf's 350 tonne crane was able to fit within the required area between the shotcrete wall and the Scalzo building. The headstock was installed in sequence commencing at pier 8 and moving backwards to pier 2. Once the precast headstock was installed, the works in the area preceding it were impacted because machinery could no longer fit underneath the headstock.

Construction methodology

Further highlights of the construction methodology are discussed below:

Eastern abutment

The eastern abutment was constructed with the use of reinforced soil straps. These were designed in conjunction with the reinforced earth straps from the reinforced earth walls. Textured fascia panels were installed post construction adjacent to the footpath on Kensington Road.

Pier 1 construction

A soil nail wall was constructed with the use of sheet piles, soil nails and a 300 UB waler beam. Due to the pier being parallel to Kensington Road and not tangential to the bridge beams, it meant that it encroached on the existing rail embankment meaning that a rigorous temporary works design was required. The pile cap was 2m deep and a reinforcement slab was required to be poured to ensure that the toe of the sheet piles did not push in. The headstock was cast in situ due to its size and being unable to be erected in a single piece.

Pier 9 construction

A total of 42 driven piles were installed. Due to its proximity to the river, sheet piling was required to ensure that the construction of the 2m deep pile cap was able to be completed. The challenge faced in the construction was the fact that large boulders approximately 2m in width were located along the bank. The holes were predrilled to ensure that the boulders were removed prior to the sheet piling and then filled will stabilised sand to ensure piles could be driven at a later stage. The sheet piles had waler beams installed and a reinforcement slab was poured at the bottom to ensure the sheet piles remained in place during construction.

3. From drainage culvert to plank bridge (Deer Park to West Werribee Junction work package)

The Deer Park to West Werribee Junction section of the project traverses largely greenfield areas of western Melbourne. It crosses a number of drainage lines including four major waterways and 26 minor waterways. The minor waterways are characterised by relatively steep longitudinal grades but with cross sections that are relatively wide and flat with shallow depths of flow.

The reference design proposed large banks of culverts with between 10 and 50 cells in order to convey the wide flat flows while meeting other design criteria. During the tender process, consultation with Melbourne Water was carried out and as a result tenderers were requested to allow for future proofing to cater for future urban growth. The Melbourne Water proposal included the incorporation of 10 future drainage reserves where constructed urban waterways were planned to be excavated below the existing ground surface in the future. This would allow for the future urban drainage network to outlet to the reserves and, by taking advantage of their steep longitudinal grades and containing future flood impacts to within the constructed waterways, the land area available for development is maximised.

This presented a two-stage design requirement to satisfy the present Day 1 flow regime and topography as well as the Ultimate future urban development flows and drainage reserve arrangement. The original design solution for the modified reference design was to employ a stacked culvert arrangement, with the Day 1 culverts at existing ground level stacked on top of the Ultimate culverts (Figure 1). The Ultimate culverts were to be installed at the future waterway channel invert level and then backfilled to the existing surface. This created the following challenges and issues:

- Structural design of the culvert units
- Method for backfilling and future excavation
- Safety issue with backfilling and future excavation
- Undesirable aesthetics of obsolete Day 1 culverts when ultimate channel is in effect.

To overcome these issues, the Deer Park to West Werribee (DP-WWJ) team worked collaboratively with Melbourne Water, RRLA and BLJV to develop an alternative solution whereby short span plank bridges were utilised instead of culverts. The overall concept was to excavate the Ultimate drainage reserve channel form within the rail corridor, construct the bridge piles/piers and then backfill between the piers to existing surface before placing the bridge deck. This allowed existing Day 1 flows at existing surface levels, with the future excavation of the pre-formed channel, to connect with the drainage reserves outside the rail corridor to accept Ultimate flows.

The use of plank bridges allowed a superior outcome from a number of perspectives:

- Improved hydraulics due to:
  - less headloss due to less structure impediment and friction on flows
  - less blockage potential compared to culverts
- Better river health due to:
  - less structure in the waterway
  - lower headloss through the structure allowing for fish passage and lower scour potential
  - more natural channel through the structure
- **Lower cost:** both in the structure and the future drainage reserve channels due to smaller width requirements
- **More sustainable outcome:** due to less materials, particularly concrete, and no waste of materials in obsolete Day 1 culverts
- **More aesthetically pleasing:** no obsolete Day 1 culverts sitting up in the air above the Ultimate culverts
- **Safer construction:** particularly for backfilling technique which could be undertaken prior to bridge deck construction rather than inside a constrained culvert
- **Easier to excavate** pre-formed channel in future which can be undertaken without affecting rail operations.

Due to improved hydraulics, the overall structure spans were less than a comparable bank of culverts which led to lower costs, less visual impact and improved river health. Throughout the design, major stakeholders, particularly Melbourne Water, were consulted about the design solution to achieve the optimum outcome. Melbourne Water have acknowledged the significant river health benefits of this solution over culverts in a presentation by Mark Coffey (Melbourne Water's interface manager for RRL) to the 15th International River Symposium Oct 2012 where he used the RRL plank bridges as a Case Study – and noted them as a major 'win' for river health.

During design the cross drainage and flow path widths were optimised to determine the required overall length of the drainage crossings. The decision was made during the tender that these bridges would be precast pre-stressed deck planks as they were simple to cast off site and install on site.

The completed cross drainage bridges vary from two spans of 10m up to four spans of 9m. Precast planks were designed with a 150mm minimum deck thickness. The planks were cast integrally with the abutment and the piers to avoid the need for bearing inspection and replacement under the low decks as discussed below. The bored piles directly connected with the crosshead removing the need for pilecaps. This represented less structure within the waterway, reducing the scour potential and improved river health values.

There was a heavy influence throughout the design process from stakeholders. To this end, a comprehensive Safety in Design (SiD) process was implemented by to ensure compliance with the current legislative requirements. This incorporated 25 formal workshops facilitated by the DP-WWJ team with participation by key stakeholders. Stakeholders included RRLA, V/Line, VicRoads, Wyndham City Council, City West Water and Melbourne Water. As a result of these SiD sessions a formal acknowledgment of residual risks transfer was received from stakeholders.

A particular emphasis of the SiD workshops during the design development phase with rail and road operators, V/Line and VicRoads, was the minimisation of maintenance items, with several agreed outcomes put in place prior to the issuing of Approved for Construction (AFC) packages. These included:

- **Removal of bearings:** It was determined that these plank bridge structures would be integral, reducing the future maintenance requirements of bearings. This meant that over the life of the structure there would be no requirement to replace the bearing strip, and as there are no expansion joints, there would be no maintenance required on the joints. These items are typically costly and very time consuming to replace and could impact on road or rail operations.
- **Rail bridge drainage:** The Project Brief required the provision of piped drainage on the rail structures. V/Line saw the piped drainage as an undesirable maintenance item with particular difficulty in flushing the pipes. As a result, detailed calculations were completed to confirm that drainage through the ballast on the deck could cater for the design flows and the piped drainage was removed. This deck drainage involved the addition of a crown in the deck along the centreline of the bridge, bridge abutments and approach slabs that allowed the water to flow easily over the top and the provision of a pipe drain at the low end of the bridge/approach slab to convey the water away from the rail formation.

As a result of the requirements discussed above, and in order to ensure an efficient and economical design was provided, the design maximised standardisation of details and off-site production. Making extensive use of precast concrete and prefabricated elements sped up on site construction of the bridges. As offsite production was maximised, it was also essential to ensure these details were standardised as much as possible in order to facilitate the onsite construction and to minimise the number of modified elements. Significant savings through standardisation and duplication was possible with these plank structures:

- **Precast prestressed plank girders:** The same plank mould was used across all the plank bridges with the only variation being to external beams that also had a ballast wall precast with the beam. The same strand layout pattern was used across the bridges with the number of strands varying depending on the span length. The same conventional reinforcement cage was used with the size and spacings of the bars, and the location of the diaphragms the only item that was modified to suit the plank spans.
- **Prefabricated steel maintenance walkway:** A fabricated steel walkway for rail plank bridges was designed to cantilever from the ballast retaining wall to provide access for maintenance and to support signalling and communications conduits. The maintenance walkway outriggers were prefabricated off site and readily erected on site through a bolted connection to cast in ferrules in the ballast walls. The standardised design for rail plank bridges ensured that any outrigger could be positioned at any location within a bridge with a maximum of eight specific outrigger designs per bridge.
- **Precast fenderwall and wingwalls:** The fenderwall and wingwall design was standardised for the cross drainage bridges, with one design for the rail plank bridges and another for the road plank bridges. The only element that changed for each type was the height with the same reinforcement spacing and pattern used across all bridges. The wingwalls and fenderwall were designed to be installed first to act as a permanent formwork to construct the abutment sill beam which was a safer option.
- **Approach slabs:** One standardised approach slab design was provided across all the rail bridges and another for the road bridges, with a minimum depth requirement and the same length on the same bridge type. The only bridge specific change was to suit the varying bridge widths.
- **End plates/waterproofing:** The design was standardised to suit all rail plank bridges with fabricated t-plates used to ensure water could not escape at the joints between the approach slab and the wingwalls and abutments.

4. Nicholson Street bridge (Footscray to Deer Park work package)

The Footscray to Deer Park (FDP) project team showcased its innovation and technical expertise in the design and construction of the new Nicholson Street Bridge in Footscray.

Goals

The key objective for the construction of a single-span bridge in Nicholson Street, Footscray, was to create critical space in the rail corridor beneath to accommodate the RRL tracks and the realigned metropolitan rail lines.

Another key goal of the project was to replace the existing heavy-set steel girder two-span bridge constructed in the 1920s with a modern, iconic structure, sympathetic to the environment that would set a new tone for neighbourhood renewal and create a sense of place for residents and the local community.

The design of the new bridge was also intended to improve pedestrian connectivity to surrounding areas, shops, schools and employment and education including to the nearby Victoria University campus.

Challenges

Phased demolition of the existing shops and bridge structure and the design and construction of the new bridge presented a range of demanding challenges for the FDP project team:

- The busy rail corridor beneath the bridge meant that demolition and construction works needed to maintain freight and passenger train services while minimising disruption.
- This required complex staging works to be conducted during short and long occupations coordinated through an access regime that combined ARTC freight movements, with Metro and V/Line services
- Disruption to road traffic and pedestrian access had to be controlled, managed and minimised
- Safety in design and construction was critical due to the live brownfield rail environment and required precision planning and meticulous methods

- Innovative design and fabrication of the bridge was also required due to the constrained space that FDP had to work within
- The bridge carried critical services such as high and low voltage electricity lines, gas and water
- A sewer was in proximity to the southern abutment, which could not be disrupted during demolition and construction
- Most challenging, an extensive number of Telstra conduits and services from its nearby exchange had to be diverted across the bridge structure while maintaining the integrity of the system to their customers
- The abutment on the northern side had to be retained and modified due to the scale of works required, and extensive works on the south abutment were needed in close proximity the residents and traders.

Solution

Design and planning

Meticulous planning and extensive consultation were critical to the Nicholson Street bridge project to deliver an innovative and outstanding solution.

- FDP worked closely with key stakeholders, local residents and traders for around 15 months before a final design and works schedule was completed
- This included consulting with rail operators, as well as Maribyrnong City Council, to ensure a functional bridge that was architecturally suitable to the neighbourhood renewal goals of the area
- The methodology included regular stakeholder meetings led by the design team with input from the construction team to find the best solution within the constrained challenges of the project. For example, the size (depth) and spacing of the bridge trusses were designed to accommodate the overhead line support structures and to optimise clearances for RRL lines while also accommodating the crane in a constrained space
- Curved trusses were adopted for the bridge design as the bridge deck needed to be as thin as possible and height above the ground was not restricted
- Land on the south side of the bridge was used for the new RRL tracks so that no land requirements were needed on the northern side, which avoided relocations or property acquisitions.
- The capping beam and pile design was engineered to form the function of a retaining wall for the 5m-deep cutting necessary for the new RRL lines
- The piles and capping beam for the southern abutment were redesigned during the construction phase to ensure an integral design solution with Telstra, prior to diversion
- Due to the height of the trusses, temporary propping of the trusses was necessary during assembly. This was designed in conjunction with permanent and temporary works designs to be incorporated into the permanent works.

Demolition works

The existing shops and bridge were demolished in stages to allow for ongoing train services beneath the bridge and to retain the footpaths carrying Telstra assets.

This allowed for the construction of a separate services bridge on the eastern section of the existing structure to carry Telstra and other service assets while demolition continued on the remaining section and the new bridge was constructed.

To address the challenges of Telstra’s conduits across the bridge, FDP developed a methodology approved by Telstra to temporarily expose these assets:

- This required non-destructive digging, use of steel casing sleeves against the conduits so FDP could pile through without connecting with and disrupting any Telstra services

- Work was conducted within 100mm of live Telstra services and demanded technical and delivery excellence as one wrong move would have disconnected a substantial number of services
- The bridge deck was removed in a total of 55 pieces weighing in excess of 800 tonne
- Extensive preparation was undertaken to the existing bridge deck including asphalt removal and the installation of circa 220 core holes to facilitate the lifting of the deck away from the structure
- The surgical demolition/removal of the existing bridge deck took a total of 72 hours in six separate rail occupations.
- No incidents or unplanned delays to train services were experienced during these works, which was a significant achievement.

Construction

The pre-fabricated new bridge was manufactured in Tasmania and transported from the Port of Melbourne by road.

It comprised two trusses each measuring 34m in length and 6.5m in height, with 23 crossbeams and 23 outrigger beams

The main trusses were lifted into place by a 350-tonne crawler crane on a single Saturday shift when FDP had full closure of all four rail lines

Over the next 36 hours all beams were added, bolted and tensioned weighing 266 tonnes, followed by installation of 56 pre-cast concrete panels to the main deck and in-situ concrete to the deck of 575m2

Following curing of the main deck, the 14 concrete panels to the outrigger footpath deck were installed as well as an additional in situ concrete slab of 117m2.

Iconic new structure

The opening of the new Nicholson Street Bridge to pedestrians on the 8 February 2014 and to cars on 24 April 2014 was a major milestone for the RRL project. Its innovative design and construction and the technical expertise required to successfully deliver this bridge showcased the skills and expertise of the FDP project team.

5. Solving the rail systems challenge (Rail Systems work package)

Train Control and Systems (TCS) was the project term adopted to define the system made up of the sub-systems of Signalling, Train Control, Communications and ICT.

These sub-systems, in Victoria, have traditionally been treated as stand-alone systems and in many cases delivered under separate contracts or as sub contracts to a civil contractor.

For the RRL project the approach was to consolidate the delivery responsibility and adopt a systems engineering approach to the control and information technologies where there is a hierarchy of a parent system (TCS) and subordinate (sub) systems (e.g. signalling).

This approach recognised that there is a lifecycle for the system with progressive phases from concept, architectural development, design, construction, commissioning, operation and maintenance, through to de-commissioning. A V-model lifecycle was adopted by the Rail Systems work package which was the principal party responsible for the TCS delivery. The V-model lifecycle is illustrated in Figure 6.

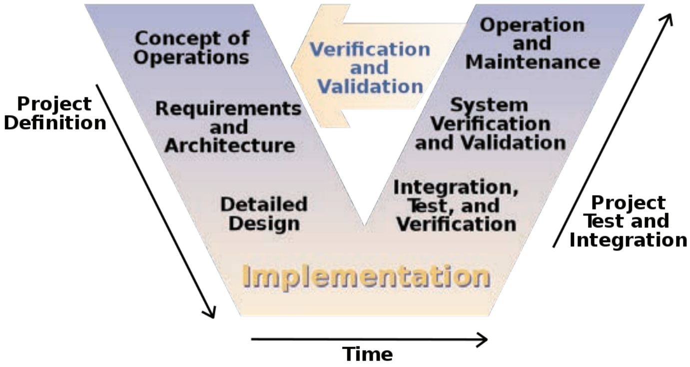


Figure 6 – Typical V-model Lifecycle

The presentation of a systems engineering approach and decomposing the system into sub systems and with further decomposition of the sub systems to lower levels was new ground for many of the participants in the project. While some of the steps are business as usual, the formalising of the process and recognising that there is/are higher-order and lower-order parts to the infrastructure solution and with direct sub-system and system relationship and integration requirements was novel to many.

Another key facet to the systems engineering approach is in the formal establishment of requirements and providing traceability of the requirements through to the sub systems and lower levels. This traceability is required for verification between phases of the development (down the V-model) and for verification and validation (across the V-model) during the test and integration phases.

For parties not experienced in the application of the process, it has been a challenge to recognise that the solution follows the requirements, i.e. it is premature to be working out the how when the why and what have yet to be determined.

In the Rail Systems work package the IBM DOORS database was used as the repository of the requirements, the allocation of the requirements to sub-systems and lower levels, and for the traceability between the various levels.

While the needs for a systems engineering approach and the establishment of a formal requirements and traceability system were identified to the Rail Systems Alliance, the Footscray to Deer Park project team also recognised the benefits from such an approach and this has been adopted in their delivery approach.

TCS and Work Package Allocation

While the Rail Systems work package is responsible for the delivery of TCS, not all TCS items and activities were performed by this project team.

Some of the principles and reasoning for splitting out certain responsibilities are listed as follows:

The work packages responsible for the design and construction of the RRL line are all large civil consortiums and will need to have a comprehensive construction work force. The TCS civil construction activities, such as foundations for signal masts and equipment boxes, pits and cable routes, are all within the capabilities of the civil consortiums and have been allocated to these consortiums, thereby eliminating the need to have two separate contractors with equivalent skill and plant needs working in the same area.

The brownfields work packages (City –Maribyrnong River and Footscray – Deer Park) have to carefully manage access, staging and construction in an operating railway environment. In these areas, the Alliances are responsible for the signalling on the existing metropolitan lines.

Reliability, Availability and Maintainability (RAM)

The requirements for reliability, availability and maintainability for local infrastructure projects have typically provided an arbitrary figure on availability or some generalised statement. In order to include a reasoned, practical and assured figure that is neither over nor under specified some first principles' analysis was performed.

The passenger operators V/Line and MTM are contracted to deliver a certain level of train performance, in particular 92% and 88% of trains delivered to schedule[1]. These present the minimum level of performance for the railway and take into account all sources of delays, failures and unavailability such as from the infrastructure, rolling-stock and operations.

A top down reliability model was constructed for the RRL line. The top level metric is services not delivered to schedule, i.e. for V/Line, the delayed services figure is 8%. The delayed services metric then needs to be allocated to the sources of delay, e.g. infrastructure failures. Infrastructure failures then need to be allocated to the various systems, e.g. TCS. From historical operational performance reporting data, between 10 to 15% of delays are attributable to infrastructure failures and of the infrastructure failures TCS contributes in the order of 80%.

The TCS failure contribution then needs to be made relevant to the infrastructure being delivered by the project. For the RRL line there are three service sections as illustrated in Figure 7.

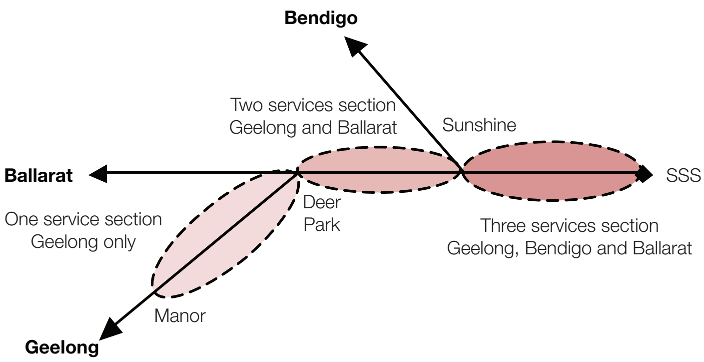


Figure 7 – Services Sections on the RRL Line

For each services section the parameters to determine are:

- Total number (maximum forecast) of passenger train services (both directions) per day through the section
- Track distance of the section (e.g. for the Geelong only section, up and down lines, 50 km)
- Ratio of track distance of the section to the journey distance (e.g. total track distance Geelong to Melbourne is 160 km. Ratio equals 50/160).

These section details, in conjunction with the contribution that TCS failures have on the delayed services then provides a TCS delayed services value for the section. With the addition of a value for the time to repair a TCS fault, a mean time between failure (MTBF) value for that section is then able to be determined.

As part of the respective Alliances' requirements reliability models and design analyses were required to be performed to optimise the system design and maintenance requirements, aimed at meeting or exceeding the determined MTBFs.

[1] To schedule is defined as no later than 5 minutes 59 seconds for V/Line and 4 minutes 59 seconds for MTM.

Signalling and CBI Arrangements

The project works had significant impacts to existing interlockings through the area. At Southern Cross through to the Melbourne Yard area the interlocking technology was geographic relay or free wired-relay. South Kensington and Sunshine was SSI, Deer Park was free-wired relay and the Geelong line through the Manor area was SSI. In forming the CBI architecture a number of options were considered including:

a. distributed interlockings with the interlockings controlling both RRL and MTM lines;

b. distributed interlockings with separate interlockings for the RRL and MTM lines;

c. centralised interlocking controlling both RRL and MTM lines;

d. centralised interlockings with separate interlockings for the RRL and MTM lines.

The analysis identified that a centralised interlocking (item c.) was the best architecture however both AROs wanted to be responsible for their lines so the centralised and separate interlockings (item d.) was the ARO preferred architecture. Mapping this architecture into the work packages matched the Rail Systems Alliance scope but in the brownfields work packages where each work package needs to be responsible for their own signalling the centralised approach did not fit and as a consequence there is number of distributed interlockings along the MTM lines. A further work package scope impact on the CBI architecture was that the Southern Cross Station package was an early works package which established a local CBI for the RRL line with the result that for the RRL line there is also more than one CBI covering the RRL line. The CBI architecture is illustrated in Figure 8.

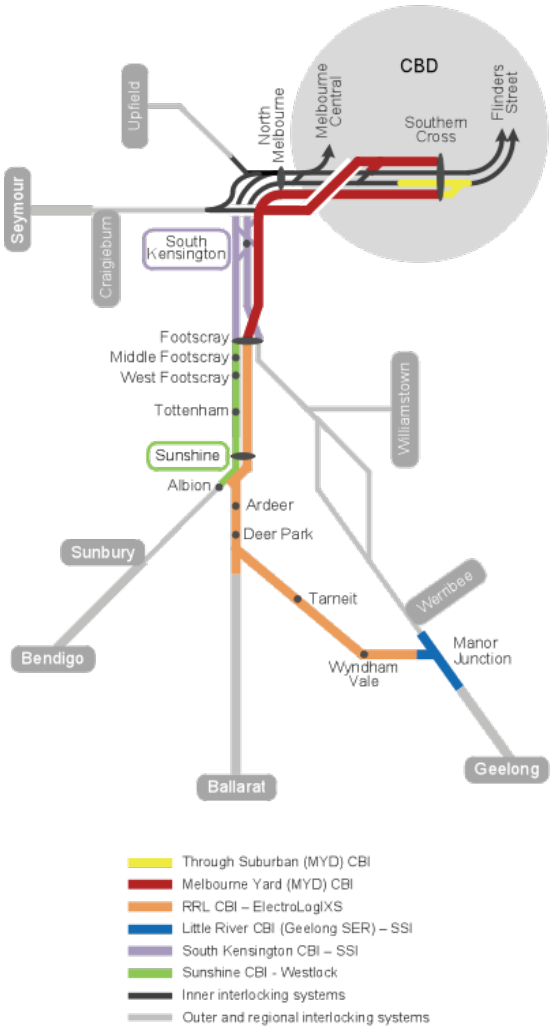


Figure 8 – Project CBI Arrangements

Other strategic architectural considerations included signal enforcement and the signal power supply distribution.

For signal enforcement, the existing arrangements in the network were mechanical train stop (MTM fleet) and TPWS (V/Line fleet) with fully braked signal overlaps. Given that the maximum headway performance for the RRL line was specified as 2 minutes, there has been no need to move away from conventional signalling and enforcement principles[2].

In the greenfield area, with there being no signalling power system in place, an analysis of potential power schemes was undertaken. The traditional country system is local street supply and diesel generator back up and a low voltage local distribution network. The traditional metropolitan system has been single high voltage ring fed from traction sub stations and a low voltage local distribution network. The outcome was to use a high voltage distribution network with 3 feed points operating in a 2 out of 3 mode. A novel feature of this network is that at each point the HV switchgear is remote controlled which provides improved maintenance and repair arrangements.

The signalling design challenge for the project was arguably the largest the Victorian rail engineering industry has ever faced. A myriad of existing signalling and train control systems required modification. A total of 23 different signalling systems and 14 different train control systems – all interconnected – were affected on RRL. The RS works had to be carefully staged to maintain critical functionality and commissioning, often requiring collaboration between three work packages, working on different parts of an interconnected system.

Train Control Arrangements

The existing regional train control arrangements are performed at a number of different sites around Victoria using different technologies. With the establishment of the new RRL line, a new train control system was introduced at V/Line's central site in Melbourne (Centrol) for control of the new line. The existing control sites at Bendigo, Ballarat and Geelong and their control areas were retained.

The new RRL train control system interfaces with the metropolitan train control system at a number of locations, these being Sunshine, South Kensington, Spion Kop, Franklin Street and Southern Cross. The metropolitan train control system required changes at these locations in order to accommodate the RRL line and the changed track and signal arrangements.

The existing metropolitan train control system at Metrol is currently being replaced by a new and advanced system (Westrol from Invensys) under the TCMS project.

[2] Future proofing for new generation signalling system was a project requirement. The use of CBIs and ensuring that expansion capacity is provided in CBI, communications and power systems and that physical space was reserved in cable routes, equipment rooms and boxes was the approach adopted.

Figure 9 – Signal Control Areas and Centres

ICT

The Information and Communications Technologies (ICT) are essential systems for the effective operation of a rail passenger network keeping rail customers informed and providing facilities for operations staff to supervise and manage operations. The technologies include passenger information displays, public address systems, customer help points, telephone and data services, ticketing systems, CCTV, security, access control, fire and lift alarm systems.

With the project introducing new and changed station platforms, offices, buildings, car parks and environs; new operations buildings; and new equipment rooms significant ICT works were required.

Recent projects with ICT scope had generally been part of a civil project for the construction of a new or modified station. The ICT value relative to these contracts is very low and technology systems are a non-core function for civil contractors. Achieving a consistent level of quality and performance for the ICT function given the scale of the work and the required expertise has often been difficult. For the RRL project the ICT works were completed by the Rail Systems work package as an expert provider of technology systems and the project's systems integrator.

Communications

The project introduced a new fibre optic trunk adjacent to the RRL line from SSS through to Manor. Of the fibre optics in the trunk, 48 were reserved for TCS communication services for the project. At the end of the project the fibre optic trunk was handed over to VicTrack (the State's communication agency) for ownership and maintenance. The cores used for the project and a number of spare cores were reserved for the railway with the balance of cores available to VicTrack for commercial services.

The fibre optic trunk is the principal communications medium used for the project with connections dropped off at Signal Equipment Rooms, Communications Rooms, Stations and location boxes along the line. At various points along the route there are existing communication hubs that provide connection to the existing VicTrack communications network which provides connectivity to Control Centres, Maintenance locations, Offices and the public network. The existing VicTrack network also provides circuits (dark fibre and managed services) that are routed by a path that is physically diverse from the new RRL fibre optic trunk which is now utilised as alternate circuits for the critical centralised signalling and train control communications.

The communication services required for the project or used in the network are summarised in Figure 10. At the higher level, there are three networks – RRL Specific, DOT Control and Monitoring Systems (CMS) and VicTrack Managed Services.

The RRL specific networks were determined by the project designers to meet their needs for signalling and other project specific services. These communications would utilise dark fibres from the fibre optic trunk or local fibre optic cable.

<table>
<tr><th colspan="2">RRL Specific Networks</th><th colspan="4">DOT Control and Monitoring Systems Networks</th><th colspan="2">RRL Specific Networks</th></tr>
<tr><td>Local Comms</td><td>Signals Network</td><td>Train Control Network</td><td>Security Network</td><td>SCADA Network</td><td>Digital Train Radio Network</td><td>IP Network</td><td>SDH Network</td></tr>
<tr><td colspan="2">CBI Communications
Axle Counter Communications
Telemetry Systems</td><td>RRL Train Control
Metropolitan Train Control</td><td>Time Server
Fault Monitoring
Security and Access Control
CCTV
PRIDE
Customer Information Systems (CIS)</td><td>Traction Power Substation SCDA
Fault Management</td><td>Data and Voice services
Service and Fault Management</td><td colspan="2">Signalling and Train Control services
Intranet, V/Net
MYKI Ticketing
PABX - phone and fax services</td></tr>
</table>

Figure 10 – Communication Networks

The CMS networks are a standard set of networks specified by DOT.

- The Train Control Network provides the communications between the Metropolitan signalling systems and Metrol (and DRS) and between the RRL line signalling systems and Centrol (and DRS). For additions to the network for the RRL project dark fibres from the fibre optic trunk were used.
- The Security network provides the communications between the ICT systems located at stations, buildings, communications equipment rooms and signal equipment rooms and the central sites. For additions to the network for the RRL project dark fibres from the fibre optic trunk were used.
- The SCADA network provides the communications between Metropolitan sub stations and electrical switching locations and the central power control location (Electrol). For additions to the network for the RRL project dark fibres from the fibre optic trunk were used.
- The Digital Train Radio network provides the communications for the Metropolitan train radio infrastructure sites. This communications network was not impacted by the RRL project.

The VicTrack managed services are various IP and SDH based circuits available to users at existing and new sites in the railway network. These services are used for various operations and infrastructure systems, including MYKI ticketing, ARO intranets and phone and fax services. These services are also used in signalling and train control systems generally where there is no existing railway infrastructure circuit available or where a diverse means of communication is required outside of the railway infrastructure.

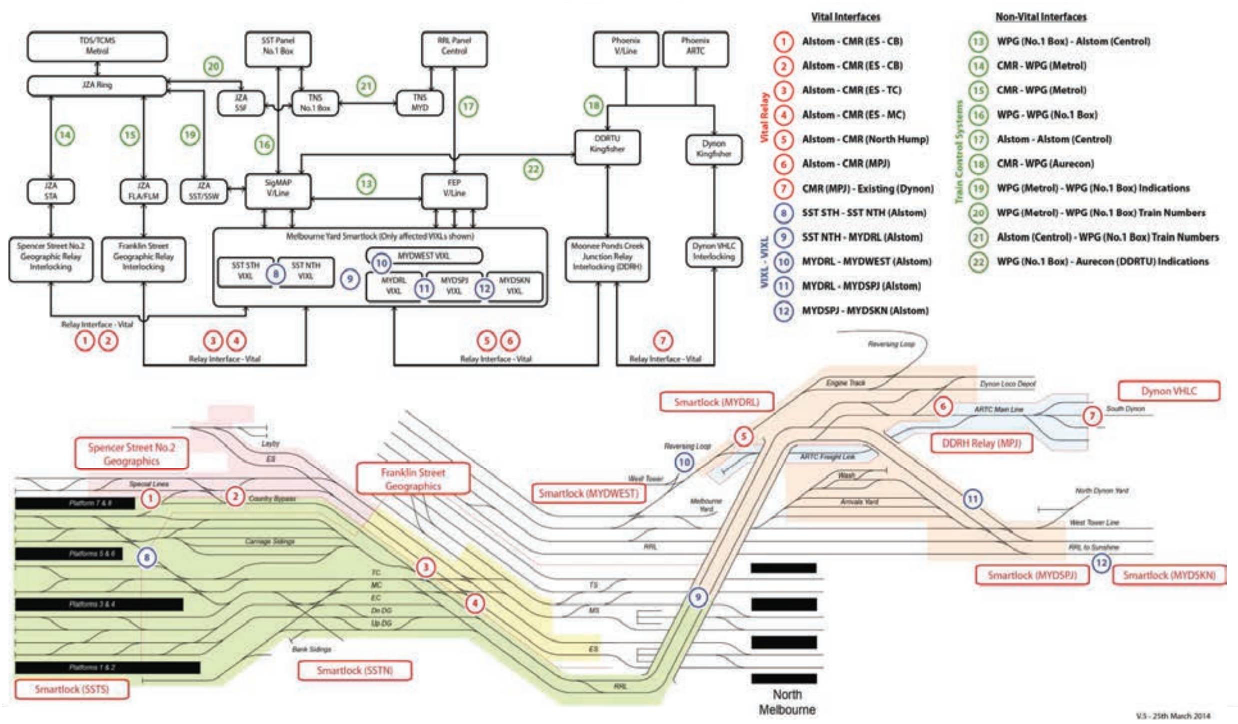
Occupation Event 48

This occupation event encompassed arguably the most complex rail systems infrastructure commissioning and change event in Victoria over the last 30 years.

The commissioning involved:

- 22 rail system interfaces changes
- Major field signalling and interlocking changes affecting 3 rail operators
  - Metro interlocking: FLX & SSS2 geographics
  - VLine interlocking" MYD (SSTN, SSTS, MYDWest, RL, SPJ & SKN VIXLs)
  - ARTC MPJ Relays: signal changes with extensive box rewiring
- Extensive Train Control System changes affecting 3 rail operators
  - VLine: RRL Interim TC at Centrol and SSS No. 1 Box (major control area and track reconfiguration and interfaces)
  - MTM: Metrol TCMS/TDS (control area and interface changes and minor track reconfiguration)
  - ARTC: Pheonix at Mile End (control area, track and interfaces changes)
- Significant involvement of the City – Maribyrnong River Alliance, the Rail Systems Alliance and Alstom.
- Major changes to existing rail operator cross boundary interfaces (6 involving 3 rail operators)
- Six separate occupation stages to manage the operational impacts.

The extract below maps the rail system interfaces that were required to be managed to successfully complete the commissioning.



9 CONCLUSION

It was critical to the successful construction of RRL that all six complex and varied work packages effectively acted as one team – combining their efforts to focus as much on the overall success of the project as on the success of individual packages.

The individual work packages, despite their package-specific issues, communicated and worked together, sharing opportunities and challenges in a collaborative manner and coordinating the works with a view to enhancing the outcomes for each work package and the project overall.

In a complex stakeholder and delivery environment, the project was delivered well ahead of schedule and well under budget. From late 2011 to late 2014, approximately 14 million man hours of work was undertaken on the project with a Lost Time Injury Frequency Rate of 0.6 and Total Recordable Injury Frequency Rate of 10.4, both well below the industry average.

A key driver of the success of RRL was the highly communicative and collaborative approach to construction adopted by work packages, rail operators, key stakeholders and RRLA. This created an environment in which all parties continually looked for opportunities to align on priorities, expedite the program, coordinate resources, share knowledge and innovations, and work together to find balanced solutions for all.

The project established new benchmarks in rail construction, particularly for rail occupations, major brownfields signalling commissioning and for the planning and implementation of completion and operational readiness procedures.