WestConnex M4-M5 Link Tunnels

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2023 AUSTRALIAN CONSTRUCTION ACHIEVEMENT AWARD

TECHNICAL PAPER

Delivering excellence

Every major infrastructure project has its specific issues and challenges. But a common challenge for all, and what generally does result, is the project running late and over budget.

When starting the WestConnex M4-M5 Link Tunnels project, the team identified several major challenges:

- How do we ensure everyone goes home safely every day?
- How do we finish on time and on budget?
- What do we do with 8.7 million tonnes of spoil?
- How do we secure concrete delivery?
- How do we achieve the integration works – with the M4 and M8 being already operational motorways?
- How can Mechanical and Electrical (M&E) work be carried out at the same time as excavation?

The project's answer to these challenges? Building a project starting with the end in mind.

ASBJV Senior Leadership Team

Leadership and culture – the mindset of the project

The success of a major infrastructure project is a story of human endeavor.

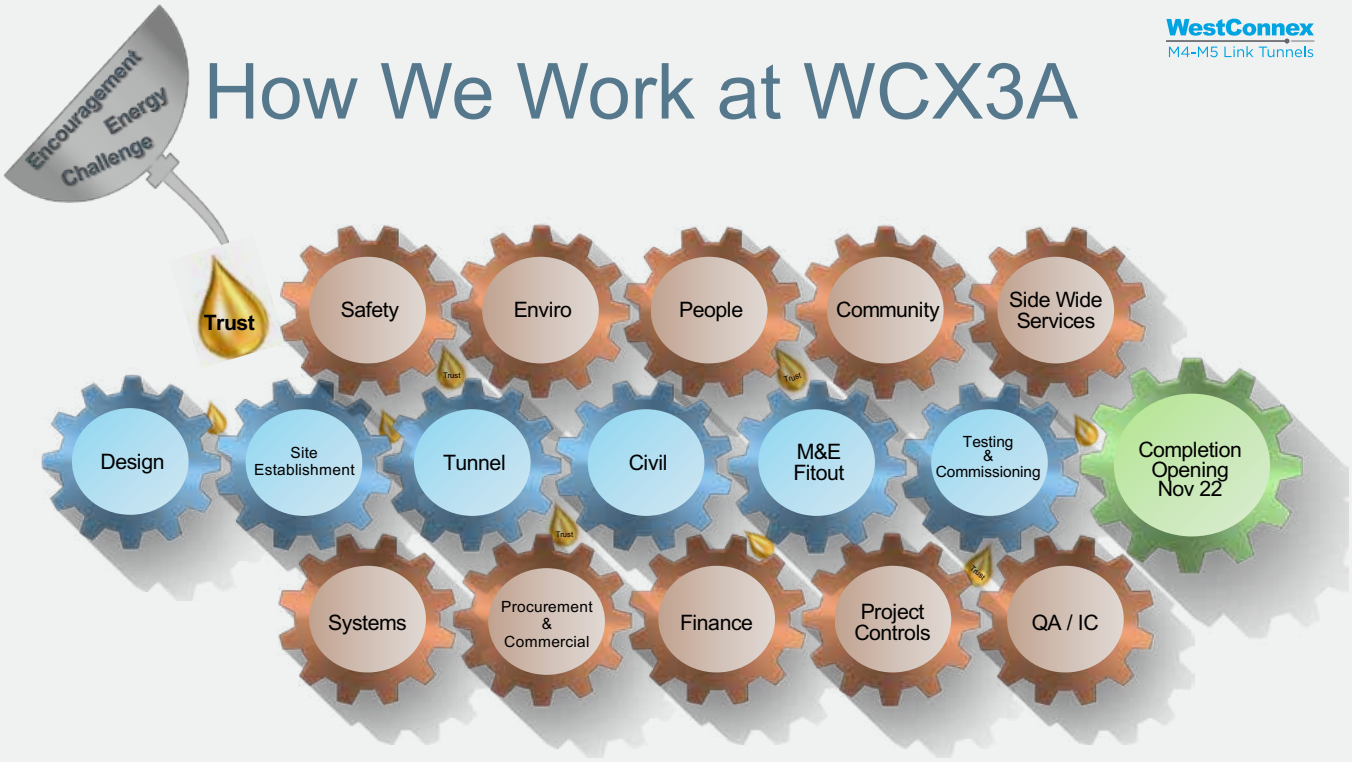
The strong leadership culture developed at the start of the project was crucial to achieving the successful delivery of a world class tunnel, ten weeks ahead of schedule and within budget.

The project was a joint venture, combining resources from three global companies. The boundaries of belonging to a different parent company were overcome as an approach was agreed upon to think and act as one integrated team.

At the start of the project the Senior Leadership Team (SLT) developed the project values and schematic for achieving this complex job.

The gear scheme represents each team as the same size and importance, all linked to each other.

How We Work at WCX3A



We were delivering an integrated motorway, not just digging a tunnel

It was decided the Mechanical and Electrical (M&E) team should commence while excavation was still taking place.

The SLT worked from the start with the end goal in mind, with everyone working towards a target opening date and completion of the Contract.

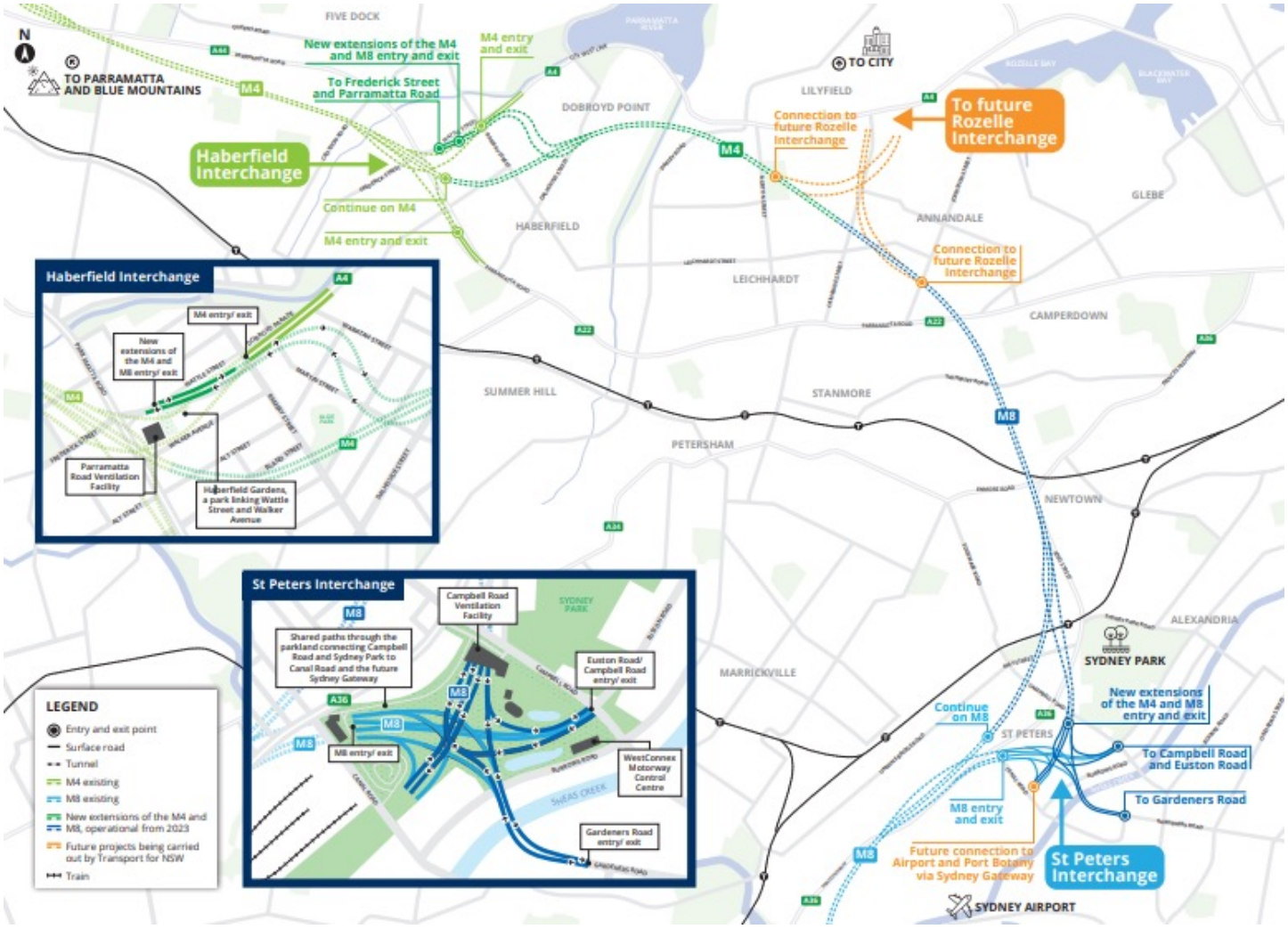
Each team was aware of their job, but more importantly, they knew how their role combined with other teams to achieve project success. Central to their thinking was that this project is not just about digging a tunnel but delivering a system to a client at an already fixed cost.

Tunnellers

Excavation

Project background

The WestConnex M4-M5 Link Tunnels project is a $3.2 billion mega project in Sydney. The project was constructed in partnership with ASB Joint Venture (ACCIONA Construction Australia, Samsung C&T Corporation and Bouygues Construction Australia) and the owner and operator of WestConnex, a consortium led by road operator, Transurban.



Tunnel alignment and connections

The M4-M5 Link Tunnels project constructed two 7.5-kilometre underground tunnels, connecting the M4 at Haberfield to the M8 at St Peters with future connections to Sydney Gateway and the M6, which are both under construction. In addition, the project provides underground connections to the future WestConnex Rozelle Interchange, due to open in late 2023.

After six years of works and challenges, the M4-M5 Link Tunnels project opened to traffic on 20 January 2023.

The project involved the excavation and full fit out of two underground 7.5 kilometre tunnels with two, three and four lane capacity in each direction, which were integrated with the existing M4 in the west and the M8 in the south, making it a critical stage of the WestConnex network.

It represents 22-kilometres of tunnels, including all the access ramps and permanent ventilation tunnels excavated predominantly in Hawkesbury (Sydney) sandstone, as well as a significant portion of Ashfield shale. The tunnels lie beneath a large number of existing facilities such as Sydney Metro, roads, railways, light rail, major water supply tunnels, sewer, watermains and gas mains.

In terms of volume excavated, the project extracted 3 million of cubic metres or 8.7 million tonnes of material.

The tunnel has a 100-year design life and is future proofed with world class traffic management systems, designed to talk to the next phase of electric, connected and automated vehicles.

Roadheader

Roadheader breakthrough

Australian firsts

To deliver the project on time, improve overall safety and logistics, optimise resources and maximise underground productivity and efficiency, a ‘Tunnel Production Line’ (TPL) strategy was developed from the start.

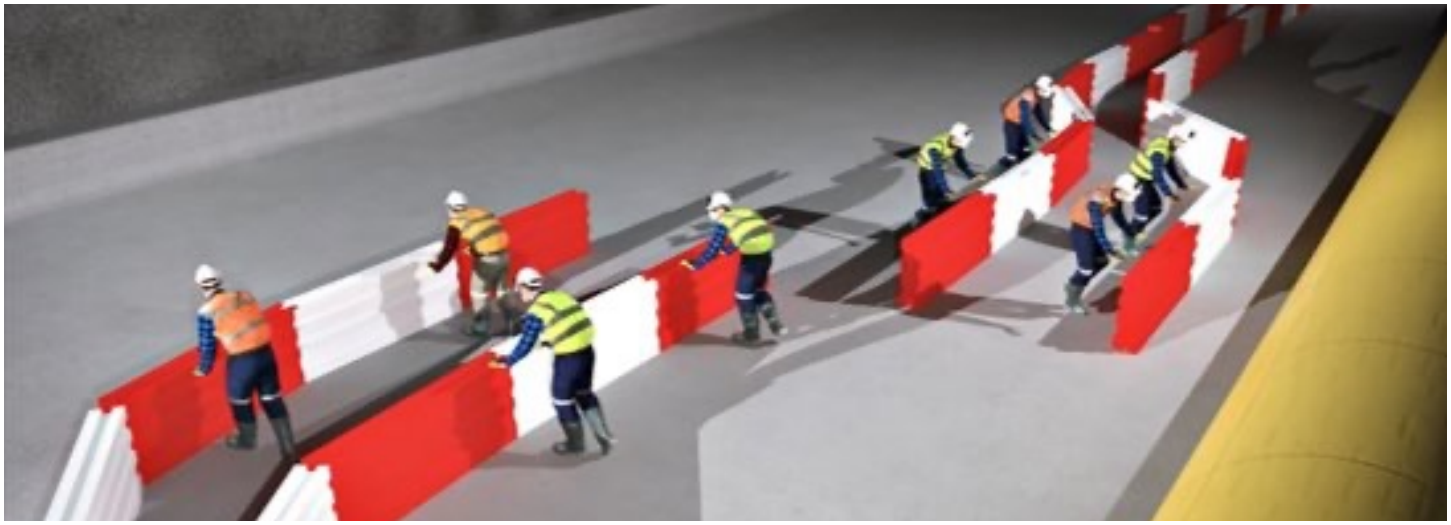
Tunnel excavation, civil fit-out, installation of mechanical and electrical equipment and testing and commissioning were planned to run concurrently in a safe environment.

Building the tunnel by starting with the end in mind was how the strategy was defined.

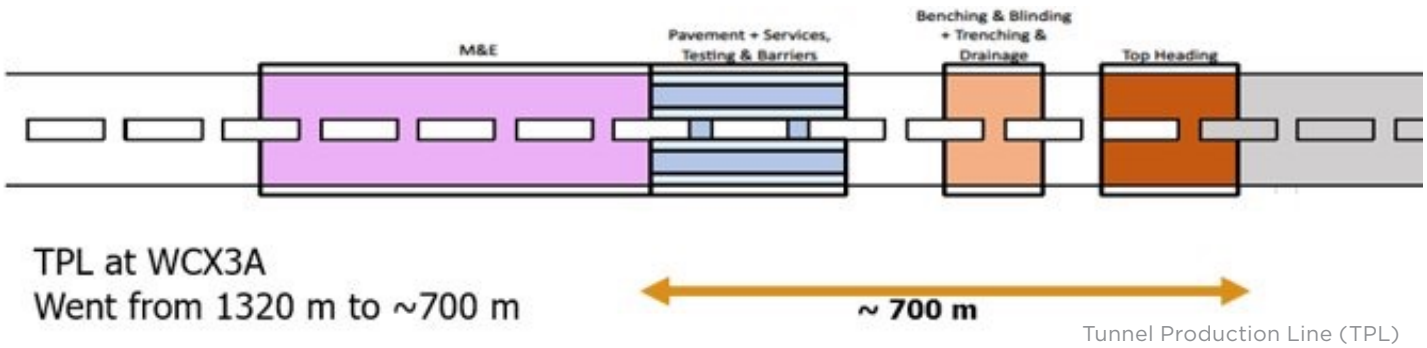
The leadership team adopted a Lean approach to achieve a continuous improvement process involving safety, construction methodologies, temporary works, logistics, adjustments to the design to suit the TPL, maintenance, data capture and analysis.

Disruptions encountered, such as the COVID-19 pandemic restrictions, during the project were mitigated due to the highly safe and organised environment. This approach avoided the chaotic mode usually observed when unplanned co-activity has to be implemented and to mitigate delays in one or many of the activities usually run in isolation.

Implementing the TPL methodology was very successful and allowed the project to be completed on time, within budget and with high-quality standards.



Tunnel Production Line (TPL)



Tunnel Production Line (TPL)

Installation of Mechanical and Electrical equipment

Among many examples of this collaborative approach between various disciplines and stakeholders on the project was the development of high-performance shotcrete.

The project team, along with the supplier and consultants, researched and developed a high-performance shotcrete. The shotcrete mix, applied as tunnel lining, was designed using previously unused steel fibres. The final mix achieved the required target structural performance, reduced shotcrete consumption by 15 percent – which resulted in significant benefits such as less construction traffic on local roads, embodied carbon by 33,000 tonnes CO2-equivilent and a saving of $11 million.

The newly developed high-performance shotcrete has created a legacy for the industry. It has set a new standard for business-as-usual practices, participating in the reduction of quantities of materials used during construction in future similar projects.

Both initiatives were firsts in Australia.

Shotcrete fibres

Sprayed shotcrete

Connecting the links

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Digging a tunnel in Sydney's sandstone has been done before, therefore the challenges could be predicted to a certain extent. However, integrating a new section of motorway with existing motorway traffic operating systems hasn't been done before in Australia. This complexity put a greater emphasis on the M&E and Software.

Tunnel decline

Knowing the biggest challenges were ahead, everything needed to be organised so maximum work output could be achieved from commencement. The key factor in the approach was that work phases were undertaken concurrently, not in a staggered approach as had been previously done in the industry.

The team installed ventilation systems for fresh air to meet the highest standards and constructed a temporary paved road throughout the entire tunnel from day one (blinding) to create a safe and efficient environment for all from the start.

The first six months were crucial in redefining the strategy to successfully deliver the project. Many changes to the plan developed at tender stage were deployed. The team focussed on opportunities presented by the client or created in-house. One of the significant changes implemented was the excavation of ramps from the surface, instead of waiting for the roadheaders to arrive in the cavern to start the ramps, creating two additional works fronts.

It was decided to not leave the most challenging excavated section – shallow ramps and adverse ground conditions to the end of the program. This was a game changer as it secured the program, which forecasted the completion of excavation works three months earlier than the tender program, creating three months of float in the overall program. It also led to the team to request the substratum delivery, to the client, in a very different sequence.

Key deliverables

The bridging slab

The M4-M5 Link Tunnels comprises on and off-ramps and tube crossovers linking it to the rest of the WestConnex network. The initial design was to build five bridging slabs to ensure the stability of the cross-overs. However, due to alignment optimisations, this number was reduced to one.

The construction of the bridging slab was undoubtedly the most anticipated task on the project. Located around the breakthrough area of the project, it was, therefore, on critical path. Previous examples indicated the duration for the construction to be around seven months.

The bridging slab needed to be integrated as much as possible into the program to avoid impacting the TPL methodology. As a result, the team worked closely with the subcontractor, building mock ups, conducting trials outdoors and fabricating steel cages. It also provided an opportunity to conduct training with the subcontractor's team, improving permanent and temporary designs before starting the works underground.

Works for the 160m long structure were completed using measures such as adding ice to the concrete to control the temperature and installing a plastic cover immediately after formwork removal. This plastic cover assisted in managing temperature constraints, potential cracking and resulted in the early removal of the formwork. The challenge was successfully overcome in 77 days versus the 90 days initially planned, allowing the following activity from the TPL to take over the zone.

Bridging slab

Bridging slab

Widest cavern in Sydney

The cavern formed at the connection of the entry ramp in St Peters and the connection with the M8 northbound led to the excavation of the widest cavern in Sydney.

This 32 metre span cavern was achieved following some different than usual excavation and bolting sequences, ensuring that the structure, only supported by shotcrete lining, is safe and stable.

Widest cavern in Sydney

Tunnel cavern

Temporary ventilation system

In an underground environment, it is paramount to manage air quality.

On this project, as all teams were expected to be working concurrently, the project had to ensure from the start that each team's regulations are met and working conditions were adequate.

A Temporary Ventilation Manager was appointed and the entire temporary ventilation design was designed to cover the needs for the four years on the tunnelling job.

Moreover, the M4-M5 Link Tunnels connects itself to the M4 and the M8, meaning ventilation also needed to be considered from an overall network point of view. After breaking through with M4 and M8, airlocks were installed at each end of the tunnel to physically separate our work from the operational motorways.

This also allowed testing of the permanent ventilation system on our section of the tunnel. Once this step was achieved, the doors could be opened to begin testing the integrated ventilation system.

Once the airlocks were removed, it was paramount to ensure that works were not disturbing the air flowing through the other two live motorways and not creating any safety hazard for live traffic.

Ventilation system

Design of the temporary access adits/decline –

The design of the decline was a key focus as it was one of the first areas of tunnelling works to be launched.

Tunnel support

The team accelerated the excavation rate of all declines to reach the main drives as quickly as possible, employing improved logistics to handle spoil, concrete for tunnel, concrete and civil material for civil works, permanent equipment and cables for M&E and all temporary services including ventilation.

A temporary design was developed and support was optimised where possible to eliminate the need of shotcrete, which was replaced by installing chicken mesh, allowing sufficient safety level and achieving an increase in the excavation progress rate in comparison to the use of shotcrete.

The size of the declines were designed to ensure the ventilation configuration would accommodate M&E installation as well as tunneling. The connection of the decline to the main drives was also designed to allow for the start in the shortest time possible for eight roadheaders per decline and also, at a later stage, concomitant traffic management of Tunnel, Civil and M&E logistics. A trouser shape approach was developed, dividing the time needed to launch eight roadheaders and to start in isolated areas from Tunnel and Civil logistic M&E installation.

The outcome of the design of the decline meant bigger volumes were excavated in comparison to declines only designed to manage tunnelling works. This allowed for the launch of the TPL as planned in an organized mode, without any impact on the tunnelling works progress.

Tunnel adits

M&E Systems: A critical piece of the puzzle –

The installation and commissioning of the Mechanical and Electrical (M&E) systems for a road tunnel of this magnitude proved to be complex and challenging.

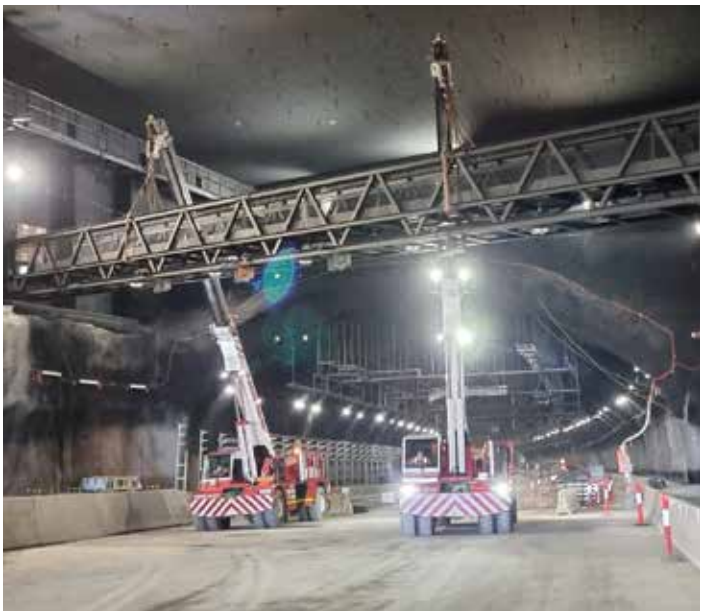
The number of main assets in the M4-M5 Link Tunnels speaks for itself:

- More than 2,000km of cable pulled
- 6 HV/LV substations
- 50 electrical rooms in cross passages
- 195 jet fans
- 19 axial fans
- 200 damper modules
- 713 deluge zones
- 350 fire hydrants points
- 850 cameras.

To deliver this crucial piece of the puzzle, it was decided that a per systems organisation rather than the usual geographical split would best suit the objectives. This approach did away with the inefficiencies usually observed on similar projects. It was a game changer that ensured consistency and efficacy throughout the project. The team was able to focus on technical opportunities (damper modules, etc.) and sequence optimisations (advance HV conduits, etc.) to build an aggressive target program. The challenge of delivering the program within this tight timeframe was successfully overcome. This resulted in a consequential reduction of the overall M&E duration, when compared to the initial Target Program.

The M&E systems Testing and Commissioning (T&C) took a self-perform approach and the combined efforts of all the parties paid off. This involved:

- Handovers from the Civil team (Tunnel and Surface)
- Quality M&E installations
- T&C team technical expertise
- Support from the Independent Certifier, the client and Transport for NSW during the process.



Mechanical and Electrical gantry

M&E Integration: More than one motorway

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On the M4-M5 Link Tunnels Project, the team faced an unprecedented level of complexity. A challenge that until now, had never been addressed in the Australian context, which was the integration of two live motorways to form one single motorway.

It is important to note the following:

- The M4 and M8 motorways were completed at different times, each with their own design, type of equipment and Operation Management and Control Systems (OMCS)
- As the M4 and M8 motorways were configured to operate independently, the behaviour of their Control Systems during this integration was difficult to anticipate
- Critical systems functionality (Tunnel Ventilation, Fire modes, Tunnel Closure, etc) had to be modified/coordinated to behave similarly throughout the different motorways
- The compatibility of old and new assets (e.g. cameras, public address) were not a given and had to be thoroughly examined
- In the interface zone, some physical works (e.g. line marking, signs) were required which included the removal of the isolating block walls between M4 and M8 motorways and our tunnel. The software had to be gradually updated following this work sequence to prevent any impact on the live motorway operations
- The M4 Operator was relocated from their current Control Centre at Homebush to the WestConnex Motorway Control Centre at St Peters. This transition of all operators to one control room was technically and logistically a huge challenge.

To overcome this ‘mission critical’, the team planned and coordinated two aspects:

• On site physical works

Some M&E systems required tunnel works on M4 and M8 motorways prior to integration (fire detection, lighting, radio, etc). These works could only be performed during night shift maintenance closures.

• Software integration

This was the most challenging and needed a structured and well thought out approach.

The first step, at the System Test facility was to test all the software with a mock-up of the complete WestConnex trough simulation (HIL: hardware in the loop) and device configuration before on site installation.

Thereafter from the Control Centre the team completed a total of 29 Independent Standard Achievement Tests to fully test the Integrated Control System IOMCS. A total of more than 100 shifts were required to achieve this goal.

Working closely with the client team, this complex integration was completed ahead of schedule. As a result, a strong, carefully managed program was achieved.

WestConnex Motorway Control Centre

Campbell Road Ventilation Facility

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The design of the façade of the Campbell Road Ventilation Facility is based on an interpretation of artwork ‘Movement of Shells, Movement of Time’, by celebrated Bidjigal artists Aunty Esme Timbery and her daughter Marilyn Russell.

The artwork references the local Bidjigal people as saltwater people and the Timbery and Russell families who continue the tradition of shellwork, handed down from mother to daughter over many generations.

All sides of the facility feature folded aluminium cladding, which forms a large three dimensional and multi-coloured ‘canvas’ allowing for changes of colour, shadows and shading.

Realistic stills and animations were used to visualise the viewing experience as one walks around (or drives past) the building. A refinement of colour that met durability requirements was selected to finalise the artwork, to ensure its legibility in bright sunlight and lasting quality after installation.

The artwork/texture map was then translated into a grey tone image and sent to manufacture to test the perforation patterning. Scaled mock-ups and high resolution 3D renderings were produced to finalise the selection of perforation sizes.

Key achievements

- First integration of two live motorways in Australia
- Impeccable safety record
- Delivered 10 weeks ahead of schedule
- Delivered within budget
- More than 12,000 people employed across the life of the project
- 40% of people employed on the project from Sydney's Western suburbs
- More than 14.3 million work hours to complete the project
- More than $60million spent in Aboriginal participation, including education and employment, cultural awareness, training, mentoring programs and procurement of goods and services from Aboriginal businesses
- Development of female participation resulting in one of the largest female workforce on a tunnelling project in NSW – peak of 7.6% achieved
- More than 8.7 million tonnes of spoil removed from the excavation of the tunnel
- 100% of spoil beneficially reused
- 98% of recycling of construction and demolition waste
- Use of 28 roadheaders consuming close to 250,000 picks
- More than 538 contracts were awarded to NSW based suppliers and companies
- Delivery of an iconic Aboriginal artwork 'Movement of Shells, Movement of Time', as the façade of the Campbell Road Ventilation Facility

Key milestones

October 2018	• site establishment on M4-M5 Link Tunnels starts
May 2019	• tunnelling begins
May 2020	• peak of excavation
January 2021	• first breakthrough
January 2022	• the last roadheader leaves
December 2022	• start of six week defect period
January 2023	• open to traffic

The ASBJV team

Completed tunnel

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