

THE INTERSECTION OF TRACK DESIGN AND SYSTEMS ENGINEERING: UNDERSTANDING STAKEHOLDER REQUIREMENTS TO SHAPE THE FUTURE OF FLEMINGTON EAST JUNCTION

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SUMMARY

This paper outlines the importance of a collaborative stakeholder engagement process used to define the requirements and develop the track layout for the Flemington East Junction Remodelling Project for Sydney Trains. The systems engineering approach is summarised before exploring how these requirements were traced through the track design for the highly constrained site. By considering the risks, challenges and opportunities faced by the project team, three different examples profile how adopting a highly collaborative approach can maximise value to end-users when shaping the future of major junction remodelling projects.

1 INTRODUCTION

Flemington East is a critical junction within the Sydney rail network, providing access between the Main Suburban, Flemington Goods and Homebush Bay Lines and Flemington Car Sidings (FCS), refer Figure 1. With over 30 pieces of special trackwork, including special turnouts, diamonds and double slips, this section of the network requires a significant level of ongoing maintenance in a highly constrained location. Sydney Trains identified that the junction's trackwork is life-expired and sought to develop a strategy to renew the junction to better suit their current and future operations.

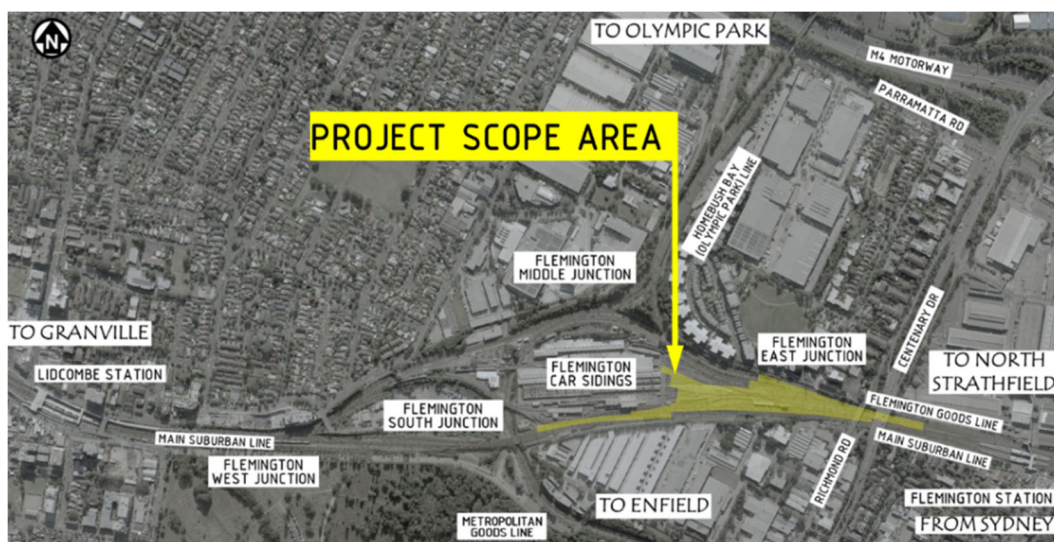


Figure 1: Project Location (Imagery: MetroMaps Extracted 14/09/22)

2 NOMENCLATURE

BRS:	Business Requirements Specification
FCS:	Flemington Car Sidings
OCD:	Operations Concept Definition

MCA:	Multi Criteria Analysis
NIF:	New Intercity Fleet (also known as Mariyung Fleet)
SRS:	Systems Requirements Specification
TfNSW:	Transport for New South Wales

3 PROJECT BACKGROUND

3.1 Objectives

With the opportunity to remodel the junction, the project objectives were quickly agreed between Sydney Trains and the design team. The overall objective of the project is to renew the existing infrastructure with a revised junction layout to suit Sydney Trains current and future operations, whilst rationalising and standardising trackwork components to minimise maintenance requirements.

3.2 Relationship Between the Requirements Definition and the Track Design

The combined project team recognised the broad range of stakeholders which would be impacted by the remodelling project, ranging from construction teams and track maintainers to shunters and signallers. It was critical to engage with stakeholders to understand their different needs and use cases, so that these could be crafted into formalised engineering requirements for the design. Initial high-level requirements were defined in the project's Operations Concept Definition (OCD) and Business Requirements Specification (BRS), with more technical detail being provided in the System Requirements Specification (SRS). These requirements were then implemented in the track design.

Uniquely, this project accelerated the track design ahead of other disciplines, conducting the track design alongside the requirements definition stage. This enabled the project team to test different layout options to fit within the constrained footprint of the site, whilst also not burdening the project with unachievable spatial or operational requirements. Four different track layout options were developed and provided to stakeholders to allow for their comment. The preferred design was determined through a Multi Criteria Analysis (MCA), and further developed into a Concept Track Design to underpin the project going forward. This combined Systems Engineering and Track Design approach is summarised in Figure 2. This process ensured the development of a design which fitted stakeholder needs into the constrained site, with clear traceability around design decisions.

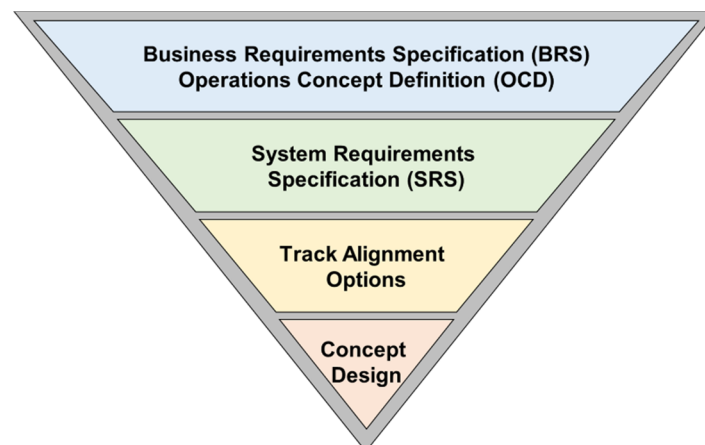


Figure 2: Approach Adopted to Develop the Project

3.3 Prioritisation of the Track Design

Sydney Trains quickly identified that the key driver of the entire project would be the highly constrained nature of the existing site. The last time that Flemington East Junction was significantly modified was in the late 1990s in preparation for the Sydney 2000 Olympics. This included the construction of the two Flemington Goods lines, along with the grade separation of the Flemington Goods and Homebush Bay

tracks [1], [2]. That project was heavily constrained by the need to maintain freight traffic, ongoing operations at FCS and the limited site footprint available.

In addition to these, some of the constraints identified early in the current remodelling project included:

- **Existing Overbridges:** Centenary Drive and Richmond Road are both major road bridges running across the site and were not able to be impacted by the proposed works.
- **Existing Mainline Turnouts:** On the Sydney side of the project area, the Main Suburban Line includes a series of relatively new follow-on crossovers, which were not to be relocated.
- **Existing Turnouts within FCS:** Similarly, FCS has a number of recently renewed turnouts, which were to be retained following the project.
- **Standing Length Requirements:** So that longer New Intercity Fleet (NIF) trains could be stabled.

4 STAKEHOLDER ENGAGEMENT AND REQUIREMENTS DEFINITION

4.1 Systems Engineering Approach and Scalability

Transport for NSW (TfNSW) defines Systems Engineering as the collaborative, interdisciplinary and structured process used to achieve a well-defined solution that satisfies stakeholder requirements [3]. The project team recognised the importance of a structured process of documenting stakeholders' needs and translating these into formalised engineering requirements which could be verified and validated throughout the delivery of the project. The project team also recognised the importance of taking a pragmatic approach to Systems Engineering, to suit the scale of the project. TfNSW's Guide to Systems Engineering also recognises this, and advocates for tailoring the level of Systems Engineering input into a project to match its complexity [3].

This project sits somewhere in the middle of the complexity scale, in that it is more complex than a turnout renewal, but less complex compared to the development of a new corridor. On this basis, the project's System Engineering input was tailored to provide maximum value to Sydney Trains. It was known that there would be a significant number of competing stakeholder needs identified, and thus the project sought to focus System Engineering input into Operations Concept Definition and the requirements definition process.

4.2 Stakeholder Consultation

Given the importance of this junction in the broader Sydney Trains network, it was crucial to understand the different perspectives of those involved in the maintenance and operations of the site. Throughout the requirements definition and design process, input was sought from stakeholders from across the operational railway. Consistently, stakeholders approached the project with an appreciation that upgrades to this existing infrastructure could lead to real improvements in operational efficiency, reliability, safety and maintenance outcomes. This led to productive workshops where stakeholders' experiences and ideas could be captured.

Figure 3 highlights the stakeholder engagement process which was followed throughout the development of this project. Over 60 different stakeholders provided input through these workshops, including:

- Shunters based at Flemington Car Sidings, who coordinate train movements in the yard.
- Signalling staff from Homebush Control Centre, who operate the junction's points and signals.
- Operational planning staff, involved in timetabling and possessions through the junction.
- Network maintenance and asset management teams involved in the day-to-day maintenance of the existing track, signals, civil and electrical infrastructure, and who will maintain the new assets.
- Sydney Trains Major Works construction planning teams, who will construct the new infrastructure.
- The NIF project team, responsible for introducing new rollingstock to the Sydney Trains network.

Following the capture of potential needs, items were classified by the project team as either a “Need,” (an absolute, must-have functionality), or a “Preference,” (potential additional functionality which could improve operations). These were then explored with focus groups of selected stakeholders, where more rigorous testing of feedback confirmed the split between Needs and Preferences.

The different scenarios were used to formalise the Needs and Preferences into the OCD. In addition, the OCD also profiled the different operational modes of the junction as raised by the stakeholders, including the different Needs associated with each. This included Normal Mode, Abnormal / Major Event Mode (where additional trains may be running to Olympic Park), Degraded Mode (e.g. failure of a set of points within the junction) and Maintenance Modes (for example, different trackwork possessions).

4.4 Formalised Business and Systems Requirements

Following on from the OCD, Business Requirements were developed for the project’s BRS. A BRS defines the overall capability of an asset over its operating life, in the context of providing the desired performance for Sydney Trains at a high level. To inform the BRS, in the needs identification workshop, stakeholders were asked to consider the entire asset lifecycle, including design, construction, maintenance, operations and disposal. Feedback relating to the operations phase of the lifecycle was captured in the OCD, and the defined needs were formalised into precisely worded requirements in the BRS. For items relating to the other lifecycle stages, additional requirements were generated directly into the BRS. These were circulated for stakeholder review and comment to ensure they accurately addressed Sydney Trains’ requirements from across all areas of the railway.

With the completion of the BRS, more detailed System Requirements were developed by applying technical engineering inputs to provide greater definition around asset performance, forming the SRS. A functional breakdown structure was used to analyse each business requirement for potential technical system requirements across different categories. This included functional, useability, performance and interface requirements. These system requirements were traced to business requirements, which in turn were traced to operational needs, showing their source and value in the project. This was also done in parallel with the start of the track design, to assess feasibility of some requirements within the constrained site footprint. System requirements were then reviewed by technical experts and circulated for stakeholder comment to check for completeness and coverage. Following the comments on each document, the BRS and SRS were provided to Sydney Trains’ decision makers for endorsement.

5 TRACK OPTIONEERING TO ARRIVE AT A PREFERRED LAYOUT

Building on the defined requirements, the track design team started to develop potential layouts to meet the needs identified by stakeholders. Four track layout options were developed as long-plot sketches, enabling stakeholders to review the entire site at a glance. A preliminary workshop enabled feedback to be incorporated into updated layouts for formalised stakeholder review. The four options included:

- **Option 1A:** A rationalised yard layout, generally consisting of like-for-like renewals in the yard area and simplified connections on the mainlines. This option would remove the connection between the Flemington Goods and Homebush Bay tracks.
- **Option 1B:** Option 1A, but with connection between Flemington Goods and Homebush Bay tracks.
- **Option 2:** Upgraded mainline trackwork including between Flemington Goods and Homebush Bay tracks. A pair of scissor crossovers would have been used to provide connections into FCS.
- **Option 3:** Upgraded mainline connections, with increased functionality and separation of turnouts.

The combined project team worked in a highly collaborative manner to determine the selection of a preferred option through the MCA. Sydney Trains initially proposed the criteria and weighting of each criterion. This included typical considerations such as safety, cost, maintainability and constructability, as well as more specialised criteria including speed, standing length and the amount of special trackwork on mainline routes. The design team then developed a draft score for each option against each criterion, before both teams came together to agree the final scoring.

The MCA found that two of the track layout options, Options 1B and 2, scored very similarly, and thus Sydney Trains’ decision makers requested a deeper analysis of both options. Again, the combined

project team worked closely together, with Sydney Trains delivering a more detailed cost breakdown, and the design team consulting further to test differentiators with operational and maintenance stakeholders. As a result, it was determined that Option 1B presented the best value for Sydney Trains.

The track design was then progressed to define new horizontal and vertical alignments, including turnout geometry for standard turnouts as well as special flexed designs to fit the trackwork into the constrained site. In addition to the design of the trackwork itself, the Concept Track Design included a review of standing lengths, a transit space assessment, buffer stop and catchpoint assessments, the development of typical sections to make provision for interfacing infrastructure (e.g. driver's walkways), and a consolidated list of Concession items for initial consultation with TfNSW's Asset Management Branch. This consolidated track design will therefore form the basis of the Concept Design for other disciplines, as well as informing the Detailed Design of the project going forward.

6 MANAGING PROJECT RISKS, CHALLENGES AND OPPORTUNITIES

As a result of the robust set of requirements which came out of the stakeholder engagement process, the design team were able to implement a number of unique features into the Concept Track Design. Three of these are profiled below, tracing the initial need identified by Sydney Trains stakeholders, before explaining how these requirements were implemented in the final concept layout.

6.1 The Risk: Uncertainty Around Future Rollingstock

One of the first items stakeholders raised with the project team was the future use of the adjacent FCS. The existing rollingstock maintained at FCS is set to be replaced by the longer NIF trains, which are maintained at Kangy Angy, on the NSW Central Coast. These trains regularly operate in 10-car consists, and at 204 m in length, they are significantly longer than standard 8-car suburban trains (approx. 168 m). Through the various different workshops, it was found that stakeholders often had different understandings of future operations at FCS, ranging from closure, to a reduction in stabling roads, to operations continuing unaltered.

It was critical that the project team listened to all stakeholders to arrive at an accurate set of underlying principles to describe future operations at FCS. To manage this risk, the project team held focus groups with an array of different stakeholders, including FCS staff, signallers and the NIF program; with a view to early agreement of assumptions and capturing the need for NIF operations in the OCD. As a result, it was concluded that the number of tracks within FCS was to remain unaltered. Whilst there was some uncertainty around whether individual sidings would be used for stabling or maintenance, this was determined to have little impact on the junction's layout, allowing the project to proceed despite this uncertainty. This enabled the different stakeholder needs to be documented in a matrix structure (Figure 5), enabling specific routes through the junction to be identified as having to accommodate NIF trains.

Junction Matrix 10-Car NIF Trains		To/From									
		Eastern Entry / Exit	Goods Entry / Exit	Western Entry / Exit	Train Wash Area	Wheel Lathe Area	Open Air Stabling X Section	Open Air Stabling Y Section	Brake Shed	Car Shed	Inspection Area / Shed
To/From	Eastern Entry / Exit	Not Needed	Not Needed	Not Needed	Preferable To Not Preclude	Not Needed	Needed	Needed	Preferable Degraded Mode Only	Preferable Degraded Mode Only	Preferable Degraded Mode Only
	Goods Entry / Exit		Not Needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed
	Western Entry / Exit			Not Needed	Not Needed	Not Needed	Preferable Degraded Mode Only	Preferable Degraded Mode Only	Not Needed	Not Needed	Not Needed
	Train Wash Area				Not Needed	Not Needed	Preferable To Not Preclude	Preferable To Not Preclude	Not Needed	Not Needed	Not Needed
	Wheel Lathe Area					Not Needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed
	Open Air Stabling X Section						Not Needed	Not Needed	Not Needed	Not Needed	Not Needed
	Open Air Stabling Y Section							Not Needed	Not Needed	Not Needed	Not Needed
	Brake Shed								Not Needed	Not Needed	Not Needed
	Car Shed									Not Needed	Not Needed
	Inspection Area / Shed										Not Needed

Figure 5: Matrix from Project OCD, Outlining Routes where NIF Operations were Needed

The different routes were able to be translated into specific “Needs,” documented in the project OCD. For example, it was identified that **“The new layout shall allow for four 10-car NIF Trains to enter from the Western Entry/Exit, and stable in the Open Air Stabling Roads.”** Stakeholders also advised the project team, that whilst this route through the junction wasn’t expected to be highly used in normal operations, it was critical in the event of degraded mode operation of the rail network, e.g. a train from the Blue Mountains develops a fault and has to be brought into FCS for minor repairs. As a result, this need was translated into a business requirement: **“The Junction shall enable four 10-car NIF Trains to enter from the Western Entry, and stable in the Open Air Stabling Roads.”**

It would initially appear that the obvious way for a train to perform this movement is to reverse via the existing Shunt Neck track. However, the highly constrained nature of the site results in the total track length on the Shunt Neck (derailer to buffer stop) being limited to approx. 172 m. Accounting for signal sighting and the “stand back,” distance from the buffer stop means that this siding is only just able to accommodate an 8-car train. If an SRS requirement was written mandating that the Shunt Neck be able to accommodate a 10-car train; this could otherwise necessitate the realignment of multiple crossovers outside the scope of works on the Sydney-end of the junction. Such a requirement could also mandate additional access to other parts of FCS, not identified as a “Need,” by the project’s stakeholders. Therefore, to avoid burdening the project with an unachievable requirement, which could otherwise significantly increase the scope of the junction renewal, the SRS did not include a requirement to lengthen the Shunt Neck. It instead provided the flexibility for the track design to accommodate this movement in other ways. As a result, the corresponding SRS requirement was: **“The Shunt Neck shall enable a 10-Car NIF train to access the following tracks jointly: 1. The Western Entry, 2. Greater than or equal to four roads within the Open Air Stabling Section of FCS.”**

Various track layout options were developed, with a key focus on this requirement. This flexibility allowed the track design to explore solutions to resolve this issue, without unnecessarily constraining the design outcome. Of the two shortlisted options, Option 1B retained the 8-car standing length on the Shunt Neck, requiring longer trains to shunt across the yard to make this movement. On the other hand, Option 2 allowed for this movement by allowing a train to stand over a crossover (see Figure 6).

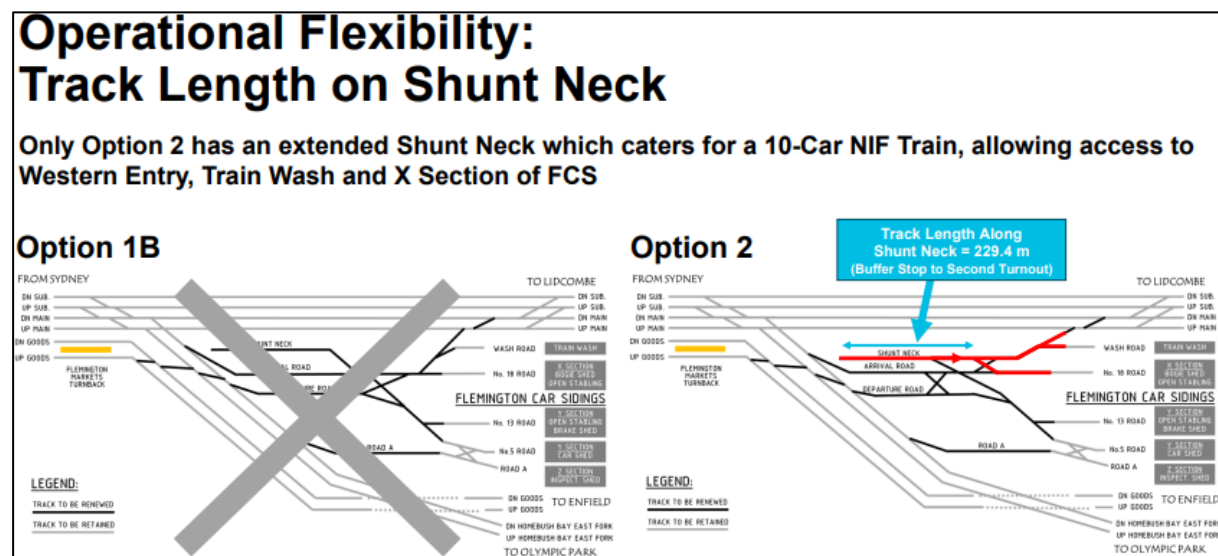


Figure 6: Slide Presented to Stakeholders to Assess Different Track Layout Options

This was a key difference between options and was tested extensively with stakeholders as part of selecting the preferred layout, including with the shunters and signallers who actively operate the current yard. Ultimately, stakeholders were able to confirm that this movement was not a regular occurrence, and as a result, the functionality afforded by Option 1B was sufficient. This movement, along with each of the other routes mandated in the requirements definition process were then assessed and confirmed as part of the Track Concept Design (see Figure 7).

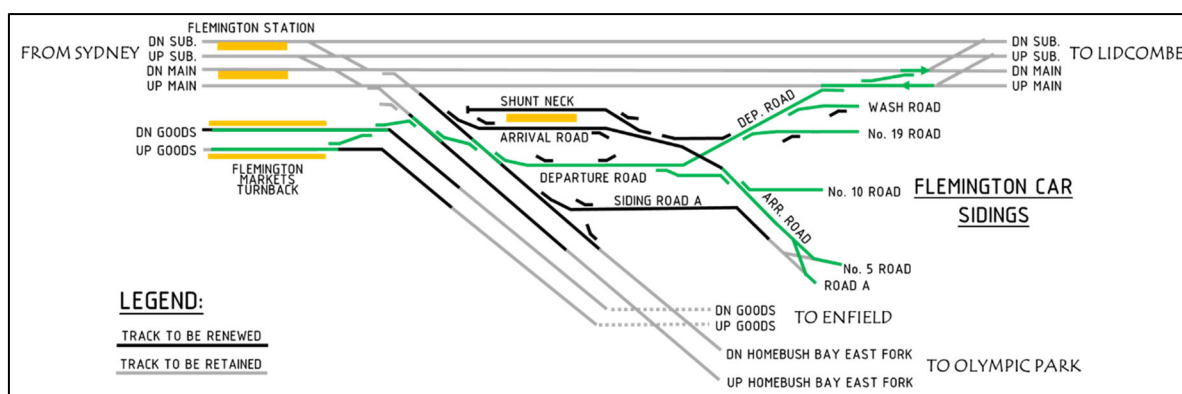


Figure 7: Final Arrangement for this Movement as Captured in the Concept Track Design

6.2 The Challenge: Maintenance Access Limitations

It was always known that the main challenge facing the project would be the site itself. In addition to the reduced footprint of the junction, access to the site is also highly constrained operationally. There are very few opportunities to safely visit the site, even for the purposes of informing the design process. Whilst the initial stage of design was able to be completed using existing surveys, front of train lidar and drone imagery; future construction and maintenance works will require more intense access to the site.

As part of engaging with stakeholders during the identification of project “Needs,” a number of stakeholders raised the different standard possession, “configurations,” which Sydney Trains use to plan their trackwork shutdowns. These are the standardised lists of tracks to be placed under possession concurrently, with generally one configuration activated at a time to allow for maintenance to occur. Flemington East Junction sits at the intersection of multiple different standard possession configurations (see Figure 8), and as a result there are virtually no opportunities to access this junction where all tracks are under possession at the same time. Stakeholders highlighted that there was a “Need” to consider these operational boundaries in the design process, and so this was captured in the OCD: **“Project is to consider maintainability, particularly in light of adjacent possession configuration boundaries.”**

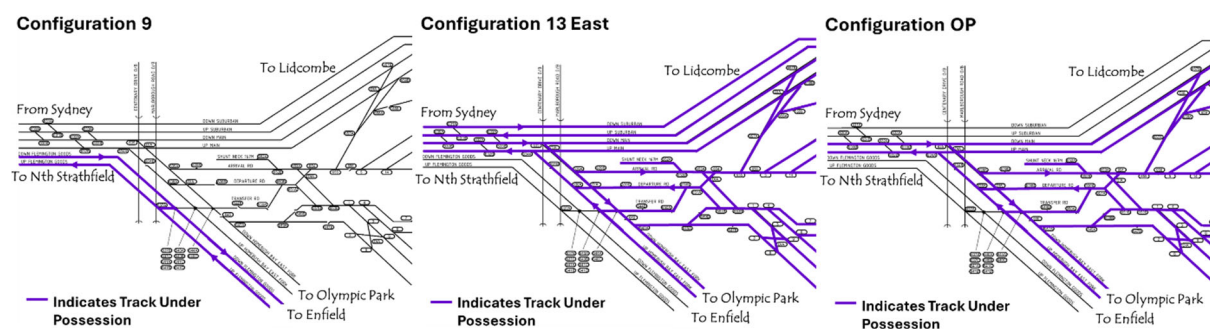


Figure 8: Extract from OCD, Showing Standard Possession Configurations at Flemington

Whilst discussing maintainability with stakeholders as part of focus groups, it became apparent that the location of existing trackwork relative to possession boundaries also posed a construction and maintenance constraint. There was strong stakeholder support for simplifying trackwork across boundaries of the different possession configurations. As a result, a business requirement was developed to relate special trackwork to these possession configurations, **“The Junction shall position integrated Special Trackwork within a single possession boundary.”**

A particularly challenging location flagged by stakeholders was between the Down Flemington Goods and Up Homebush Bay East Fork, both of which fall into different possession configurations. The connection between these two tracks consists of a double slip on timber bearers, which is considered a highly maintenance intensive asset. Further, there is only one opportunity a year where the two

different possession configurations occur simultaneously, limiting the ability to perform maintenance on this piece of special trackwork. Through discussion with the track design team, it was proposed that the project's requirements would mandate the use of an independent crossover arrangement at this location (i.e. two separated turnouts with a section of plain track in between). By providing a plain track section between mainlines, some maintenance activities may be able to be completed without both tracks being under possession concurrently. Thus, a more detailed SRS requirement was defined for this location: ***“Any crossovers between the Down Flemington Goods and Up Homebush Bay East Fork shall consist of independent turnouts (i.e. no long bearers under both tracks).”***

This requirement was traced through all the different track options developed, with all options proposing an independent crossover arrangement, or removing the requirement for a connection between these tracks entirely. These different arrangements were tested with key project stakeholders, and it was confirmed that from an operational perspective, the connection between both tracks was still required to enable services between the Main North and FCS as well as Olympic Park, via the Flemington Goods tracks. As a result, the Track Concept Design (Figure 9) proposed using a standard tangential turnout on the Up Homebush and a special contraflex turnout on the Down Flemington Goods, with plain track between the last long bearers of both turnouts. This arrangement was able to balance operational needs, whilst minimising impacts on existing signalling and civil infrastructure under the road bridges.

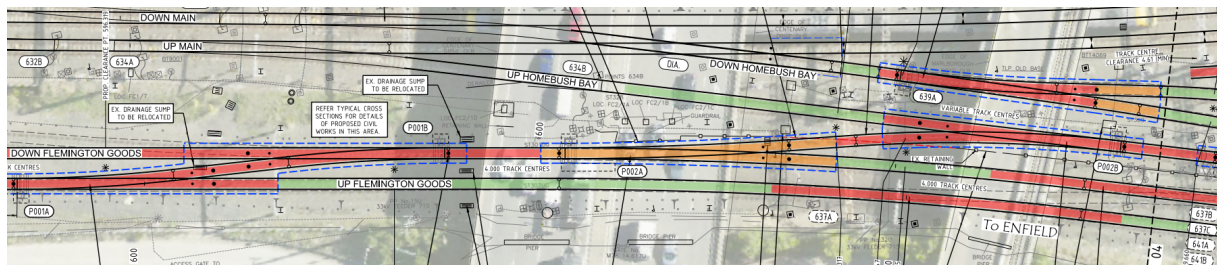


Figure 9: Extract from Track General Arrangement Drawing, Showing Standard New Track (Red), Non-Standard New Track (Orange) and Turnout Bearer Extents (Blue). Note Area of Plainline Provided Between Turnouts P002A and P002B.

6.3 The Opportunity: Design for Disassembly

Rarely do projects get the chance to start with a blank sheet of paper, and the project team took the opportunity to mandate good design practices as part of responding to stakeholder's needs. As part of the focus groups, stakeholders were encouraged to consider the entire lifecycle of the asset, from planning, to implementation, operation, maintenance, and eventual disposal. Whilst not all of these lifecycle stages related to the operations of the junction (and so weren't all documented in the OCD); all stages of the asset lifecycle produced BRS requirements. For example, the eventual disposal of the assets to be installed as part of this project were captured in the BRS, ***“The Project shall select components considering costs in demolition phase.”***

One item which came out of the stakeholder engagement sessions was the disassembly of the existing special trackwork at the site, which stakeholders noted would be particularly complex in the “Central Junction” area of the project. This is the existing complex area of turnouts and diamonds providing access between the Arrival, Departure and Shunt Neck tracks, and the different sidings within FCS. The staging of the renewal of the track infrastructure in this area, whilst maintaining access to FCS, was flagged as a key consideration for the project. There was recognition that the proximity of these turnouts, and the fact that multiple turnouts are supported by the same timber bearers, would make disassembly of the current layout more challenging.

The new special trackwork within the junction is all to be constructed of 60 kg/m rail on concrete bearers. Whilst this will provide improved maintenance outcomes over the lifespan of the asset, disassembly of the new trackwork once it reaches the end of its life could be more difficult than the disassembly of the existing track being removed as part of the current project. Unlike the existing timber bearers which can be modified on site as part of staged disassembly; cutting or drilling concrete bearers is not feasible. On this basis, the project team developed an SRS requirement with the future disassembly of the new junction in mind: ***“Special Trackwork long bearers shall be positioned such that they run under***

no more than two pieces of special trackwork.” This sought to mandate that the design considered the staged removal of the proposed trackwork, ensuring that discrete sections will be able to be removed and replaced in the future.

Each of the track layout options developed considered the placement of the long bearers of all special trackwork components, with a particular focus on the Central Junction area. This included ensuring that sufficient separation distance between turnouts and other special trackwork components were achieved within the constraints of the site. The location of last long bearers was provided on sketches for review by stakeholders, allowing them to consider the impacts on the disposal stage of the asset lifecycle.

Once a preferred option had been selected, a more detailed analysis of turnout bearer extents was undertaken as part of the Concept Design (see Figure 10). This enabled the more detailed set-out of the turnouts, whilst considering bearer placement as required to suit the special flexed geometry in the Central Junction, including through the non-standard diamond at the centre of the layout. As a result, it was confirmed that this requirement was able to be efficiently implemented, ensuring that the future design stages will allow for the ease of disposal of the asset once it reaches the end of its usable life.

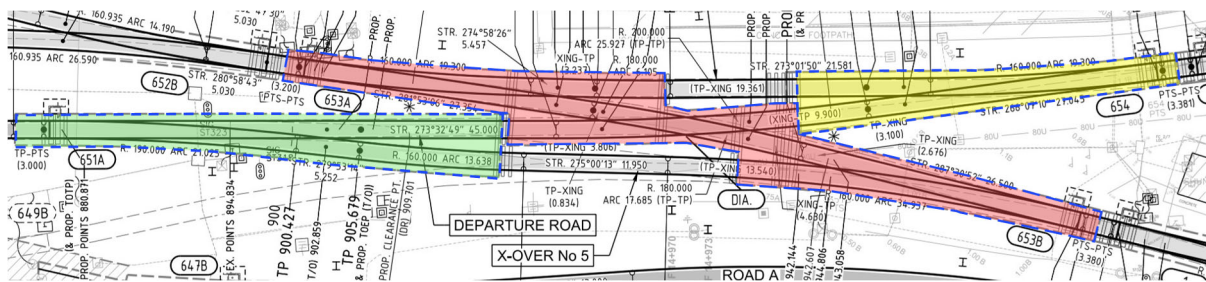


Figure 10: Extract from Track Concept Design, Showing Long Bearers, with Different Special Trackwork Sections Highlighted Red, Green and Yellow

7 CONCLUSION

The Flemington East Junction project demonstrates the benefits of drawing together systems engineering and track design inputs in an integrated way when establishing a junction remodelling scheme. Through undertaking targeted stakeholder engagement and collaborating with individuals working across all areas of the operational railway, a pragmatic requirements definition process was used to maximise the value of the remodelling works. Documenting these requirements at the beginning of the project saw their inclusion in the Concept Track Design for minimal cost. This enabled the track design to respond to different stakeholders' needs for all stages of the asset lifecycle. As a result, these requirements will be able to be "traced through," to the future stages of the project's design and delivery to ensure better construction and maintenance outcomes are achieved as part of the renewal.

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