National Transport Authority

DART Expansion Project

Four Tracking from West of Hazelhatch to Phoenix Park Tunnel

Final Issue | 26 November 2018

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

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Executive Summary

DART Expansion was initially conceived in the early 1990's as a scheme to expand the capacity of the electrified commuter network in the greater Dublin area in response to the increasing commuter passenger numbers. Design of the initial scheme linking all the lines through an underground tunnel link beneath the city centre was progressed and a Railway Order was made by An Bord Pleanála in December 2011 and perfected by the High Court in March 2014.

However, in September 2015 the Government deferred authorisation for construction of DART Underground and instructed Iarnród Éireann to examine the current design with an objective of delivering a lower cost technical solution, whilst retaining the required rail connectivity for the DART Expansion Programme.

The assessment review, including transport benefits modelling carried out by Iarnród Éireann and the NTA in 2016 and 2017 concluded that:

- DART Expansion with DART Underground offers the greatest benefits;
- Other network arrangement scenarios focused on delivering non-tunnel city centre capacity enhancements, with integration through the Phoenix Park Tunnel, allow early delivery of service capacity and met projected passenger demand in the short to medium term at a lower cost.

This short to medium term non-tunnel DART Expansion network was included in the National Development Plan 2018-27 but noted that a DART Underground Tunnel alignment would be protected for potential future development. This decision requires alteration to the Kildare Line previously designed with the tie-in through the DART Underground tunnel from Inchicore.

This Study reviews the options to tie-in the Kildare Line to the DART Expansion scheme connecting to the Phoenix Park Tunnel, in a manner which does not impede development of a DART Underground in the future. The current assessment has taken account of previous studies, including the DART Underground design and a subsequent Western Tie-In study carried out as part of the 2016 and 2017 DART Expansion review.

The ultimate purpose of this Study is to review and co-ordinate all studies in light of the revised DART Expansion network and to recommend an integrated solution covering the immediate requirements of the DART Expansion with provision to allow future development of the DART Expansion.

The key features of the review contained herein are to review options to complete the four tracking from its existing limit near Park West / Cherry Orchard into Heuston (previously incomplete due to the tie-in to the proposed DART Underground) and co-ordinate the alignment with the tie-in to the Heuston Yard and the Phoenix Park Tunnel in the East, and the existing four track to Hazelhatch in the West.

This co-ordination includes the effects of changing the future track operational configuration from DART Lines on the north side of four tracking in the Phoenix Park Tunnel solution to DART Lines on the south side of four tracking in a DART Underground solution.

The revised options include a station at Kylemore in lieu of the previous proposal for an Inchicore Station and different overbridge and structural solutions than those previously considered.

This Study has concluded with a recommended solution to meet these requirements.

1 Introduction

1.1 DART Expansion and National Transport Policy

In September 2015, the revised Business Case for the DART Expansion Programme was published, and the Minister for Transport, Tourism and Sport Paschal Donohoe TD announced the National Transport Authority's recommendations based on the outcome of the Business Case, which the Minister endorsed.

The NTA recommended that given the very significant cost of the DART Expansion Programme, and recognising that a lower cost alternative for the tunnel element is possible;

1. *That the DART Underground Project is redesigned to provide a lower cost technical solution for the project, whilst retaining the required rail connectivity;*
2. *That the non-tunnelled elements of the DART Expansion Programme be progressed in line with available funding.*

The Minister for Transport, Tourism and Sport indicated that the forthcoming Capital Investment Plan would make provision for advancing this expansion programme.

The National Development Plan 2017-2027 published in 2018 provides for *the DART Expansion Programme to be a series of projects that will create a full metropolitan area DART network for Dublin with all of the lines linked and connected.*

The initial sequencing of investment will focus on delivery of non-underground tunnel elements of the programme using the recently opened rail link and existing connector tunnel under the Phoenix Park. This includes buying additional fleet for the DART network and measures such as re-signalling, junction and station changes to provide expanded services.

The next step will be to provide fast, high-frequency electrified services to Drogheda on the Northern Line, Celbridge/Hazelhatch on the Kildare Line, Maynooth and M3 Parkway on the Maynooth/Sligo Line, while continuing to provide DART services on the South-Eastern Line as far south as Greystones. It will also include new stations to provide interchange with bus, LUAS and Metro networks, see Figure 1 overleaf.

The route for the remaining element of the overall DART Expansion Programme, the DART Underground Tunnel, will be established and protected to allow for its future delivery.

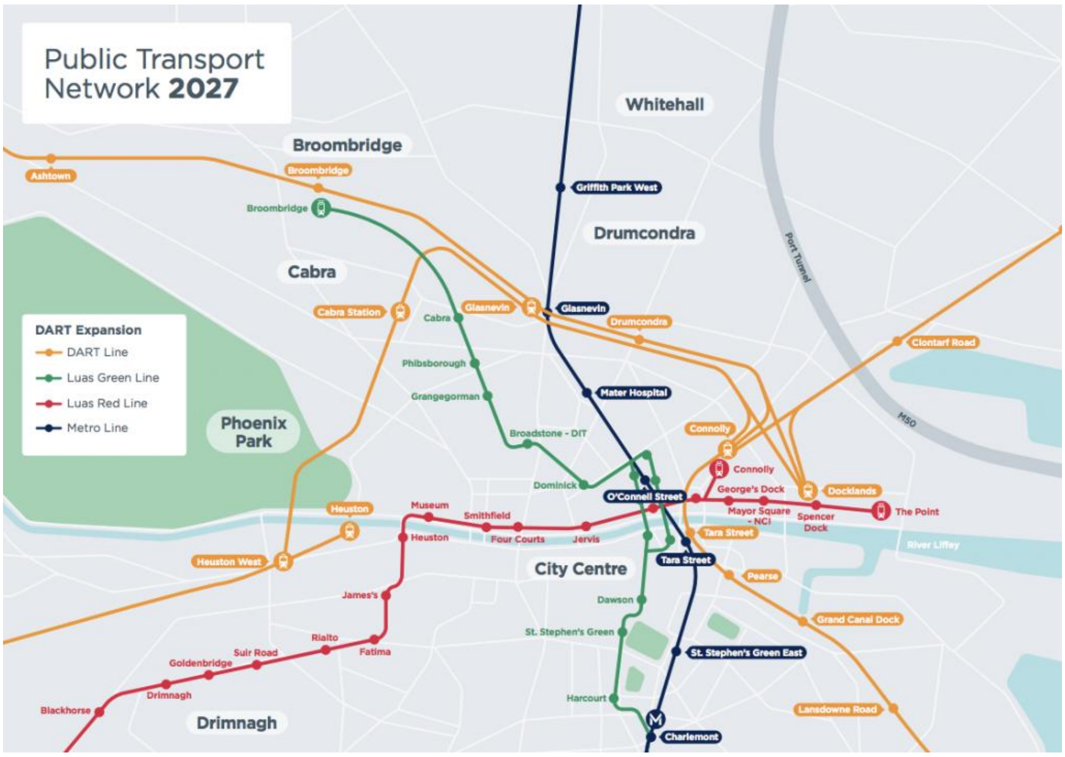


Figure 1: Public Transport Network 2027, reproduced courtesy of the NTA

1.2 Background

The DART Underground Programme was devised in the CIÉ commissioned "Dublin Suburban Rail Strategic Review" (2000) and later adopted within the Government's integrated transportation planning strategy for the Greater Dublin Area in the Dublin Transport Office publication "Platform for Change". In 2005 the DART Underground Programme was included within the Government's Transport 21 Infrastructure Investment Framework.

The following is a high level summary of the current status of the DART Underground Programme:

- DART Upgrade Phases 1 and 2 completed in 2006: including lengthening of platforms, upgrading of power supply and expansion and upgrading of DART fleet to facilitate 8 car operations;
- Kildare Route Project Phase 1 completed 2009: including four tracking Hazelhatch to Kildare along with a number of new / upgraded stations;
- Dunboyne spur completed in 2010: introduction of new services including services to a number of new stations including Docklands;
- City Centre re-signalling phases 1 & 2 are currently in the construction phase: Upgrading the signalling system in the city centre;

- In 2007, design of the DART Underground for Railway Order commenced and was Approved by An Bord Pleanála in 2011 but subject to Judicial Review Proceedings;
- Centralised Traffic Control Centre currently is in the planning phase: providing a new traffic control centre;
- In September 2015, the Government deferred authorisation for construction of DART Underground and instructed Iarnród Éireann to examine the current design with an objective of delivering a lower cost technical solution, whilst retaining the required rail connectivity for the DART Expansion Programme;
- Further to the Government decision in September 2015 to look for a redesign of the DART Underground element of DART Expansion an assessment review, including transport benefits modelling carried out by Iarnród Éireann and the NTA in 2016 and 2017, concluded that while the DART Expansion with DART Underground offers the greatest benefits, other scenarios considered in the transportation modelling exercise, focused on delivering non-tunnel city centre capacity enhancements, with integration through the Phoenix Park Tunnel, allow early delivery of service capacity and met projected passenger demand in the short to medium term at a lower cost;
- This short to medium term DART Expansion network was included in the National Development Plan 2018-27 but which noted that a DART Underground Tunnel alignment would be protected for potential future development.

The scope of this Study is related to the advancement of the non-tunnelled elements of the Kildare Line electrification from the Phoenix Park Tunnel to just west of Hazelhatch.

In all previous studies undertaken for DART Underground, the Western Portal was either considered within the Heuston Yard, CIÉ Inchicore Works or in the case of the Western Tie-In Study, a portal just east of Sarsfield Road Underbridge. When the original Kildare Route Project was assessed only concept design was undertaken for the section from Heuston to Inchicore, pending clarification of the DART Underground final design alignment.

Accordingly, no detailed investigations had ever been undertaken to assess the feasibility of a non-tunnelled four tracking section from Sarsfield Road to the Heuston Yard and further to tie into the Phoenix Park Tunnel.

Investigating the feasibility and impacts of four tracking this “missing section” from Sarsfield Road to the Heuston Yard formed the primary objective of this Study together with the issues related to track configuration, electrification and signalling of how this design co-ordinates with the existing four track network to Hazelhatch.

In turn, this Study will be used as a scoping study definition for the development of a future Railway Order.

The National Transport Authority (NTA) and Iarnród Éireann (IÉ) also specified that Arup should develop solutions which do not preclude any future DART Underground with a tunnel portal structure either in the Heuston Yard or just east of Sarsfield Road as was proposed in the Western Tie-In report.

1.3 Extent of Study Area

The relevant Study Area for this brief extends from Hazelhatch in the west to Heuston Station and Phoenix Park Tunnel in the east, encompassing the area of the CIÉ Inchicore Works Depot and their environs.

The Study has examined the following:-

1. Solutions to widen the existing rail corridor to accommodate four tracks from the Heuston Yard, as far as the end of the previously constructed Kildare Route Project Phase 1 Works (KRP Phase 1). The end of the KRP Phase 1 four track widening of the Heuston Mainline is positioned approximately 810 metres (m) to the east of the Park West / Cherry Orchard Station;

2. The preparation of drawings west of Park West / Cherry Orchard Station to just west of Hazelhatch which identifies any necessary changes to the existing trackwork to accommodate the revised or future DART Expansion running;

3. The impact of DART Expansion under Conyngham Road Overbridge and for the initial section of the Phoenix Park Tunnel;

4. The impacts of changing the operational track configuration from the existing Fast-Slow-Slow-Fast design with commuter trains in the centre lanes as designed for the initial DART Underground design, to Slow-Slow-Fast-Fast for the DART Expansion network to match the Phoenix Park route which is on the North side of Heuston and Fast-Fast-Slow-Slow for a future DART Underground network to match the tunnel route recommended on the south side of Heuston Station.

1.4 Aims and Objectives of the Study

The aims and objectives of this Study are as follows:-

- To produce an integrated preliminary design suitable to be used as a scoping study definition for development of a Railway Order at the next stage of Design Development;
- Build upon and coordinate previous studies undertaken;
- Review the four tracking section from Heuston to Park West / Cherry Orchard Station in terms of track alignment, costings, property, connections to CIÉ Inchicore Works and a future possible station at Kylemore Road;

- Review the structures necessary to implement the proposed four tracking alignment;
- Review the four tracking design in the vicinity of the South Circular Road / Con Colbert Road and advise on the required structures which could facilitate DART Expansion and comment on impacts associated with both Fast-Fast-Slow-Slow and Slow-Slow-Fast-Fast operational running;
- Review the alignment from west of Park West / Cherry Orchard Station to just west of Hazelhatch to identify any changes to the existing trackwork or systems to accommodate future DART Expansion running.

The required output of the Study is a report with a recommendation for the Emerging Preferred Option, design drawings covering alignment, structures and property, and a feasibility working cost estimate.

2 Review of Previous Studies

2.1 Overview

A series of studies have been carried out for this area for DART Underground which covered all options for the tunnel and its connections to the Kildare Route.

The history of the development and design of DART Underground can be categorised into three distinct phases as follows:

- **Phase 1**: In 2002, Parsons Brinckerhoff Ireland Ltd. (PB) was commissioned by Coras Iompair Éireann (CIÉ) to examine various permutations of the east-west alignment recommended in the Dublin Suburban Rail Strategic Review (Arup, 2000) and to look at optimum station locations. The outcome report further developed, refined and costed the identified alignment.

- **Phase 2 (Preliminary Design)**: In 2006, Mott MacDonald Pettit Ireland (MPI) was commissioned by CIÉ to undertake the feasibility (or preliminary) design for DART Underground. As part of the preliminary design, alternatives for various aspects of the scheme were reviewed. The route alignment and station options identified in the Phase 1 reports were reviewed and in conjunction with CIÉ and stakeholders, the preferred route and station options were identified.

- **Phase 3 (Reference Design)**: In September 2008, Arup Halcrow Joint Venture (AHJV) was commissioned by CIÉ to undertake the reference design for the DART Underground project which culminated in the preparation of this EIS and Railway Order Documentation. As part of this design process a number of further options were considered in order to optimise the final scheme design.

2.2 DART Underground Phase 1

As outlined above, Phase 1 of this project was commissioned by CIÉ in 2002 to generate options for the provision of a heavy rail interconnector' through Dublin City linking the Drogheda (Northern Line) and Maynooth Line (Northwestern Line) with the Kildare Lines at Heuston.

In parallel to these works the Kildare Route Project (KRP) saw the commencement of the first phase of four tracking on the Kildare lines into Heuston. This project adopted a fast/slow/slow/fast track configuration. Phase 1 of KRP was developed to end at Cherry Orchard and Phase 2 of KRP was envisaged to tie the remaining section of track from Cherry Orchard to the point at which it was concluded to end the DART Underground Scheme.

It was a requirement of the project that the preferred alignment should connect into the Western (Kildare) Line in the vicinity of Heuston or Inchicore. Two options were considered for the DART Underground line to continue towards the Kildare

Route; one to the north of the existing Heuston station approaches via the general area of the car park, and one to the south of the Heuston station approaches using a route under the N4 main road.

For both route options, an Underground station would be provided close to or underneath the Heuston Mainline Terminus Station.

2.3 DART Underground Phase 2

As in the Phase 1 studies, the Phase 2 alignment was a tunnelled route extending for 5.2 km from a cut and cover "West Portal" located immediately west of the Heuston Mainline Terminus Station to a cut and cover portal at East Wall to the east of Connolly Station.

Development of an Underground Station in the Heuston vicinity required consideration of a number of major constraints which resulted in numerous options being developed for the potential underground station and portal configuration. The major constraints are summarised as follows:

- **Land:** The station footprint is constrained by the River Liffey, operations within Diageo Lands, operations within the Heuston Station and residential properties to the West of Heuston Station.
- **Cultural Heritage:** Several protected structures are located in proximity to Heuston Station.
- **Operational Requirements:** The following criteria were identified as important for the design:
    - Functionality, e.g. ability to handle the peak passenger loads, ability to support the proposed operating plan, robust with respect to peak service operation i.e. provide a fast/slow/slow/fast track configuration.
    - Passenger friendly e.g. ease of wayfinding, fast simple interchange to national rail, to Luas and to local bus and taxi services.
    - Close integration with the main line station facilitating fast simple interchange.
    - Minimal construction nuisance impact, e.g. local traffic disruption, diversion, delay, impact on Diageo production and distribution, minimal construction site footprint in a busy environment.
    - Minimum construction risk and safety implications.
    - Strong architectural statement befitting its location on a landmark development site.
    - Alignment with Dublin City Council planning intent for future development.
- **Urban context:** The underground Heuston Station should facilitate interchanges with the existing main line station, Luas and buses.

- **Station Layout:** A platform length of 174 m is required to provide capacity for 8 car trains. A minimum island platform width of 5 m was required to meet IÉ Standards.
- **Emergency Escape Strategy:** The station should be designed to accommodate 3 escape points, at either end of the platforms and at a central location along the platform.
- **Construction:** Construction impacts should be minimised, particularly with respect to sensitive operations at Diageo, on Heuston Station as a protected structure and on traffic at Victoria Quay.
- **Groundwater and Drainage:** All underground structures must be watertight.
- **Ground Movement:** The construction of the tunnels, station boxes and shafts would lead to ground movement and settlement.

For the Western Portal locations, options west of Islandbridge were discounted, and ultimately two options remained which are discussed in the following sections.

2.3.1 Heuston Plan A

In the arrangement developed for Plan A, the location for the proposed Heuston Underground station was beneath the Diageo-owned St. James' Gate Brewery, east of the existing Heuston mainline station and adjacent to Victoria Quay. The station structure was to be constructed within a cut and cover box and the alignment follows the arrangement shown in Figure 2 below.

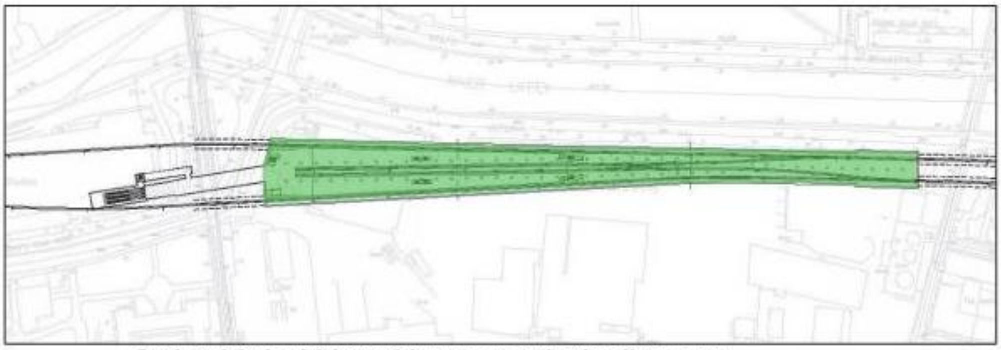

Option A4: As A0 but with more southerly alignment

Figure 2: Heuston Plan A with Cut and Cover Station in St. James' Gate Brewery

The Western Portal was located in the confines of the Heuston Station car park in the area between the Kildare Line and the River Liffey. The refined alignment commenced at ground level along the existing railway tracks approximately 700m west of the back entrance to Heuston Station. From there it followed an easterly direction, at ground level for 500m where it began to make its descent downwards into the tunnel at the entrance to the Western Portal. From this entrance, the tunnel followed an eastern line towards St. James's Gate Brewery. The proposed Heuston

Station would be located within the northern section of the St. James's Gate Brewery and the southern section of Victoria Quay.

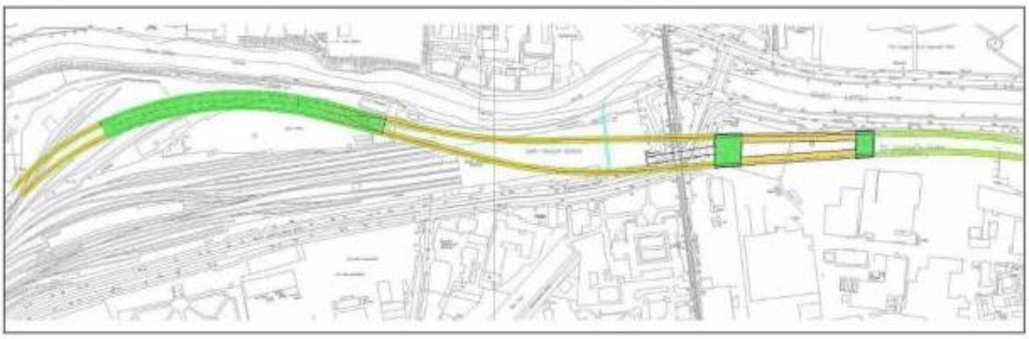
2.3.2 Heuston Plan B

The Plan A option of a cut and cover box station was dependent on finding solutions to address the issues raised by Diageo as to the operation of the St James's Gate Brewery during construction relating to air quality, noise, disruption to their manufacturing and transport process and clearance to kegging sheds. It was also dependent on developing a temporary traffic management solution to address traffic volumes along Victoria Quay and at the junction with Heuston Bridge.

Consequently, IÉ became concerned about the potential impacts associated with Plan A and future 4-tracking into Heuston. In particular, the requirement for a flyover to connect with the fast/slow/slow/fast track configuration and the impact on Heuston services, the Quays, St. John's Road West and Diageo. A further assessment was carried out to investigate solutions to these issues. The purpose of the assessment was to determine the feasibility of locating the DART Underground station vertically beneath Heuston Station and incorporating a twin track reversing turnback to allow it to perform as a terminus station when first opened for operation.

This infrastructure arrangement, referred to as the Heuston Plan B, was an alternative to the base case described above (referred to as Heuston Plan A) wherein the DART Underground station was moved westwards partially out of Diageo Lands and partially into CIÉ lands. The underground turnback facility was incorporated at the western end of the proposed underground station. The alignment surfaces within the vicinity of the existing mainline tracks.

The Plan B alignment would come to the surface level in the centre of the KRP track configuration thereby negating the need to provide a grade-separated junction as is required for Plan A, see Figure 3. Therefore based on the above, Plan B was selected as a more preferred option as compared to Plan A.



Option B0: Tunnelled in Diageo lands, turnback in siding

Figure 3: Heuston Plan B, Station Tunnelled in St James' Gate Brewery

2.4 DART Underground Phase 3

During the Phase 3 design development, it became clear that the constraints at Heuston Station were significant and potentially could have a major impact on the existing train operations into and out of Heuston Station and generally on the local environs. In particular, a significant impact for Plan B is that the construction phasing required for the tie-in from DART Underground to the existing mainline is located within the constrained Heuston throat.

This would require numerous construction phases in a very constrained area and the demolition of at least one existing road bridge with the associated traffic impact as a result. This would impede the existing train operations and furthermore prevent CIÉ from expanding services until DART Underground was complete. In addition, the phasing for temporarily relocating two platforms (as a result of the closure of Platforms 1 to 3 during construction) and the associated track remodelling work and resignalling would have a significant impact on train services.

Therefore in order to address the impacts of Plan B, the option of extending the DART Underground tunnel to Inchicore, referred to as Plan C was investigated. There was an added advantage associated with this option in that the future impact as a result of the completion of the four tracking into Heuston Station would be avoided.

A further advantage of Plan C over Plan B was that the large underground turnback facility would be moved to Inchicore. This is significant as the ground conditions at Heuston are such that the construction of the mined turnback would be difficult and potentially very costly. Plan C removed this risk. Other perceived benefits of locating the turnback facility in Inchicore as opposed to Heuston were as follows:-

- The tunnel portals would be located in Inchicore and not adjacent to Islandbridge Junction, thereby avoiding the need for substantial remodelling of the rail junction.
- The ability to improve train services at Heuston if required prior to completion of DART Underground. Plan B would have restricted any improvements until completion of the project.
- Access to construct the tunnel portal in the Heuston throat would be very problematic due to the nature of working next to a live railway environment.
- Avoid transporting the tunnel spoil through the city centre and avoid the junction of St. John's Road West /Victoria Quay/Heuston Bridge.

Given that the concept of the Plan C extension was a new development to the DART Underground project, a number of assessments had to be carried out to bring the proposed extension into line with the remainder of the project.

A Phase 1 feasibility assessment was undertaken in late 2008 which considered the options for moving the portal west and its impact on 4-tracking into Heuston. A recommendation was made as to the most preferred route option for that stage of the design development. The options considered are summarised below.

Following completion of this assessment in early 2009 it was decided to advance with the extension to Inchicore and to connect with the existing mainline in the vicinity of Kylemore Road. KRP Phase 2 would then consist of four tracking from the previous end of KRP1 at Cherry Orchard through to the end of DART Underground Plan C within the CIÉ Inchicore Works.

2.5 DART Underground Western Tie-In Study

The National Transport Authority in collaboration with Iarnród Éireann as part of the DART Underground scheme review to find a lower cost solution, commissioned Arup in 2017 to re-evaluate the possible connection options to link the proposed DART Underground tunnel project to the existing surface rail line serving Heuston Station.

This proposed connection was referred to as the **"Western Tie-in"** and covers an area from Watling Street in the east to Park West / Cherry Orchard Station in the west. The Western Tie-in report outlines the methodology developed to undertake the DART Underground Western Tie-In Study, presents the possible options identified, and describes the Multi-Criteria Assessment undertaken of the feasible and practicable options, which resulted in the emergence of a "Preferred Option".

The Study considered various options for a new underground station at Heuston, facilitating either through running connection onto the Heuston Mainline or terminating underground with passenger interchange with the existing Heuston surface station.

The Study was undertaken in four distinct phases, culminating in the Emerging Preferred Option identified from the Multi-Criteria comparative assessment. The outcome of the Study was a through running connection onto the Heuston Mainline, occurring immediately east of the existing Sarsfield Road Underbridge and four track widening of the existing rail corridor until the end of the previously completed Kildare Route Project Phase 1. A twin bore tunnel configuration was recommended with the tunnel portal sited on the Ballyfermot approach to the junction of the Chapelizod Bypass and the Con Colbert Road, see Figure 4.

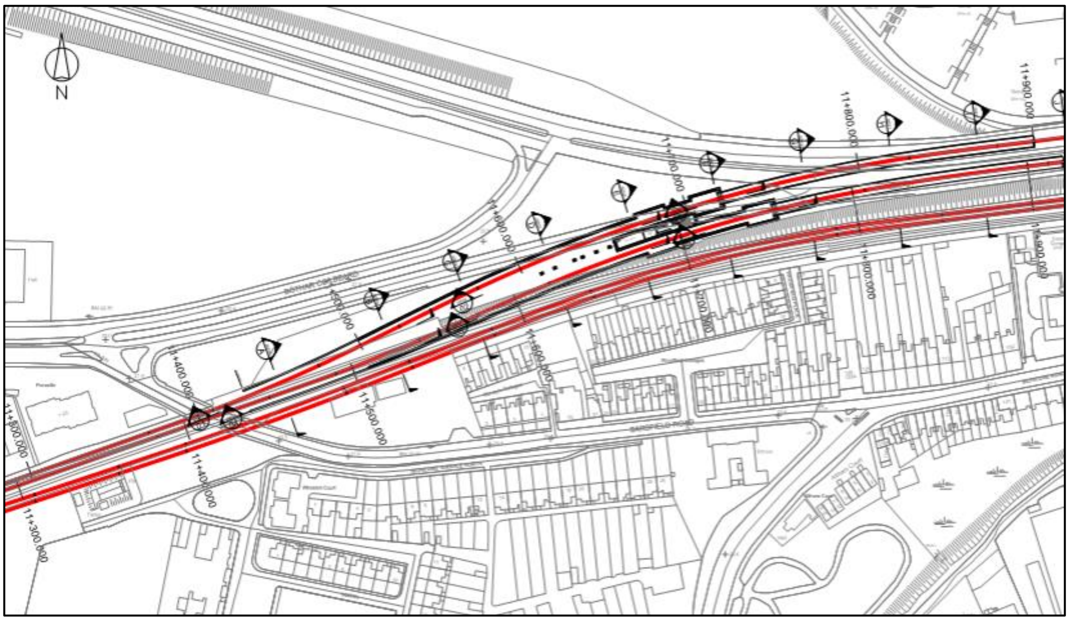


Figure 4: Plan layout of Western Portal as proposed in Western Tie-In Report

2.6 Summary

Previous studies undertaken for DART Underground considered a Western Portal within the Heuston Yard, CIÉ Inchicore Works or in the case of the Western Tie-In Study, a portal just east of Sarsfield Road Underbridge. No detailed investigations had ever been undertaken to assess the feasibility of a non-tunnelled four tracking section from Sarsfield Road to the Heuston Yard and further to tie into the Phoenix Park Tunnel. The feasibility and impacts of this non-tunnelled four tracking forms the primary objective of this Study.

3 Data Collection and Available Surveys

In addition to the survey information, reports and records collected during the DART Underground Western Tie-In Study, for the purposes of this Study, the NTA and IÉ has supplied the following:-

- LiDAR surveys from Park West to West of Hazelhatch;
- OS mapping from Park West to West of Hazelhatch;
- Utility survey drawings for Kylemore, Le Fanu and trackside, based on surveys undertaken during the original KRP2 project design;
- Extracts from IAMs showing the grid reference for the Cork Mainline, One milepost and the 1¼ milepost;
- Original drawings of the Phoenix Park Tunnel, current alignment details through the Tunnel and details of the Tunnel drainage system;
- Details of the current Clancy Quay redevelopment;
- Drawings of rail overbridge OBO2 Conyngham Road Bridge;
- Drawings of rail underbridge UB01 Liffey Bridge and Viaduct; and
- Drawings and alignment details of the existing Kildare Route Project from Hazelhatch to Cherry Orchard.

4 Identification of Principal Impacted Assets

The principal assets impacted by the proposed four tracking and tie-in with the Phoenix Park Tunnel are summarised as follows:-

4.1 OB7 Le Fanu Road Bridge

The existing rail overbridge OB7 which carries Le Fanu Road over the Kildare Line is a masonry arch carrying a sub-standard single carriageway over the double-track railway. The constrained width of the existing bridge does not allow for the provision of the footpaths and creates a hazard to the pedestrians using the bridge.

It has always been proposed to demolish the existing bridge as part of the Kildare Line four tracking in order to accommodate the additional two railway tracks.

4.2 OB5A Kylemore Road Bridge

Rail overbridge OB5A was constructed during the 1950s and currently carries two lanes of vehicular traffic on the Kylemore Road over the Heuston Mainline. The drawings indicate a clear span of 12.624m. A full complement of three railway lines currently passes under this bridge. The minimum vertical clearance is approximately 4.45m.

The deck consists of a reinforced concrete slab supported on in excess of thirty reinforced concrete beams. These beams rest on bearings on top of the concrete abutments. Concrete wingwalls with a decorative treatment, form the sides of the bridge. The wide bases of the abutments and wingwalls bear directly onto the ground.

4.3 CIÉ Inchicore Works

To support the massive undertaking of the construction of the railways, GS and WR Company purchased a 73 acre site in Inchicore for engine workshops and a depot. Before the development of the railway on the 1843 OS map, Inchicore is depicted as two townlands, Inchicore North and Inchicore South, which are subdivided by the main road from Dublin.

The townland consisted of open fields; very much part of the countryside with a small number of properties and one large house marked Inchicore House. The development of the depot sparked the industrial development of this part of west County Dublin. The Inchicore rail works are located on the down side of the line.

Figure 5 - Inchicore Works Ariel View

The Inchicore Railway Works opened in 1846 and became the largest engineering complex of its kind in the country. The original buildings, in a Tudor style of substantial limestone, were also designed by Sancton Wood, and the general contractor was Copthorne. Apart from a small works facility at Limerick, the Inchicore depot represents the sole survivor of several independent railway works in Ireland.

When the first workshops were opened, the company had to house the workers in what was an isolated area, they erected several terraces (e.g. George's Villas and St Patrick's terraces) of cottage-style houses. A dining hall, library and recreation centre were also provided, and the company paid part of the cost of a school for the children of the employees.

The original works include a running shed; two erecting shops; a boiler; carriage, paint and wagon shops; a smithy and foundry; and administration and design offices. The roofs of a number of the buildings are supported by iron roof trusses carried on cast-iron columns. These date from the 1840s and were supplied by the Dublin foundry of J. and R. Mallet; they are like those found at Heuston Station. The foundry building at the Inchicore depot has an interesting timber-trussed roof from the same period. The façade of the original and existing station building at Inchicore is distinctive and durable with its castellated form and durable blue limestone.

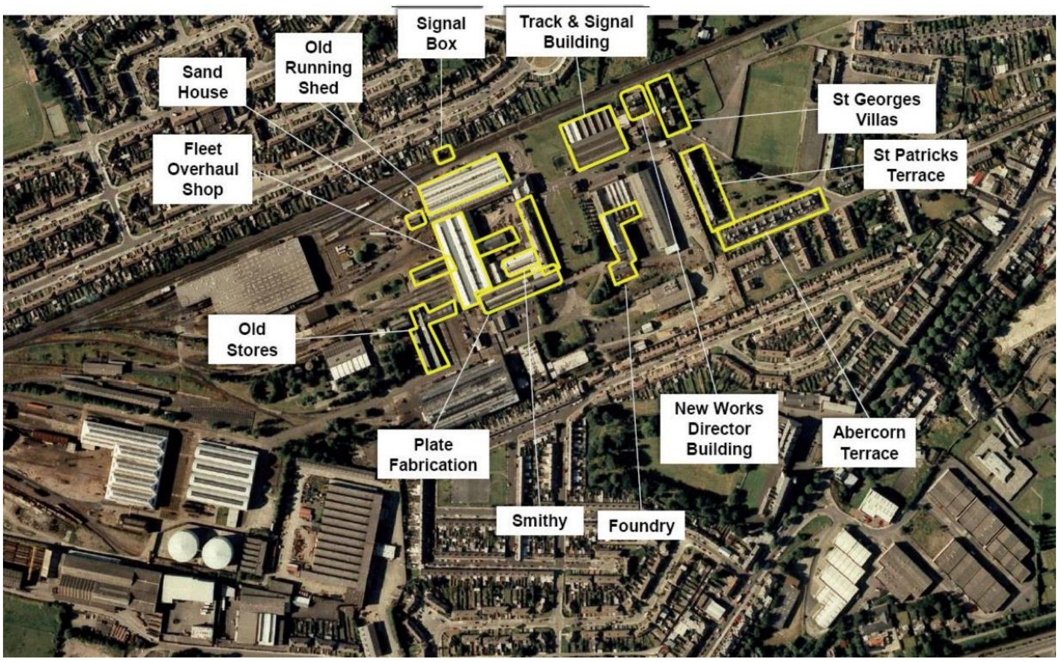


Figure 6 - Inchicore works - Building Plan

4.4 OB5 Khyber Pass Footbridge

Bridge OB5 at Inchicore, also known as the ‘Khyber Pass’, is a steel footbridge spanning at a skew over the railway at the CIÉ Inchicore Works, see Figure 7 overleaf. A footbridge has historically been provided at this location to provide access to St. Mary’s Terrace.

The walkway is essentially a steel frame tube consisting of a pair of Vierendeel trusses (no diagonal members) made from welded steel box sections. Other box sections laid orthogonally to the trusses tie the top and bottom chords together, and support the steel plate deck. The walkway is supported on latticed column legs at either end. These legs bear on reinforced concrete pad footings.

The clear span measured between the bridge supports, square to the running tracks, is 19.16m. The vertical clearance from the top of the running rails to the soffit of the bridge deck is approximately 5.15m.

Figure 7 - Rail Bridge UB4 over Sarsfield Road looking north

4.5 UB4 – Sarsfield Road Underbridge

The rail bridge over Sarsfield Road, UB4, consists of a 'silent' steel deck, bearing on reinforced concrete bed stones. The available IÉ drawings indicate that the 'silent' steel deck sits on the existing masonry abutment walls whilst the track maintenance walkway is a separate standalone structure, which spans between concrete pile abutment walls with stone facing, which were added when the new underbridge was installed. The bridge was upgraded to its current form in 2001 - 2002, see Figure 8.

The skewed span of the bridge is approximately 12.1 m. The width of the bridge is approximately 13.1m measured square to the three railway lines which run over the bridge. The positions of the running rails are fixed by the steel deck units and cannot be modified without replacement of the units themselves. Sarsfield Road rises significantly to the south and north of underbridge UB4.

Figure 8 - Rail Bridge UB4 over Sarsfield Road looking north

4.6 OB3 – Longmeadows Bridge

Overbridge OB3 at Inchicore, opposite Memorial Park, carries two lanes of one-way traffic from Memorial Road over the railway and by doing so forms a T-Junction with the Chapelizod Bypass / Con Colbert Road.

Available drawings for Longmeadows Bridge date from 1940 and 1957. They indicate that the deck consists of concrete encased steel I-beams that support a transverse spanning concrete slab. It appears that widening to the original bridge deck was provided on each side for footpaths, post 1940. Two No. 457mm diameter water mains are indicated within the structural depth of the deck.

The deck sits on closed concrete abutments, clad with stone to the north of the tracks. The span of the bridge is approximately 12.2m. Three railway lines currently pass underneath with no available space for additional tracks.

The vertical clearance from the underside of the deck to the top of the running rails is between 4.4m and 4.6m, see Figure 9.

Figure 9 - OB3 looking south-east

4.7 Retaining Walls and Signal Box on Heuston Approaches

The battered masonry retaining wall to the south of the railway cutting terminates shortly after Sarsfield Road in the approach to CIÉ's Inchicore Works.

The need for a retaining wall on the south side of the tracks returns as the tracks run alongside an Industrial Estate to the west of the Inchicore Works and continues as far as Rail Overbridge OB5A at Kylemore Road as shown in Figure 10 and Figure 11.

Figure 10 - Retaining wall west of Rail Overbridge OB1

Figure 11 - Retaining Wall east of Longmeadows Bridge

Residential developments to the north run parallel to the tracks, west of Sarsfield Road, necessitating the use of freestanding walls to maintain the railway cutting. This arrangement continues until just before Overbridge OB5A where earth embankments are provided.

4.8 Road Junction at Islandbridge

The junction of the R148 Chapelizod Bypass and R111 South Circular Road is one of Dublin's busiest road junctions. A pair of rail overbridges, OB1A and OB1, carries traffic over the Heuston Mainline, approximately 800m west of Heuston Station. Figure 12 illustrates a plan arrangement of the junction.

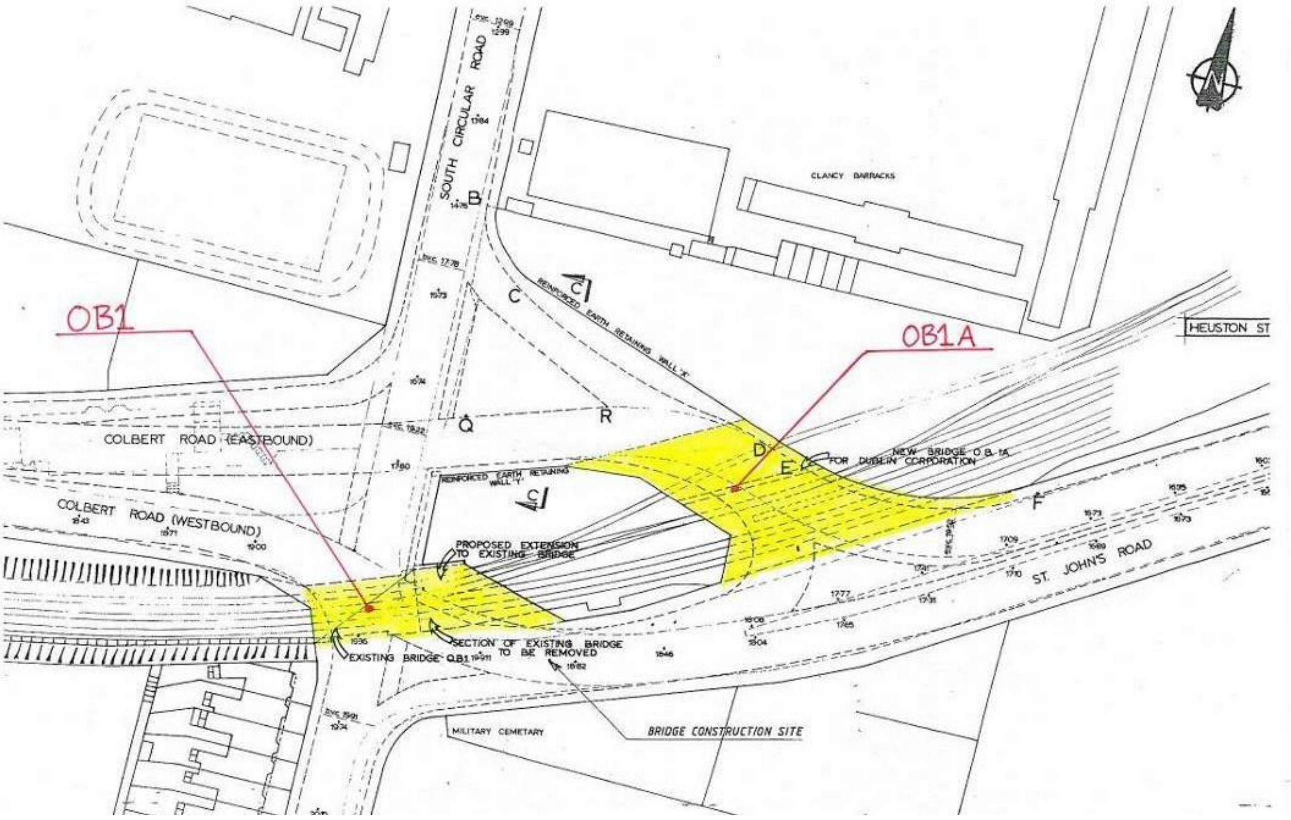


Figure 12 - Plan of Rail Overbridges OB1 and OB1A at Islandbridge

4.8.1 Rail Overbridge OB1

OB1 carries the South Circular Road over the railway. The original OB1 rail overbridge was widened in the early 1990s. The deck of both the original OB1 Bridge and its widening consist of pre-stressed concrete bridge girders on bearings that support a reinforced concrete deck slab, see Figure 13.

Figure 13 – View of the Eastern Elevation of Rail Overbridge OB1

4.8.2 Rail Overbridge OB1A

OB1A takes traffic over the railway from the South Circular Road and the Chapelizod Bypass / Con Colbert Road onto St. John's Road West. This is a two-span bridge constructed in the late 1980s / early 1990s. The square clear width available for running lines beneath the southern span, is approximately 17.4m. Three divergent rail lines currently pass under the southern span as can be seen in Figure 14.

The square clear width available for running lines under the northern span is approximately 15.7m. One rail line currently runs under the northern span. It appears from laser surveys carried out by IÉ that the vertical clearance from the top of the running rails to the underside of the structure are in the range of approximately 4.9m to 5.2m. Pre-stressed concrete bridge girders, resting at a skew on bearings, support the reinforced concrete deck slab. The abutments and central pier are constructed from reinforced concrete and are founded on reinforced concrete strip footings. The distance from the underside of the deck at its lowest point to the top of the foundations is shown on the construction drawings as being approximately 6.2m.

Figure 14 – View of Western Elevation of Rail Overbridge OB1A

4.9 Heuston Station and Yard

Kingsbridge station named after King George IV was commissioned in 1846 from Sancton Wood, an English architect following a design competition. In 1966, CIÉ renamed its principal railway stations in honour of the executed leaders of the 1916 Easter Rising. Kingsbridge station was renamed in honour of Seán Heuston, who had worked in the station's office.

During construction of the station, the River Camac was culverted and carried under the new development. Later the shore of the River Liffey was walled to form a private road along the north side of the station, which presently leads to the Station Car Park, IÉ Offices and the through Platform 10, which is situated on the Phoenix Park Tunnel line. This wall is reported by IÉ to have previously shown signs of distress with movement having occurred.

The main front of Heuston Station faces eastward towards the River Liffey and has two wings with small towers that were intended to have clocks in them. Following south, a range of offices extend along St. John's Road West. The main passenger entrance has a handsome porte-cochére with eight columns. Additional office accommodation, subsequently built on the north side, compliments the original building, which has the advantage of being well set back from the surrounding roadways.

The interior of the station initially contained two platforms separated by five carriage sidings, but, in recent years, a two-sided central platform has been added and the sidings have been reduced to one. The overall roof covers 2.5 acres; its original 72 columns of cast iron and connecting spans are still in use, but the roof has been renewed several times.

In 1872, another platform was added on the down side, where military traffic could be handled away from the commercial trains. The goods yard was located to the north of the passenger terminal, occupying the area between the mainline and the river.

The Great Southern and Western Railway (GS and WR) became the third main railway to open in the country in the 1840s and was known as the Premier Line of Ireland. The train shed now contains nine platforms and is one of the largest early station buildings in the country and the retention of its substantial original cast-iron substructure attests to the engineering abilities of its builders.

InterCity rail services from Heuston go to and from Cork, Limerick, Waterford, Galway, Mayo and Kerry. Commuter services stop at all stations to Portlaoise on Mondays to Saturdays and Kildare on Sundays.

There are nine platforms on the station, eight terminal platforms (numbered 1 to 8) and one through platform (platform 10).

4.10 UB01 Liffey Bridge and Viaduct

The Liffey Railway Bridge is a rail bridge spanning the River Liffey near Heuston Railway Station. It is a wrought iron box truss structure and joins the lines from Heuston Station to Connolly Station through the Phoenix Park Tunnel as shown in Figure 15 below. Historically used for freight traffic, the bridge has been reopened to regular passenger traffic since November 2016.

Figure 15 - Liffey Railway Bridge

The bridge and the tunnel were built by the Great Southern and Western Railway (GSWR) company to connect Heuston (formerly Kingsbridge) Station to the Dublin Docklands.

The Liffey Railway Bridge crosses the River Liffey from a point west of the Heuston Train Station complex on the south side to a residential area on the north river bank. There is no pedestrian or road traffic access to the bridge, while trains approach the bridge from the only through platform at the station – platform number 10 - and from the north side through the Phoenix Park Tunnel.

Constructed between 1872 and 1877, the bridge is of wrought iron, The truss design, with the distinctive triangular lattice work pattern, is also a classic of the era. Iron lattice girder bridges were introduced to Ireland by Irish railway engineer Sir John Benjamin McNeill, who was a pupil, and later an associate, of Thomas Telford. McNeill was also the engineer of the Dublin - Cork railway line.

On either side of the Liffey Railway Bridge, there are approach spans of three masonry, semi-circular arches built in stone. Seen from the ground, the bridge setting is striking notwithstanding its urban location: the river twists and turns gently below and trees frame the neat, box truss structure which is painted in muted shades to blend with the surrounding greenery.

The bridge was built to facilitate the interchange of rail traffic between three of the five Dublin railway termini at the time: Heuston, Broadstone and Amiens Street stations. Between them they catered for rail traffic from the south, the west, the midlands and the north. A valuable part of Dublin's industrial heritage, it is one of two railway bridges crossing the Liffey within the city, the other known as the Loopline Bridge.

4.11 Phoenix Park Tunnel

The Phoenix Park Tunnel was built in 1877 and begins at the Liffey Railway Bridge near Heuston Station, running underneath the Phoenix Park for 690m before re-emerging close to the junction of the Cabra Road and Navan Road. It joins with the Sligo line near Glasnevin, before continuing towards Dublin Connolly and Docklands Stations, and the North Wall Freight Yard.

The tunnel was originally built by the Great Southern and Western Railway company to connect Heuston Station to the Dublin Docklands, and was primarily used for freight. Historically the line had not been used for regular passenger trains, with most traffic through the tunnel being freight or carriages and engines shunted between Connolly and Heuston for maintenance. It had occasionally been used for special passenger services, including traffic for major GAA fixtures at Croke Park.

It reopened on 21 November 2016 for regular passenger traffic. The lines through the Phoenix Park tunnel are fully signalled to passenger standards with signal spacing adequate to support trains at approximately five-minute intervals in both directions. Transit time to either Connolly or the North Wall is approximately 10-12 minutes.

Figure 16 - Phoenix Park Tunnel

4.12 OBO2 - Conyngham Road Overbridge

Conyngham road overbridge is a road bridge of approximate width 21m and clear span 8.524m, which partially covers the entrance to the Phoenix Park Tunnel on the Heuston side. The bridge is single span with precast reinforced concrete beams of depth 760mm and spacing 2280mm, with precast reinforced concrete transverse slabs of thickness 225mm. The deck support surfacing of approximate thickness 250mm, with services in the footpath including a gas and water main on the south footpath.

The bridge was designed to carry bridge loading to British Standard BS 153, the Lucan tramway was previously positioned on the northern side on what is currently the bus lane. The date of construction of the bridge is unknown but thought to be in the 1930s.

The vertical clearance to the bridge soffit is 4.385m on the Down Line and 4.285m on the Up line based on the current alignment. The existing bridge is in very poor condition with severe corrosion visible, concrete bursting and spalling, and water penetrating through the deck.

Figure 17 - Conyngham Road Bridge

Figure 18: View of the soffit and the visible defects present in the deck

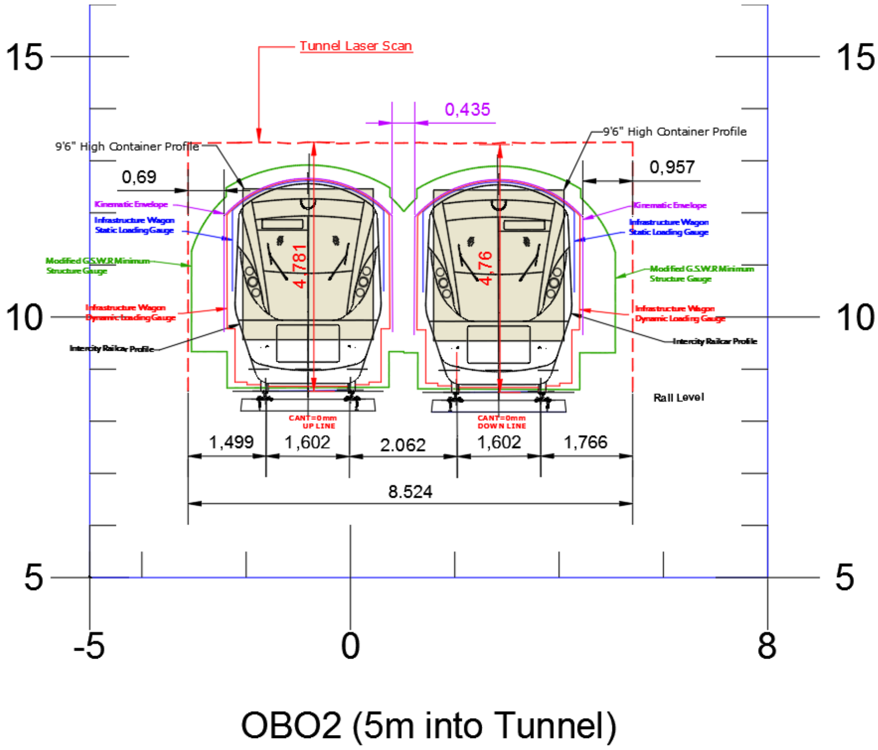


Figure 19: Track Cross Section under OB02 Conyngham Road Bridge at 5m into Tunnel

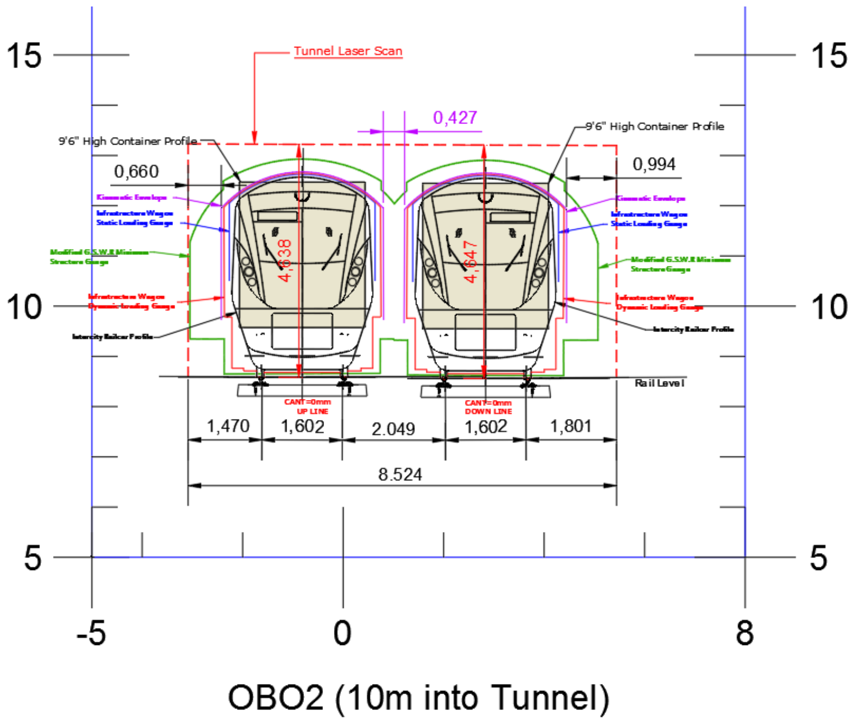


Figure 20: Track Cross Section under OB02 Conyngham Road Bridge at 10m into Tunnel

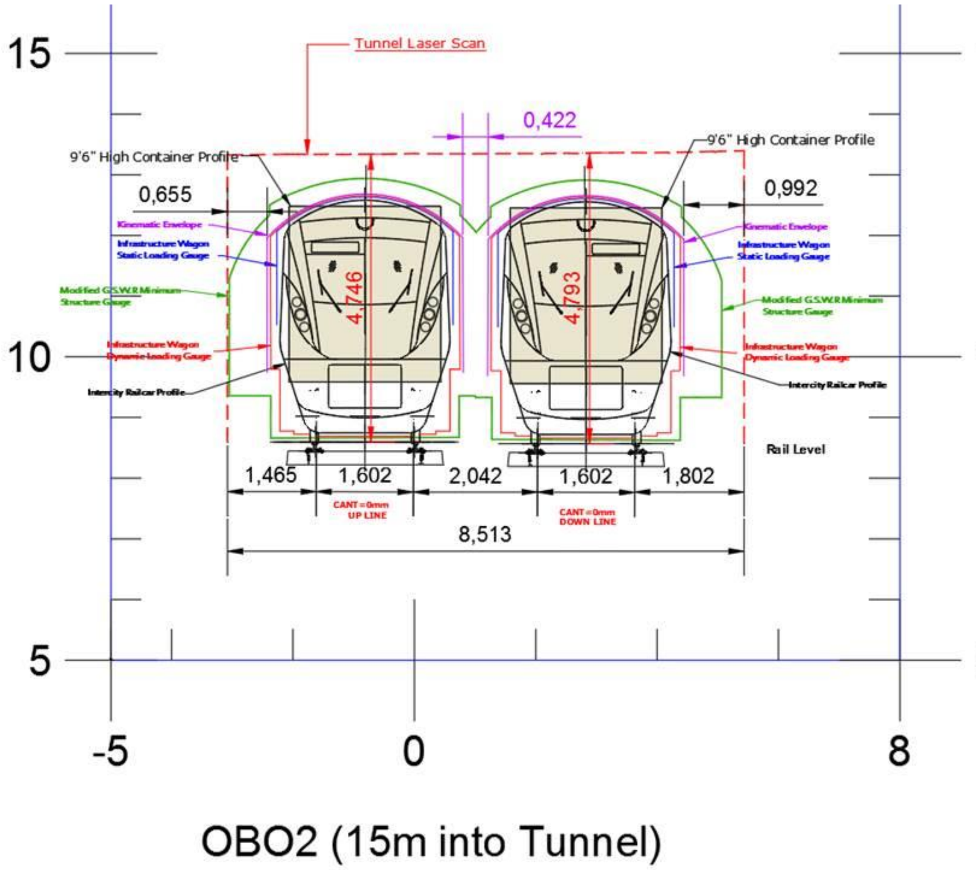


Figure 21: Track Cross Section under OB02 Conyngham Road Bridge at 15m into Tunnel

5 Track Alignment

5.1 Alignment Objectives

The alignment of the emerging preferred concept is based on satisfying the design and operating principles to meet the aims and objectives as set out in Section 1.4 of this Study, together with a desire to:

- Minimise any alterations to existing infrastructure;
- Minimising any potential landtake;
- Ensure the longevity of the system and facilitate ease of maintenance;
- Ensuring safety for all users of the system.
- Ensure the design does not impede any future IÉ projects.

5.2 IÉ Track Design Standards

The IÉ track design standards adopted to develop the alignment design are based upon the following standards:

1. IÉ standard I-PWY-1101: Requirements for Track and Structures Clearances;
2. CCE-TMS-300: Track Construction Requirements and Tolerances;
3. IÉ standard I-PWY-1141: Engineering Requirements for Passenger Platforms and Barrow Paths;
4. IÉ standard I-PWY-1150 Track Design requirements – Points & Crossings;
5. CCE-TMS-340: Horizontal Curvature Design;
6. CCE-TMS-341: Vertical Curvature Design.

5.3 DART System Requirements

The DART system requirements are summarised as follows:

- Commuter lines (Slow Lines) to be electrified;
- A new proposed station is to be provided near Kylemore Road;
- Based on findings from the Depot study by IE, location for maintenance of DART rolling stock will be recommended;
- DART rolling stock will only be permitted to use the slow tracks. Mainline rolling stock will be permitted to run on the slow tracks because of major events or operational perturbation. Allowance is made

in the cost estimates for the provision of crossovers from the Mainline to the slow DART tracks, but the exact location is not yet defined.

5.4 Track Design Speeds and Horizontal Geometry Requirements

The design speeds adopted in the developments of the proposed alignment are listed in Table 1 below.

	Limiting Design Criteria
Maximum Line Speed, DART	100 km/h
Maximum Line Speed, Mainline Services (See Note 1)	120/160 km/h
Minimum Design Speed, Switches and Crossings (See Note 2)	30 km/h
Maximum Line Speed, Yard (See Note 3)	15 km/h (Design Speed)

Table 1: Design speeds

Note 1: The maximum design line speed east of Park West Cherry Orchard Station is 120 km/h and west of this station is 160 km/h.

Note 2: The speeds through switch and crossings may be increased based on design considerations on a case by case basis. For this study the lowest design speed has been taken.

Note 3: Drivers Rule book limits actual speeds in a siding to 8 km/h.

5.4.1 Horizontal Track Geometry

Table 2 below lists Minimum Element Length for straights and curves.

	Limiting Design Criteria
Absolute Minimum Element Length	30m
Minimum Element Length, 75 km/h	41.667m*
Minimum Element Length, 100 km/h	55.556m*
Minimum Element Length, 120 km/h	66.667m*

Table 2: Minimum element length

*This is based on 2 seconds of travel at linespeed.

5.4.2 Transitions

Figure 22 below shows a typical transition curve, according to IÉ standards, the cubic parabola is used for all transition curves.

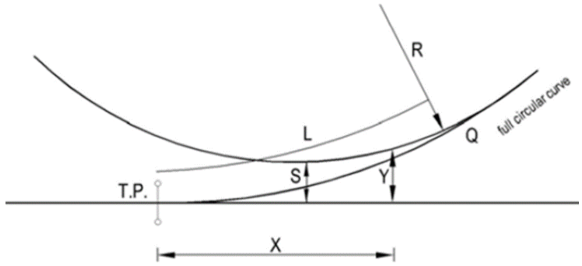


Figure 22: Typical transition curve

The equation of a cubic parabola is Y = X^3/6LR and curvature at a given point = X/RL (curvature is proportional to distance).

The shift (S) of a circular curve is found as follows:

The ordinate at the shift point = S/2 and X = L/2

$Y = S/2 = (L/2)^3/6LR = L^3/48R = L^2/48R$

$S = L^2/24R$

IÉ standards also permit the use of a clothoid transition curve as Section 2.1.3.5 of standard CCE-TMS-340.

5.4.3 Jerk Rate

Table 3 below lists Jerk Rates.

	Limiting Design Criteria
Desirable	0.2mm/s3
Limiting	0.3mm/s3
Maximum Used	0.2mm/s3

Table 3: Jerk rates

5.4.4 Circular Curves and Tangents

Minimum horizontal curve for CWR track is a radius of 400m. This is to be applied to all new track. Where existing alignments are maintained a minimum radius of 250m is adopted.

5.5 Track Cant

To counteract the effect of the lateral acceleration and the resulting centrifugal force, the outside rail of a curve is raised by a distance above the inside rail ‘E’. A state of equilibrium is reached in which both wheels exert equal force on the rails, that is, where ‘E’ is sufficient to bring the resultant force to right angles with the plane of the top of the rails.

To determine the distance that the outside rail must be raised to reach a state of equilibrium, cant shall be applied by rotating the track about the crown of the head of the low rail.

The equilibrium equation is defined as follows:

$$E = (13.116V^2)/R \qquad \text{(TMS-340 4.2.3.2)}$$

5.5.1 Rate of Change of Cant / Cant Deficiency

Table 4 and Table 5 outline the rates of change of cant and cant deficiency.

	Limiting Design Criteria
Maximum Desirable	40 mm/s
Maximum Allowable	60 mm/s
Maximum Used	39.64 mm/s

Table 4: Rate of change of cant

	Limiting Design Criteria
Maximum Desirable	40 mm/s
Maximum Allowable for speeds less than 110 km/h	60 mm/s
Maximum Used	36.23 mm/s

Table 5: Rate of change of cant deficiency

5.5.2 Maximum Cant

Table 6 below outlines the maximum cant.

	Limiting Design Criteria
Absolute Maximum Cant Allowable in Standards	185mm (TMS-340 4.2.2.4)
Maximum Cant Allowable	165mm (Technical Requirements)
Maximum Cant through platforms	90mm
Maximum Cant Used	100mm

Table 6: Maximum cant

5.5.3 Maximum Cant Deficiency

Table 7 below outlines the maximum cant deficiency.

	Limiting Design Criteria
Maximum Desirable Cant Deficiency Allowable in Standards	130mm (TMS-340 4.2.3.2)
Maximum Exceptional Cant Deficiency Allowable in Standards	150mm (TMS-340 4.2.3.2)

Maximum Cant Deficiency Used	108mm

Table 7: Maximum cant deficiency

5.6 Vertical Track Geometry

The vertical alignment in this Study is based on the low rail level of each track.

IÉ sets three levels of comfort, which can be seen in Table 8 below.

	Limiting Design Criteria
Desirable	1% g (TMS-341 4.1.1.2)
Acceptable	2% g (TMS-341 4.1.1.2)
Limiting	3% g (TMS-341 4.1.1.2)

Table 8: IÉ Passenger comfort levels

5.6.1 Limiting Values for Radius

Table 9 below lists the Limiting Vertical Curve Radii

	Limiting Design Criteria
Minimum Vertical Curve Radius, CWR Track	1,000m (TMS-341 4.1.3.1)
Maximum Vertical Curve Radius	40,000m (TMS-341 4.1.3.2)

Table 9: Limiting vertical curve radii

5.6.2 Vertical Curve Values for Radius and Speed

Minimum vertical curves are dictated by the formulae in Table 10 below.

Selected Rate of Acceleration	***Applicable Formula R (km)***	***V (km/h)***
Desirable (1%g)	$R=\frac{V^2}{1271}$	$V=\sqrt{Rx1271}$
Acceptable (2%g)	$R=\frac{V^2}{2543}$	$V=\sqrt{Rx2543}$
Limiting (3%g)	$R=\frac{V^2}{3814}$	$V=\sqrt{Rx3814}$

Table 10: Formulae for vertical curves

The minimum vertical curve radius used in the design is 2000m located on the southern approach to the Phoenix Park Tunnel. It is proposed to limit the linespeed in this area to 50kph due to the geometry in within the Phoenix Park Tunnel, therefore providing less than 1% g on the vertical curve.

All vertical curves used in the design are compliant with TMS-341 Fig. 2, Figure 23 below. meeting the desirable rates of acceleration of 1% g.

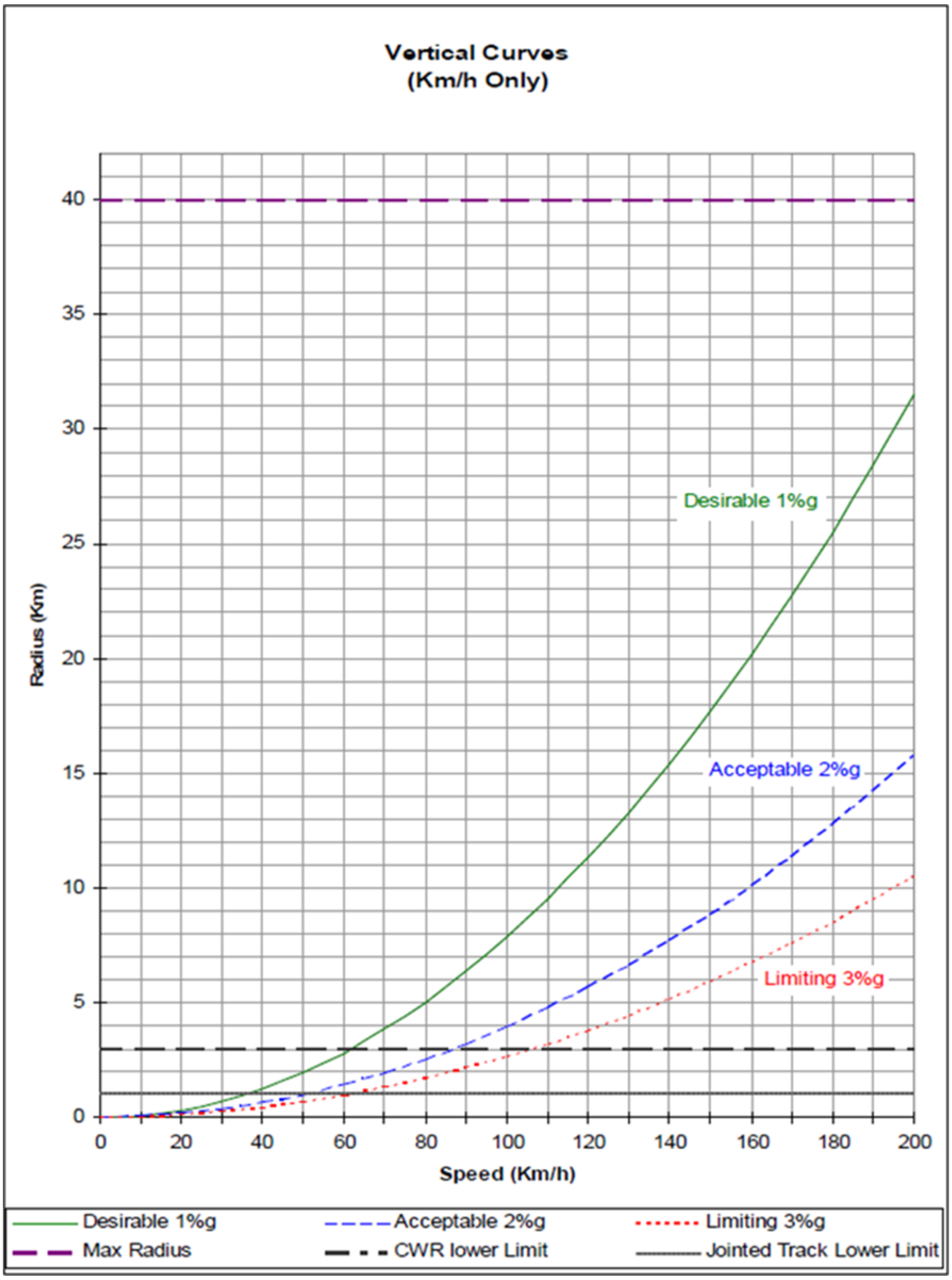


Figure 23: TMS-341 Fig.2

5.6.3 Vertical Grades

Table 11 below lists the Limiting Vertical Grades.

		Limiting Design Criteria
Absolute Maximum Grade	3.5%	For a maximum length of 1.66 km and 3% over longer distances
Maximum Grade	3%	
Minimum Grade	0.2%	To Facilitate Track Drainage
Maximum Grade, Freight	2%	
Maximum Grade Used	1.73%	

Table 11: Limiting vertical grades

5.6.4 Calculation of Equivalent Gradients

In locations where there are both vertical and horizontal curvature, it may be necessary to determine the equivalent gradient. This allows a train traction unit to have consistent demands and ensures that the maximum allowable gradient is not exceeded. The actual gradient can be found using the following method:

1. Establish criteria. Radius of curve in metres = R
2. Calculated gradient as a percentage = G
3. Find the degree of curvature.

   Degree of curvature, $D = 2 \sin^{-1}(15.24/R)$
4. Determine compensation value, p, from Table 12 below;

Track Type	CWR	CWR	JTD	JTD	JTD
For Degree of Curvature, D	<5°	5° - 6°	<5°	5° - 10°	>10°
Under 50 km/h, value of p is:	0.04	0.03	0.05	0.04	0.03
50 km/h & over, value of p is:	0.03	0.02	0.04	0.03	0.02

Table 12: Formulae to determine compensation value

5. Apply compensation to the gradient.

   Effective final gradient = G + D x p, where p is the applied %.
6. All gradients in this design are taken from the low rail level.

5.7 Horizontal and Vertical Geometry at Stations

5.7.1 Horizontal Alignment at Stations

The horizontal track alignment through station platforms is on a straight section of track for the entire length of the platform.

The absolute minimum length beyond the end of each platform is 5m.

5.7.2 Vertical Grade at Stations

Table 13 below lists the Limiting Station Grade.

	Limiting Design Criteria
Maximum Grade Proposed at Kylemore Station	0.20%

Table 13: Limiting station grade

5.8 Track and Structure Clearances

5.8.1 Platform Clearances

Platform clearances were taken as 760mm from the running edge of the rail. All the platforms in the current design are positioned on straight sections of track and so no curvature effects needed to be taken into account.

5.8.2 Spacing of Lines and Lineside Clearances

5.8.2.1 New Works and Alteration to Existing Works

The primary new works that have an impact on this Study is the construction of new overbridges to replace the existing infrastructure. The bridge abutments of these new structures causing the greatest concern.

The new overbridge at Le Fanu provides 4500mm lateral clearance plus allowance for throw and cant effects from the nearest running edge to the new bridge abutment.

The new overbridges at Kylemore, Memorial Road and OB1 are to provide the minimum lower lateral clearance of 2500mm plus allowance for throw and cant effects. The abutments in this case will be designed to withstand derailment collision loading.

Cant	H	Cant	H	Cant	H
0	4830	60	4910	120	4989
10	4843	70	4923	130	5002
20	4857	80	4936	140	5016
30	4870	90	4949	150	5029
40	4883	100	4963	160	5042
50	4896	110	4976	165	5055

Table 14: Additional allowance for cant effect

5.8.2.2 Clearance Between Tracks and Sidings

The standard six-foot (1970mm) has been maintained between a pair of running lines, measured between the running edges and on straight and level track. Spacings have been increased to allow for the effects of throw and cant as necessary. At crossovers, the minimum track spacing increases to 2000 mm, the change from 1970 mm taking place over a distance greater than or equal to 10 m.

Between the second and third pair of running rails, the required 10 foot (3580 mm) is generally maintained as per IÉ track standards, with increased allowance for throw and cant, with the following proposed derogations to be applied, which are agreed in principle by IÉ.

The ten-foot (10’) is maintained where practical, with reduction in this dimension subject to approval on a case by case basis. The rationale for the reduction in the 10’ is excluding this as a place of safety for track crossing of site staff. This has recently been adopted in the UK with Network Rail as best practice and in prioritising passing and structural clearances above the maintenance of a 10’. Required Permanent Way Derogations & TNCs Applicable to the Project are outlined in Table 15 below.

Areas with Reduced 10’	Chainage (m)	Reasoning
Islandbridge Junction	9,935.530-10,654.905*	To provide a safe lineside walkway on the south cess and reduce the span at Memorial Road Bridge.
Inchicore Works	10,654.905-10,866.508*	Available width of rail corridor too narrow
Park West / Cherry Orchard	13,856.081-13,548.911*	To allow for safe standing area on back Station Turnback

Table 15: Reduced 10' dimension

* Chainages based on the Up Mainline.

5.8.2.3 Lineside Clearances to Structures

The alignment design adheres to IÉ standards with regards to clearances between tracks and wayside structures / OHLE masts.

Wherever possible a greater clearance between the tracks and structures has been provided than the minimum specified by the IÉ track standards.

5.8.3 Overhead Clearances

I-PWY-1108 states the vertical clearance from the highest rail level to the soffit of all new overbridges must be a minimum of 5.3m. Where the minimum clearance cannot be achieved, it further states that a vertical height of 4830mm may be used, resulting in limitations to maintenance where extra ballast is proposed or a track lift is necessary in order to improve longitudinal profile. Under certain circumstances, the figure of 4830mm may be reduced to 4690mm

A further assessment of overhead clearances is provided in Appendix A, which provide the minimum clearances in Table 16 below:

Clearance classification	Height of PAN electrical clearance envelope
Enhanced Minimum	5535mm
Normal Minimum – Free Running	4799mm
Normal Minimum – Fitted	4679mm
Reduced Minimum	4534mm
Special Reduced Minimum	4454mm

Table 16: Minimum advised electrical clearances

Table 17 below shows the existing and proposed overhead clearances:

Overbridge	Proposed Clearance	Existing Clearance
OB7 Le Fanu Road	5300mm	5067mm
OB5 Kylemore Road	4830mm	4420mm
055A Khyber Pass Footbridge	4830mm	5207mm
OB3 Longmeadows Bridge	4690mm	4429mm
OB1	4690mm	4607mm
OB1a*	4830mm Min	4948mm
OBO2 Conyngham Road	4690mm	4135mm

Table 17: Existing and proposed overhead clearances

* Additional clearance is achieved as a result of track lowering for OB1.

5.8.4 Rail Types

5.8.4.1 Running Rail

All tracks shall be continuously welded CEN 54E1 profile rails inclined at 1:40 towards the centre of the track.

5.8.5 Track and Effective Gauge

The track gauge shall be 1602mm measured at right angles between the running edges of the rails in a plane 14mm below their top surface. In the CIÉ Inchicore Works Yard, there are numerous curves, which have a radius below 200m. For curves of 200m radius or less, the nominal gauge must be widened as per Table 18 below.

Track Radius	*Gauge*	*Check Rail Flangeway*
200–141 m	1606 mm	57 mm
140–111 m	1613 mm	64 mm
≥110 m	1619 mm	70 mm

Table 18: Gauge for track less than 200m radius

Notes:

1. Rate of change in gauge and flangeway widening must not exceed 1 in 400, e.g. 3 mm in 1200 mm (or two sleepers).
2. The dimension from the running edge of the non-checked rail to the inner flangeway face of the check rail must be 1556 (+1, -3) mm.

5.8.6 Rail Support System

5.8.6.1 Ballasted Track

All surface track is to be ballast track in accordance with IÉ Standards.

5.8.6.2 Slab Track

It is proposed to use low maintenance slab-track between the Liffey Bridge and Phoenix Park Tunnel under Conyngham Road, providing high track fixity and reduced depth of track bed. It shall have high electrical insulation properties to mitigate stray currents.

5.8.7 Switches and Crossings

Turnouts and Crossovers comply with IÉ standard geometries.

5.8.8 Vehicle Overrun Protection

In the proposed alignment design, buffer stops and trap points are required to prevent vehicle overruns. The current IÉ standard friction buffer type is a RAWIE 4 ZEB/6. This should be reviewed at the time of implementation to check if the standard buffer has changed. The trap points are positioned on the eastern end of the Inchicore works and Heuston Station to prevent vehicles entering the mainline without permission. The trap point is to use a P8 switch.

5.9 Rolling Stock

It is proposed that the existing DART rolling stock will be used on the Slow tracks with allowance for the Mainline services to run on the Slow tracks as a result of a major event or operational perturbation. Mainline services would operate on the Slow tracks under speed restrictions. This Study has taken the GSWR gauges, as defined in I-PWY-1101, into consideration for clearances at the various structures along the route.

5.10 Further Alignment Work Required

Areas identified as requiring further work at the next stage of design development are:

- An investigation into the effects of the new yard layout at Inchicore on rail operations and maintenance;
- Investigation into the effects of the new proposed turnback at Park West / Cherry Orchard Station and the redesign of the station platforms. It should be noted that due to the re-designation of the lines from a Fast-Slow- Slow-Fast configuration to a Slow-Slow-Fast- Fast configuration, this has an impact on line capacity at all the turnbacks as the trains will now have to crossover the Down Slow track to reach the Up Slow track when leaving any of the turnbacks;
- Investigation into the on-track auxiliary equipment required such as rail lubricators for some of the tighter radius curves;
- Ground Investigation including track bed investigation from Sarsfield Road to Le Fanu overbridge. Accordingly investigate the possibility of providing 5.3 m vertical clearance at Kylemore Road overbridge and achieving;
- Construction planning of the phased railway works related to the slewing of the Mainline tracks and construction of the four tracking from the end of KRP Phase 1 Works to Sarsfield Road. This shall include the phased construction of the retaining walls, ensuring that IÉ operational and access into the Inchicore Works are maintained, identifying the need for railway possessions and night-time working;

- Construction and traffic phasing for the demolition and construction of the proposed Kylemore Road overbridge and new station concourse area;
- Construction and traffic phasing for the demolition and construction of the proposed Memorial Road, OB1 overbridges and new station concourse area;
- Identification of the location of OHLE Masts and confirmation of all land take. Identify areas where a relaxation in the 10-foot requirements can be accommodated which would influence the form and location of the OHLE masts, and any derogations from standard in terms of placing OHLE Masts closer to the running rails to avoid acquiring lands beyond the existing IÉ property boundary.
- A summary of recanting/transition lengthening maintenance works needed to be carried out to perform re-designation of the lines from a Fast-Slow- Slow-Fast configuration to a Slow-Slow-Fast- Fast configuration are provided in Appendix B.

5.11 Potential Options for Future Development of the Alignment

Potential areas for further design development in the next stage of the Project include:

- Facilitate access from DART lines into the Inchicore Works if desired by IÉ;
- Review of the track alignment to identify the optimal crossover locations from the Mainline track onto the slow DART tracks;
- Changing bearing on Park West / Cherry Orchard Station to allow turnback and crossover to be placed closer together.
- Extending slab track system into Phoenix Park Tunnel and upgrading the drainage system to suit;
- Alterations to the alignment at Islandbridge Junction and OB1a to provide suitable solution for a future DART Underground connection.

6 Options Considered throughout the Study

6.1 Potential Kylemore Road Station

Table 19 below summarises the options which were considered for a possible station and track configuration for Kylemore Road Station.

Option Considered	Advantages	Disadvantages	Decision
Staged island platform arrangement.	Lower upfront construction cost. Less landtake required.	Must demolish and rebuild platform in new location for DART Underground causing disruption to operations and further costs. Alignment work may be required.	Not to proceed
Standard 4 platform arrangements.	One platform for each line. More operational flexibility.	Extra stairs and lifts would be required to serve all 4 platforms. Increased landtake outside of existing IÉ lands.	Not to Proceed
2 island platform arrangement.	Fits within Irish Rail Corridor. Both platforms built at the same time. Two sets of access lifts and stairs required.	One platform may be seldom used.	Preferred Option

Table 19: Kylemore Road Station options considered

6.2 Islandbridge Junction Approach

6.2.1 Option 1AS

The DART Underground Western Tie-In Study identified three suitable locations for a western tunnel portal in the Heuston Yard and for connection onto the Kildare Line. These options were referenced as Option 1AS, Option 2AS and Option 3AS, with the suffix 'S' recognising that the proposed underground station at Heuston is positioned along the southern end of the existing Heuston Station.

The key elements of Option 1AS are as follows, as illustrated in Figure 24 and listed in **Error! Reference source not found.**:

- The Portal for DART Underground is to be located in Heuston station rail Yard with the tie-in to the main line under Overbridge OB1;

- The portal can be used as either a launch or reception chamber for construction of the running tunnels;
- Four tracking of the mainline railway will be required from Park West to the end of the portal beneath bridge OB1;
- There will be an Underground Station at Heuston which will be located in the same position as that for the Railway Order. However, to meet limitations that can be achieved in terms of running tunnel depth it will be 0.9m higher than the railway order scheme;
- There will be no station at Inchicore;
- There will be a single turn-back which will be located at Park West station.

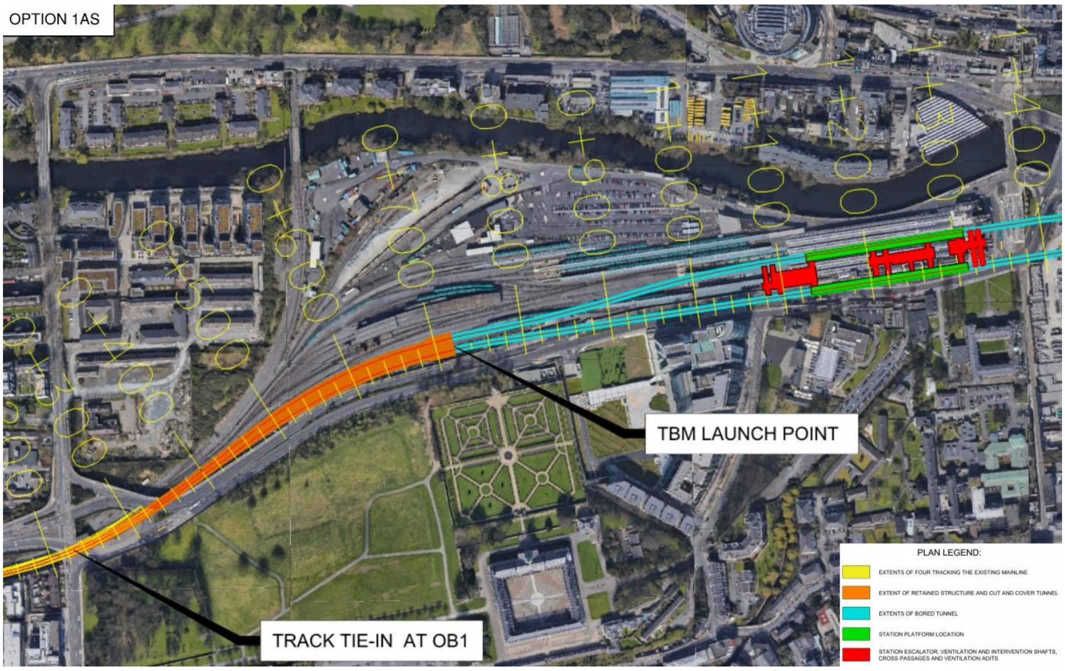


Figure 24: Option 1AS Station and Tunnel Portal Layout

Tunnel Configuration	Single Track Twin Bore Tunnel Configuration
Overview Description	Tunnel Portal in Heuston Yard, Station on South Side under the footprint of the existing station. Rail level at western end of Platform is circa -19.4 mOD Track Tie-In occurs under Rail Overbridge OB1.

Proposed Underground Station Location	Proposed Station is located on the south side of the existing Heuston Station. The bored tunnels will be enlarged to create the platform tunnels. Three cut and cover shafts are proposed; one on the east providing emergency intervention/ escape and ventilation; a central escalator shaft, and a western emergency intervention / escape and ventilation shaft. The eastern and central cut and cover shafts are separated by the Camac Culvert which will be strengthened / underpinned ahead of tunnelling and station excavation.
Proposed Location of Bored Tunnel Portal	The eastern and central cut and cover shafts are separated by the Camac Culvert which will be strengthened / underpinned ahead of tunnelling and station excavation. Tunnel portal is located within the Heuston Yard at Chainage +720 m and tie-in to the existing Mainline occurs under Overbridge OB1. This solution will require new rail overbridges at the location of the existing overbridges OB1 and OB1A to facilitate four tracking of the existing rail corridor.
Commentary	The platform rail level has been selected such that it is high enough to achieve a tie-in at Overbridge OB1 while ensuring that the footprint remains under the existing station. This option achieves a short tie-in length from the Underground Station platform level to the existing Mainline. The rockhead cover above the mined enlarged platform tunnels is approximately 2 m at the western end of the platform. Thus, it is considered that some alternative form of temporary ground support and additional settlement mitigation measures will be required.

Table 20: Summary of Option 1AS

6.2.2 Option 2AS

The key elements of Option 2AS are as follows, as illustrated in Figure 25 and listed in **Error! Reference source not found.**:-

- Portal in Heuston Yard with the station partially in Heuston Yard and extending beyond the eastern footprint on the existing mainline station;
- Tie-In occurs directly under existing OB1 Overbridge;
- Four tracking of the mainline will be required from Park West to the end of the portal beneath OB1 overbridge;

- Station straddles under existing mainline station footprint and under the station forecourt and Luas Stop/Traction Sub-station;
- To make provision for four tracking in the throat, DART alignment must move south and portal would slightly encroach into the citybound carriageway of St John's Road West;
- New overbridges needed at OB1 and OB1A.

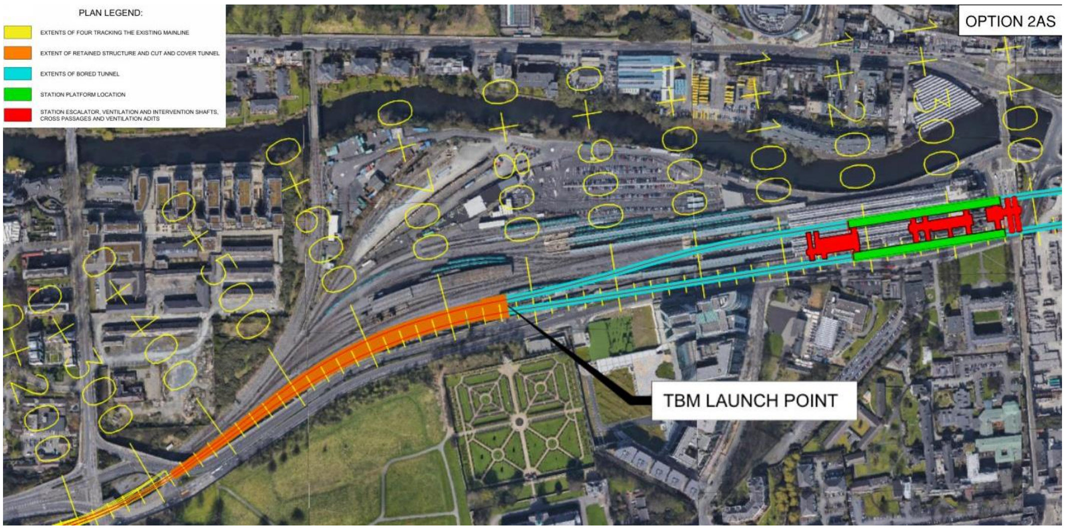


Figure 25: Option 2AS Station and Tunnel Portal Layout

Tunnel Configuration	Single Track Twin Bore Tunnel Configuration
Overview Description	Tunnel Portal in Heuston Yard, Station on South Side, under footprint of existing station and straddling under the Luas Stop and Traction Sub-Station. Rail level at western end of Platform is circa -19.4 mOD Track Tie-In occurs under Rail Overbridge OB1A.
Proposed Underground Station Location	Proposed Station is located on the south side of the existing Heuston Station. The bored tunnels will be enlarged to create the platform tunnels. Three cut and cover shafts are proposed; one on the east providing emergency intervention/ escape and ventilation; a central escalator shaft, and a western emergency intervention / escape and ventilation shaft. The proposed station straddles under the existing mainline station footprint, under the station forecourt and under the Luas Heuston Stop and the below ground Luas Traction Sub-station. The eastern cut and cover shaft would be located adjacent to the existing station façade. The Camac Culvert underpinning/strengthening would have to be incorporated into the structure of the central cut and cover shaft.

Proposed Location of Bored Tunnel Portal	Tunnel portal is located within the Heuston Yard at Chainage +770 m, 50 m west of Option Twin 1AS and thus creates more space at the tie-in to accommodate the temporary diversion of the existing Mainline. The proposed DART vertical alignment would tie-in under Overbridge OB1A. This solution will require new rail overbridges at the location of the existing overbridges OB1 and OB1A to facilitate four tracking of the existing rail corridor.
Commentary	The platform rail level has been selected such that it is high enough to achieve a tie-in at Overbridge OB1A while ensuring that the footprint remains under the existing station. This option achieves a short tie-in length from the Underground Station platform level to the existing Mainline.

Table 21: Summary of Option 2AS

6.2.3 Option 3AS

The key elements of Option 3AS are as follows, as illustrated in Figure 26 and summarised in Table 22:-

- The Portal for DART Underground is to be located in Heuston station rail Yard with the tie-in to the main line to the east of Overbridge OB1a;
- The portal can be used as either a launch or reception chamber for construction of the running tunnels;
- Four tracking of the mainline railway will be required from Park West to the end of the portal east of bridge OB1a;
- There will be an Underground Station at Heuston which will be partially located below Heuston Station and partially below the Diagio site;
- The rock head dips beneath Diagio's land and therefore the station needs to be lowered by 0.80m compared to the railway order scheme;
- There will be no station at Inchicore;
- There will be a single turn-back which will be located at Park-west station.

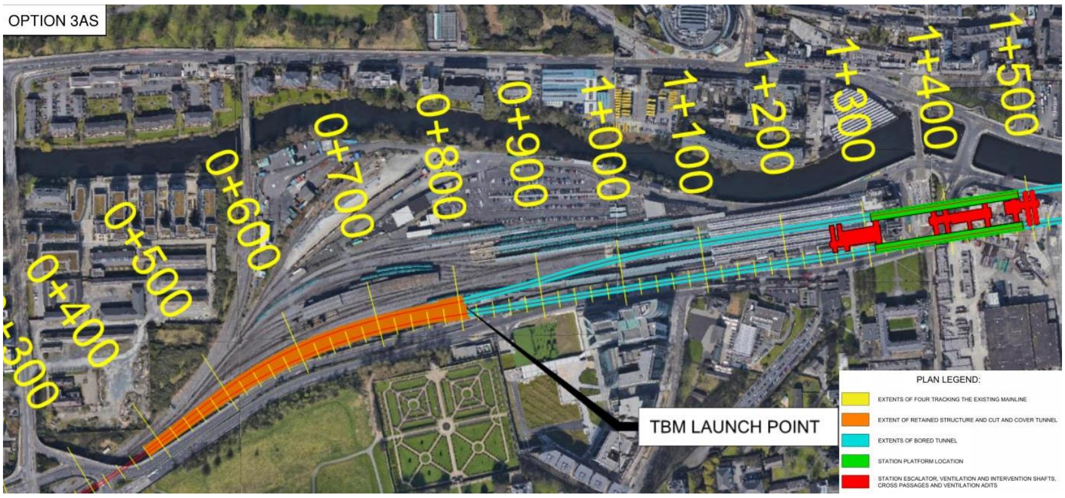


Figure 26: Option 3AS Station and Portal Layout

Tunnel Configuration	Single Track Twin Bore Tunnel Configuration
Overview Description	Tunnel Portal in Heuston Yard, Station on South Side straddling the St. James' Gate Brewery and below the footprint of the existing Station. Rail level at western end of Platform is circa -21.1 mOD Track Tie-In occurs east of Rail Overbridge OB1A.
Proposed Underground Station Location	Proposed Station is located on the south side of the existing Heuston Station. The bored tunnels will be enlarged to create the platform tunnels. Three cut and cover shafts are proposed; one on the east providing emergency intervention / escape and ventilation; a central escalator shaft, and a western emergency intervention / escape and ventilation shaft. The proposed station straddles under the existing mainline station footprint, under St. John's Road West and into the St. James' Gate Brewery. The eastern cut and cover shaft will be constructed in an area currently designated as the Kegging Yard of the Brewery whilst the central escalator cut and cover shaft will be constructed within the existing station.
Proposed Location of Bored Tunnel Portal	There is then a need to construct a mined escalator tunnel to the track level and construct a mined passenger access tunnel and adits leading onto the platforms, and leading to the eastern cut and cover shaft. Tunnel portal is located within the Heuston Yard at Chainage +805 m, 85 m west of Option Twin 1AS and thus creates more space at the tie-in to accommodate the temporary

	diversion of the existing Mainline. The proposed DART vertical alignment would tie-in approximately 40m to the east of overbridge OB1A. This solution will require a new rail overbridge at the location of the existing overbridge OB1 to facilitate four tracking of the existing rail corridor.
Commentary	The platform rail level has been selected such that it is low enough to enable the mined passenger and escalator tunnels to be constructed between the St. James' Gate Brewery and Heuston Station with generally sufficient rockhead cover with the exception of the eastern end where the rockhead cover reduces and alternative construction methodologies and settlement mitigation will be required. The rockhead level dips significantly beneath St. James' Gate Brewery reflecting the location of the pre-glacial River Liffey as discussed in Section 2.4 of this report.

Table 22: Summary of Option 3AS

6.2.4 Summary of Options Considered

Table 23 below summarises the options which were considered for the track alignment and configuration on the approaches to the Islandbridge Junction.

Option Considered	Advantages	Disadvantages	Decision
Retain existing bridges OB1 and OB1a.	Current traffic arrangement maintained. Low cost option. Alignment layout does not impede Option 3AS of the DART Underground Western Tie-In Study.	Vertical clearance too low for overhead catenary. Tight horizontal clearances to bridge abutments. Alignment layout impedes Option 1AS and 2AS of the DART Underground Western Tie-In Study. Option 3AS of the DART Underground Western Tie-In Study may not provide the most efficient operational solution.	Not to proceed
Replace OB1 with Single Span bridge and retain existing bridge OB1a.	Sufficient vertical clearance for overhead catenary. Increased horizontal clearance leading to more flexibility of rail design.	Vertical rail alignment will need to be lowered due to larger beams required in single span.	Preferred Option

Option Considered	Advantages	Disadvantages	Decision
	More cost effective and less disruptive solution than replacing both bridges. Alignment layout does not impede Option 1AS, 2AS or 3AS of the DART Underground Western Tie-In Study. Thus can accommodate a FFSS as well as a SSFF operational running.		
Replace OB1 with Double Span bridge and retain existing bridge OB1a.	Greater vertical clearance between rail level and OB1 soffit achievable. Alignment layout does not impede Option 2AS or 3AS of the DART Underground Western Tie-In Study.	Central pier limits flexibility of the rail alignment. Further impacts to the road level due to lines shifting north to accommodate central pier. Alignment layout impedes Option 1AS of the DART Underground Western Tie-In Study. Option 2AS and 3AS of the DART Underground Western Tie-In Study may not provide the most efficient operational solution.	Not to proceed
Replace OB1 and OB1a with Single Span bridges.	Greater vertical clearance between rail level and soffit achievable. Increased horizontal clearance leading to more flexibility of rail design. Alignment layout does not impede Option 1AS, 2AS or 3AS of the DART Underground Western Tie-In Study.	Severe disruption to road and rail traffic during demolition and construction. High cost of replacing both bridges.	Not to proceed

Table 23: Islandbridge Junction options considered

6.3 OBO2 Conyngham Road Bridge

Table 24 below summarises the options considered for the track alignment on the approaches to and below the existing Conyngham Road Bridge where the existing vertical clearance is inadequate.

Option Considered	Advantages	Disadvantages	Decision
Track lowering.	No changes required to Conyngham road bridge. Minimal disruption to operations if staged with tunnel remedial works. No road closures / diversion required. Works are limited to Irish Rail lands.	May impact the structural integrity of the tunnel base. Remedial works will be required for the bridge including spalling of concrete, extensive corrosion and missing waterproofing membrane. Structural life of existing bridge will mean replacement is required in the medium term.	Preferred Option
Raised road and new bridge with utility diversion structure.	Structural life of existing bridge will mean replacement is required in the medium term. Track lower not required, with flatter vertical curves possible.	Higher cost. Road diversions / closures will be necessary. Utility diversions req'd. Extent of associated roadworks to achieve raise in road level.	Not to Proceed
Combination solution.	Extent of track lower reduced, with flatter vertical curves possible. Extents of associated roadworks to achieve raise in road level reduced. Structural life of existing bridge will mean replacement is required in the medium term.	Road Diversions and closures will be necessary. Utility diversions will be required. Rail lower may impact the structural integrity of the tunnel base. Impact on rail operations.	Not to Proceed

Table 24: Conyngham Road Bridge options considered

6.4 FFSS vs SSFF up to Hazelhatch and Track Amendments

For the DART Expansion Project, the line designation from Hazelhatch to Heuston, reading from north to south, will be

- Slow (DART)
- Slow (DART)
- Fast (Intercity)
- Fast (Intercity)

The slow lines have been designed for the following speeds detailed in Table 25 below:-

Location	Speed (kph)
Heuston – OB1	30kph
OB1 – M50 Bridge West of Park West	100kph
Park West to Hazelhatch	100kph

Table 25: Slow Line Design Speeds

The fast lines have been designed for the following speeds detailed in Table 26 below:-

Location	Speed (kph)
Heuston – OB1	30kph
OB1 – M50 Bridge West of Park West	120kph
Park West to Hazelhatch	160kph

Table 26: Fast Line Design Speeds

In the DART Underground scenario, the line designations, when reading from north to south, will switch to:-

- Fast (Intercity)
- Fast (Intercity)
- Slow (DART)
- Slow (DART)

Consideration to be given to the signalling design of FFSS final line designation to incorporate the transition period from SSFF to FFSS. This could be achieved by signalling for bi-directional running on FFSS. Therefore, only requiring one re-signalling design.

6.4.1 Alignment Works required for Future Line Designation

A check was carried out to investigate what work would need to be carried out to ensure that the northern lines would be able to achieve the desired line speeds. Please note that for the purposes of this check the line designation used when reading north to south was:-

- Up Slow (DART)
- Down Slow (DART)
- Up Fast (Intercity)
- Down Fast (Intercity)

To facilitate the DART Underground, some curves on the northern lines between Heuston and Park West will need to be re-canted as part of the works to increase the speeds on the line. The curves in question are summarised in Table 27 and Table 28 below;

Up Slow Line			
Chainage			
From	To	Radius	Comments
10770.550	10830.550	4500	Recant element: 0mm to 20mm
12623.610	12680.750	5000	Recant element: 0mm to 10mm
12795.750	12862.530	4750	Recant element: 0mm to 15mm
13267.530	13327.500	2996.4	Recant element: 0mm to 20mm
13497.460	13654.730	3800	Recant element: 0mm to 20mm
13765.730	13821.730	4496.4	Recant element: 0mm to 15mm

Table 27: Up Slow Re-Canting

Down Slow Line			
Chainage			
From	To	Radius	Comments
10768.910	10828.970	4503.6	Recant element: 0mm to 10mm
13268.680	13328.730	3000	Recant element: 0mm to 20mm
13498.710	13655.810	3796.4	Recant element: 0mm to 15mm
13766.810	13822.860	4500	Recant element: 0mm to 15mm

Table 28: Down Slow Re-Canting

The section between Park West and Hazelhatch has been previously designed for speeds of up to 160kph as part of the KRP project. The current layout of these lines from north to south is:-

- Fast
- Slow
- Slow
- Fast

Some minor changes are advised to improve the running speed in some areas, detailed in Table 29, Table 30 and Table 31 below.

Down Slow Line			
Chainage			
From	To	Radius	Comments
		1991	Recant element: 50mm to 65mm
		5000	Recant element: 20mm to 25mm
		3238	Recant element: 30mm to 50mm
		3146	Recant element: 30mm to 50mm
		11508	Recant element: 10mm to 0mm

Table 29: Down Slow Curve Re-Canting

Up Fast Line			
Chainage			
From	To	Radius	Comments
		1996	Recant element: 50mm to 65mm
		7996	Recant element: 15mm to 20mm
		8004	Recant element: 0mm to 20mm
		11503	Recant element: 0mm to 15mm
		2143	Recant element: 40mm to 45mm

Table 30: Curve Re-Canting

Down Fast Line			
Chainage			
From	To	Radius	Comments
		8000	Recant element: 0mm to 20mm
		11499	Recant element: 0mm to 15mm

Table 31: Curve Re-Canting

Appendix C provides permanent way design calculations that highlight the areas where work will be required for the future line designation. Refer also to the alignment drawings contained in **Volume 1** of this Study.

6.4.2 Turnback Provision at Park West and Hazelhatch

As part of the DART Underground Western Tie-In Study, a turnback solution was proposed at Park West Station on the basis of the following track operational running, reading from north to south:-

- Up Slow (DART)
- Down Slow (DART)
- Up Fast (Intercity)

- Down Fast (Intercity)

Upon the completion of the future DART Underground tunnel, the operational running configuration will switch, reading from north to south as:-

- Fast (Intercity)
- Fast (Intercity)
- Slow (DART)
- Slow (DART)

As such and to provide maximum flexibility to IÉ, Arup has demonstrated that the track alignment on the approaches to the turnbacks at both Park West Station and Hazelhatch Station can be altered to accommodate either track running configuration.

7 Description of Emerging Preferred Option

7.1 Horizontal Track Design

The alignment commences at approx. Ch8+960 on a curved element adjacent to the Clancy Barracks property boundary. A right-hand curve of radius 20,000m allows the bearing of the straight to negotiate the existing abutment and piers of OB1 with sufficient lateral clearance of minimum 2.5m from edge of rail to structure.

In order to accommodate the 4 tracking within the existing corridor, there is a reduced 6 foot from the western end of OB1, to the eastern end of Sarsfield road Bridge, from approx. Ch9+180 to Ch9+880. The alignment fans out on the left-hand curve to the standard 6 foot, 10 foot configuration.

The alignment then fans out further to maintain operations during the construction of the new Sarsfield road bridge before returning to the standard track configuration.

To construct the preferred platform layout at Kylemore road bridge the alignment fans out to track centres of 10.870m between the up slow and down slow; and between up fast and down fast. The alignment then returns to the standard configuration on the right-hand curve at approx. Ch12+209.

The up fast and down fast lines then follow the existing alignment through Park West station and on to Hazelhatch. The up slow and down slow lines fan out from the fast lines to facilitate the turnback at Park West station.

In order to accommodate the turnback, the northern platform needs to be moved west as the clearance to the abutment of the M50 bridge is reduced. The alignment design includes provision for the turnback to be accessed from the down slow in the initial case and from the up fast in the DART Underground scenario. The slow line alignments then tie into the existing alignment to Hazelhatch at approx. Ch14+600.

Refer to **Volume 1** for the Permanent way drawings detailing the planned alignment between Heuston station to Park West. **Volume 1** details the re-canting required to change the track layout form slow, slow, fast, fast to fast, fast, slow, slow.

The horizontal alignment has been produced in accordance with I-PWY-1154 with the key design checks shown in Table 32 below:-

Parameter	Design	Compliant with Desirable parameters	Compliant with Limiting parameters	Compliant with Exceptional parameters
Minimum element length between transition curves	22.556	Yes	Yes	Yes

Parameter	Design	Compliant with Desirable parameters	Compliant with Limiting parameters	Compliant with Exceptional parameters
Desirable Minimum Straight between Curves	34.650	Yes	Yes	Yes
Desirable Minimum Curve Radius	250m	Yes	Yes	Yes
Minimum Transition Length	25m	Yes	Yes	Yes

Table 32: Horizontal Geometry Design

7.2 Vertical alignment Design

The vertical alignment has been produced taking into account the existing track levels *(reference: Cork Mainline Lidar)*. The vertical alignment is based upon the low rail levels. Please refer to **Volume 1** for the long sections detailing the vertical alignment for the up slow.

It should be noted that as per normal design practice, a vertical alignment has been produced for a single line, in this case the up slow. The vertical profile for down slow, up fast and down fast would be produced during the detailed design phase. It would be offset from the current vertical profile to provide a co-planar alignment on all curves throughout the length of the scheme.

The vertical alignment has been produced in accordance with I-PWY-1158 with the key design checks shown in Table 33 below:-

Parameter	Design	Compliant with Desirable parameters	Compliant with Limiting parameters	Compliant with Exceptional parameters
Desirable Maximum Curve Gradient	1.731%	Yes	Yes	Yes
Desirable Maximum Gradient at Platforms	0.4%	Yes	Yes	Yes
Minimum Sag Curve Radius	2,000m*	No	Yes	Yes
Minimum Hog Curve Radius	2,000m*	No	Yes	Yes

Parameter	Design	Compliant with Desirable parameters	Compliant with Limiting parameters	Compliant with Exceptional parameters
Desirable Minimum distance between Vertical Curves	25m	Yes	Yes	Yes
Minimum Length of Vertical Curve	21.750m	Yes	Yes	Yes

Table 33: Vertical Geometry Design

*This radius is limited to the approach to the Phoenix Park Tunnel.

7.3 Horizontal and Vertical Alignment Combinations

A check has been undertaken on the horizontal and vertical curve combinations.

There are some locations where a horizontal transition has been placed within a vertical curve due to alignment constraints. These locations are detailed in Table 34 below:-

Chainage (m)	Transition Length (m)	Vertical Curve length (m)	Vertical Curve Radius (m)	Justification
10+488.395 – 10545.726	25m	57.331m	6000m	Geometry is limited by proximity of P&C
13+727.390 – 13+777.843	25m	50.453m	8010.776m	Geometry is limited by proximity of P&C
14+095.667 – 14+134.073	30.036m	38.406m	9292.263m	Geometry is limited by proximity of P&C

Table 34: Horizontal Transition within Vertical Curve

Due to alignment constraints and placement of P&C, there is one location where a vertical curve has been placed within a horizontal transition. This location is detailed in Table 35:-

Chainage (m)	Transition Length (m)	Vertical Curve length (m)	Vertical Curve Radius	Justification
9+432.579 – 9+457.060	65m	24.481m	7600m	Vertical geometry is limited by significant track raise to the west or significant track lower to the east, impacting on existing retaining wall and presence of P&C.

Table 35: Vertical curve within Horizontal Transition

7.4 Applied Cant and Speed Assessment

The speed varies through the alignment. There is a 30kph limit on speed from Heuston to OB1 and a 120kph limit from OB1 to Park West. Using the 120kph linespeed, the proposed curvature and transition lengths have been checked to ensure compliance with the relevant standards in Table 36 below:

Parameter	Design	Compliant with Desirable parameters	Compliant with Limiting parameters	Compliant with Exceptional parameters
Maximum Applied Cant	100mm	Yes	Yes	Yes
Maximum Applied Cant - Platforms	0mm	Yes	Yes	Yes
Desirable Maximum Rate of Change of Cant	40mm/s	Yes	Yes	Yes
Desirable Gradient of Applied Cant	2.50mm/m	Yes	Yes	Yes

Table 36: Applied Cant and Speed Check

Refer to Appendix C for a detailed applied cant and speed assessment.

7.5 Bridge Structures along the Alignment

7.5.1 Replacement of Overbridge OB1

Overbridge OB1 must be replaced to accommodate four tracking as the existing bridge can only accommodate three tracks. Furthermore, the existing vertical clearance is below minimum standards.

As presented in Chapter 6 of this report, various alignment scenarios have been considered and the optimum solution is a single span bridge which would facilitate four tracks passing beneath the bridge deck which widen to six tracks at the east end, provide the minimum required vertical clearance of 4690mm, facilitates the connection of the DART Expansion lines to the Phoenix Park Tunnel and would permit a future DART Underground Western Portal to be constructed within the Heuston Yard and tie into the proposed track levels. Such a future DART Underground tie-in could be in line with the Options 1AS, 2AS or 3AS assessed under the Western Tie-In study with the best option to be selected at that time.

The existing OB1 bridge structure is an amalgam of different forms of construction, span configuration, skewed bridge beams and is highly unusual. The proposed replacement structure is driven by the horizontal road alignment at the existing signalised junction which connects the South Circular Road, Con Colbert Road and St. John’s Road West.

The road layout at this junction is again a bespoke solution and the proposed replacement OB1 bridge has sought to leave the horizontal alignment unchanged. If Overbridge OB1A had required to be replaced, then it is our view that this road junction layout could have been much improved from a junction capacity perspective. Consequently, the proposed bridge structure is on a varying skew angle of approximately 46 degrees and necessitates the bridge structure to be supported on bridge bearings with bridge expansion joints at either end, the provision of abutment inspection galleries and allowance for the maintenance and replacement of bearings and joints.

The general arrangement drawings for the proposed replacement bridge and the method of construction are contained within **Volume 1** of this report – including a potential viable Road Traffic Management Scheme which is a major element in selecting the final design.

It is envisaged that the bridge supporting piles would be constructed behind the existing bridge abutments of OB1 in phases to minimise traffic disruption. Then the bridge capping beam and abutment gallery would be constructed, a 72-hour possession would be granted to enable the existing bridge to be demolished and the new precast pretensioned W beams to be lifted into place plus the precast permanent formwork. Following the possession, the deck reinforcement, in-situ topping slab, surfacing, services and the like could be installed whilst trains remain operational.

The bridge deck consists of different types of precast pretensioned W beams which reflect both the span length and the fact that the clearance is restricted at the west end of the bridge deck and throughout the width of the structure. The sightline requirements at the junction, combined with the restricted land available at the southern abutment has driven the eventual highly skewed bridge proposal and the overall width of approximately 43.5m.

7.5.2 OB03 Longmeadows (Memorial Road) Bridge

A replacement overbridge is proposed at Memorial Road with an increased span length to accommodate four tracks and increased footpath widths of 4500mm to comply with current standards. The nominal span from centre of piled retaining walls is approximately 22.7m.

The proposed structural arrangement consists of a single span integral deck adopting precast pretensioned concrete Y and YE beams with composite in-situ reinforced concrete deck slab supported on piled reinforced concrete abutments. The vertical clearance is a minimum of 4690mm, as the existing clearance is sub-standard and there is limited scope to lower the existing track bed.

To minimise impacts on existing rail operations, it is envisaged that the proposed 900mm diameter piles and the abutment capping beams could be constructed behind the existing bridge abutments. Then during a weekend possession of the railway, as a minimum, the existing bridge structure could be demolished, the precast pretensioned concrete beams and precast permanent formwork installed. Then the deck reinforcement, precast H4a concrete parapets and in-situ concrete slab could be constructed whilst trains are operational.

During the bridge construction works, traffic which currently uses the crossing will need to be diverted elsewhere. It could be that the works will need to be undertaken during the summer holidays and that traffic be diverted to Sarsfield Road. The general arrangement drawings for this bridge replacement are contained within **Volume 1**.

7.5.3 Sarsfield Road Underbridges

Two new underbridges are required at Sarsfield Road, one to accommodate the DART Expansion tracks and which also acts as a replacement for the existing underbridge, and a second to carry the diverted Mainline tracks to the south of the proposed DART tracks. The rails are fixed to the structure of the existing 'Silent' underbridge and as the track geometry differs for the proposed DART Expansion, this existing bridge must be replaced.

It is proposed that both new underbridges at Sarsfield Road be 'E' type steel decks supported on piled abutments which are positioned behind the existing Sarsfield Road retaining walls, and the piles be sleeved over a length equal to the retained wall height, to prevent any additional horizontal pressures acting on the retained face of the existing masonry retaining walls. The general arrangement drawings for these bridge replacements are contained within **Volume 1**.

7.5.4 Khyber Pass Footbridge

A new pedestrian bridge and staircase will be required which serves as an emergency escape pathway. A new design has not been proposed for the pedestrian bridge as part of this Study which accepts the design was previously developed as part of the DART Underground Phase 3 Reference Design.

7.5.5 Kylemore Road Bridge

A new overbridge is required at Kylemore Road to support the highway and to act as a station entrance concourse for a future proposed station at Kylemore Road. A three span shallow braced steel composite deck is proposed with integral abutments and integral intermediate pier connections.

It is envisaged that by building the station concourse structure to the west of the existing overbridge, it would be feasible to maintain two lanes of traffic along Kylemore Road by phasing the construction sequence to use the station concourse as a temporary highway deck, whilst the existing overbridge is demolished and rebuilt. This construction and traffic phasing is recommended for the next stage of design development of the project.

The vertical clearance from top of the highest rail to the soffit of the bridge deck, proposed at Kylemore Road, is 4830 mm. There is no opportunity to alter the road levels on the approaches to Kylemore Road overbridge. The geotechnical site investigation previously undertaken in the vicinity of Kylemore Road overbridge is inconclusive.

However, the water table at Le Fanu overbridge was found to be approximately 1000mm below track formation level and without undertaking a detailed site investigation at track bed level, it is considered prudent to assume that the proposed rail levels in the area of Kylemore Road overbridge should not significantly alter from the current rail levels.

The general arrangement drawing for this bridge replacement are contained within **Volume 1**.

7.5.6 Le Fanu Overbridge

A new overbridge is proposed at Le Fanu Road, similar to that previously developed by IÉ as part of the proposed KRP2 Works. The proposed bridge is an integral deck consisting of precast pretensioned concrete beams supported on piled reinforced concrete abutments. The vertical alignment of Le Fanu Road is raised locally at the bridge and the approaches to achieve sufficient vertical clearance from track level to the soffit of the proposed bridge deck. The general arrangement drawings for this bridge replacement are contained within **Volume 1**.

7.6 Kylemore Road Station

A new station is proposed to the west of Kylemore Road, to act as a replacement for the Inchicore Station proposed in the original DART Underground. The station would only serve the DART train services; the fast mainline tracks would initially be located to the south of the slow tracks, and after the completion of the future DART Underground, so this arrangement would be reversed, thus requiring two island platforms.

The Station configuration proposed is modelled to some extent on that of the existing Park West / Cherry Orchard Station, but amended to suit the track configuration and with the potential for two island platforms.

The existing tracks at this location are rising on a vertical gradient of approximately 1.20%, heading west. At a station, the desired maximum vertical gradient is 0.2%. Over a platform of length 174 m, this would mean that the DART tracks would have to be lowered by approximately 1.74 m. Without a detailed site investigation and knowledge of the highest groundwater levels in this area, it is not feasible to propose a platform with 0.2% maximum gradient. Such a proposal could require the tracks to be constructed within a concrete U trough structure, which would have to be watertight, the rail corridor would need to be widened and additional landtake acquired.

It is recommended that following a detailed site investigation, the alignment of the DART tracks and platforms at Kylemore Road can be studied, examining the possibility of achieving a vertical gradient of 0.2% over the length of the station platform.

For the purposes of this Study, a vertical gradient of 0.385%, approximately 1 in 250, has been proposed over the length of the platform. This gradient was adopted as there is precedence elsewhere on the Hazelhatch Line for a station with this vertical gradient.

The Emerging Preferred Solution has sought to minimise landtake throughout the Project and this is reflected in the Property Interface drawings contained in Volume 1 of the Study. By bringing the track alignment to grade within the existing rail corridor, property impacts are largely limited to the widening of the existing rail corridor.

7.7 Retaining Walls

Retaining walls are required along the length of the widened rail corridor to accommodate the four tracking. In the areas from Sarsfield Road to the end of the KRP Phase 1 Works, the extent of the envisaged retaining walls is indicated in the Property Line interface drawings in **Volume 1** of the Study. The retaining walls are typically formed of contiguous bored piles for retained height greater than 3 m, due to rock being encountered or anticipated at relatively low depths below the existing track formation. For retained heights less than 3 m, a number of options are feasible including a king post wall and crib wall.

In the region of Kylemore Road Station, the plan location of the retaining walls is immediately on or adjacent to the existing property boundaries. Temporary landtake will be required on either side of the rail corridor to facilitate the installation of the new permanent retaining walls, the landtake typically falls within the back gardens to residential properties.

Running parallel to the Con Colbert Road, a new retaining wall is required from Overbridge OB1 until the area referred to as the “Horses Field”, on the northern side of the existing rail corridor. With the exception of a length of 90m of reinforced concrete retaining wall in the “Horses Field”, the retaining wall will be typically a 900mm diameter bored pile contiguous wall for a length of circa 800m. Where the retained height is approximately 6.5m of which the top 2.5m is made ground, the 900mm diameter piles at 1200mm centres will be required to have a length of approximately 15m. The bored pile installation will require temporary closing the outbound Bus Lane on the Con Colbert Road and local excavation of the embankment to create a piling platform.

The final alignment design has moved the tracks approximately 1.5m to the north of the existing battered masonry retaining wall which runs on the south side from Murray’s Cottages to Overbridge OB1. There is uncertainty over the details of this battered masonry retaining wall in terms of dimensions, depth to foundation level and the like.

However, in the course of the development of the structural arrangement for rail overbridge OB1, it was necessary to lower the track alignment in the vicinity of this retaining wall by a maximum of circa 700mm. Consequently at the next stage of development, it is recommended that trial excavations and cores be undertaken to determine the foundation level, structural dimensions and a structural assessment be undertaken to determine the residual strength of the wall. For costing purposes, a provisional allowance has been made to install a length of contiguous bored pile wall in front of the existing battered masonry wall in the event that the wall strength and stability proves inadequate.

Due to uncertainty around the actual foundation levels of the retaining walls between the existing overbridges OB1 and OB1A and the underside of foundation of the OB1A piers and abutments, it is proposed that trial excavations be undertaken during the next stage of the project. Again for costing purposes, a provisional sum has been allowed for any possible foundation underpinning in this area.

7.8 Track alignment through the Inchicore Works

The existing Mainline tracks will be slewed to the south through Inchicore to widen the existing rail corridor. As a consequence, it is necessary to:-

- Remove and relocate the Sancton Wood Tower (also referred to as the Turret) which projects from the Old Running Shed;
- Remove and relocate the Signal Box opposite the Sancton Wood Tower;
- Remove the lean back portion of the Maintenance Shed Building;

- Provide new crossovers to provide connection from the Mainline, into and out of the Works Depot. This includes a rearrangement of the sidings to include trap points and a head shunt;
- Remove some annexes behind the New Works Director Building;
- Impacts the boundary wall and property of No. 4 St George's Villas;
- Requires a new footbridge at the location of the current Khyber Pass footbridge and requires amendments to the access road at the northern side of the Track and Signal Building;
- Requires the current track drainage attenuation facility, located north of the CIÉ Sports Ground to be relocated;
- Construct a new underbridge at Sarsfield Road;
- Acquire the Dan Ryan Truck Rental site.

The proposed Mainline diversion ties back into the rail corridor just west of Murray's Cottages. The Mainline track is proposed to be vertically higher than that of the current track levels in order to achieve the road clearance at the location of the new Sarsfield Road Underbridge. Consequently, the actual tie-in to the existing Mainline levels occurs just west of Memorial Road overbridge.

The current Relief line, which exists over Sarsfield Road and on the approach to Heuston will be removed from Memorial Road to the CIÉ Inchicore Works.

7.9 Property

As discussed in the sections above, the Emerging Preferred Solution has sought to minimise landtake throughout the Project and this is reflected in the Property Interface drawings contained in **Volume 1** of the Study. By bringing the track alignment to grade within the existing rail corridor, property impacts are largely limited to the widening of the existing rail corridor.

7.10 Civils Design

The increase span requirements at Overbridge OB1 and the increased vertical clearance to permit electrified trains to run beneath, has only been possible by altering the vertical road levels at the junction over OB1. In turn, these increased road levels, necessitate altering the road levels on the approach roads to the junction.

Drawings detailed the required alteration to the road levels and any shallow retaining walls between the road carriageways are contained within **Volume 1** of this Study. Typically the road levels remain unaltered at the south abutment and rise up to approximately 800mm higher at the north abutment of the bridge, varying to suit the crossfall and the existing topography.

8 Feasibility Working Cost Estimate

8.1 Basis of Cost Estimate

The feasibility working cost estimate for the emerging preferred option has built upon the work which was previously undertaken during:-

- the DART Underground Western Tie-In Study in 2017;
- the original DART Underground Basis of Estimate dated 2009; and
- the feasibility working cost estimate prepared by Iarnród Éireann for the at grade four track widening of the existing rail corridor from Inchicore to the end of KRP Phase 1 and dating from 2010.

These cost databases had all previously been adjusted to allow for the effects of inflation up to Quarter 3 of 2017 such that they could be adopted for use in the preparation of the DART Underground Western Tie-In Study 2017. At that time and as part of the Western Tie-In Study, benchmarking was separately conducted against a selection of current prices which proved that there was little significant difference with the inflated rates.

These 2017 rates have further been adjusted for construction infrastructure inflation from 2017 to 2018, which has been assumed to be 2.5%.

The objective of the Basis of Estimate was to prepare the Capital Cost Estimate in a manner that comprised:

- The Main Works;
- Costs outside the main works, which included:
  - (i) Iarnród Éireann's management costs;
  - (ii) Land and property costs.

Costs outside the main works contract include Iarnród Éireann's direct costs, such as management costs, and other areas of Iarnród Éireann responsibility, such as the acquisition of land and property. Permanent and temporary property acquisition costs associated with the emerging preferred option have been provided by Iarnród Éireann property division.

The operations, maintenance and renewals (OMR) costs are not considered as part of the feasibility working cost estimate.

8.2 Feasibility Working Cost Estimate

The Feasibility Working Cost Estimate for the Emerging Preferred Option is €453,806,716 based on 2018 rates. No provision is made for future construction inflation. A breakdown of the costs is provided in Table 37 overleaf and contained within Appendix D of this report.

Description		Cost (€) 2018
1	Heuston Station - Enabling Works	3,000,000
2	Increased Electrification Costs into Heuston Platforms	3,500,000
3	Inchicore Works & Contractor Surveys	2,313,425
4	Park West / Cherry Orchard Station Turnback	10,250,000
5	Kylemore Station	6,303,750
6	Four Track Widening Memorial Road - Inchicore	100,396,010
7	Inchicore Building Removals / relocations	3,500,000
8	Inchicore Access Works	1,025,000
9	Fast Fast Slow Slow track adjustments	7,175,000
10	Provisional allowance for Temporary Closure of Sarsfield Road	768,750
11	Property for Park West / Cherry Orchard Station, Kylemore, B4T	7,687,500
12	Hazelhatch – Le Fanu Works	62,220,270
13	Le Fanu – Kylemore Works	31,290,411
14	Kylemore – Inchicore Works	26,126,035
	A) Direct Works Sub-Total	**€265,556,151**
15	Uplift on Estimate for level of Design Risk	8,749,907
	B) Direct Works Sub-total	**8,749,907**
	A + B Overall Direct Works Sub-Total	**€274,306,058**
16	Insurance	7,131,958
17	Design	17,589,876
18	Management	25,417,371
19	Risk	81,111,316
20	Vat	54,750,138
	Overall Indirect Works Sub-Total	**€186,000,658**
	Total Working Cost Estimate	**€453,806,716**

Table 37: Feasibility Working Cost Estimate

9 Conclusions and Recommendations

9.1 Aims and Objectives

The NTA in collaboration with Iarnród Éireann (IÉ) commissioned Arup to:-

- Produce an integrated preliminary design for the four tracking of the Kildare Line from the Phoenix Park Tunnel to the end of KRP Phase 1, suitable to be used as a scoping study definition for development of a Railway Order at the next stage of Design Development;
- Build upon and coordinate previous studies undertaken;
- Review the four tracking section from Heuston to Park West / Cherry Orchard Station in terms of track alignment, costings, property, connections to CIÉ Inchicore Works and a future possible station at Kylemore Road;
- Review the structures necessary to implement the proposed four tracking alignment;
- Review the four tracking design in the vicinity of the South Circular Road / Con Colbert Road and advise on the required structures which could facilitate DART Expansion and comment on impacts associated with both Fast-Fast-Slow-Slow and Slow-Slow-Fast-Fast operational running;
- Review the alignment from west of Park West / Cherry Orchard Station to just west of Hazelhatch to identify any changes to the existing trackwork to accommodate future DART Expansion running.

The output of the Study is a report with a recommendation for the Emerging Preferred Option, design drawings covering alignment, structures and property, and a feasibility working cost estimate.

9.2 Options Assessment

Various options have been considered for the track configuration, for a potential station at Kylemore Road, the modelling of both rail and road alignment at the Islandbridge Junction, achieving the required vertical clearance at Overbridge OB1 and OBO2 Conyngham Road, and facilitating both a fast-fast-slow-slow and a slow-slow-fast-fast operational running of DART services.

The options considered and the rationale for identifying the preferred options is presented in Chapter 6 of this report.

9.3 Feasibility Working Cost Estimate

The Feasibility Working Cost of the Emerging Preferred Option is €453.8M. The Feasibility Working Cost Estimate has been calculated for Quarter 4, 2018 and includes no construction inflation beyond this baseline date.

9.4 Recommendations

A number of studies and investigations are required at the Railway Order and Reference Design Stage of the Project to ensure that the scheme is fully optimised, these include the following:-

1. Inspect and Assess the residual life of Rail Overbridge OBO2 Conyngham Road Overbridge which appears to be in a very poor condition and which may influence the choice of either lowering the track alignment on the approach to the bridge or replacing the bridge in its entirety;
2. Determine the drainage capacity within the existing Phoenix Park Tunnel, determine how the numerous significant leaks within the tunnel can be reduced, repairs undertaken to the tunnel lining and how the electrification design will account for the present condition within the Tunnel. It is recommended that a detailed dimensional survey, inspection and structural assessment, and understanding of how the tunnel can be upgraded to permit electrified trains to operate be undertaken.
3. A fatigue assessment should be undertaken of the Liffey Bridge including an updated inspection and structural assessment to identify any critical structural elements;
4. There is an opportunity to revisit the choice of a single span bridge replacement for OB1 to consider a two span structure, depending on the location of double junctions in the approach to the Heuston Yard;
5. There is no information on the condition of the existing battered masonry retaining wall which runs along the south side of the existing rail corridor from OB1 towards Sarsfield Road, and past strengthening. A detailed condition survey and structural assessment of this wall is required;
6. The existing structural drawings of OB1A and the retaining walls between OB1A and OB1 are believed to show erroneous road levels and therefore there is doubt around the foundation levels to these structures which may then necessitate a need for underpinning the foundations. Trial pits should be undertaken to understand the actual foundation levels;
7. Detailed geotechnical, LiDAR, utilities investigations are required as a minimum along the alignment;
8. Sections 5.10 and 5.11 of this Study respectively itemise areas where further investigations could permit the alignment to be optimised and potential options for improving the Scheme at the next Stage dependent on the project requirements.

Appendix A

Basis of Design - Electrical Pantograph Clearance Envelopes

A1

Appendix B

Four Tracking Speed Study

B1

Appendix C

DART Expansion - Kildare Line - Alignment Calculations

C1

Appendix D

Feasibility Working Cost Estimate Breakdown

D1