METROLINK

Integrated Transport. Integrated Life.

A7.10 Trinity College – Alignment Options Assessment

Contents

APPENDICES

Executive Summary

This assessment is being undertaken in order to assess if moving the Metrolink tunnel alignment further westwards is feasible or preferable with the objective to reduce potential EMI/settlement/vibration impacts on sensitive receptors at Trinity College Dublin (TCD), Leinster House and other buildings.

Programmes of public consultation on MetroLink were conducted in 2018 and in 2019, during which members of the public and other stakeholders were invited to submit their views and observations on the Emerging Preferred Route (EPR) and Preferred Route respectively. At that time the MetroLink alignment between Tara and St. Stephen's Green (SSG) stations incorporated a 400m radius curve taking the alignment close to or under TCD properties. This alignment was adopted as the Preferred Route and subsequently developed as part of the current Preliminary Design alignment.

Subsequent consultations, assessment of existing baseline conditions and identification of construction and operational impacts along the corridor to inform the environmental assessment of the route supported concerns raised by TCD at the 2019 and earlier 2018 public consultations with particular respect to items of sensitive research equipment, potentially susceptible to either EMI/EMC effects or vibration. Further specific assessment indicated that the potential impacts on these items of equipment could be mitigated by both design measures on the track slab to mitigate noise and vibration together with specific mitigation at the affected equipment through the addition of 'Active Shielding', a recognised mitigation measure which has been successfully adopted in other similar situations. Support for the provision of this mitigation has been confirmed by TII to TCD.

Notwithstanding the above, TCD requested consideration of alternative track alignments further to the west to provide greater EMI mitigation to their equipment and to minimise the need for installation of Active Cancellation or other measures associated with the current Preliminary Design alignment.

Alternative alignment options were assessed equally along with the original EPR alignment, which is termed **Option 0** in this report. The Options assessed are as follows:

- **Option 0 PDR (Preliminary Design Report) Alignment:** This is the original EPR, retained as the current Preliminary Design alignment, with a 400m curve radius (R400) past the TCD campus and under Government Buildings to the south.

- **Option 1:** R400m Modified PDR **–** this retains the same horizontal alignment as Option 0 but with an adjusted vertical profile to increase rail depth below Leinster House and TCD buildings. (i.e. essentially the PDR Option 0 mitigated to reduce currently assessed impacts on the buildings above). No change to the Tara and St Stephen's Green station locations.

- **Option 2:** New R350m Horizontal Alignment – an alternative horizontal alignment running to the west of Option 1 and with the same adjusted vertical profile (increased depth) as per Option 1. Taking advantage of the proximity of Tara Station and the fact that all commercial trains will be stopping there, the transition curve south of and next to the station is shortened to 30m to assist the westward movement of this alignment option.

- **Option 3:** New R302m Alignment - an alternative horizontal alignment running to the west of Option 2 and with the same adjusted vertical profile (increased depth) as per Option 1.

- **Option 4:** New 302m Alignment including a 1-degree rotation of Tara station in order to further increase the westwards movement of the metro alignment past the TCD campus.

Note that Options 1,2 and 3 retain the current station arrangement at Tara and SSG stations. Option 4 provides a slight rotation of Tara station but retains SSG station unaltered.

Multi Criteria Analysis Process

The Multi Criteria Analysis (MCA) of these options has been developed in line with The Common Appraisal Framework (CAF) for Transport Projects and Programmes which develops a common framework for the appraisal of transport investments for DTTaS. It is consistent with the PSC (Public Spending Code). The TII Project Appraisal Guidelines for National Roads (PAG) translate the requirements of CAF in relation to National Road infrastructure Projects and Programmes

This MCA process for the Options assessment has adopted a 2 Stage process. Stage 1 is a high-level pass/fail assessment from which a Stage 2 more detailed assessment is undertaken of the remaining options. The options assessment methodology is set out in section 3 of this report.

Outcome of the Assessment and MCA Process

The assessment indicates the following:

Option 0 - the current PDR horizontal and vertical alignment. This alignment requires the provision of Floating Slab Track (FST) through this section to mitigate operational noise and vibration together with Active Cancellation measures at all identified TCD sensitive equipment locations to mitigate EMI effects. It would have slightly worse noise and vibration impacts than other options due to the alignment passing directly under some TCD and Government buildings and would require additional damping at track to mitigate a specific vibration frequency arising from the FST impacting equipment in the SNIAM and Fitzgerald buildings.

Option 1 – the current PDR horizontal alignment, but with lowered vertical alignment would provide improved settlement and noise mitigation compared to Option 0. However, it does not provide any significant benefit in terms of EMI or vibration effects on TCD equipment, which would continue to require provision of Active Cancellation measures for all assessed equipment, noting that this is a proven method for mitigation of EMI effects and has been successfully used elsewhere. It would continue to require additional damping measures at track for the specific equipment in the SNIAM and Fitzgerald buildings.

Option 2 - provides both a revised horizontal and vertical alignment, remaining compatible with design parameters along the alignment and with no impact on train operation speeds. It provides improved settlement and noise mitigation compared to Option 0 and is a significant improvement in terms of potential EMI/EMC effects at TCD. Residual mitigation of remaining EMI effects can be addressed through the introduction of Active Cancellation at 3 no. NMRs and possibly 3 no. SEMs with a current installation cost estimate of €150,000-€300,000. Active Cancellation is an accepted and proven method of addressing this issue and is compatible with the equipment identified. It would be an effective mitigation for those items of equipment that would potentially still require some protection and TII have previously committed to funding this form of protection. This option would also require some additional mitigation at track to address the potential localised specific vibration frequency issue at the SNIAM building equipment only.

Option 3 - incorporates a further reduction to 302m for the horizontal curve radius and maintains the lowered vertical alignment. This Option would provide a further westward movement of the alignment and our assessment indicates that no Active Cancellation measures would be required at known TCD equipment locations under this Option and no additional damping required for the track. However, this alignment has particular disadvantages:

- It will reduce or remove current design tolerance between train DKE and tunnel furniture, limiting future construction and Operator design options and which will remain a constraint on the system for its operational life. Such restrictions at this Preliminary Design stage are not considered desirable due to the future construction/operation risks introduced.
- There would be additional risk during the TBM drive of potential further speed limitations if the tunnel drive deviated from the design alignment and needed correction through tighter curves.

- It will have a permanent speed restriction due to the tighter radius curve south of Tara Station, impacting journey time and incurring an ongoing economic cost incurred over the life of the system.
- An exceptional element would be introduced within the overall alignment, outwith the proposed design parameters for MetroLink.
- The risk of wheel rail interface issues arising during the operational phase is considered to significantly increase on curves down to 300m radius or less, with a 350m radius recommended as the minimum radius.
- It potentially opens up opportunities for other locations to be challenged regarding alignment design provided.

Option 4 – incorporating 302m radius curves both north and south of Tara station, with an associated 1-degree rotation of the station, was shown to provide only around a 5m additional westward movement of the alignment compared to Option 3 at sensitive TCD equipment locations. It would have the same concerns and constraints as Option 3 and was not considered to provide any additional benefit to the EMI mitigation whilst increasing the construction and operational impacts associated with the two tighter 302m curves required compared to the minimum 350m curve adopted elsewhere.

Recommendation

The overall assessment has considered the balance of advantages and disadvantages of all the options equally. It is considered that Option 2 offers advantages over Option 0 (the PDR alignment), and when considered against the other alternatives is the preferred Option to be taken forward.

It is therefore recommended than an amendment is made to the proposed PDR alignment for incorporation in the Railway Order application. The horizontal alignment should be adjusted by moving it west of the current proposed alignment using a R350m horizontal curve and further adjusted in the vertical section to deepen the alignment by approximately 3m under the TCD Campus area.

TII will continue to work with TCD with respect to provision of appropriate mitigation to protect sensitive equipment at locations that would still require some protection based on this revised alignment.

1. Introduction

1.1 MetroLink Route

Project Ireland 2040 and the National Development Plan (2018-2027), promoted MetroLink as a fast, high capacity, high frequency, modern and efficient public transport Light Rail service for people travelling along the Swords/Airport to City Centre corridor. The commitment to MetroLink was again confirmed in the recent 2022-2042 Greater Dublin Area Transport Strategy Update.

The route from Estuary to the City Centre is approximately 19km in length and the completed system will have 16 Stations, and a journey time of approximately 25 minutes. The route from Estuary to Charlemont is shown in Figure 1.1

Figure 1.1 MetroLink Route – Estuary to Charlemont

The NTA commissioned Arup Consulting Engineers to undertake a Route Alignment Options Study for the Scheme in 2016. The objective of the study was to identify an Emerging Preferred Route (EPR). It was completed at the end of February 2018 and included a Concept Design for the EPR. The document 'New Metro North

Alignment Options Report, Volume 1: Main Report' identified and assessed a number of alternative route options for the Metro scheme through the city centre. In January 2018, the NTA/TII commissioned Jacobs/Idom to provide ongoing engineering design services through to scheme completion.

This Alternative Alignment Options Assessment has been undertaken to assess if moving the Metrolink tunnel alignment further westwards to reduce potential EMI/settlement impacts on sensitive receptors in the TCD campus is feasible or preferable given potential new impacts on adjacent areas including Leinster House and other buildings along the route corridor. This assessment also takes account of additional criteria such as engineering, economics, alignment and noise of moving the alignment westwards.

1.2 Public Consultation Status Quo – Tara Station to St Stephen's Green Station

A programme of public consultation was conducted in 2019 between 22nd March and 11th May, during which members of the public and other stakeholders were invited to submit their views and observations on the Preferred Route. For the section between Tara station and St Stephen's Green (SSG) stations, a number of comments were received on the location of the Tara station.

In addition, TCD reiterated specific concerns (first raised at the 2018 Emerging Preferred Route consultation) in regard to the tunnel alignment under the TCD Campus and its potential interference on current and future research activities. Although consideration was given to the comments received, the subsequent development of the route to its current Preliminary Design alignment retained both the tunnel alignment and station locations at Tara and at St Stephen's Green pending more detailed assessment of impacts and mitigations.

The development of the Tara MetroLink station has taken account of the specific constraints in this location, with the station tightly constrained by the adjacent Irish Rail station structures; retention during construction and operation of Poolbeg Street and services within that road; retention of Townsend Street; and maintaining the large brick sewer in Townsend Street which lies very close to the proposed station construction.

During development of the Preliminary Design, consultations and meetings with TCD considered the specific concerns regarding operational impacts and EMI/Vibration effects on sensitive equipment and sensitive receptors within the Trinity campus due to the tunnel alignment. A number of potential mitigation options have been discussed with TCD by TII and Jacobs Idom (JI) to mitigate these potential impacts. These are considered in detail in this report and assessed. A Multi-Criteria Analysis assessment has been carried out to determine the most advantageous mitigation option taking into account all the appropriate criteria.

1.2.1 TCD affected buildings and sensitive receptors within

The main concerns raised by TCD regarding the current PDR alignment relate to operational effects of electromagnetic interference and vibration associated with trains running in the tunnels below or offset from sensitive equipment. Based on a list of sensitive equipment and their locations, as supplied by TCD, distances to these sensitive receptors have been calculated and are shown in Table 1.1 below. The Table also shows these distances increased with the alternative tighter radii on the tunnel alignment using R350m and R302m radius curves past the TCD campus.

Figure 1.2 shows a map of the buildings where the equipment is located and the currently proposed tunnel alignment (PDR alignment) in blue.

Table 1.1 TCD Equipment notified as sensitive to EMI/EMC effects

Building		Equipment	Distance to Alignment (in plan) R=400m	R=350m	R=302m
11 - Chemistry					
	Room 0.4	2 x NMRs [SURVEY]	8.7	48	70
	Room 0.5	1 x NMR	16.8	56	78.1
14 - Panoz Institute					
	Room B23	1 x SEM	65.6	109	131.1
	Room B24	1 x SEM	75.5	115.1	137.2
	Room B28	1 x SEM [SURVEY]	68.4	108.9	130.7
23-LLoyd Institute					
	Room UB15/16	1 x MRI	52.4	78.6	94.2
	Room UB14	1 x MRI [SURVEY]	52	78.9	95.2
24 - SNIAMS					
	Room 0.16	1 x SQUID [SURVEY]	35.2	57.2	69.9

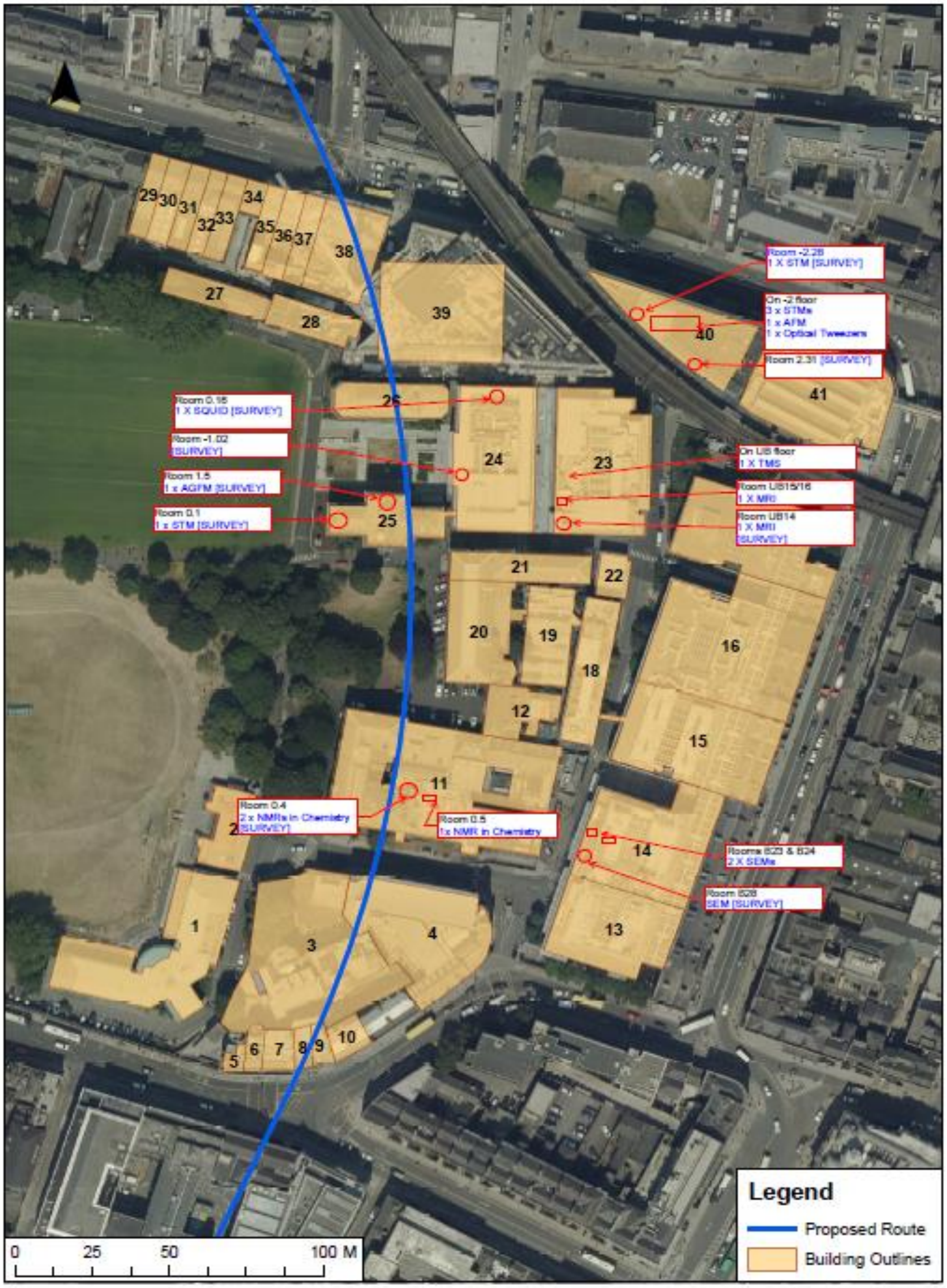

Fig 1.2 TCD sensitive receptors and PDR tunnel alignment

1.3 Tara to SSG Stations Tunnel Alignment Options Assessment

Following consultation with TCD it was agreed to undertake a review of the Preliminary Design tunnel alignment between Tara and SSG stations in order to determine if an alternative alignment could be identified which would mitigate EMI and vibration impacts at the TCD campus whilst not incurring significant new impacts elsewhere. The assessment would have regard for all relevant assessment criteria including engineering, economic/cost, construction/operations and environmental criteria.

A number of options were developed to assess against the current Preliminary Design alignment option termed Option 0. The options are described in the following section.

2. Tunnel Alignment Options Description

In Section 1.2 we have identified equipment that may be affected by EMI/EMC and vibration impacts arising from the Metrolink construction and operational phases. These effects could be somewhat mitigated by, by moving the tunnel alignment to the west; or by implementing specific mitigation measures applied within the affected rooms or at the receptor equipment itself. However, movement of the tunnel alignment could also result in impacts at other sites along the new alignment.

Whilst moving the affected equipment to other sites more distant from the alignment is also a mitigation possibility this option has not being assessed in this report.

Whilst it is recognised that a realignment of the tunnel westwards away from the Campus would provide varying degrees of mitigation to the TCD equipment, a change to the alignment may also have environmental impacts on other buildings along the varied route and which require assessment.

A list of alternative options to the existing PDR - Option 0 were developed for this further investigation and assessment. The options assessed are as follows:

- **Option 0 PDR (Preliminary Design Report) Alignment:** This is the original EPR, retained as the current Preliminary Design alignment, with a 400m curve radius (R400) past the TCD campus and under Government Buildings to the south.
- **Option 1:** R400m Modified PDR **–** this retains the same horizontal alignment as Option 0 but with an adjusted vertical profile to increase rail depth below Leinster House and TCD buildings. (i.e. essentially the PDR Option 0 mitigated to reduce currently assessed impacts on the buildings above).
- **Option 2:** New R350m Horizontal Alignment – an alternative horizontal alignment running to the west of Option 1 and with the same adjusted vertical profile (increased depth) as per Option 1
- **Option 3:** New R302m Alignment - an alternative horizontal alignment running to the west of Option 2 and with the same adjusted vertical profile (increased depth) as per Option 1.
- **Option 4:** New R302m Alignment incorporating a skew of approximately 1 degree to the Tara St Station Box with an alternative horizontal alignment running to the west of Option 2 and with the same adjusted vertical profile (increased depth) as per Option 1.

Fig 2.1 below is an overview of the existing PDR alignment and the alternative alignments considered. Plan and vertical details of each alignment Option above are provided in Appendix D.

The ‘modified preliminary design’ (Option 1) retains the same horizontal alignment but changes the vertical profile to increase the tunnel depth between Tar and St. Stephen’s Green stations to provide increased cover to buildings above the tunnel alignment. This will provide additional settlement mitigation and potential assistance with mitigation through the TCD campus.

Option 2 is an alignment adopting the MetroLink proposed minimum design radius (350m) for consistency with the remainder of the Project. However, in order to push the alignment to the west as much as possible, the transition curve next to Tara Station is shortened to 30m, extending the cant transition 55m into the circular curve. This results in non-standard track geometry, which has a slight negative impact on track maintenance and passenger comfort, although values are kept within Metrolink design parameter limits.

Option 3 and Option 4 adopt a lower radius curve (302m) in order to move the alignment further away from the TCD campus. However, they introduce a curve requiring a locally reduced design speed of 60kmph compared to the 80kmph design speed adopted elsewhere on MetroLink. Option 4 also incorporated an additional 302m curve to the north of Tara station and a small skew of Tara station to achieve a slight further westward movement in the alignment past the TCD campus

Differences in depths from ground level to top of rail for the different options including the base Option 0 are shown in Table 2.1 below.

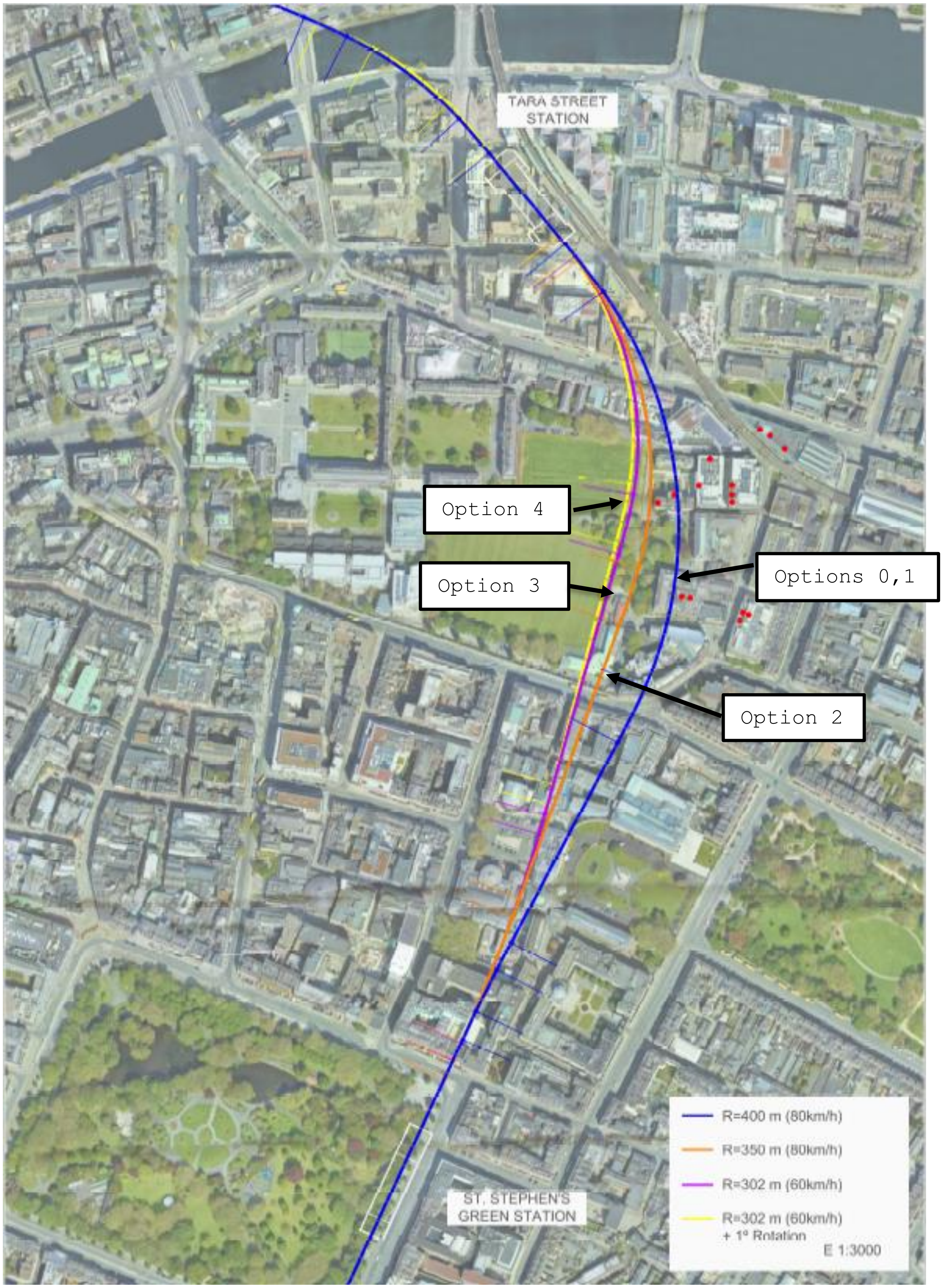

Fig 2.1 Option alignments Tara Street to St Stephen’s Green

Table 2.1 Differences in depths from ground level to top of rail

Option		Depth GL to TOR (m)		
		17+700	17+800	17+900
PDR	Preliminary Design, original VA, R=400m	21.9	20.8	23.8
Option 1	Prelim Design, modified VA, R=400m	24.9	26.2	28.9
Option 2	R=350m	25.4	26.4	28.2
Option 3	R=302m	25.5	26.1	26.6
Option 4	R=302m with rotation of Tara Station box	25.5	25.9	26.7

Note: The vertical profile for Options 1, 2, 3 and 4 are following similar vertical profiles with almost identical depths of cover.

2.1 Tara Station and proposed tunnel re-alignment options to SSG Station

Any changes to the tunnel alignment between Tara Station and SSG Station (ie under TCD and Government and other buildings) can also be effected by changes in station alignment, particularly at Tara station.

Whilst developing the options 1 to 3 in Section 2, consideration was given to the impact of also moving or skewing the station box at Tara Street to facilitate a more westerly movement of the alignment under TCD. This is discussed in Section 2.1.2 below.

2.1.1 Interchange with Tara DART Station

The plan layout of the DART Station is shown in Figure 2.2 below, which indicates the two existing DART station entrances. The main Tara St station access is off Georges Quay near to and east of its junction with Tara Street on the south side of the River Liffey. The second southern entrance provides access off Townsend Street. This second entrance is currently only available to passengers during the week-day peak hours.

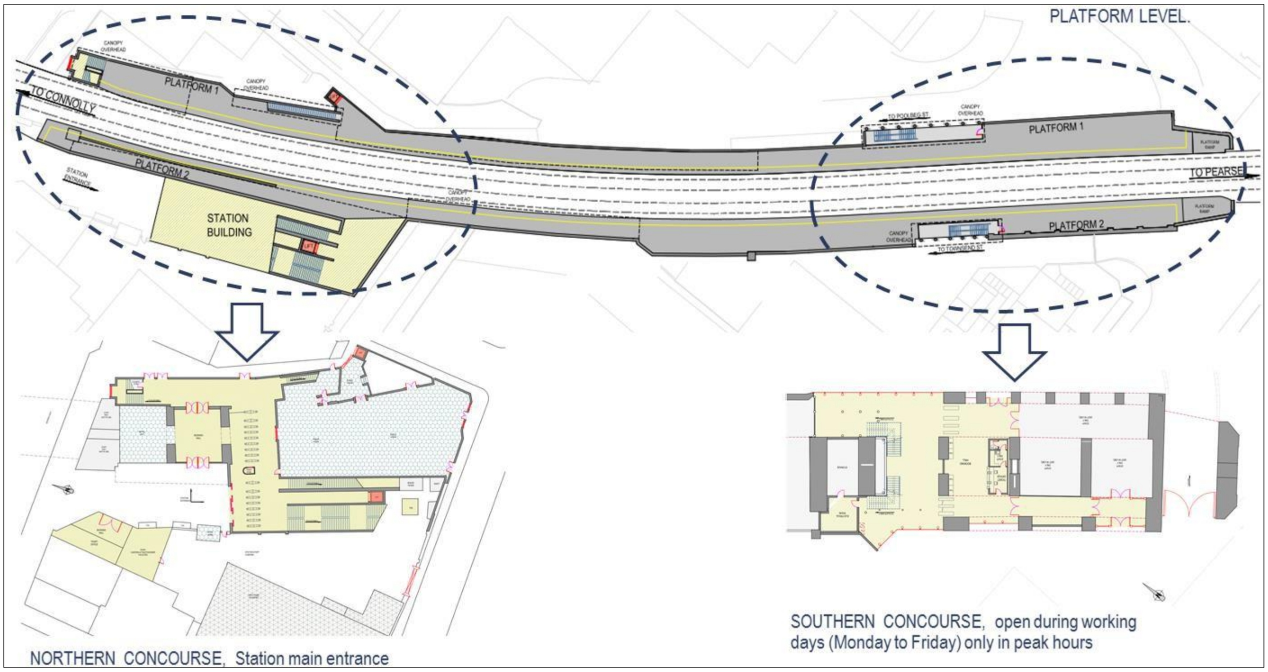

Figure 2.2 Layout of Tara Street DART Station.

The proposed Tara Street Station is located such that the necessary construction works would cause only a limited impact to DART station operations and the design would allow for good connections to be made between MetroLink and DART services. This is also more critical as the DART + project is developed. Any alteration works to the current MetroLink Tara Station would thus need to maintain these connections so significant relocation of Tara MetroLink Station away from the current station is not considered.

2.1.2 Rotation and/or moving the Tara Station Box

During consultations with Trinity College representatives and the consultant Engineer (Arup) it was suggested that rotating the current Tara Station box might provide the ability to move the alignment further to the west, than is currently possible if the station orientation were to remain as per the current preliminary design.

As part of this assessment a slight rotation of the selected Tara station box was considered in order to offer potential for an additional westwards movement of the metro alignment past the TCD campus and thereby pushing the tunnel further from the sensitive receptors in TCD – this is represented by Option 4 as shown in Figure 2.1.

The location of the Tara station is tightly constrained by the following which must be considered for any rotation of the station:

- The requirement to provide efficient access between the metro station and the Tara Dart station
- The presence of the large brick Irish Water foul sewer running along Townsend Street
- The proximity of Poolbeg Street to the north of the station box and need for maintenance of this road and its traffic flows during construction

To consider the potential impact and benefit of a rotation of the station box to provide a further alteration to the metro alignment, assessment was made of the following changes.

The current alignment between O'Connell Street and Tara stations is formed by a 350m radius curve followed by a reverse curve with radius 375m. By reducing the second curve radius down to 302m and retaining the current requirement for a 20m straight off the platform ends to accommodate options from future rolling stock suppliers, this limits a rotation of the Tara station to 1-degree but which facilitates an additional movement of the alignment westwards as it runs south from the station past the TCD campus. These alignment changes at the station location are illustrated in Figures 2.3 and 2.4 below, comparing Option 4 with Option 0.

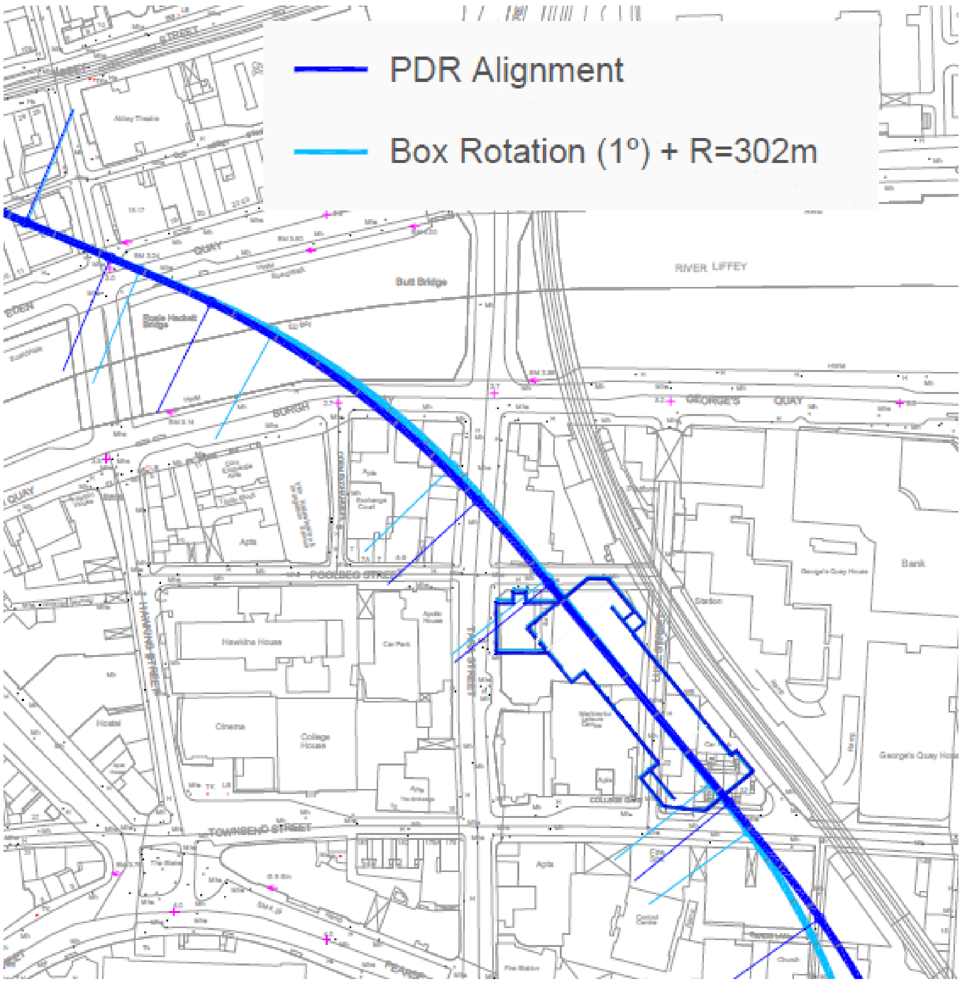

Figure 2.3 Option 4 alignment compared to Option 0 alignment

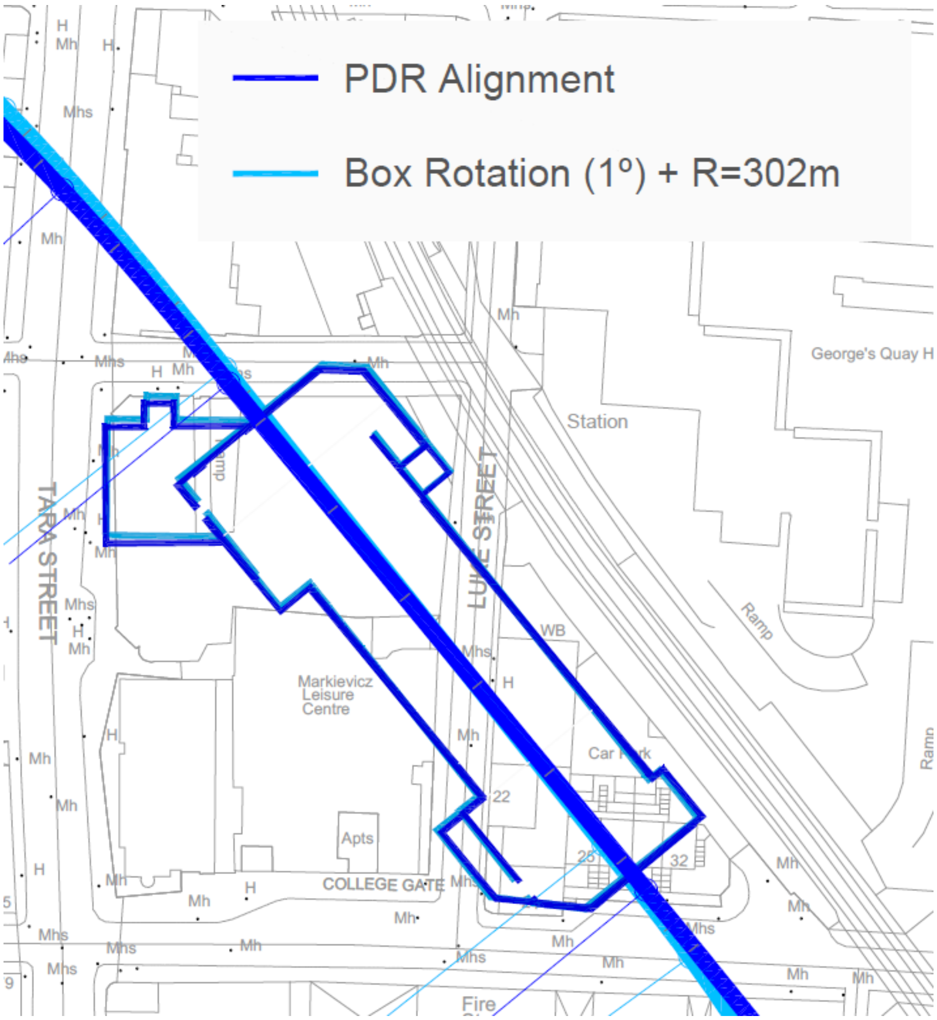

Figure 2.4 1-degree rotation of Tara Station box

Impacts associated with this change are:

- The introduction of a 302m radius curve north of Tara Station requires an associated speed reduction through the curve to 60kmph to maintain minimum tunnel space proofing. This would require an associated speed constraint on this section of 60kmph compared to the MetroLink normal design speed of 80kmph.
- The station rotation would be combined with a similar 302m radius curve leaving Tara Station southwards to maximise offset of the alignment, this would also require a localised design speed of 60kmph.
- Reducing the radius from 400m or 350m down to 302m with a rotation of the station box reduces available space proofing design tolerances between DKE and tunnel furniture, restricting future space in the tunnel for additional or changes to required equipment.
- The tighter alignment radii of 302m would require closer control of the TBM drive as recovery of any deviation through a correction curve would require a further reduction in alignment radius with associated future further potential metro operational speed reduction

- Transition curves for the 302m radius curves would start at the end of the 20m straight from the platform ends but would start inside the station box, passing through the diaphragm wall of the box at a slight angle.

- The station box rotation would encroach approximately 1m further into Poolbeg Street, further constraining available road space for utility diversions and traffic access during construction.

- MetroLink travel time would be increased by +3.76s southbound and 3.88s northbound or 7.64s over a return journey cycle. Based on current passenger forecasts this would accumulate to a significant monetary loss in terms of value of time over the operational life of the system.

- The additional offset achieved with this option would be limited compared to provision of a 302m radius south of the station only as in Option 3. In particular, the additional offset achieved by the SNIAMS building would be approx. 5.1m and approx. 4.8m by the chemistry building.

The presence of large trunk sewers in Townsend Street are a major challenge to any proposal requiring works close to or within Townsend Street. Included in the road are the 2.4m circular brick (combined) foul sewer and a 1.2m circular concrete (combined) foul sewer. These sewers handle the waste flows from much of Dublin City and represent a very significant engineering challenge in this built-up area.

The current station layout lies close to a short length of these sewers as shown on Figure 2.5. Option 4 has been developed to provide a rotation of the station box whilst maintaining the same minimum offset to these utilities.

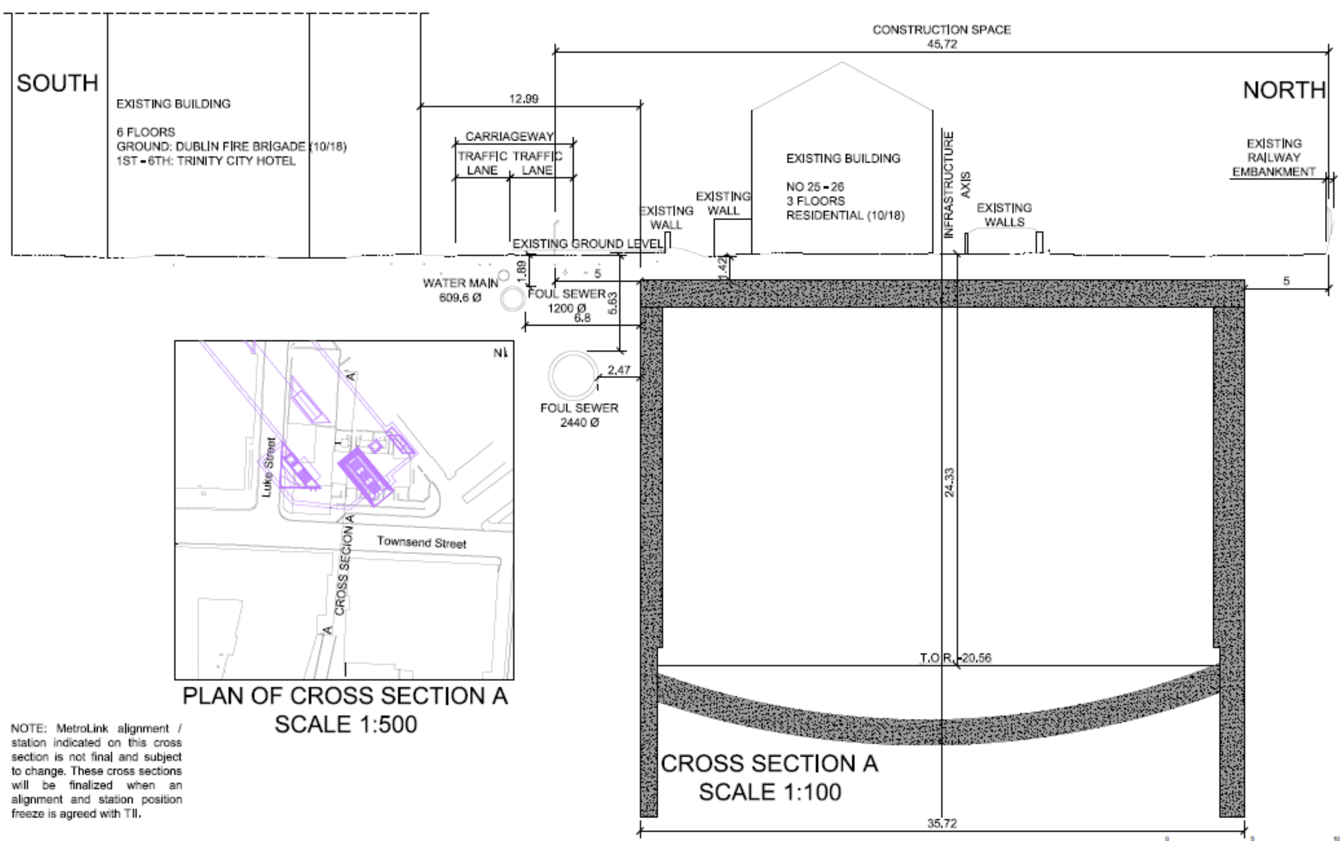

Figure 2.5 Construction interface with Townsend Street utilities.

3. Options Assessment Methodology

3.1 Introduction

The options assessment methodology has been developed in line with The Common Appraisal Framework 2016 (CAF) for Transport Projects and Programmes which develops a common framework for the appraisal of transport investments for DTTaS. It is consistent with the PSC (Public Spending Code). The TII Project Appraisal Guidelines for National Roads (PAG) translate the requirements of CAF in relation to National Road infrastructure Projects and Programmes.

An assessment system of multi-criteria analysis (MCA) is typically employed to develop a common framework for appraising transport investments in accordance with the Public Spending Code for Ireland. This method is set out in the Common Appraisal Framework for Transport Projects and Programmes, published in March 2016 by the Department of Transport, Tourism and Sport. This section sets out the assessment methodology developed for this report.

The method adopted for this options assessment is a 2 Stage process. Stage 1 is a high-level pass/fail assessment and options remaining from this stage will be subject to a Stage 2 more detailed assessment and scoring. Any Option deemed not feasible in Stage 1 is removed from the Stage 2 assessment.

3.2 Multi Criteria Assessment (MCA)

The Common Appraisal Framework March 2016 sets out the purpose, scope and when to use Multi Criteria Analysis as follows:

> *MCA can be used to describe any structured approach to determine overall preferences among alternative options, where the options should accomplish multiple objectives. The term covers a wide range of techniques that share the aim of combining a range of positive (benefits) and negative (costs) effects in a single framework to allow for easier comparison of alternative options in decision-making.*

> *MCA can complement a CBA if certain important parameters are not monetizable. In this way, it can provide a useful framework to evaluate different transport options with several criteria. In line with the Public Spending Code, a Multi Criteria Analysis (MCA) should be carried out at minimum for projects between €5 million and €20 million. Conventionally, MCA can be either qualitative and/or quantitative – both are valid approaches to MCA.*

> *The Public Spending Code determines that Multi-Criteria Analysis (MCA) should be carried out at a minimum for projects between €5 million and €20 million.*

MCA enables projects to be assessed against more than one objective. It is also worth noting that the application of MCA is not restricted to situations where the aim is to find only the single most appropriate option to follow through. MCA is particularly useful when it can offer a quick and cost effective way of short listing projects and comparing them against strategic objectives in a structured way.

What information is needed to carry out a Multi-Criteria Analysis? In general terms, the information necessary to perform a multi-criteria analysis are:

- The options alternatives, or strategies that have to be compared to each other;
- The evaluation criteria that will be used to assess these options;
- The importance of these criteria (that is, the weights); and

- The evaluation of the options on the different criteria. These evaluations can be given a numerical or ordinal (comparative) scale.

The process and options to be assessed are described below.

3.2.1 Stage 1 Assessment

The Stage 1 Scoring and Assessment Tables are shown in Tables 3.1 and 3.2 below. The scores for each option are included in Section 5 of this report, with further details of pre assessment provided in the Appendices.

Table 3.1 MCA Scoring Key - Stage 1 Assessment

Options Assessment	Significance
	Feasible with least impacts/lowest risks
	Feasible with moderate impacts/moderate risks
	Feasible with negative impacts / high risks
	Not Feasible

Table 3.2 Stage 1 Assessment table

		Alignment Options				
Overall Factors		**Option 0 PDR R400m**	**Option 1 PDR (Modified VA) R400m**	**Option 2 (Modified VA) R350m**	**Option 3 (Modified VA) R302m**	**Option 4 Rotation of Tara Station (Modified VA) R302m**
Tunnel Alignment	Construction					
	Operation					
Economic/Engineering	Construction					
	Operation					
Environmental	Construction					
	Operation					
Safety/Risk	Construction					
	Operation					
Overall						

See section 5 for Assessment Results

3.2.2 Stage 2 Assessment

Stage 2 assesses the remaining options from Stage 1 in more detail according to the same parameters used in stage 1 but with more specific assessment criteria as set out in section 3.3 below. The assessment is split into construction and operational impacts, scored and set out and as shown in Table 3.3 below. Scores for the Stage 2 assessment of the Options are shown in Section 5 below.

Table 3.3 MCA Scoring Key – STAGE 2 Assessment

Assessment Score for Individual Assessment Criteria	Significance Advantages/Disadvantages
	Significant advantages over other options
	Some advantages over other options
	Comparable to other options
	Some disadvantages over other options
	Significant disadvantages over other options

3.3 Assessment Criteria

The criteria used to assess the options are set out below and each option is subject to investigation under each of these criteria as discussed in section 2 of this report. An MCA summary table is produced see Table 3.4 below

- Alignment – is a proposed option acceptable based on the Metrolink alignment standards adopted for this project (as set out in Appendix A), or the ability of the tunnel boring machine to achieve the tunnel alignment. Does an alignment option with a tight radius curve not in use on any other section of the alignment impact on the design of future alignments. Do some options offer better operational characteristics than others in terms of operational speed and safety.

- Noise/Vibration – do some options offer reduced risk of noise/vibration under buildings over other options, both during construction and operation.

- Settlement - do some options offer reduced risk of settlement under buildings over other options.

- EMI/EMC impacts to buildings/equipment – do some options reduce or eliminate operational EMI/EMC to a greater or lesser extent to other options.

- Engineering – do some options increase / decrease construction risks, is one option preferable to another in terms of constructability. Do some options require more or less operational or maintenance constraints.

- Economy/Costs – a comparative assessment of the construction and potential operational costs and risks of individual options. Do some alignment options have increased operational costs or impacts over others.

Table 3.4 Overall MCA Summary Table layout

STAGE 2 ASSESSMENT TABLE		Alignment Options				
Overall Factors/Assessment Criteria		**Option 0** **PDR** **R400m**	**Option 1** **PDR (Mod)** **R400m**	**Option 2** **PDR (Mod)** **R350m**	**Option 3** **PDR (Mod)** **R302m**	**Option 4** **Station rotation with 2 x R302m**
Alignment radius/depth	Construction					
	Operation					
Noise/Vibration/	Construction					
	Operation					
EMI/EMC to buildings/Equipment	Construction					
	Operation	See section 5 – Assessment Results				
Settlement	Construction					
	Operation					
Engineering	Construction					
	Operation					
Economy/Cost	Construction					
	Operation					
Overall Result						

4. Review of the Receiving Environment

4.1 Introduction

Other than Noise & Vibration, EMI and settlement (covered in the soils and geology chapter of the EIAR), the majority of environmental disciplines would not be a differentiator in the decision making process for this assessment. This is due to the route in this location being wholly within tunnel thus limiting surface impacts.

EMI and vibration have been noted as issues of concern by TCD and settlement during construction is of potential concern along this section of route due to the number of historic and other sensitive buildings in close proximity to the tunnel alignment. These include the Department of Agriculture, the National Museum of Ireland, Department of the Taoiseach, Leinster House, National Library and Oireachtas libraries, Royal College of Physicians, National Gallery and Trinity College buildings.

The alternative alignments potentially impact on different buildings as noted in the following section.

4.1.1 Additional Buildings potentially affected by settlement from alternative Options 2, 3 and 4

There are a number of additional buildings requiring assessment under Options 2, 3 and 4 which were not previously impacted by the Preliminary Design alignment (Option 0). A list of these buildings is shown in Table 4.1 and maps with the alignment options and assessed buildings are shown in Appendix B.

Table 4.1 additional buildings assessed potentially affected by alternative alignments 2,3 and 4

BUILDING CODE	BUILDING INFORMATION				
	NAME	CONSIDERATION	Chainage	Height (m)	Nº Floors
AB-41	Residential / Retail	Commerce & Residential	17+640	9,00	3
AB-42	Pavilion Bar	Public & Commercial	17+860	7,00	2
AB-43	Moyne Institute	Public	17+900	10,00	3
AB-44	Burrito Hut	Commerce & Residential	17+960	10,00	3
AB-45	Multipurpose building	Public	18+040	10,00	3

4.1.2 Additional buildings potentially affected by alternative alignments

The following buildings are also shown on the settlement contour maps included in Appendix B.

- AB41 – contains TCD Nursery, TCD arts workshop and School of Clinical Speech and language; (potentially sensitive to N&V)
- AB42 – Pavilions Bar – Building potentially sensitive to settlement/vibration
- AB43: Moyne Institute: Dept of Microbiology. Potential for sensitive equipment and listed on the NIAH (architectural heritage). Should be considered sensitive.
- AB44 – Contains a number of occupants including a psychotherapist practice (Bateson Clinic) and National Library (possibly office or storage space). Potentially sensitive to settlement/vibration

- AB45 – It is not clear what this building is but a review of google maps identify it as possibly part of the National library campus and partially Royal College of Physicians. Could be sensitive to settlement/vibration.

Table 4.2 Summary table of buildings settlement damage assessment

	PDR Alignment	OPTION 1 PDR modified vertical alignment	OPTION 2 R350 curve	OPTION 3 R302 curve
	CLASSIFICATION - STAGE 2a	CLASSIFICATION - STAGE 2	CLASIFICATION - STAGE 2	CLASSIFICATION - STAGE 2
	DAMAGE CATEGORY	DAMAGE CATEGORY	DAMAGE CATEGORY	DAMAGE CATEGORY
Moderate	2	0	0	0
Slight	8	7	9	7
Very slight	11	4	3	3
Negligible	21	26	19	18
N/A	12	17	23	26
Total buildings	54	54	54	54

The full building damage assessment table is provided in Appendix B and settlement contour drawings are provided in Appendix C. The total number of buildings affected by the assessment is 54 however some buildings are not affected or "off the alignment" being considered.

JACOBS IDOM

5. Assessing the Options

5.1 Methodology for this assessment

Jacobs/Idom has considered the submissions made during the Public Consultation process and examined several alternative options to that proposed in the EPR. We have taken account of the design changes made since the EPR was developed, including the proposed single bore tunnel and reduced platform lengths made possible by the greater capacity of the proposed high-floor trains. Consultations with TCD have also been undertaken following the public consultation process to better understand the implications of both the current proposed alignment and alternative alignments past the campus.

Following the above, 5 Options as described in Section 3 have been developed to assess different alignments between Tara St Station and SSG. These options including the PDR are assessed equally against each other in two stages and against a number of key criteria which are scored/ranked against each other. The results are described below.

5.2 Stage 1 Assessment

Aligned with the assessment methodology described in section 3 of this report, a Stage 1 assessment is undertaken of all options including the base EPR option. The assessment is undertaken in two stages. Stage 1 is to remove those options that are not feasible for operational reasons and options that present significant construction or safety issues.

4 key criteria have been selected for the Stage 1 assessment as follows

- Tunnel Alignment
- Economic/Engineering
- Environmental
- Safety/Risk

Each Option (described below) is ranked according to Table 5.1 against the above 4 Criteria and the results are shown in

Table 5.2.

Table 5.1 Stage 1 Assessment scoring table

Options Assessment	Significance
(green)	Feasible with least impacts/ lowest risks
(yellow)	Feasible with moderate impacts/moderate risks
(orange)	Feasible with negative impacts / high risks
(red)	Not likely to be Feasible

Table 5.2 Stage 1 Assessment Results

		Alignment Options				
Overall Factors		**Option 0**	**Option 1**	**Option 2**	**Option 3**	**Option 4**
		PDR	**PDR (Mod VA)**	**(Mod VA)**	**(Mod VA)**	**Rotation of Tara St Box (Mod VA)**
		R400m	**R400m**	**R350m**	**R302m**	**R302m**
Tunnel Alignment	Construction				5	5
	Operation					
Economic/Engineering	Construction					
	Operation					
Environmental	Construction	1	3	4	4	4
	Operation	2	2	6	7	7
Safety/Risk	Construction					
	Operation				8	8
Overall						

Note: red under operations will result in a fail and removal of option from further assessment

Table cell notes:

1	Settlements (particularly Leinster House) and TBM noise
2	EMI highest impact at TCD, operational noise requires mitigation by FST and Gerb springs
3	Settlement reduced and noise reduced
4	Settlement further reduced, TBM noise affects overall similar building numbers

5	Tighter TBM radius requires closer control and recovery of deviation would require further reduction in radius and potential speed reduction
6	EMI and Noise & Vibration impacts at TCD partially mitigated by alignment change cf Options 0 and 1
7	EMI and Noise & Vibration impacts fully resolved at TCD
8	Tighter radius, DKE impact on space proofing for future equipment design

5.3 Result of Stage 1 Assessment

The Stage 1 assessment is undertaken to remove those options that are not feasible for operational reasons and identify options that present significant construction or safety issues. The results of this assessment are shown in Table 5.2 above.

Options 3 and 4 both have negative impacts around operational speeds, economics and the ability of the tighter tunnel radius to adequately provide appropriate “space proofing” between train DKE and tunnel equipment. Use of R302m curves would create an “outlier” (exception) on the MetroLink alignment as it would be the only location where such a reduced radius was used on the system. This speed restricted section of rail could not be upgraded over the life of the system (100+ years), could result in additional speed restricted radii being introduced as part of any future expansion of the system and result in deterioration in the overall system level of service. This radius has also previously been rejected for operational reasons elsewhere along the alignment.

Given the above concerns, Option No. 4 overall is deemed “not likely feasible” as it offers no significant further advantages over Option 3 and is ranked lower than Option 3 under Economics, Engineering and Safety/Risk. Option 4 does not warrant further assessment and is removed for the stage 2 assessment. However, Option 3 is retained and taken forward to the Stage 2 assessment for more detailed comparison.

Therefore options 0,1,2 and 3 only will be brought forward for the more detailed Stage 2 assessment with Option 2 being slightly more preferable than the other options.

5.4 Stage 2 Assessment

The Stage 2 assessment is undertaken as described in sections 3.2 and 3.3 above and according to the criteria set out in section 3.3 and Table 3.3 (repeated below as Table 5.3 for ease of reference). This table shows the ranking/scoring used for the Stage 2 assessment. The options are assessed against each other with each option being ranked as being more/less advantageous to all the other options according to the criteria used. All options are assessed equally against all the criteria identified, then summarising the total of the advantages/disadvantages for each option to identify the preferred Option

Table 5.3 MCA Scoring Key – STAGE 2 Assessment

Assessment Score for Individual Assessment Criteria	Significance Advantages/Disadvantages
(dark green)	Significant advantages over other options
(light green)	Some advantages over other options
(yellow)	Comparable to other options
(orange)	Some disadvantages over other options
(red)	Significant disadvantages over other options

The following drawings (in Appendix D) have been used to assist in developing the Engineering and Cost assessments:

- Option 0 - Existing PDR Vertical Alignment drawings
- Option 1 - Modified PDR Vertical Alignment (up to approx. 5m deeper south of Tara St Station)
- Option 2 - R350m Alignment design
- Option 3 - R302m Alignment design

A table showing offset distances from the tunnel alignments to mitigate EMI/EMC interference is shown in Appendix C

The criteria used for this assessment are set out below:

- Alignment – is a proposed option acceptable based on metro alignment standards or the ability of the tunnel boring machine to achieve the tunnel alignment. Do some options offer better operational characteristics than others in terms of operational speed, comfort and safety.
- Noise/Vibration – do some options offer reduced risk of noise/vibration under buildings over other options.
- Settlement - do some options offer reduced risk of settlement under buildings over other options.
- EMI/EMC to buildings/Equipment – do some options reduce or eliminate operational EMI/EMC to a greater or lesser extent to other options.
- Engineering – do some options increase / decrease construction risks, is one option preferable to another in terms of constructability. Do some options require more or less operational or maintenance constraints.
- Economics – a comparative assessment of the potential operational costs and risks of individual options. Construction costs of each option are considered to be equal.

The environmental, engineering, EMI/EMC, vibration/sound and settlement specialists inputted their respective comments against all the above criteria to the 4 Options against each criteria/option as per Table 5.3 above.

A full environmental appraisal was undertaken, however the environmental disciplines listed above (EMI/EMC, Noise & Vibration, Settlement (Soils and Geology) were the only disciplines that had potential to differentiate between the options being assessed.

A report dealing with electromagnetic radiation and the potential to experience interference from MetroLink operations has been undertaken and is included as Appendix C. Results from this report have been taken into account and incorporated into the Stage 2 assessments

A Settlement assessment and associated building damage assessment has also been undertaken to differentiate potential advantages/disadvantages of moving the horizontal and vertical alignments on buildings affected along the Tara Station to SSG Station corridor. This is shown in Appendix A and B. Results from this report have been taken into account and incorporated into the Stage 2 assessments.

Alignment design and engineering considerations associated with the alternative track alignments are considered, including impacts on speed/travel time and tunnel construction and space proofing for equipment.

5.5 Results of the Stage 2 Assessment

Table 5.4 below sets out the Stage 2 Assessment results of the options.

Table 5.4 Overall MCA Summary

STAGE 2 ASSESSMENT TABLE		Alignment Options			
Overall Factors/Assessment Criteria		**Option 0 PDR R400m**	**Option 1 PDR (Mod) R400m**	**Option 2 (Mod VA) R350m**	**Option 3 (Mod VA) R302m**
Alignment / Design	Operation	Design speed throughout alignment is 80kmph, as per design requirement. Normal operational speeds achieved.	Design speed throughout alignment is 80kmph, as per design requirement Normal operational speeds achieved.	Non-standard geometry with short transition curve and cant transition extended onto the circular curve. Throughout the curve design speed/normal operational speed of 80kmph achieved. Passenger comfort slightly affected but within established limits.	Design speed locally restricted to 60 kph; Required design speed not achieved. R302m curve would be an exception on the alignment
Noise/Vibration	Construction	Temporary impact from passage of TBM. Potential to temporarily impact sensitive equipment	Impacts similar to Option 0	Temporary impact from passage of TBM on sensitive equipment in laboratory buildings reduced	Temporary impact from passage of TBM on sensitive equipment in laboratory buildings further reduced
	Operation	Floating slab track (FST) can fully mitigate operational effects on Government and other Buildings but not fully mitigate impacts on TCD sensitive equipment FST with additional dampers required to fully mitigate TCD impact	Floating slab track (FST) can fully mitigate operational effects on Government and other Buildings but not fully mitigate impacts on TCD sensitive equipment. FST with additional dampers required to fully mitigate TCD impact	Floating slab track (FST) can fully mitigate operational effects at Government and other Buildings. FST sufficient for TCD buildings except for SNIAM building which requires additional track damping.	Floating slab track (FST) can fully mitigate operational effects at TCD and Government and other Buildings

STAGE 2 ASSESSMENT TABLE		Alignment Options			
Settlement	Construction	Settlement damage category at TCD buildings close to alignment varies 'Negligible' to 'Slight'. Leinster House damage category 'Moderate'. Adjacent Government & other buildings settlement assessment varies 'Slight' to 'Very Slight'	All TCD buildings close to alignment assessed at 'Negligible' damage category from settlement risk during construction. Leinster House damage category reduced to 'very slight'. Mitigated to Negligible under other Government & adjacent Buildings	A reduced number of TCD buildings potentially impacted by settlement during construction; negligible settlement risk under residual TCD buildings Leinster House damage category reduced to negligible. Mitigated to Negligible under other Government & adjacent Buildings Additional slight/very slight impacts on additional buildings between Tara Street and TCD campus	Most TCD buildings unaffected by settlement during construction Leinster House damage category remains as 'Negligible' Other Government and adjacent buildings damage category remain as 'Negligible' Additional slight/very slight impacts on additional buildings between Tara Street and TCD campus
	Operation	N/A	N/A	N/A	N/A
EMI/EMC to buildings/ Equipment	Construction	N/A	N/A	N/A	N/A
	Operation	EMI/EMC effects require active cancellation mitigation to 9 No. identified equipment items of concern at TCD	EMI/EMC effects reduced for most equipment, but Active Cancellation mitigation is still assumed to be required for all equipment at TCD	EMI/EMC effects mitigated but Active Cancellation still required at 3No NMRs and possibly 3no. SEMs at TCD	EMI/EMC effects resolved, and no active cancellation required through this section of the route.
Engineering	Construction	Storm water from track between Tara and SSG stations collected at Tara Station pump	Modified vertical alignment introduces additional low point and pumped water discharge requirement.	Modified vertical alignment introduces additional low point and pumped water discharge requirement.	Risk of TBM deviation further reducing tunnel alignment radius and hence operational speed reduction Modified vertical alignment introduces additional low point and pumped water discharge requirement.
	Operation		Similar to Option 0	Residual space allowance between train DKE and tunnel equipment same as remainder of route	Residual space allowance between train DKE and tunnel equipment reduced restricting equipment options. Risk of wheel/rail interface issues increases.
Economics/Cost	Construction		Similar to Option 0	Similar to Option 0	Similar to Option 0
	Operation		Similar to Option 0	Similar to Option 0	Reduced speed associated with 302m radius reduces economic time benefits during operations
Overall Result					

5.6 Assessment Summary

The following sections summarise the results of the assessment and provide an overall summary.

5.6.1 Alignment/Design

The MetroLink design speed is proposed at 80kmph and the alignment design currently accommodates this design speed throughout with a minimum radius of 350m specified for horizontal curves. The current design has three curves in the TBM sections below 400m horizontal radius: a 350m radius curve south of Griffith Park station and a 350m curve followed by a 375m reverse curve between O'Connell St. and Tara stations. These are in locations where the alignment is constrained by the available space to position the station boxes. With a minimum radius of 350m this provides for a TBM drive with allowance for some construction deviation which could locally reduce the curve radius to recover the design alignment.

Option 0 and Option 1 exceed the required minimum radius of 350m and have a design speed of 80kmph. The options score dark green in our assessment.

Option 2 maintains the required minimum radius of 350m, and operational design speed of 80kmph. However, to maximise the alignment offset past the TCD campus, it introduces non-standard geometry by shortening the transition curve next to Tara Station and extending the cant transition onto the circular curve. This slightly impacts passenger comfort, although the design is kept within limiting values. It also introduces a local speed reduction of 50kmph along this cant transition to non-stopping trains passing through Tara Station (i.e. non-commercial runs). This local speed limit, being directly adjacent to Tara Station, does not impact commercial services which are either already slowing on approach into the station or can still accelerate freely to 80 km/h on leaving the station.

Option 2 maintains the same space-proofing tolerances within the tunnel as provided throughout the other tunnelled sections of route.

This option therefore scores light green in our assessment.

Option 3 reduced the minimum radius to 302m and as a consequence reduces the design speed to 60kmph negatively impacting on journey time. This option scores orange in our assessment and is considered to have "Significant disadvantages over other options".

A particular concern with further reductions below a 350m design radius is that it will reduce or remove current design tolerance between train DKE and tunnel furniture, limiting future construction and Operator design options. This is because the current tunnel design has been space proofed with sufficient margins to accommodate all the required lineside equipment, taking into account the size ranges of particular equipment available in the market. The Preliminary Design allows for space envelopes that provide sufficient flexibility to accommodate variations in the size of this equipment. For horizontal radii of 350m and greater, the DKE can accommodate the lineside equipment space proofed for, whilst maintaining a line speed of 80 km/h. However, for the 302m radius curve there would be a wider DKE which would be hard up against the lineside equipment envelope and would require a speed reduction as noted to maintain the DKE.

Option 3 would introduce additional tunnelling risk during the TBM drive. Whilst a desirable minimum radius for a TBM for our tunnel diameter would be around 500m, the TBM could be specifically manufactured to accommodate a 302m radius. However, this tighter alignment radii of 302m would require closer control of the TBM drive as recovery of any deviation through a correction curve would require a further reduction in alignment radius with associated future further potential metro operational speed reduction.

Option 3 introduces an exceptional element within the overall alignment which although not a safety risk (associated with excessive speed) during the automated GoA4 system proposed, will introduce a local constraining factor on the alignment speed. Speed is reduced to 60kmph and under degraded conditions, if trains are manually operated, then this section would need to be traversed at the reduced speed by the manual operator.

For options 0, 1 or 2, the MetroLink design speed of 80kmph is retained. Introducing a speed restriction to the alignment is considered to confer a significant disadvantage on current and future alignment planning and will remain an operating constraint on the system for its operational life.

5.6.2 Noise & Vibration

The inclusion of Floating Slab Track (FST) is part of the current Option 0 (preliminary Design) proposals to mitigate operational noise and vibration impacts for the alignment past TCD and by Leinster House and would also be required for Option 1. Options 0 and 1 are therefore scored yellow in our assessment as they are "Comparable to other options".

FST can fully mitigate operational effects on Leinster House for all alignment options, as the criterion there is audible sound not vibration. For TCD buildings, the alignment under Options 2 and 3 incorporating FST offer better mitigation overall for noise and vibration through this section.

However, FST does not itself fully mitigate operational vibration effects in all cases. This is because a side effect of FST is the 5Hz peak, and at this frequency as distance effects are reduced for the first few tens of metres, it could affect specific equipment in the SNIAM and Fitzgerald buildings where a specific vibration criterion of VC-E has been indicated as being required. Mitigation for this effect would require additional damping for the track. Proprietary rail systems are available to provide similar damping as FST, alternatively the installation of dampers, with the use of Gerb springs designed to provide 25% critical damping, could achieve the required VC-E threshold level for potentially affected TCD equipment.

For Option 2, additional damping is currently considered to be required for the Squid machine in the SNIAMS building with FST providing adequate noise and vibration mitigation elsewhere. This option is scored light green in our assessment as it is considered to have "Some advantages over other options".

Option 3 provides the opportunity to mitigate all noise and vibration effects during operation though the provision of FST only with no additional damping required. This option is scored dark green in our assessment as it is considered to have "Significant advantages over other options".

During the construction phase, the TBM will cause limited temporary disturbance with all the alignments, both at TCD and elsewhere in close proximity to the drive alignment. Assessment of the groundborne noise contours from the TBM for the differing alignments indicates the following:

- Moyne Institute, Trinity Point has an increase in noise moving up to the 47dB range under options 2 and 3
- Likewise, the National Gallery incurs slightly increased ground borne noise for options 2 and 3 and moves up to the 35-45dB range across the building
- All buildings under option 0 and 1 alignment would move down to the 35 – 38dB range compared against options 2 and 3
- Leinster House is affected similarly with options 0 and 1 but the impact moves to the west side of the building with options 2 and 3
- Options 2 and 3 due to their proximity are difficult to distinguish precise impact differences but are generally similar, with the higher impact on option 3 being slightly to the west of the peak impact area for Option 2 particularly at the Moyne Institute and Trinity Point buildings

As noted above, these impacts are short term construction impacts only.

5.6.3 Settlement

The current PDR alignment has 'Slight' to 'Negligible' assessed damage category due to construction settlement at TCD buildings, and moderate damage at Leinster House. The introduction of a modified vertical alignment reduces settlement damage at both locations to 'Negligible' or 'Very Slight'.

The alternative alignments R350 and R302 further reduce potential settlement damage at both locations, but due to the revised alignment introduce new settlement impacts between Tara Street and SSG. However, given that these are not significant, Options 1, 2 or 3, would all offer benefits compared to the current Option 0. See Appendix B for explanation of damage categories and detailed listing of settlement impacts and Appendix C for settlement contour maps and locations of buildings potentially affected by the different options.

5.6.4 EMI/EMC

Sensitive research equipment is critical to the world class research being undertaken at a number of TCD departments now and in the future. As a result, it is important that MetroLink is designed such that impacts on sensitive equipment are minimised where possible.

Option 0, the PDR alignment, has been assessed as requiring Active Cancellation as the necessary effective mitigation measure at the receptor equipment, based on the proximity of the alignment to these particular items of equipment.

Active Cancellation is an industry recognised and accepted and cost-effective method of providing appropriate EMI protection to sensitive equipment when protection at source is either not feasible or desirable. JI specialist consultants and industry recognised experts Compliance Engineering International (CEI) have confirmed that Active Cancellation is a viable option to address residual EMI effects on TCD equipment. This is based on their practical experience gathered from projects including:

1. Neils Bohr Building, Copenhagen, Denmark (SEMs)
2. Qatar Science and Technology Park, Doha
3. Francis Crick Institute, London (NMRs, SEMs)
4. Irvine Materials Research Institute, California (TEMs) – used in combination with shielded room
5. Royal Hospital Melbourne, Australia (Linac) - Ongoing

This Option thus scores orange ('some disadvantages over other options') in our assessment.

Option 1 offers some improvements to EMI/EMC particularly on the NMR equipment due to the increased depth of the alignment, however, Active Cancellation would still be required due to the proximity of the NMR equipment. The requirement for mitigation for the MRIs and SEMs is also reduced but as with Option 0 may still need to be installed. This Option similarly scores orange in our assessment.

Option 2 would provide EMI/EMC mitigation to a larger area of the campus than the current PDR alignment and provide improved mitigation to the specific equipment assessed, with some equipment fully mitigated but others still possibly requiring Active Cancellation. The NMRs would still be recommended to utilise Active Cancellation as a mitigation measure. The SEMs may not require mitigation, however, the residual levels may in practice mean that the operators may still favour having these systems installed. No mitigation measures would be expected to the required at the other equipment locations. This Option scores light green ('Some advantages over other options') in our assessment.

Option 3 would provide the most protection and it is unlikely that any of the listed equipment will experience any interference from the proposed development. While the levels modelled for the NMRs are still slightly above their stated sensitivity these are worst case modelled conditions, and unlikely to occur during normal day to day operations. The credible worst-case conditions modelled use a single substation for traction along with two trains accelerating at maximum acceleration at the same time on this section of the line. This is a situation that could occur in one off incidents (e.g. planned shutdowns) but it would not occur day to day under normal operation. The typical operational levels will be below the 0.5 µT stated limit for this equipment at their locations. This Option thus scores dark green 'Significant advantages over other options' in our assessment.

Whereas Option 3 allows all current identified research equipment to operate in the absence of localised mitigation measures, all route options considered would allow the equipment to successfully operate with the implementation of Active Cancellation measures at sensitive equipment locations. See Appendix D for a more detailed EMI/EMC report.

5.6.5 Train Operations

Options 0, 1 and option 2 offer significant advantages over option 3 in that there are no requirements on train operations to locally reduce normal operational speeds in the tunnel section between Tara and SSG Stations. These options score dark green in our assessment.

Option 3 will have a speed restriction due to the tighter radius curve south of Tara Station, impacting journey time. Whilst time impacts are modest, the addition of speed restrictions incurs an operational impact over the full life of the system operation, which is considered below. This then becomes a permanent impact on the Metro with no recourse to mitigate it during further development or future operation of the system.

Further introducing a 302m outlier curve on the alignment also allows existing design curves to be challenged and future alignment curves on the system potentially reduced to under 350m creating further operational degradation of the system. Option 3 scores orange in our assessment and is considered to have "Significant disadvantages over other options".

5.6.6 Economics/Cost

Option 3, adopting a 302m radius curve, would result in an exceptional element in the alignment. This carries a series of disadvantages such as increased travel times/costs which although perhaps not significant when assessed individually, would reduce the economic time benefit of the Scheme when added cumulatively over the life of the system making it less advantageous compared to Option 1 or 2. Option 3 thus scores orange ('Some disadvantages over other options') compared to a dark green 'Significant advantages over other options' in our assessment for Options 0,1 and 2.

An indicative assessment of the potential economic cost can be made as follows:

- Additional round trip travel time due to sped constraint = 4.3 seconds
- Value of time assumed for commuter passengers = €44/hr (from UK train commuters) = €0.0122/second
- Additional cost per round trip per passenger = 4.3*€0.0122 = €0.0524
- Total passengers/day approx. 90,000, say 50% commuters
- Total lost benefit = 45000*€0.0524*252 days say = approx. €600,000/annum.

Note: Line flow in both directions at Tara Station at +30 years is calculated using 91,062 passengers. No Value of Time has been taken for the remaining 50% of travellers in this assessment.

The journey time impact costs assessed above depend on the metrics used ie passenger line demand, horizon year, average speed loss, however the assessment does demonstrate a reduced economic time benefit over the life of the system by introducing an additional speed limit restriction. The methodology used for this assessment is indicative and a proxy as actual cost/benefits would require use of a specific trip purpose demand model as well as elastic transport cost of time calculations.

The estimated costs of incorporating Active Cancellation measures to address EMI/EMC effects at the assessed TCD equipment locations is in the order of €40-50,000 per item of equipment. For Options 0 and 1, the 9 items of equipment noted would infer an overall installation cost of up to €450,000 plus some potential need for additional passive shielding associated with Option 0. For Option 2, costs would lie between €150,000-300,000, depending on the final assessed/agreed need for shielding of the 3 No. SEM machines. This is significantly less than the time loss costs as assessed above for Option 3.

5.6.7 Summary of Stage 2 Outcome

It can be seen from the Stage 2 Assessment summary table that Option 1 (PDR modified VA) and Option 2 (R350m and modified VA) both show a range of advantages compared to the PDR (Option 0) particularly in terms of EMI/EMC reduction/mitigation, settlement, noise & vibration whilst essentially remaining cost neutral in terms of system operations.

Option 2 requires introduction of some additional mitigation at receptor equipment to address residual EMI/EMC effects, though less than the current PDR option. The NMRs would still be recommended to utilise Active Cancellation as a mitigation measure. The SEMs may not require mitigation, however, the residual levels may in practice mean that the operators may still favour having these systems installed. As such, three, or potentially 6 items of equipment would require Active Cancellation mitigation, with a current cost estimate of €150,000-€300,000. Some additional track mitigation could also be necessary to address a specific vibration frequency effect at the SNIAM building. Notwithstanding this, this Option is considered to provide 'Significant advantages over other options' and is thus scored dark green in the summary assessment in Table 5.4. Option 0 and Option 1 are assessed as 'yellow' or neutral, in that they have some advantages but also do not address key EMI concerns of the current Option 0.

Option 3 has a clear advantage over all the other options when EMI/EMC criteria are assessed in isolation, having regard to the importance of sensitive equipment to TCDs research activities. Most of the potential interference on sensitive equipment is mitigated with the exception of EMI effects on the NMR equipment which can be mitigated with Active Cancellation if required in practice.

However, Option 3 will reduce or remove current design tolerance between train DKE and tunnel furniture, limiting future construction and Operator design options and which will remain a constraint on the system for its operational life. During construction, additional risk is introduced regarding the TBM, as any potential deviation from the target alignment could introduce the need for further tightening of the alignment radius with the need for additional speed reduction or further space proofing issues.

In regard to economic advantage/disadvantage Option 3 scores worse than any of the other options. This is due to the speed restriction on the tighter radius curve and resultant drop in average speed of the system. Whilst the time penalty appears small on one journey, over a 30-year operational period of the Metro the cumulative impact of the time losses builds up. Applying a journey time cost calculator, we can demonstrate a loss in terms of value of time as a result of the 60kmph speed limited section.

Further, introducing a 302m outlier curve on the alignment would also potentially allow other existing design curves to be challenged with the risk of creating further operational degradation of the system.

On the basis of the above considerations, Option 3 is overall considered to score Orange on our summary assessment despite the fact it has additional EMI protection over other options.

In summary Option 2 (R350m) outperforms Options 1, and 0 against EMI/EMC and noise/vibration particularly to equipment in the TCD Laboratories and potential noise/vibration effects under Leinster House' It also outperforms and has a significant advantage over Option 3 in regard to maintaining system average speeds, system operations, alignment consistency, and without the journey time penalty of Option 3.

5.6.8 Other Considerations for mitigation of EMI/EMC effects

Rather than providing alternative alignments as a means of mitigating EMI effects on the TCD equipment, the potential for controlling the maximum current in the section in order bring EMI emissions within the limits that are compatible with the sensitive equipment was considered.

However, appraisal of the potential requirements to achieve the necessary reduction in EMI effects indicated particular problems in achieving the necessary power reduction. Even applying a significant reduction of 50% in the power in this section is considered unlikely to achieve the desired outcomes, with for example, the Chemistry department sensitivity levels will likely still be exceeded.

Achieving a power reduction through this section would require a reduction in the traction power and, therefore, the maximum current at the OLE conductors. In the TCD section it would require either:

- increasing the headway of trains; or
- reducing the operational speed.

Both solutions would need to be applied along the entire section between the traction substations at Tara and Charlemont (assuming worst condition from a current point of view in the TCD area in N-1 with Charlemont substation out of service). To achieve a power reduction level of around 50% in the TCD section would then require either:

- An increase of the headway from 90s minimum to 180s minimum; or
- A reduction in the operational speed from 80kmph to circa 11kmph (this strict limitation is due to the fact that the traction power curve assumed for MetroLink reaches its peak at 22kmph and remains constant for higher speeds).

Neither of these outcomes is viable from an operational requirement, indicating that current reduction as a mitigation option is not a viable option.

6. Conclusions & Recommendation

6.1 Conclusions

Option 0 is the current PDR horizontal and vertical alignment. This alignment requires the provision of Floating Slab Track (FST) through this section to mitigate operational noise and vibration together with Active Cancellation measures at all identified TCD sensitive equipment locations to mitigate EMI effects. It would have slightly worse noise and vibration impacts due to the alignment passing directly under some TCD and Government buildings and would require additional damping at track to mitigate a specific vibration frequency arising from the FST impacting equipment in the SNIAM and Fitzgerald buildings.

Option 1, the current PDR horizontal alignment but with lowered vertical alignment, would provide improved settlement and noise mitigation compared to Option 0. However, it does not provide any significant benefit in terms of EMI or vibration effects on TCD equipment, which would continue to require provision of Active Cancellation measures for all assessed equipment, noting that this is a proven method for mitigation of EMI effects and has been successfully used elsewhere. It would continue to require additional damping measures at track for the specific equipment in the SNIAM and Fitzgerald buildings.

Option 2 provides improved settlement and noise mitigation compared to Option 0 whilst remaining compatible with design parameters along the alignment and is a significant improvement in terms of potential EMI/EMC effects at TCD. Residual mitigation of remaining EMI effects can be addressed through the introduction of Active Cancellation at the NMRs and potentially the SEM equipment. Active Cancellation is an accepted and proven method of addressing this issue and is compatible with the equipment identified. It would be an effective mitigation for those items of equipment that would potentially still require some protection and TII have previously committed to funding this form of protection. This option would require some additional mitigation at track to address the potential localised specific vibration issue at the SNIAM building equipment.

Option 3 (R302m curve) provides the most advantageous alignment in terms of mitigating most EMI/EMC effects at the TCD campus. It requires no additional damping for the track and provides improved settlement and noise mitigation along the route compared to Option 0, but it has significant drawbacks as follows:

- It will reduce or remove current design tolerance between train DKE and tunnel furniture, limiting future construction and Operator design options and which will remain a constraint on the system for its operational life. Such restrictions at this Preliminary Design stage are not considered desirable due to the future construction/operation risks introduced.
- There would be additional risk during the TBM drive of potential further speed limitations if the tunnel drive deviated from the design alignment and needed correction through tighter curves.
- It will have a permanent speed restriction due to the tighter radius curve south of Tara Station, impacting journey time and incurring an ongoing economic cost incurred over the life of the system
- An exceptional element would be introduced within the overall alignment, outwith the proposed design requirements for MetroLink
- The risk of wheel rail interface issues arising during the operational phase is considered to significantly increase on curves down to 300m radius or less, with a 350m radius recommended as the minimum radius
- It potentially opens up opportunities for other locations to be challenged regarding the alignment design provided.

6.2 Recommendation

The overall assessment has considered the balance of advantages and disadvantages of all the options equally. It is considered that Option 2 offers advantages over Option 0 (the PDR alignment), and when considered against the other alternatives is the preferred Option to be taken forward.

It is therefore recommended than an amendment is made to the proposed PDR alignment for incorporation in the Railway Order application. The horizontal alignment should be adjusted by moving it west of the current proposed alignment using a R350m horizontal curve and further adjusted in the vertical section to deepen the alignment by approximately 3m under the TCD Campus area.

TII will continue to work with TCD with respect to provision of appropriate mitigation to protect sensitive equipment at locations that would still require some protection based on this revised alignment.

7. List of Acronyms

AC	Alternating current
DC	Direct Current
EM	Electromagnetic
EMF	Electromagnetic fields
EMR	Electromagnetic Radiation
EMI	Electromagnetic Interference
NMR	Nuclear Magnetic Resonance Spectrometer
RF	Radiofrequency
SEM	Scanning Electron Microscope
SSG	St. Stephen’s Green Station
TCD	Trinity College Dublin

Appendix A. Track Alignment Parameters

FUNCTIONAL PARAMETERS				Normal	Exceptional	Comments
Design Speed	***V***	km/h		80		
Track Gauge				1435		
Unbalanced lateral acceleration	a_q	m/s^2		0,65	0,85	
Rate of change of unbalanced lateral acceleration	da_q/dt	m/s^3		0,35	0,65	
CANT				Normal	Exceptional	Comments
Maximum cant	D_{max}	mm		150	150	
Maximum cant deficiency	I_{max}	mm		100	130	
Rate of change of cant as function of time	***dD/dt***	mm/s		50	55	
Maximum cant gradient	***dD/ds***	mm/m		1,50 - 2,00	2,50	
Rate of change of cant deficiency as function of time	***dI/dt***	mm/s		55	100	
Maximum abrupt change in cant deficiency	ΔI_i	mm	Crossover/ Turnouts	100	120	
HORIZONTAL ALIGNMENT				Normal	Exceptional	Comments
Minimum radius - out of TBM section	R_{min}	m	Without applied cant	$0.12\ V^2$	$0.09\ V^2$	
			With applied cant	$0.047\ V^2$	$0.042\ V^2$	
Minimum radius - TBM section	R_{min}	m		350		
Minimum radius - platforms	R_{min}	m		Straight	1500	
Minimum length of radius curve	$L_{i\ min}$	m		V/3	Length of longest admitted car. Assumed to be 20	
Minimum length of straight element between 2 transition curves	$L_{i\ min}$	m		V/3		
Minimum length of transition curve	$L_{k\ min}$	m	Based on ΔI	0.005 V ΔI	0.003 V ΔI	Minimum of the 3 values.
			Based on ΔD (per time) *	0.006 V ΔD	0.005 V ΔD	
			Based on ΔD (per length) *	0.5 ΔD	0.4 ΔD	
VERTICAL ALIGNMENT				Normal	Exceptional	Comments
Maximum Gradient	G_{max}	‰	Main Line	40	60	
			Platform	0	10	
Minimum Gradient	G_{max}	‰	General	-	-	
			Tunnel	10	5	
Minimum vertical parabolic parameter - sag	KV_{min}	m		$0.77\ V^2$	$0.13\ V^2$	
Minimum vertical parabolic parameter - crest	KV_{min}	m		$0.77\ V^2$	$0.16\ V^2$	
Minimum length of vertical alignment	$L_{v\ min}$	m		0.4 V	0.3 V	

Appendix B. Settlement Assessment

Building Risk Categories (Boscardin and Cording with Rankin Criteria)

Building and Structure Damage Classification (after Burland et al (1977) and Boscarding and Cording (1989))					Approximately Equivalent Ground Settlements and Slopes (after Rankin 1988)	
Risk Category	**Degree of Damage**	**Description of Typical Damage and Likely Forms of Repair for Typical Masonry Buildings**	**Approx. Crack Width (mm)**	**Limiting Max Tensile Strain (%)**	**Max Slope of Ground**	**Maximum Settlement of Building (mm)**
0	Negligible	Hairline cracks	<0.1	Less than 0.05		
1	Very Slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building Cracks in exterior brickwork visible upon close inspection	0.1 to 1	0.05 to 0.075	Less than 1:500	Less than 10
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible some re-pointing may be required for weather tightness. Doors and windows may stick slightly	1 to 5	0.075 to 0.15	1:500 to 1:200	10 to 50
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can me masked by suitable linings. Re-pointing and possibly replacement of a small amount of extent brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired	5 to 15 or a number of cracks greater than 3	0.015 to 0.3	1:200 to 1:50	50 to 75
4	Severe	Extensive repair involving removal and replacement of sections of walls, especially over doors and windows required. Windows and frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably, some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	Greater than 0.3	1:200 to 1:50	Greater than 75
5	Very Severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion Danger of instability	Greater than 25 but also depends on number of cracks	Greater than 0.3	Greater than 1:50	Greater than 75

Damage category Assessment

BUILDING CODE	BUILDING DESCRIPTION	BUILDING LOCATION	PDR Alignment	ALTERNATIVE 1 PDR new vertical alignment	ALTERNATIVE 2 Option 1_R350 south of Tara	ALTERNATIVE 3 Option 2_R302 south Tara
			CLASIFICATION - STAGE 2a	CLASIFICATION - STAGE 2	CLASIFICATION - STAGE 2	CLASIFICATION - STAGE 2
	NAME	Chainage	CATEGORY OF DAMAGE	CATEGORY OF DAMAGE	CATEGORY OF DAMAGE	CATEGORY OF DAMAGE
B-7	Ivor Fitzpatrick and Co	18+420	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-8	Boston College;St.Stephen's Green	18+400	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-9	Forty one restaurant	18+380	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-10	Bank of Ireland	18+380	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-11	International Rugby Board	18+340	Negligible	Negligible	Negligible	Negligible
B-12	The Spa	18+340	Very Slight	Negligible	Negligible	Negligible
B-13	Shelbourne Hotel	18+320	Negligible	-	-	-
B-14	Department of Agriculture, Food & Marine	18+280	Negligible	Negligible	Negligible	Negligible
B-15	Government Building	18+240	Negligible	Negligible	Negligible	Negligible
B-16	Government Building	18+080	Moderate	Negligible	Negligible	Negligible
B-17	**Irish Parlament**	18+120	Moderate	Negligible	Negligible	Negligible
B-18	National Museum of Ireland	18+180	Slight	Negligible	Negligible	Negligible
B-19	Natural History Museum	18+160	Not analysed	OUT OF ALIGNMENT	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-20	National Library	18+080	Not analysed	Negligible	Negligible	Negligible
B-21	National galery of Ireland	17+980	Very Slight	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-22	**Trinity Point**	17+980	Negligible	Negligible	Negligible	Negligible
B-23	**Trinity Point**	18+020	Not analysed	Negligible	Negligible	Negligible
B-24	**Trinity Point**	18+020	Negligible	Negligible	Negligible	Negligible
B-25	Student Counselling Service	17+980	Negligible	Negligible	Negligible	OUT OF ALIGNMENT
B-26	National galery of Ireland	18+020	Not analysed	OUT OF ALIGNMENT	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-27	National Gallery	18+020	Very Slight	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-28	Residential	17+980	Not analysed	OUT OF ALIGNMENT	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-29	Residential	17+940	Not analysed	-	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-30	Insomnia	17+940	Negligible	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-31	**Trinity College**	17+920	Negligible	-	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-32	Depto of Mechanical Manufacturing Engineering	17+900	Negligible	Negligible	Negligible	OUT OF ALIGNMENT
B-33	Dublin Dental University Hospital	17+900	Very Slight	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-34	Dublin Dental University Hospital	17+880	Very Slight	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-35	HTrinity College-Zoology	17+840	Very Slight	Negligible	Negligible	OUT OF ALIGNMENT
B-36	**Trinity College-Chemistry**	17+800	Negligible	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-37	**Trinity College-Laser Unit**	17+740	Negligible	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-38	**Trinity College-Phisics**	17+760	Very Slight	Negligible	Negligible	Negligible
B-39	**Trinity College-Botany**	17+720	Slight	Slight	Slight	Very slight
B-40	Luce Hall	17+700	Slight	Slight	Very slight	OUT OF ALIGNMENT
B-41	Engineering laboratory	17+680	Slight	Slight	Slight	Slight
B-42	**Trinity Business School**	17+660	Slight	Slight	Slight	Slight
B-43	St. Mark's Church	17+640	Not analysed	OUT OF ALIGNMENT	OUT OF ALIGNMENT	OUT OF ALIGNMENT
B-44	GoHop-Ireland's internet travel company	17+620	Very Slight	-	-	OUT OF ALIGNMENT
B-45	O'Neils whiskey bonders	17+620	Very Slight	Very slight	Slight	Slight
B-46	O'Neils TownHouse	17+600	Very Slight	Very slight	Slight	-
B-47	World Travel	17+600	Slight	Very slight	Slight	Slight
B-48	The school Tour company	17+580	Slight	Slight	Very slight	Very slight
B-49	Mc Carty Centre	17+560	Very Slight	Slight	Slight	Slight
B-50	Solvar Fields Ltd.	17+540	Negligible	Negligible	Negligible	Negligible
B-51	Dublin Fire Brigade & Commercial	17+500	Negligible	Negligible	Negligible	Negligible
AB-33	Commercial	17+520	Negligible	Very slight	Very slight	Very slight
AB-34	Residential / Retail	17+640	Slight	Slight	Slight	Slight
AB-35	Residential / Retail	17+920	Negligible	Negligible	OUT OF ALIGNMENT	OUT OF ALIGNMENT
AB-36	Residential / Retail	17+940	Negligible	Negligible	-	OUT OF ALIGNMENT
AB-41	Residential / Retail	17+640	OUT OF ALIGNMENT	OUT OF ALIGNMENT	Slight	Slight
AB-42	Pavilion Bar	17+860	OUT OF ALIGNMENT	OUT OF ALIGNMENT	Negligible	Negligible
AB-43	Moyne Institute	17+900	OUT OF ALIGNMENT	OUT OF ALIGNMENT	Negligible	Negligible
AB-44	Burrito Hut	17+960	OUT OF ALIGNMENT	OUT OF ALIGNMENT	Not Analysed	Negligible
AB-45	Multipurpose building	18+040	OUT OF ALIGNMENT	OUT OF ALIGNMENT	Not Analysed	Negligible
	Building assessment Ch17+500 to 18+400					
		Moderate	2	0	0	0
		Slight	8	7	9	7
		Very slight	11	4	3	3
		Negligle	21	26	19	18
		N/A	12	17	23	26
			54	54	54	54

Appendix C. Settlement Contour Maps

Option 1 ML1-JAI-CPS-ROUT_XX-PL-Z-00008

Option 2 ML1-JAI-CPS-ROUT_XX-PL-Z-00006

Option 3 ML1-JAI-CPS-ROUT_XX-PL-Z-00007

Appendix D. Electromagnetic Radiation (EMR) and the potential to experience electromagnetic interference (EMI) from Metrolink Operations

1. Introduction

Trinity College Dublin has been considered a major stakeholder with respect to the Electromagnetic Radiation (EMR) chapter of the EIAR due to their potential to experience electromagnetic interference (EMI), from the proposed MetroLink development, on some of the sensitive equipment housed within their campus across multiple faculties and institutes. More specifically, the type of EMI in question is DC and quasi DC magnetic fields. These fields are associated with the DC traction supply utilised to drive the trains via the overhead lines and return rails.

It was concluded that Trinity would not be susceptible to the other sources of EMI that could be potentially associated with the proposed development, namely AC frequency and radiofrequency fields.

The susceptibility of identified equipment near the alignment of the preliminary design was investigated. This included meeting staff members, modelling predicted DC and quasi DC magnetic fields as well as simulated field testing at the equipment locations (see reports 19E7900-1 and 19E8382-1). For the most part equipment that was expected to be sensitive, was verified to be.

Mitigation measures have also been discussed through consultations and within the EIAR. This document is aimed at discussing the effect of a more significant measure, that of utilising alternative alignments as a means of reducing the potential for EMI. Also discussed briefly in this document is the potential effect of alignment changes on OPW buildings (including Government buildings) located between Tara Station and St. Stephens Green.

2. Equipment Review

A preliminary list of sensitive equipment was provided by Trinity College that was reviewed by CEI. This included a broad range of equipment types from computers to the most sensitive scanning systems (again detailed in report 19E7900-1). After review this list was refined to equipment that would be sensitive to DC and Quasi DC magnetic field perturbations such as those associated with an electrified DC rail line. These are listed in the table below including details of their distance from the Preliminary Design Alignment, their sensitivity and the modelled worst-case magnetic field perturbations.

Table 1: Identified Sensitive Equipment and associated modelled field levels for the given distances for Option 0

Building Name and Equipment	Chainage and Distance from Alignment	Equipment distance to tunnel crown	Current DC Field fluctuations	Sensitivity	Modelled levels At current distances
SNIAM - SQUID machine	Chainage: 17+710 Distance: 30 m	15 m to tunnel crown	± 0.7 µT	0.01 µT	2.75 µT
Chemistry – Three NMRs	Chainage: 17+840 Distance: 3-9m	16 m to tunnel crown	± 0.1 µT	0.5 µT (DC)	10-14 µT (DC)

Building Name and Equipment	Chainage and Distance from Alignment	Equipment distance to tunnel crown	Current DC Field fluctuations	Sensitivity	Modelled levels At current distances
Lloyd Institute – Two MRI Systems	Chainage: 17+750 Distance: 52 m	8 m to tunnel crown (-8 m below ground)	± 0.2 µT	1 µT *	1.5 µT
Panoz (EE4) – Three SEMs	Chainage: 17+840 Distance: 63 m	12 m to tunnel crown (-4 m below ground)	± 0.15 µT	0.1 µT	0.8 µT

* Estimated since data was not received

Figure 1 illustrates the equipment locations relative to the proposed alignment with those listed in Table 1 circled in yellow. What is evident is that those identified as being sensitive are all east of the proposed alignment. Therefore, any realignment to the west would reduce the modelled field levels of column 6. This document discusses the magnitude of these reductions on the affected equipment and also whether there is the potential for creating a negative impact elsewhere.

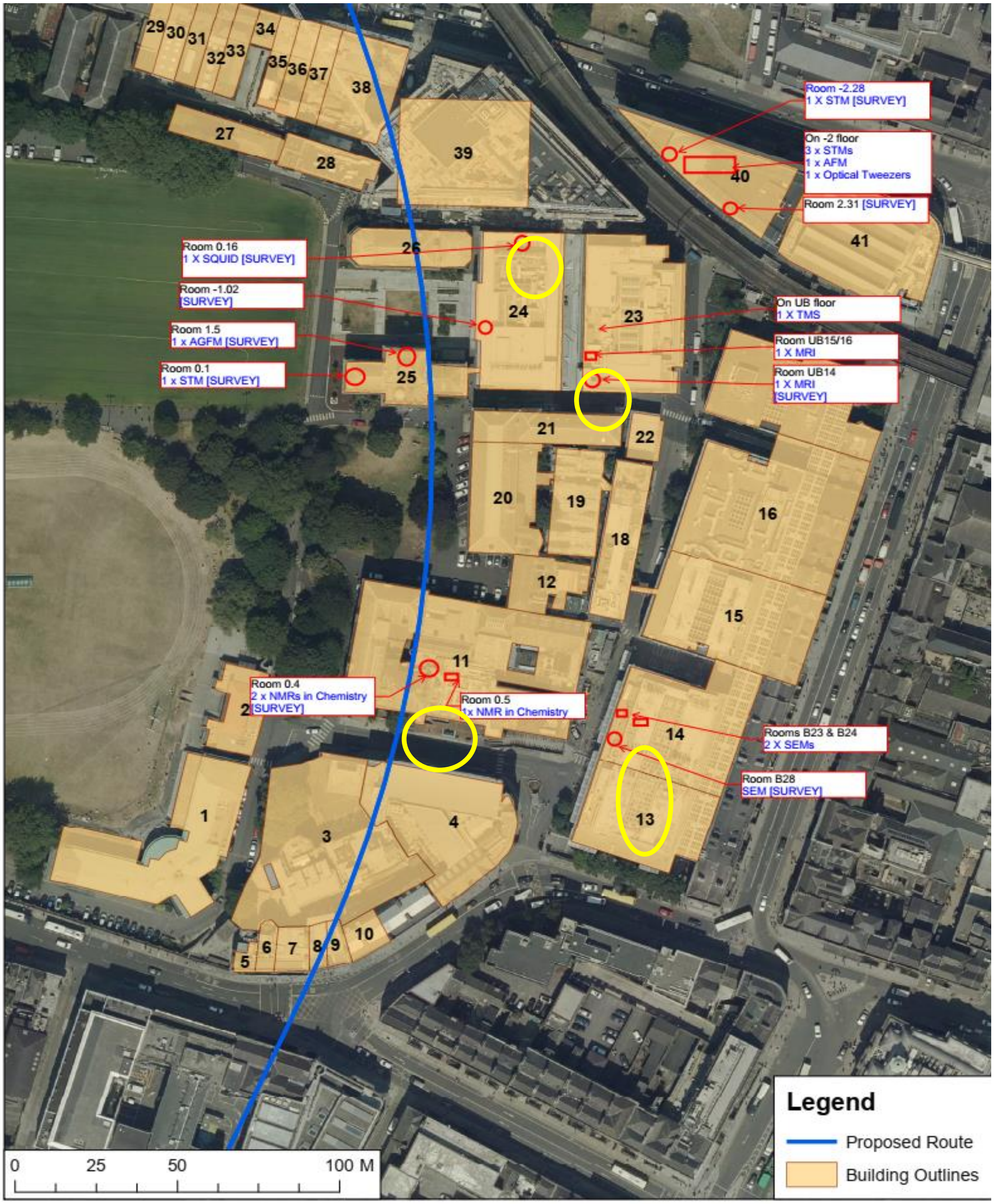

Figure 1: Equipment locations and measurement locations within Trinity College Dublin relative to PDR (Option 0) Alignment

3. Assessment of Modified PDR and Alternative Alignment Options

The simplest way to illustrate the effect of increasing the distance west is in graphical form. The magnetic field strength is a decaying exponential whereby the significance of increasing the distance diminishes the further from the proposed development the equipment is to begin with. Conversely, the closest equipment will benefit the most significantly from deviations in a westward direction i.e. the NMRs.

For the illustration in Figure 2 the equipment locations were taken from Table 2: Equipment distances for Option 1 with at R=400m (i.e. Option 1). Since some of the equipment is below ground level the vertical distance is taken into account by adding “11 m to tunnel crown” and “14 m to tunnel crown” lines for the MRIs and SEMs respectively.

Visually it’s easy to see that moving the alignment West increases the distances of the equipment along the X-axis in the direction of the green arrows thus exposing them to lower level of DC magnetic fields.

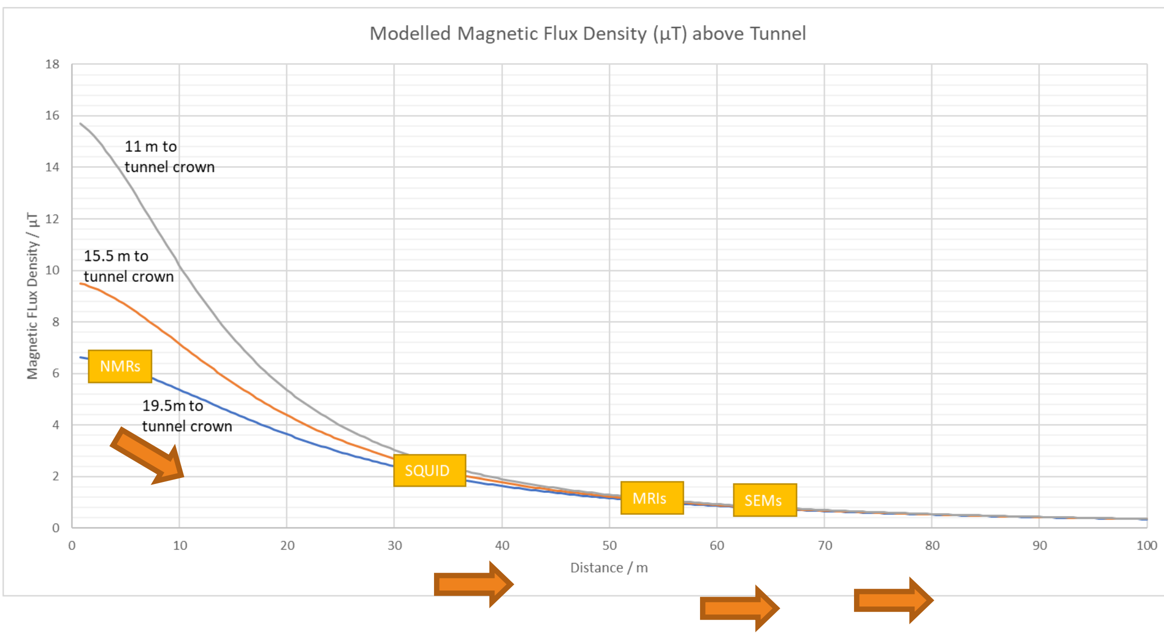

Figure 2: Magnetic Flux density at respective depths for Option 1

Similarly, the effect of increasing the depth of the alignment is also evident as indicated by the three graphs with their magnitudes decreasing with additional distance to the tunnel crown.

3.1 Alternative Option 1, Modified PDR, R = 400m radius curve

The R400m Modified PDR follows the same horizontal alignment as the original PDR but with increased tunnel depth. The table below summarises the updated equipment distances (vertically) based on this modification.

Table 2: Equipment distances for Option 1 with at R=400m

Building Name and Equipment	Chainage and Distance from Alignment at R=350m	Tunnel Depth and Equipment distance to crown
SNIAM – SQUID machine	Chainage: 17+710 Distance: 30 m	18.5 m tunnel depth 18.5 m to tunnel crown
Chemistry – Three NMRs	Chainage: 17+840 Distance: 3-9 m	19.5 m tunnel depth 19.5 m to tunnel crown
Lloyd Institute – Two MRI Systems	Chainage: 17+750 Distance: 52 m	19 m tunnel depth 11 m to tunnel crown (- 8 m below ground)
Panoz (EE4) – Three SEMs	Chainage: 17+840 Distance: 63 m	19.5 m depth 15.5 m to tunnel crown (- 4 m below ground)

The magnetic field levels were then modelled based on the revised vertical distance to the tunnel crown for each piece of equipment. These are shown in Table 1.1 for this Option 1 with the original modelled levels for Option included also for comparison.

Table 3: Trinity College Dublin – Revised modelled levels for Option1

Building Name and Equipment	Modelled levels for Option 1	Sensitivity	Original modelled levels (Option 0)
SNIAM – SQUID machine	2.5 µT	0.01 µT	2.75 µT
Chemistry – Three NMRs	5-6.5 µT (DC)	0.5 µT	10-14 µT (DC)
Lloyd Institute – Two MRI Systems	1.2 µT	1 µT *	1.5 µT
Panoz (EE4) – Three SEMs	0.8 µT	0.1 µT	0.8 µT

For Option 1, it is evident that the biggest beneficiaries of the increased depth are the NMRs due to their proximity to the alignment. The modelled worst-case levels are reduced by 50%. Even at these levels the NMRs would still be expected to experience an impact and require mitigation.

The SQUID machine will be unlikely to experience an impact due to previous simulation testing (discussed in report 19E8382-1) where DC field level perturbations of 2.75 µT were applied without causing an impact. This is in comparison to the modelled levels of 2.5 µT for Option 1.

The MRIs receive less of a benefit from the increased depth due to them being further from the proposed alignment. The assumed sensitivity is still exceeded but on account of the modelled worst-case levels being reduced mitigation being required for this equipment is not a certainty, but it must be assumed that they will require it.

For the SEMs, the modelled level still exceeds the equipment's stated sensitivity. Similar to the MRIs it is not guaranteed that for day-to-day operation they would require additional mitigation measures to be implemented since these worst case levels which would be in excess of actual day to day operational levels from the proposed scheme.

3.2 Alternative Option 2, R = 350m radius curve

The effect of reducing the radius curve of the tunnel beneath Trinity College to R = 350m results in the following revised distances for the highlighted equipment.

Table 4: Equipment distances at R=350m

Building Name and Equipment	Chainage and Distance from Alignment at R=350m	Tunnel Depth and Equipment distance to crown
SNIAM – SQUID machine	Chainage: 16+690 Distance: 48 m	18.5 m tunnel depth 18.5 m to tunnel crown
Chemistry – Three NMRs	Chainage: 17+830 Distance: 35-44 m	20 m tunnel depth 20 m to tunnel crown
Lloyd Institute – Two MRI Systems	Chainage: 17+730 Distance: 70 m	18 m depth 10 m to tunnel crown (- 8 m below ground)
Panoz (EE4) – Three SEMs	Chainage: 17+830 Distance: 95-104 m	20 m depth 16 m to tunnel crown (- 4 m below ground)

This results in the following revised modelled field levels:

Table 5: Trinity College Dublin – Revised modelled levels for Option 2

Building Name and Equipment	Modelled levels for Option 2	Sensitivity	Original modelled levels for Option 0
SNIAM – SQUID machine	1.2 µT	0.01 µT	2.5 µT
Chemistry – Three NMRs	1.4-1.9 µT	0.5 µT	5-6 µT
Lloyd Institute – Two MRI Systems	0.7 µT	1 µT *	1.2 µT
Panoz (EE4) – Three SEMs	0.3 µT	0.1 µT	0.8 µT

For R=350m, it is possible that the NMRs will still experience an impact with modelled worst case levels as high as 1.9 µT modelled and therefore mitigation may still need to be explored.

The SQUID machine will not experience an impact due to previous simulation testing (discussed in report 19E8382-1) where DC field level perturbations of 2.75 µT were applied without causing an impact. Therefore, modelled levels of 1.2 µT would mean it is even less likely.

The revised modelled levels fall below the expected sensitivity for the MRIs and therefore they would not be expected to experience an impact at the new distance.

While for the SEMs, the modelled level still exceeds the equipment's stated sensitivity the likelihood of the equipment being operationally impacted is greatly reduced.

While these worst-case modelled levels of 0.3 μT, still exceed the equipment's sensitivity of 0.1 μT and the current baseline variations of 0.15 μT, during normal day to day operation the actual levels would fall below sensitivity threshold with the risk of interference arising during the rare instances of substation downtime on this section of the line and two trains accelerating at maximum current draw simultaneously.

It would be expected that the Chemistry building with its 3 NMRs would be the only one requiring the implementation of mitigation measures for Option 2. Mitigation through active cancellation could be implemented within SNIAM also given the worst-case modelling for this option but the system could possibly never be required to be switched on.

3.3 Alternative Option 3, R = 302m radius curve

The effect of reducing the radius curve of the tunnel beneath Trinity College to R = 302 m results in the following revised distances for the highlighted equipment.

Table 6: Equipment distances at R=302m

Building Name and Equipment	Chainage and Distance from Alignment at R = 302m	Tunnel Depth and Equipment distance to crown
SNIAM – SQUID machine	Chainage: 17+690 Distance: 60 m	18.5 m tunnel depth 18.5 m to tunnel crown
Chemistry – Three NMRs	Chainage: 17+820 Distance: 62-70 m	19.5 m tunnel depth 19.5 m to tunnel crown
Lloyd Institute – Two MRI Systems	Chainage: 17+710 Distance: 84 m	18 m tunnel depth 10 m to tunnel crown (- 8 m below ground)
Panoz (EE4) – Three SEMs	Chainage: 17+820 Distance: 123-132 m	19.5 m tunnel depth 15.5 m to tunnel crown (-4 m below ground)

This results in the following revised modelled field levels:

Table 7: Trinity College Dublin – Revised modelled levels for Option 3

Building Name	Equipment	Modelled levels for Option 3	Sensitivity	Original modelled levels for Option 0
SNIAM	SQUID machine	0.86 µT	0.01 µT	2.75 µT
Chemistry	Three NMRs	0.68 – 0.8 µT	0.5 µT	10-14 µT
Lloyd Institute	Two MRI Systems	0.5 µT	1 µT *	1.5 µT
Panoz (EE4)	Three SEMs	0.2 µT	0.1 µT	0.8 µT

For R = 302m, it is unlikely that any of the listed equipment will experience any interference from the proposed development. While the levels modelled for the NMRs are still slightly above the stated sensitivity these are worst case modelled conditions, as stated in previous reports. The worst case conditions being modelled are the use of a single substation for traction along with two trains accelerating at maximum acceleration at the same time on that section of the line. A situation that could occur in once off incidents (e.g. planned shutdowns) but would not occur day to day under normal operation. The typical operational levels will be below the 0.5 µT stated limit for this equipment at their locations.

The SQUID machine was noted not to experience interference with a simulated field of 2.75 µT such that the revised modelled level of 0.8 µT will not cause interference. This is also compared against a baseline survey conducted at the equipment location where over a 20 minute survey window fluctuations of 0.7 µT were noted with no impact being experienced on the equipment's operation.

Similar to the SQUID machine the revised modelled levels for the SEMs are close to the current background levels within which these machines operate without issue (0.2 µT worst-case modelled versus 0.15 µT measured during surveys). The normal operational levels at the revised distance of greater than 100 m will not be perceptible above background levels at this location.

Finally, the modelled levels are below the expected limit for the MRIs which should not experience interference during normal operation of the proposed scheme.

4. Discussion of Alignment Options and Mitigation Options

4.1 Original Preliminary Design (Option 0), R=400m

CEI's assertion has been that an Active Cancellation (costed at €40,000 - €50,000 per system) should achieve the required level of mitigation on its own without the need for supplementary passive shielding for the majority of the systems, if they require it. In the case of the NMRs (where initial modelling suggested magnetic fields of 10-14 µT) the installation would not be without challenge and the possibility of passive shielding may need to be explored if investigations determine that the desired Active Cancellation system efficacy cannot be achieved.

The physical installation of Active Cancellation is relatively straightforward in comparison to passive shielding (typical system downtime of 3 days or at least at a reduced operational resolution to facilitate the installation, routing of cables and tuning of the system). Passive shielding would require a much longer downtime as the affected room would need to be stripped back and existing services re-routed. Passive shielding utilised for the main lab housing the NMRs would cost approximately €90,000 (utilising silicon steel as Mu-metal should not be required for the NMRs). There is no guarantee that it would be needed if the Active Cancellation system successfully achieves the desired results.

Active cancellation on its own should be sufficient to provide mitigation for the other equipment locations (MRIs, SQUID and SEMs) if it is decided that it is required.

4.2 Modified PDR (Option 1), R=400m

The vertical depth of the alignment for the modified preliminary design has been increased for Option 1. As discussed in Section 3, increasing distance along both the horizontal as well as the vertical from the source will reduce any equipment vulnerability to interference with the biggest reductions in magnetic fields are made at the equipment that is closest to the proposed alignment. In the case of the NMR equipment in the Chemistry Department, previous modelling projected worst case magnetic fields of 10-14 µT. With the added depth at the relevant chainage this is reduced to 5-6 µT which was depicted in Table 3.

This reduction is significant and would mean the implementation of an active cancellation system should be more straightforward and reduces the likelihood of any passive shielding being needed even further. As an example, taking a system specified by a manufacturer to cancel a 15 µT field. This would need to be installed to close to 100 % efficacy when tuning the system. It is more straightforward for a system than would need to be tuned for lower field perturbations of the order of 5-6 µT.

The requirement for mitigation for the MRIs and SEMs is reduced but as with Option 0 may still need to be installed.

4.3 Alternative Option 2, R=350m

The modelled fields and the likely effects on the equipment are discussed in section 3 for R=350m. The NMRs would still be recommended to utilise Active Cancellation as a mitigation measure with worst-case field levels of 1.9 µT modelled for this alignment option.

While the SEMs may not require mitigation in practice the fact that the modelled worst-case levels of 0.3 µT exceeds the equipment's stated sensitivity may mean that the operators may still favour having these systems installed, even if they are never required to be used once the MetroLink is operational.

No mitigation measures would be expected to the required at the other equipment locations.

4.4 Alternative Option 3, R=302m

The modelled fields and the likely effects on the equipment are discussed in section 3 for R=302m which concludes that for this alignment, none of the listed equipment should require additional mitigation measures.

As with Option 2 (R=350m), however, the theoretical worst case levels still exceed the sensitivities for both the NMRs and the SEMs but the implementation of mitigation measures would likely be of no benefit to the equipment whereby the systems should not be required to be used in practice.

5. Conclusions

From our assessment of the equipment types currently in use on the Trinity College campus, moving the alignment further west reduces the fields at all of the previously identified sensitive equipment and therefore the likelihood of any impact being noticeable at their locations. Increasing the depth of the tunnel also provides the same benefit albeit with a less available distance to modify the PDR being available.

While realignment may result in the alignment moving closer to other buildings and equipment no new equipment types outside of those discussed in this report will be introduced as being a new risk.

Of the alternative alignment options presented (Option 1, Option 2 and Option 3) Option 3 would be the recommended option from an electromagnetic interference perspective as it reduces the DC field lines more significantly for the identified of equipment. And for much of the campus where the most sensitive equipment is currently located and could be located in the future.

No DC magnetic field issues were identified for any OPW building along with preliminary alignment nor would alternative alignments result in any new issues. However, the preliminary alignment does come close to the underground committee rooms of the Dáil that contains audiovisual systems including an induction loop. Potential interference at this location is already considered unlikely on the assumption that the currently installed systems meet their EMC directive requirements. That said any deviation westward and away from this location would be considered to positive simply on account of the fact that any slight chance of audio acoustic interference on these systems from AC fields will become even less likely.

Understanding that EMI is not necessarily the sole factor in final alignment selection both the alternative alignment options outlined (Option 2 and Option 3) along with the preliminary design alignment (Option 0) and modified preliminary design (Option 1) can all be successfully implemented with the necessary mitigation measures in place at the identified equipment if necessary. This is with the proviso that alignments further east will require more on site mitigation in the form of Active Cancellation and potentially passive shielding (in the case of the NMRs) as discussed in section 4.

Appendix E. Horizontal / Vertical Alignment Design Drawings

Option 1 ML1-JAI-CPS-ROUT_XX-DR-Y-00011

Option 2 ML1-JAI-CPS-ROUT_XX-DR-Y-00012

Option 3 ML1-JAI-CPS-ROUT_XX-DR-Y-00013

Option 4 ML1-JAI-CPS-ROUT_XX-DR-Y-00014