Economic and Technical Report

May 2023 Report Appendices

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Contents

1 Appendix 1: Longlist of Scheme Options

The tables below provide the full longlist of Scheme Options, split by route section. The options discarded at each test/sift are then listed.

1.1 Oxford to Bedford

Full Longlist

Alignment ID	Service/Alignment Options	Mode	Trains / Users PH	MVL Pattern Summary
CS2-HR-S1	Existing - Oxf to Mkc 2tph/ Bletchley to Bed 1tph stopper (Base case) + existing freight	Heavy Rail	2tph	2
CS2-HR-S1	Existing - Oxf to Mkc 2tph/ Bletchley to Bed 1tph stopper (Base case) + existing freight	Heavy Rail	2tph	5
CS2-HR-S1	Existing - Oxf to Mkc 2tph/ Bletchley to Bed 1tph stopper (Base case) + existing freight	Heavy Rail	2tph	2 (EWR) + 10 (existing)
CS2-HR-S2	Existing - Oxf to Mkc 2tph/Oxf to Bed 2tph + existing freight	Heavy Rail	4tph	2
CS2-HR-S2	Existing - Oxf to Mkc 2tph/Oxf to Bed 2tph + existing freight	Heavy Rail	4tph	5
CS2-HR-S2	Existing - Oxf to Mkc 2tph/Oxf to Bed 2tph + existing freight	Heavy Rail	4tph	2 (EWR) + 10 (existing)
CS2-HR-S3	Oxf to Mkc 2tph/Oxf to Bed 1tph + existing freight	Heavy Rail	3tph	2
CS2-HR-S3	Oxf to Mkc 2tph/Oxf to Bed 1tph + existing freight	Heavy Rail	3tph	5
CS2-HR-S3	Oxf to Mkc 2tph/Oxf to Bed 1tph + existing freight	Heavy Rail	3tph	2 (EWR) + 10 (existing)
CS2-HR-S4	Oxf to Mkc 1tph/Oxf to Bed 2tph + existing freight	Heavy Rail	3tph	2
CS2-HR-S4	Oxf to Mkc 1tph/Oxf to Bed 2tph + existing freight	Heavy Rail	3tph	5
CS2-HR-S4	Oxf to Mkc 1tph/Oxf to Bed 2tph + existing freight	Heavy Rail	3tph	2 (EWR) + 10 (existing)
CS2-HR-S5	Oxf to Mkc 1tph/Oxf to Bed 1tph + existing freight	Heavy Rail	2tph	2
CS2-HR-S5	Oxf to Mkc 1tph/Oxf to Bed 1tph + existing freight	Heavy Rail	2tph	5
CS2-HR-S5	Oxf to Mkc 1tph/Oxf to Bed 1tph + existing freight	Heavy Rail	2tph	2 (EWR) + 10 (existing)

Alignment ID	Service/Alignment Options	Mode	Trains / Users PH	MVL Pattern Summary
CS2-HR-S6	Oxf to Mkc 0tph/Oxf to Bed 2tph + existing freight	Heavy Rail	2tph	2
CS2-HR-S6	Oxf to Mkc 0tph/Oxf to Bed 2tph + existing freight	Heavy Rail	2tph	5
CS2-HR-S6	Oxf to Mkc 0tph/Oxf to Bed 2tph + existing freight	Heavy Rail	2tph	2 (EWR) + 10 (existing)
CS2-HR-S7	Oxf to Mkc 1tph - Bed to Mkc 1tph	Heavy Rail	1tph	2
CS2-HR-S7	Oxf to Mkc 1tph - Bed to Mkc 1tph	Heavy Rail	1tph	5
CS2-HR-S7	Oxf to Mkc 1tph - Bed to Mkc 1tph	Heavy Rail	1tph	2 (EWR) + 10 (existing)
CS2-HR-S8	Existing - Oxf to Mkc 2ph - Bed to Mkc 1tph stopper	Heavy Rail	2tph	2
CS2-HR-S8	Existing - Oxf to Mkc 2ph - Bed to Mkc 1tph stopper	Heavy Rail	2tph	5
CS2-HR-S8	Existing - Oxf to Mkc 2ph - Bed to Mkc 1tph stopper	Heavy Rail	2tph	2 (EWR) + 10 (existing)
CS2-HR-S9	Oxf to Mkc 2ph - Bed to AYS 1tph stopper	Heavy Rail	2tph	2
CS2-HR-S9	Oxf to Mkc 2ph - Bed to AYS 1tph stopper	Heavy Rail	2tph	5
CS2-HR-S9	Oxf to Mkc 2ph - Bed to AYS 1tph stopper	Heavy Rail	2tph	2 (EWR) + 10 (existing)
CS2-HR-S10	Oxf to Mkc 1tph - Bed to Mkc 1tph stopper - Oxf to Bed 1tph stopper	Heavy Rail	2tph	2
CS2-HR-S10	Oxf to Mkc 1tph - Bed to Mkc 1tph stopper - Oxf to Bed 1tph stopper	Heavy Rail	2tph	5
CS2-HR-S10	Oxf to Mkc 1tph - Bed to Mkc 1tph stopper - Oxf to Bed 1tph stopper	Heavy Rail	2tph	2 (EWR) + 10 (existing)
CS2-HR-S11	Oxf to Bed via Mkc 1ph stopper - Oxf to Bed 1tph stopper	Heavy Rail	2tph	2
CS2-HR-S11	Oxf to Bed via Mkc 1ph stopper - Oxf to Bed 1tph stopper	Heavy Rail	2tph	5
CS2-HR-S11	Oxf to Bed via Mkc 1ph stopper - Oxf to Bed 1tph stopper	Heavy Rail	2tph	2 (EWR) + 10 (existing)
CS2-HR-S12	Freight only	Heavy Rail	Freight	
CS2-HR-S13	Oxf to Mkc 1tph - 1 Oxf - Bed 1tph stopper - 1 AYS to Mkc	Heavy Rail	2tph	2
CS2-HR-S13	Oxf to Mkc 1tph - 1 Oxf - Bed 1tph stopper - 1 AYS to Mkc	Heavy Rail	2tph	5
CS2-HR-S13	Oxf to Mkc 1tph - 1 Oxf - Bed 1tph stopper - 1 AYS to Mkc	Heavy Rail	2tph	2 (EWR) + 10 (existing)
CS2-HR-S14	Oxf to Mkc 1tph/Oxf to Bed 2tph/Ayl – MK 1tph + existing freight	Heavy Rail	3tph	2
CS2-HR-S14	Oxf to Mkc 1tph/Oxf to Bed 2tph/Ayl – MK 1tph + existing freight	Heavy Rail	3tph	5

Alignment ID	Service/Alignment Options	Mode	Trains / Users PH	MVL Pattern Summary
CS2-HR-S14	Oxf to Mkc 1tph/Oxf to Bed 2tph/Ayl – MK 1tph + existing freight	Heavy Rail	3tph	2 (EWR) + 10 (existing)
CS2-LR-S1	Existing - Oxford to Milton Keynes Central	Light Rail	4tph	
CS2-LR-S2	Bletchley to Bedford (MVL)	Light Rail	4tph	2
CS2-LR-S2	Bletchley to Bedford (MVL)	Light Rail	4tph	5
CS2-LR-S4	Existing - Oxford to Bletchley	Light Rail	4tph	
CS2-LR-S1	Oxford to Milton Keynes Central	Tram/Train	4tph	
CS2-LR-S2	Bletchley to Bedford (MVL)	Tram/Train	4tph	2
CS2-LR-S2	Bletchley to Bedford (MVL)	Tram/Train	4tph	5
CS2-LR-S2	Bletchley to Bedford (MVL)	Tram/Train	4tph	2 (EWR) + 10 (existing)
CS2-TT-S3	Aylesbury to Gavray Junction	Tram/Train	4tph	
CS2-LR-S4	Existing - Oxford to Bletchley	Tram/Train	4tph	
CS2-LR-S1	Existing - Oxford to Milton Keynes Central	Guided Bus	6bph	
CS2-LR-S2	Bletchley to Bedford (MVL)	Guided Bus	6bph	2 (EWR) + 10 (existing)
CS2-TT-S3	Aylesbury to Gavray Junction	Guided Bus	4bph	
CS2-R-S1	Existing - New replace railway	Road	NA	
CS2-HL-S1	Existing - New replace railway with hyperloop	Hyperloop	NA	
CS2-ML-S1	Existing - New replace railway with Maglev	Maglev	NA	`
CS2-CC-S1	Existing - New replace railway with cable car	Cable car	NA	

Discarded at Credibility Test

Alignment ID	Service/Alignment Options	Mode	Trains / Users PH	Reason why discarded at credibility sift
CS2-LR-S1	Oxford to Milton Keynes Central	Light Rail	4tph	Technical complexity of shared running and cost of Light Rail on WCML. Light Rail requires additional enforced separation by the signalling system between light rail and heavy rail due to crash worthiness requirements. This would result in significant alterations to the existing signalling and 25% of the existing capacity would be lost driving additional infrastructure (track). Another solution to mitigate would be to fit ETCS on the west coast but would still result in longer overrun protection. Likely cost to be £500m+
CS2-LR-S4	Oxford to Bletchley	Light Rail	4tph	Technical complexity of shared running and cost of Light Rail on WCML. Light Rail requires additional enforced separation by the signalling system between light rail and heavy rail due to crash worthiness requirements. This would result in significant alterations to the existing signalling and 25% of the existing capacity would be lost driving additional infrastructure (track). Another solution to mitigate would be to fit ETCS on the west coast but would still result in longer overrun protection. Likely cost to be £500m+
CS2-LR-S1	Oxford to Milton Keynes Central	Guided Bus	6bph	Cost and impact on existing services. Footprint of existing railway would only support single road with passing places (constrained bridges). Significant capacity, environmental and cost implications. In excess of £500m.
CS2-R-S1	New replace railway	Road	NA	Cost and impact on existing services. Footprint of existing railway would only support single road with passing places (constrained bridges). Significant capacity, environmental and cost implications. In excess of £500m.
CS2-HL-S1	New replace railway with hyperloop	Hyperloop	NA	Technical complexity, risk of new technology, high operating costs, wrong distance for solution, high cost, small capacity. Cost in excess of £750m
CS2-ML-S1	New replace railway with Maglev	Maglev	NA	Technical complexity, high operating costs, high cost, inappropriate distance for solution. Cost in excess of £750m.
CS2-CC-S1	New replace railway with cable car	Cable car	NA	Long journey time, limited capacity.

Discarded at Affordability Test

Alignment ID	Service/Alignment Options	Mode	Trains / Users PH	MVL Stopping Pattern Summary	Reason why discarded at affordability sift
CS2-HR-S2	Oxf to Mkc 2tph/Oxf to Bed 2tph + existing freight	Heavy Rail	4tph	2	Would require 4 tph between Bletchley and Oxford. Required spend at Oxford station (£25m construction) and Bicester LX (£21m construction) with considerable risk.
CS2-HR-S2	Oxf to Mkc 2tph/Oxf to Bed 2tph + existing freight	Heavy Rail	4tph	5	Would require 4 tph between Bletchley and Oxford. Required spend at Oxford station (£25m construction) and Bicester LX (£21m construction) with considerable risk.
CS2-HR-S2	Oxf to Mkc 2tph/Oxf to Bed 2tph + existing freight	Heavy Rail	4tph	2 (EWR) + 10 (existing)	Would require 4 tph between Bletchley and Oxford. Required spend at Oxford station (£25m construction) and Bicester LX (£21m construction) with considerable risk.
CS2-HR-S8	Oxf to Mkc 2ph - Bed to Mkc 1tph stopper	Heavy Rail	2tph	2	Complexity, cost and capacity on WCML. This results in 3tph between Bletchley and MK. Existing WCML is at capacity and Platform constraints to turn services. Likely to required Additional platform capacity to enable train to turn. Existing signalling is conventional and no further capacity can be provided unless additional infrastructure (track) or migration to ETCS with traffic management is provided. Cost estimated to be £500m+ considering infrastructure alterations /land or ETCS traffic management for the Rugby ROC desk (inc rolling stock fitment).
CS2-HR-S8	Oxf to Mkc 2ph - Bed to Mkc 1tph stopper	Heavy Rail	2tph	5	Complexity, cost and capacity on WCML. This results in 3tph between Bletchley and MK. Existing WCML is at capacity and Platform constraints to turn services. Likely to required Additional platform capacity to enable train to turn. Existing signalling is conventional and no further capacity can be provided unless additional infrastructure (track) or migration to ETCS with traffic management is provided. Cost estimated to be £500m+ considering infrastructure alterations /land or ETCS traffic management for the Rugby ROC desk (inc rolling stock fitment).

Alignment ID	Service/Alignment Options	Mode	Trains / Users PH	MVL Stopping Pattern Summary	Reason why discarded at affordability sift
CS2-HR-S8	Oxf to Mkc 2ph - Bed to Mkc 1tph stopper	Heavy Rail	2tph	2 (EWR) + 10 (existing)	Complexity, cost and capacity on WCML. This results in 3tph between Bletchley and MK. Existing WCML is at capacity and Platform constraints to turn services. Likely to required Additional platform capacity to enable train to turn. Existing signalling is conventional and no further capacity can be provided unless additional infrastructure (track) or migration to ETCS with traffic management is provided. Cost estimated to be £500m+ considering infrastructure alterations /land or ETCS traffic management for the Rugby ROC desk (inc rolling stock fitment).
CS2-LR-S4	Oxford to Bletchley	Tram/Train	4tph		Cost of upgrading track to light rail. As identified in other options additional separation is required between light rail and heavy rail. This could be provided through altering existing system with loss of capacity (25%) or ETCS. Trams would be fitted with own signalling system. Existing rolling stock would be required to be fitted if ETCS selected. Estimated cost is in excess of £300m.

Discarded at Strategic Sift

Service/Alignment Options	Mode	Trains / Users PH	MVL Stopping Pattern	Strategic Driver Category not met
Oxf to Mkc 2 tph/ Bletchley to Bed 1tph stopper (Base case) + existing freight	Heavy Rail	2 tph	2 stations	Capacity, Population, Growth Opportunity, Jobs
Oxf to Mkc 2 tph/ Bletchley to Bed 1tph stopper (Base case) + existing freight	Heavy Rail	2 tph	2 EWR + 10 Stopper	Capacity
Oxf to Mkc 2 tph/Oxf to Bed 1tph + existing freight	Heavy Rail	3 tph	2 stations	Demand, Population, Growth Opportunity, Jobs
Oxf to Mkc 2 tph/Oxf to Bed 1tph + existing freight	Heavy Rail	3 tph	5 stations	Capacity
Oxf to Mkc 2 tph/Oxf to Bed 1tph + existing freight	Heavy Rail	3 tph	2 EWR + 10 stopper	Demand
Oxf to Mkc 1tph/Oxf to Bed 2 tph + existing freight	Heavy Rail	3 tph	2 stations	Population, Growth Opportunity, Jobs
Oxf to Mkc 1tph/Oxf to Bed 1tph + existing freight	Heavy Rail	2 tph	2 stations	Demand, Population, Growth Opportunity, Jobs
Oxf to Mkc 1tph/Oxf to Bed 1tph + existing freight	Heavy Rail	2 tph	5 stations	Demand
Oxf to Mkc 1tph/Oxf to Bed 1tph + existing freight	Heavy Rail	2 tph	2 EWR + 10 stopper	Demand
Oxf to Mkc 0tph/Oxf to Bed 2 tph + existing freight	Heavy Rail	2 tph	2 stations	Population, Growth Opportunity, Jobs
Oxf to Mkc 1tph – Bed to Mkc 1tph	Heavy Rail	1tph	2 stations	Population, Growth Opportunity, Jobs
Oxf to Mkc 2ph – Bed to AYS 1tph stopper	Heavy Rail	2 tph	2 stations	Demand, Growth Opportunity
Oxf to Mkc 2ph – Bed to AYS 1tph stopper	Heavy Rail	2 tph	5 stations	Demand, Population Jobs
Oxf to Mkc 2ph – Bed to AYS 1tph stopper	Heavy Rail	2 tph	2 EWR + 10 stopper	Demand

Service/Alignment Options	Mode	Trains / Users PH	MVL Stopping Pattern	Strategic Driver Category not met
Oxf to Mkc 1tph – Bed to Mkc 1tph stopper – Oxf to Bed 1tph stopper	Heavy Rail	2 tph	2 stations	Population, Growth Opportunity, Jobs
Oxf to Mkc 1tph – Bed to Mkc 1tph stopper – Oxf to Bed 1tph stopper	Heavy Rail	2 tph	2 EWR + 10 stopper	Population, Jobs
Oxf to Bed via Mkc 1ph stopper - Oxf to Bed 1tph stopper	Heavy Rail	2 tph	2 stations	Population, Growth Opportunity, Jobs
Freight only	Heavy Rail	Freight Only	-	No Passenger Service
Oxf to Mkc 1tph - 1 Oxf - Bed 1tph stopper - 1 AYS to Mkc	Heavy Rail	3tph	2 EWR + 10 Stopper	Attractive to Users
Oxford to Milton Keynes Central	Tram/Train	4 tph	-	Population, Growth Opportunity, Jobs
Bletchley to Bedford (MVL)	Tram/Train	4 tph	2 stations	Population, Growth Opportunity, Jobs
Bletchley to Bedford (MVL)	Tram/Train	4 tph	2 EWR + 10 Stopper	Attractive to User
Aylesbury to Gavray Junction	Tram/Train	4 tph	-	Demand, Population, Growth Opportunity, Jobs
Bletchley to Bedford (MVL)	Guided Bus	6bph	-	Demand
Aylesbury to Gavray Junction	Guided Bus	4bph	-	Demand

Alignment ID	Service/Alignment Options	Mode	Trains / Users PH	Reason for failing attractiveness to users?

Scheme Options Retained

Mode	Alignment ID	Long List Description	MVL Stations	Bicester - Bletchley Frequency (Trains / Users PH)	Bletchley - Bedford Frequency (Trains / Users PH)	Dependency
Heavy Rail	CS2-HR-S1	Oxf to Mkc 2 tph/ Bletchley to Bed 1tph stopper (Base case) + existing freight	5	2	1	none
	CS2-HR-S4	Existing - Oxf to MKC 1tph/Oxf to Bed 2 tph + existing freight	5	2	2	
	CS2-HR-S4	Existing - Oxf to MKC 1tph/Oxf to Bed 2 tph + existing freight	2 (EWR) + 10 (existing)	2	3	
	CS2-HR-S6	Existing - Oxf to MKC 0tph/Oxf to Bed 2 tph + existing freight	5	2	3	
	CS2-HR-S6	Existing - Oxf to MKC 0tph/Oxf to Bed 2 tph + existing freight	5	2	3	
	CS2-HR-S6	Existing - Oxf to MKC 0tph/Oxf to Bed 2 tph + existing freight	2 (EWR) + 10 (existing)	2	3	
	CS2-HR-S7	Existing - Oxf to MKC 1tph - Bed to MKC 1tph	5	1	1	
	CS2-HR-S7	Existing - Oxf to MKC 1tph - Bed to MKC 1tph	2 (EWR) + 10 (existing)	1	1	
	CS2-HR-S10	Oxf to Mkc 1tph – Bed to Mkc 1tph stopper – Oxf to Bed 1 tph stopper	5	2	2	
	CS2-HR-S11	Oxf to Bed via Mkc 1ph stopper - Oxf to Bed 1tph stopper	5	2	2	

Mode	Alignment ID	Long List Description	MVL Stations	Bicester - Bletchley Frequency (Trains / Users PH)	Bletchley - Bedford Frequency (Trains / Users PH)	Dependency
	CS2-HR-S11	Oxf to Bed via Mkc 1ph stopper - Oxf to Bed 1tph stopper	2 (EWR) + 10 (existing)	2	2	
	CS2-HR-S13	Existing - Oxf to MKC 1tph - 1 Oxf - Bed 1tph stopper - 1 AYS to MKC	2	2	1	
	CS2-HR-S13	Existing - Oxf to MKC 1tph - 1 Oxf - Bed 1tph stopper - 1 AYS to MKC	5	2	1	
	CS2-HR-S14	Existing - Oxf to MKC 1tph/Oxf to Bed 2 tph/AYS – MKC 1tph + existing freight	2	3	2	
	CS2-HR-S14	Existing - Oxf to MKC 1tph/Oxf to Bed 2 tph/ AYS – MKC 1tph + existing freight	5	4	2	
	CS2-HR-S14	Existing - Oxf to MKC 1tph/Oxf to Bed 2 tph/ AYS – MKC 1tph + existing freight	2 (EWR) + 10 (existing)	4	3	
Light Rail	CS2-LR-S2	Existing - Bletchley to Bedford (MVL)	2	N/A	4	Bedford to Cambridge is also light rail
Light Rail	CS2-LR-S2	Existing - Bletchley to Bedford (MVL)	5	N/A	4	Bedford to Cambridge is also light rail
Tram Train	CS2-LR-S2	Existing - Bletchley to Bedford (MVL)	5	N/A	4	Bedford to Cambridge is also light rail

1.2 Bedford to Cambridge

Full Longlist

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode
CS3-HR-A1	Bedford North - RA1 - Cambridge via South (Current Scheme)	4tph	Heavy Rail
CS3-HR-A1	Bedford North - RA1 - Cambridge via South	3tph	Heavy Rail
CS3-HR-A1	Bedford North - RA1 - Cambridge via South	2tph	Heavy Rail
CS3-HR-A2	Bedford North - RA1 - Cambridge South terminate	2tph	Heavy Rail
CS3-HR-A2	Bedford North - RA1 - Cambridge South terminate	3tph	Heavy Rail
CS3-HR-A2	Bedford North - RA1 - Cambridge South terminate	4tph	Heavy Rail
CS3-HR-A3	Bedford North - RA1 - Cambridge via North	4tph	Heavy Rail
CS3-HR-A3	Bedford North - RA1 - Cambridge via North	3tph	Heavy Rail
CS3-HR-A3	Bedford North - RA1 - Cambridge via North	2tph	Heavy Rail
CS3-HR-A4	Bedford North - RA2 - Cambridge via South	4tph	Heavy Rail
CS3-HR-A4	Bedford North - RA2 - Cambridge via South	3tph	Heavy Rail
CS3-HR-A4	Bedford North - RA2 - Cambridge via South	2tph	Heavy Rail
CS3-HR-A5	Bedford North - RA2 - Cambridge South terminate	2tph	Heavy Rail
CS3-HR-A5	Bedford North - RA2 - Cambridge South terminate	3tph	Heavy Rail
CS3-HR-A5	Bedford North - RA2 - Cambridge South terminate	4tph	Heavy Rail
CS3-HR-A6	Bedford North - RA6 - Cambridge via South	4tph	Heavy Rail
CS3-HR-A6	Bedford North - RA6 - Cambridge via South	3tph	Heavy Rail

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode
CS3-HR-A6	Bedford North - RA6 - Cambridge via South	2tph	Heavy Rail
CS3-HR-A7	Bedford North - RA6 - Cambridge South terminate	2tph	Heavy Rail
CS3-HR-A7	Bedford North - RA6 - Cambridge South terminate	3tph	Heavy Rail
CS3-HR-A7	Bedford North - RA6 - Cambridge South terminate	4tph	Heavy Rail
CS3-HR-A8	Bedford North - RA8 - Cambridge via South	4tph	Heavy Rail
CS3-HR-A8	Bedford North - RA8 - Cambridge via South	3tph	Heavy Rail
CS3-HR-A8	Bedford North - RA8 - Cambridge via South	2tph	Heavy Rail
CS3-HR-A9	Bedford North - RA8 - Cambridge South terminate	2tph	Heavy Rail
CS3-HR-A9	Bedford North - RA8 - Cambridge South terminate	3tph	Heavy Rail
CS3-HR-A9	Bedford North - RA8 - Cambridge South terminate	4tph	Heavy Rail
CS3-HR-A10	Bedford North - RA9 - Cambridge via South	4tph	Heavy Rail
CS3-HR-A10	Bedford North - RA9 - Cambridge via South	3tph	Heavy Rail
CS3-HR-A10	Bedford North - RA9 - Cambridge via South	2tph	Heavy Rail
CS3-HR-A11	Bedford North - RA9 - Cambridge South terminate	2tph	Heavy Rail
CS3-HR-A11	Bedford North - RA9 - Cambridge South terminate	3tph	Heavy Rail
CS3-HR-A11	Bedford North - RA9 - Cambridge South terminate	4tph	Heavy Rail
CS3-HR-A12	Bedford North - RA9 - Cambridge via North	4tph	Heavy Rail
CS3-HR-A12	Bedford North - RA9 - Cambridge via North	3tph	Heavy Rail
CS3-HR-A12	Bedford North - RA9 - Cambridge via North	2tph	Heavy Rail
CS3-HR-A13	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via North	4tph	Heavy Rail
CS3-HR-A13	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via North	3tph	Heavy Rail
Added at shortlist	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via South	2tph	Heavy Rail

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode
Added at shortlist	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via South	4tph	Heavy Rail
CS3-HR-A13	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via North	2tph	Heavy Rail
CS3-HR-A14	Bedford St Johns – Varsity Hybrid - RA6/8 (Cambourne South) – Cambridge via Varsity line guided busway	2tph	Heavy Rail
CS3-HR-A58	Bedford St Johns - Varsity Hybrid via St Neots - Cambourne North - Cambridge via North	2tph	Heavy Rail
CS3-HR-A15	Bedford St Johns - Varsity Line (shortcut) - Cambridge via Varsity	4tph	Heavy Rail
CS3-HR-A15	Bedford St Johns - Varsity Line (shortcut)- Cambridge via Varsity	3tph	Heavy Rail
CS3-HR-A15	Bedford St Johns - Varsity Line (shortcut)- Cambridge via Varsity	2tph	Heavy Rail
CS3-HR-A15 - Added at shortlist	Bedford St Johns - Varsity Line (shortcut) - Cambridge via Cambridge South	2tph	Heavy Rail
CS3-HR-A16	Bedford St Johns - Varsity Line (shortcut) - Cambridge Varsity Trumpington terminate	4tph	Heavy Rail
CS3-HR-A16	Bedford St Johns - Varsity Line (shortcut) - Cambridge Varsity Trumpington terminate	3tph	Heavy Rail
CS3-HR-A16	Bedford St Johns - Varsity Line (shortcut) - Cambridge Varsity Trumpington terminate	2tph	Heavy Rail
CS3-HR-A17	Bedford St Johns - ECML - Hitchin - Royston - Cambridge South	2tph	Heavy Rail
CS3-HR-A59	Bedford St Johns - ECML - Royston - Cambridge South	2tph	Heavy Rail
CS3-HR-A18	Bedford South Parkway – Varsity Hybrid - Cambourne North – via Cambridge North	2tph	Heavy Rail
CS3-HR-A19	Bedford South Parkway – Varsity Hybrid - Cambourne North – Cambridge North terminate	2tph	Heavy Rail
CS3-HR-A20	Bedford South Parkway – Varsity Hybrid - Cambourne South – Cambridge South	2tph	Heavy Rail
CS3-HR-A21	Bedford South Parkway – Varsity Line (shortcut) – via Cambridge South	2tph	Heavy Rail
CS3-HR-A22	Bedford South Parkway – Varsity Line (shortcut) – Cambridge South terminate	2tph	Heavy Rail
CS3-HR-A23	Bedford South Parkway – Sandy (re-located south) & Bassingbourn - via Cambridge South	N/A	Heavy Rail
CS3-HR-A24	Bedford South Parkway - Tempsford Area - Sandy & Bassingbourn - via Cambridge South	N/A	Heavy Rail

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode
CS3-HR-A25	Bedford North - Tempsford area - Sandy & Bassingbourn - via Cambridge South	N/A	Heavy Rail
CS3-HR-A26	Bedford (North) to Tempsford only	2tph	Heavy Rail
CS3-HR-A27	Bedford - Tempsford - Cambourne only	2tph	Heavy Rail
CS3-HR-A28	Bedford St Johns to Tempsford only	2tph	Heavy Rail
CS3-HR-A29	Cambridge North - Cambourne only	2tph	Heavy Rail
CS3-HR-A30	Cambridge South - Cambourne only	2tph	Heavy Rail
CS3-HR-A31	Cambridge North - Cambourne - Tempsford only	2tph	Heavy Rail
CS3-LR-A3	Bedford North - RA1 - Cambridge via Northern rail alignment	4tph	Light Rail
CS3-LR-A33	Bedford via Bedford St Johns - Varsity Hybrid - RA1/9 - Cambridge North Guided Busway	4tph	Light Rail
CS3-LR-A34	Bedford via Bedford St Johns - A421 & A428 - A14 into Cambridge	4tph	Light Rail
CS3-LR-A35	Bedford A4280 -A421 & A428 - A14 into Cambridge	4tph	Light Rail
CS3-LR-A36	Bedford St Johns - Longholme Way, Newham Ave, A4280 - A421 & A428 - A14 into Cambridge	4tph	Light Rail
CS3-LR-A15	Bedford via Bedford St Johns - Varsity - Cambridge via South guided busway	4tph	Light Rail
CS3-LR-A18	Bedford South Parkway – Varsity Hybrid (Cambourne) – Cambridge via North Guided busway	4tph	Light Rail
CS3-LRGB-A37	Light Rail Bedford A4280 to Tempsford - Guided bus A428 & C2C	4 tph/bph	Light Rail - Guided Bus
CS3-LRGB-A38	Light Rail Bedford St Johns to Tempsford - Guided Bus A428 & C2C	4 tph/bph	Light Rail - Guided Bus
CS3-LRGB-A39	Light Rail Cambridge North - Cambourne - Guided Bus to Bedford	4 tph/bph	Light Rail - Guided Bus
CS3-LRGB-A40	Light Rail Cambridge South - Cambourne - Guided Bus to Bedford	4 tph/bph	Light Rail - Guided Bus
CS3-LRGB-A41	Light Rail Cambridge North - Cambourne - Tempsford - Guided Bus to Bedford	4 tph/bph	Light Rail - Guided Bus

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode
CS3-LRGB-A42	Light Rail Cambridge South - Cambourne - Tempsford - Guided Bus to Bedford	4 tph/bph	Light Rail - Guided Bus
CS3-LRB-A37	Light Rail Bedford A4280 to Tempsford - Bus A428 & C2C	4 tph/bph	Light Rail - Bus
CS3-LRB-A38	Light Rail Bedford St Johns to Tempsford - Bus A428 & C2C	4 tph/bph	Light Rail - Bus
CS3-LRB-A39	Light Rail Cambridge North - Cambourne - Bus to Bedford	4 tph/bph	Light Rail - Bus
CS3-LRB-A40	Light Rail Cambridge South - Cambourne - Bus to Bedford	4 tph/bph	Light Rail - Bus
CS3-LRB-A41	Light Rail Cambridge North - Cambourne - Tempsford - Bus to Bedford	4 tph/bph	Light Rail - Bus
CS3-LRB-A42	Light Rail Cambridge South - Cambourne - Tempsford - Bus to Bedford	4 tph/bph	Light Rail - Bus
CS3-GB-A43	Bedford via Bedford St Johns - A421 & A428 - Cambridge via Northern rail alignment	6bph	Guided Bus
CS3-GB-A44	Bedford via Bedford St Johns - A421 & A428 - Cambridge North Guided Busway	4bph	Guided Bus
CS3-GB-A45	Bedford via Bedford St Johns - A421 & A428 - C2C into Cambridge	4bph	Guided Bus
CS3-GB-A34	Bedford via Bedford St Johns - A421 & A428 - A14 into Cambridge	4bph	Guided Bus
CS3-GB-A46	Bedford A4280 -A421 & A428 - C2C into Cambridge	6bph	Guided Bus
CS3-GB-A35	Bedford A4280 -A421 & A428 - A14 into Cambridge	6bph	Guided Bus
CS3-GB-A47	Bedford via Bedford St Johns - Varsity (original via Sandy and Potton) - Cambridge via Varsity	4bph	Guided Bus
CS3-GB-A15	Bedford via Bedford St Johns - Varsity (Shortcut) - Cambridge via Varsity	4bph	Guided Bus
CS3-GB-A48	Bedford South Parkway – A421 & A428 – Cambridge via Northern rail alignment	6bph	Guided Bus
CS3-GB-A49	Bedford South Parkway – A421 & A428 – Cambridge via North Guided Busway	4bph	Guided Bus

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode
CS3-GB-A51	Bedford St Johns - Varsity (Shortcut) - Cambridge via Varsity - via North Guided Busway, C2C and Southern Guided Busway	12bph	Guided Bus
CS3-GB-A52	Bedford via Bedford St Johns - Varsity (Shortcut) - Cambridge via Varsity	6bph	Guided Bus
CS3-GB-A53	Bedford St Johns via northern Alignment corridor into Cambridge via North, South and C2C	12bph	Guided Bus
CS3-GB-A50	Bedford A4280 -A421 & A428 - C2C - Cambridge Automated Metro (CAM)	6bph	Guided Bus
CS3-HRGB-A51	Heavy Rail Bedford (North) to Tempsford - Guided Bus A428 & C2C	2tph/4bph	Heavy Rail - GuidedBus
CS3-HRGB-A52	Heavy Rail Bedford via Bedford St Johns to Tempsford - Guided Bus A428 & C2C	2tph/4bph	Heavy Rail - GuidedBus
CS3-HRGB-A53	Heavy Rail Cambridge North - Cambourne - Guided Bus to Bedford	2tph/4bph	Heavy Rail - GuidedBus
CS3-HRGB-A54	Heavy Rail Cambridge South - Cambourne - Guided Bus to Bedford	2tph/4bph	Heavy Rail - GuidedBus
CS3-HRGB-A55	Heavy Rail Cambridge North - Cambourne - Tempsford - Guided Bus to Bedford	2tph/4bph	Heavy Rail - GuidedBus
CS3-HRB-A51	Heavy Rail Bedford (North) to Tempsford - Bus A428 & C2C	2tph/4bph	Heavy Rail - Bus
CS3-HRB-A52	Heavy Rail Bedford via Bedford St Johns to Tempsford - Bus A428 & C2C	2tph/4bph	Heavy Rail - Bus
CS3-HRB-A53	Heavy Rail Cambridge North - Cambourne - Bus to Bedford	2tph/4bph	Heavy Rail - Bus
CS3-HRB-A54	Heavy Rail Cambridge South - Cambourne - Bus to Bedford	2tph/4bph	Heavy Rail - Bus
CS3-HRB-A55	Heavy Rail Cambridge North - Cambourne - Tempsford - Bus to Bedford	2tph/4bph	Heavy Rail - Bus

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode
CS3-AVRT-01	AVRT - Bedford to Camrbridge	20	AVRT
CS3-R-A56	Bedford A4280 -A421 & A428 - A14 into Cambridge	N/A	Existing Road
CS3-R-A57	Bedford - Cambridge new road	N/A	Road
CS3-HL-A58	Hyperloop Solution	N/A	New

Discarded at Credibility Test

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for discounting
CS3-HR-A17	Bedford St Johns - ECML - Hitchin - Royston - Cambridge South	2tph	Heavy Rail	Substantial extensive investment would be required to enable EWR services to operate on existing mainlines, which would be extremely disruptive to existing services. These solutions differ from those considered at non-statutory consultation in 2021 by reason of the extent of necessary interventions on existing busy railway lines.
CS3-HR-A59	Bedford St Johns - ECML - Royston - Cambridge South	2tph	Heavy Rail	
CS3-HR-A23	Bedford South Parkway – Sandy (re-located south) & Bassingbourn - via Cambridge South	N/A	Heavy Rail	
CS3-HR-A24	Bedford South Parkway - Tempsford Area - Sandy & Bassingbourn - via Cambridge South	N/A	Heavy Rail	
CS3-HR-A25	Bedford North - Tempsford area - Sandy & Bassingbourn - via Cambridge South	N/A	Heavy Rail	
CS3-LR-A34	Bedford via Bedford St Johns - A421 & A428 - A14 into Cambridge	4tph	Light Rail	Complexity of operation in urban areas, particularly Cambridge, where there would be significant costs at junctions to enable traffic control. There was also considered to be very limited space on roads in Cambridge for joint running with cars and other vehicles, which would have a significant impact on the existing highway network and would incur significant cost. There

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for discounting
CS3-LR-A35	Bedford A4280 -A421 & A428 - A14 into Cambridge	4tph	Light Rail	would also be significant disruption to traffic, including bus services, during construction.
CS3-LR-A36	Bedford St Johns - Longholme Way, Newham Ave, A4280 - A421 & A428 - A14 into Cambridge	4tph	Light Rail	
CS3-GB-A43	Bedford via Bedford St Johns - A421 & A428 - Cambridge via Northern rail alignment	6bph	Guided Bus	Physical constraints on the West Anglia Main Line, where there would either be a loss of the Heavy Rail network, presumed to be unacceptable, or required provision of significant infrastructure (bridges and stations) in excess of £500m.
CS3-GB-A48	Bedford South Parkway – A421 & A428 – Cambridge via Northern rail alignment	6bph	Guided Bus	
CS3-GB-A50	Bedford A4280 -A421 & A428 - C2C - Cambridge Automated Metro (CAM)	6bph	Guided Bus	Challenge of connection to a new transport system that was not committed and would be too expensive unless the CAM was funded separately.
CS3-R-A56	Bedford A4280 -A421 & A428 - A14 into Cambridge	N/A	Existing Road	Road improvements within National Highways's remit and insufficient to deliver required connectivity.
CS3-HL-A58	Hyperloop Solution	N/A	New	Technical complexity, the risk of deploying new technology, high capital and operating costs, and capacity limitations. The distance involved was also not considered appropriate for a Hyperloop solution.

Discarded at Affordability Test

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for Discounting
CS3-HR-A1	Bedford North - RA1 - Cambridge via South	4tph	Heavy Rail	Cost of work on Royston Branch and WAML, including Cambridge throat area
CS3-HR-A1	Bedford North - RA1 - Cambridge via South	3tph	Heavy Rail	
CS3-HR-A2	Bedford North - RA1 - Cambridge South terminate	2tph	Heavy Rail	Cost of work on Royston Branch and WAML – the early termination would require significant works at Cambridge South station and substitution of services is not an option
CS3-HR-A2	Bedford North - RA1 - Cambridge South terminate	3tph	Heavy Rail	
CS3-HR-A2	Bedford North - RA1 - Cambridge South terminate	4tph	Heavy Rail	
CS3-HR-A3	Bedford North - RA1 - Cambridge via North	4tph	Heavy Rail	Cost of work on WAML from the north, including additional tracks and Cambridge throat area
CS3-HR-A3	Bedford North - RA1 - Cambridge via North	3tph	Heavy Rail	
CS3-HR-A4	Bedford North - RA2 - Cambridge via South	4tph	Heavy Rail	Cost of work on Royston Branch and WAML, including Cambridge throat area
CS3-HR-A4	Bedford North - RA2 - Cambridge via South	3tph	Heavy Rail	

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for Discounting
CS3-HR-A5	Bedford North - RA2 - Cambridge South terminate	3tph	Heavy Rail	Cost of work on Royston Branch and WAML – the early termination would require significant works at Cambridge South station and substitution of services is not an option
CS3-HR-A5	Bedford North - RA2 - Cambridge South terminate	4tph	Heavy Rail	
CS3-HR-A6	Bedford North - RA6 - Cambridge via South	4tph	Heavy Rail	Cost of work on Royston Branch and WAML, including Cambridge throat area
CS3-HR-A6	Bedford North - RA6 - Cambridge via South	3tph	Heavy Rail	
CS3-HR-A7	Bedford North - RA6 - Cambridge South terminate	3tph	Heavy Rail	Cost of work on Royston Branch and WAML – the early termination would require significant works at Cambridge South station and substitution of services is not an option
CS3-HR-A7	Bedford North - RA6 - Cambridge South terminate	4tph	Heavy Rail	
CS3-HR-A8	Bedford North - RA8 - Cambridge via South	4tph	Heavy Rail	Cost of work on Royston Branch and WAML, including Cambridge throat area
CS3-HR-A8	Bedford North - RA8 - Cambridge via South	3tph	Heavy Rail	
CS3-HR-A9	Bedford North - RA8 - Cambridge South terminate	3tph	Heavy Rail	Cost of work on Royston Branch and WAML – the early termination would require significant works at Cambridge South station and substitution of services is not an option
CS3-HR-A9	Bedford North - RA8 - Cambridge South terminate	4tph	Heavy Rail	
CS3-HR-A10	Bedford North - RA9 - Cambridge via South	4tph	Heavy Rail	Cost of work on Royston Branch and WAML, including Cambridge throat area

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for Discounting
CS3-HR-A10	Bedford North - RA9 - Cambridge via South	3tph	Heavy Rail	
CS3-HR-A11	Bedford North - RA9 - Cambridge South terminate	3tph	Heavy Rail	Cost of work on Royston Branch and WAML – the early termination would require significant works at Cambridge South station and substitution of services is not an option
CS3-HR-A11	Bedford North - RA9 - Cambridge South terminate	4tph	Heavy Rail	
CS3-HR-A12	Bedford North - RA9 - Cambridge via North	4tph	Heavy Rail	Cost of work on WAML from the north, including additional tracks and Cambridge throat area
CS3-HR-A12	Bedford North - RA9 - Cambridge via North	3tph	Heavy Rail	
CS3-HR-A13	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via North	4tph	Heavy Rail	
CS3-HR-A13	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via North	3tph	Heavy Rail	
CS3-HR-NEW2	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via South	4tph	Heavy Rail	Cost of work on Royston Branch and WAML, including Cambridge throat area
CS3-LR-A3	Bedford North - RA1 - Cambridge via Northern rail alignment	4tph	Light Rail	Technical complexity of shared running and cost of Light Rail on WAML requiring significant alterations to the existing signalling and 25% of the existing capacity would be lost driving additional infrastructure (track).
CS3-R-A57	Bedford - Cambridge new road	N/A	Road	Equivalent to Expressway which was cancelled due to Cost/Benefit assessment

Discarded at Strategic Sift and Attractiveness to use

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for discounting
CS3-HR-A5	Bedford North - RA2 - Cambridge South terminate	2tph	Heavy Rail	Population, Employment, Growth opportunity
CS3-HR-A7	Bedford North - RA6 - Cambridge South terminate	2tph	Heavy Rail	Population, Employment, Growth opportunity
CS3-HR-A9	Bedford North - RA8 - Cambridge South terminate	2tph	Heavy Rail	Population, Employment, Growth opportunity
CS3-HR-A11	Bedford North - RA9 - Cambridge South terminate	2tph	Heavy Rail	Population, Employment, Growth opportunity
CS3-HR-A19	Bedford South Parkway – Varsity Hybrid - Cambourne North – Cambridge North terminate	2tph	Heavy Rail	Population, Employment
CS3-HR-A20	Bedford South Parkway – Varsity Hybrid - Cambourne South – Cambridge South	2tph	Heavy Rail	Population, Growth opportunity
CS3-HR-A22	Bedford South Parkway – Varsity Line (shortcut) – Cambridge South terminate	2tph	Heavy Rail	Population, Employment
CS3-HR-A26	Bedford (North) to Tempsford only	2tph	Heavy Rail	Population, Employment, Growth opportunity
CS3-HR-A27	Bedford - Tempsford - Cambourne only	2tph	Heavy Rail	Population, Employment, Growth opportunity
CS3-HR-A28	Bedford St Johns to Tempsford only	2tph	Heavy Rail	Population, Employment, Growth opportunity

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for discounting
CS3-HR-A30	Cambridge South - Cambourne only	2tph	Heavy Rail	Population, Growth opportunity
CS3-LRGB-A37	Light Rail Bedford A4280 to Tempsford - Guided bus A428 & C2C	4 tph/bph	Light Rail - Guided Bus	Population, Employment, Growth opportunity
CS3-LRGB-A38	Light Rail Bedford St Johns to Tempsford - Guided Bus A428 & C2C	4 tph/bph	Light Rail - Guided Bus	Population, Employment, Growth opportunity
CS3-LRGB-A39	Light Rail Cambridge North - Cambourne - Guided Bus to Bedford	4 tph/bph	Light Rail - Guided Bus	Employment, Growth opportunity
CS3-LRB-A39	Light Rail Cambridge North - Cambourne - Bus to Bedford	4 tph/bph	Light Rail - Bus	Employment, Growth opportunity
CS3-GB-A46	Bedford A4280 -A421 & A428 - C2C into Cambridge	6bph	Guided Bus	Population, Employment, Growth opportunity
CS3-GB-A35	Bedford A4280 -A421 & A428 - A14 into Cambridge	6bph	Guided Bus	Population, Employment, Growth opportunity
CS3-HRGB-A51	Heavy Rail Bedford (North) to Tempsford - Guided Bus A428 & C2C	2tph/4bph	Heavy Rail - GuidedBus	Population, Employment, Growth opportunity
CS3-HRGB-A52	Heavy Rail Bedford via Bedford St Johns to Tempsford - Guided Bus A428 & C2C	2tph/4bph	Heavy Rail - GuidedBus	Population, Employment, Growth opportunity
CS3-HRB-A51	Heavy Rail Bedford (North) to Tempsford - Bus A428 & C2C	2tph/4bph	Heavy Rail - Bus	Population, Employment, Growth opportunity
CS3-HRB-A52	Heavy Rail Bedford via Bedford St Johns to Tempsford - Bus A428 & C2C	2tph/4bph	Heavy Rail - Bus	Population, Employment, Growth opportunity

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for discounting
CS3-HR-A29	Cambridge North - Cambourne only	2tph	Heavy Rail	Insufficient scheme option capacity to 2030
CS3-HR-A31	Cambridge North - Cambourne - Tempsford only	2tph	Heavy Rail	Insufficient scheme option capacity to 2030
CS3-LRGB-A40	Light Rail Cambridge South - Cambourne - Guided Bus to Bedford	4 tph/bph	Light Rail - Guided Bus	Insufficient scheme option capacity to 2030
CS3-LRGB-A41	Light Rail Cambridge North - Cambourne - Tempsford - Guided Bus to Bedford	4 tph/bph	Light Rail - Guided Bus	Insufficient scheme option capacity to 2030
CS3-LRGB-A42	Light Rail Cambridge South - Cambourne - Tempsford - Guided Bus to Bedford	4 tph/bph	Light Rail - Guided Bus	Insufficient scheme option capacity to 2030
CS3-LRB-A37	Light Rail Bedford A4280 to Tempsford - Bus A428 & C2C	4 tph/bph	Light Rail - Bus	Insufficient scheme option capacity to 2030
CS3-LRB-A38	Light Rail Bedford St Johns to Tempsford - Bus A428 & C2C	4 tph/bph	Light Rail - Bus	Insufficient scheme option capacity to 2030
CS3-LRB-A40	Light Rail Cambridge South - Cambourne - Bus to Bedford	4 tph/bph	Light Rail - Bus	Insufficient scheme option capacity to 2030
CS3-LRB-A41	Light Rail Cambridge North - Cambourne - Tempsford - Bus to Bedford	4 tph/bph	Light Rail - Bus	Insufficient scheme option capacity to 2030
CS3-LRB-A42	Light Rail Cambridge South - Cambourne - Tempsford - Bus to Bedford	4 tph/bph	Light Rail - Bus	Insufficient scheme option capacity to 2030
CS3-GB-A44	Bedford via Bedford St Johns - A421 & A428 - Cambridge North Guided Busway	4bph	Guided Bus	Insufficient scheme option capacity to 2030

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for discounting
CS3-GB-A34	Bedford via Bedford St Johns - A421 & A428 - A14 into Cambridge	4bph	Guided Bus	Insufficient scheme option capacity to 2030
CS3-GB-A47	Bedford via Bedford St Johns - Varsity (original via Sandy and Potton) - Cambridge via Varsity	4bph	Guided Bus	Insufficient scheme option capacity to 2030
CS3-GB-A15	Bedford via Bedford St Johns - Varsity (Shortcut) - Cambridge via Varsity	4bph	Guided Bus	Insufficient scheme option capacity to 2030
CS3-GB-A49	Bedford South Parkway – A421 & A428 – Cambridge via North Guided Busway	4bph	Guided Bus	Insufficient scheme option capacity to 2030
CS3-HRGB-A53	Heavy Rail Cambridge North - Cambourne - Guided Bus to Bedford	2tph/4bph	Heavy Rail – Guided Bus	Insufficient scheme option capacity to 2030
CS3-HRGB-A54	Heavy Rail Cambridge South - Cambourne - Guided Bus to Bedford	2tph/4bph	Heavy Rail – Guided Bus	Insufficient scheme option capacity to 2030
CS3-HRGB-A55	Heavy Rail Cambridge North - Cambourne - Tempsford - Guided Bus to Bedford	2tph/4bph	Heavy Rail – Guided Bus	Insufficient scheme option capacity to 2030
CS3-HRB-A53	Heavy Rail Cambridge North - Cambourne - Bus to Bedford	2tph/4bph	Heavy Rail - Bus	Insufficient scheme option capacity to 2030
CS3-HRB-A54	Heavy Rail Cambridge South - Cambourne - Bus to Bedford	2tph/4bph	Heavy Rail - Bus	Insufficient scheme option capacity to 2030
CS3-HRB-A55	Heavy Rail Cambridge North - Cambourne - Tempsford - Bus to Bedford	2tph/4bph	Heavy Rail - Bus	Insufficient scheme option capacity to 2030
CS3-HR-A18	Bedford South Parkway – Varsity Hybrid - Cambourne North – via Cambridge North	2tph	Heavy Rail	Insufficient demand

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Rationale for discounting
CS3-HR-A21	Bedford South Parkway – Varsity Line (shortcut) – via Cambridge South	2tph	Heavy Rail	Insufficient demand
CS3-LR-A18	Bedford South Parkway – Varsity Hybrid (Cambourne) – Cambridge via North Guided busway	4tph	Light Rail	Insufficient demand
CS3-LR-A33	Bedford via Bedford St Johns - Varsity Hybrid - RA1/9 - Cambridge North Guided Busway	4tph	Light Rail	Insufficient demand
CS3-GB-A45	Bedford via Bedford St Johns - A421 & A428 - C2C into Cambridge	4bph	Guided Bus	Insufficient demand

Scheme Options retained

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Dependency
CS3-HR-A1	Bedford North - RA1 - Cambridge via South	2tph	Heavy Rail	Removal of 2 heavy rail services from WAML
CS3-HR-A3	Bedford North - RA1 - Cambridge via North	2tph	Heavy Rail	-
CS3-HR-A4	Bedford North - RA2 - Cambridge via South	2tph	Heavy Rail	Removal of 2 heavy rail services from WAML
CS3-HR-A6	Bedford North - RA6 - Cambridge via South	2tph	Heavy Rail	
CS3-HR-A8	Bedford North - RA8 - Cambridge via South	2tph	Heavy Rail	
CS3-HR-A10	Bedford North - RA9 - Cambridge via South	2tph	Heavy Rail	
CS3-HR-A12	Bedford North - RA9 - Cambridge via North	2tph	Heavy Rail	-
CS3-HR-NEW1	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via South	2tph	Heavy Rail	-
CS3-HR-A13	Bedford St Johns – Varsity Hybrid - Cambourne North – Cambridge via North	2tph	Heavy Rail	-
CS3-HR-A14	Bedford St Johns – Varsity Hybrid - RA6/8 (Cambourne South) – Cambridge via Varsity line guided busway	2tph	Heavy Rail	-
CS3-HR-A58	Bedford St Johns - Varsity Hybrid via St Neots - Cambourne North - Cambridge via North	2tph	Heavy Rail	-

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Dependency
CS3-HR-A15	Bedford St Johns - Varsity Line (shortcut) - Cambridge via Varsity	4tph	Heavy Rail	-
CS3-HR-A15	Bedford St Johns - Varsity Line (shortcut)- Cambridge via Varsity	3tph	Heavy Rail	-
CS3-HR-A15	Bedford St Johns - Varsity Line (shortcut)- Cambridge via Varsity	2tph	Heavy Rail	-
CS3-HR-NEWA15	Bedford St Johns - Varsity Line (shortcut) - Cambridge via Cambridge South	2tph	Heavy Rail	-
CS3-LR-A33	Bedford via Bedford St Johns - Varsity Hybrid - RA1/9 - Cambridge North Guided Busway	4tph	Light Rail	Reintroduced despite failing the Demand Index to provide an alternative Light Rail option to A51 into Cambridge..
CS3-HR-A16	Bedford St Johns - Varsity Line (shortcut) - Cambridge Varsity Trumpington terminate	4tph	Heavy Rail	-
CS3-HR-A16	Bedford St Johns - Varsity Line (shortcut) - Cambridge Varsity Trumpington terminate	3tph	Heavy Rail	-
CS3-HR-A16	Bedford St Johns - Varsity Line (shortcut) - Cambridge Varsity Trumpington terminate	2tph	Heavy Rail	-
CS3-LR-A15	Bedford via Bedford St Johns - Varsity - Cambridge via South guided busway	4tph	Light Rail	Busway converted to light rail

Alignment ID	Alignment	Trains / Users PH	Transport Solution Mode	Dependency
CS3-GB-A51	Bedford St Johns - Varsity (Shortcut) - Cambridge via Varsity - via North Guided Busway, C2C and Southern Guided Busway	12bph	Guided Bus	-
CS3-GB-A52	Bedford via Bedford St Johns - Varsity (Shortcut) - Cambridge via Varsity	6bph	Guided Bus	-
CS3-GB-A53	Bedford St Johns via northern Alignment corridor into Cambridge via North, South and C2C	12bph	Guided Bus	-
CS3-AVRT-01	AVRT - Bedford to Cambridge	20	AVRT	-

2 Appendix 2: Brief summary of demand modelling approaches

2.1 Introduction

2.1.1 Affordable Connections is a strategy-led project. The project is focused on two dimensions of the Five Case Model approach for developing business cases recommended by HM Treasury:

- The Strategic dimension: the 'case for change' of the EWR scheme, founded upon a 'theory of change' that focuses on Cambridge; and
- The Economic dimension: the 'value for money' of the EWR scheme, estimated under rigorous and assured modelling

2.1.2 We have developed two demand modelling approaches to reflect both dimensions:

- A gravity modelling that satisfies assurance requirements and feed into appraisals: the EWR 'Full Demand Model' incorporates a conventional rail uni-modal gravity model, where demand between two places is a function of selected econometric parameters; and
- Trip-end modelling to reflect a potential higher demand that reflects the 'Theory of Change' and overcomes limitations in conventional gravity modelling.

2.1.3 The rest of this appendix describes the methodology followed for both demand modelling The ToC analysis was applied to the Option Families and was validated by gravity modelling. approaches in more detail.

2.2 Gravity Modelling

2.2.1 The gravity model is an econometric model and is a component of the EWR 'Full Demand Model'. EWR's Gravity Model estimates rail passenger demand as a function of several socio-demographics characteristics (including population, employment and GVA per capita within a 2km radius of the station) coupled with a generalised journey time (GJT) measure of rail service between stations. The gravity model is calibrated upon factors calculated from 2018-19 econometric data.

2.2.2 The main characteristics of EWR's Gravity Model are:

1. **TAG-compliant:** The model has been endorsed by DfT Centres of Excellence and can stand up to scrutiny in a programme review.
2. **The model has been calibrated against observed travel patterns**: Calibrated against rail travel observed in the South-East in 2018-19 before COVID-19 pandemic.
3. **Covers whole region of interest:** The model is applicable for all flows and stations throughout the whole Oxford-Cambride arc.

4. **Large number of flows:** Models over 20,000 flows, including interchange and cross-country intercity.
5. **Models train-by-train level:** This is useful for operational planning such as rolling capacity requirements and stock specification.
6. **Journey purposes:** The model covers business, leisure and commute. Most rail travel is outside the peak and for non-commuting purposes, and peak commuting is a limited sub-set of demand.

2.2.3 Like most rail models, demand is presented in the shape of ticket sales data, calculating annual demand model outputs. A conversion process is required to calculate single train demand for a mean average weekday. Train-level or peak-hour level forecasts are not used in the economic appraisal but for presenting and explaining demand, and for operational planning purposes such as capacity planning. MOIRA2 converts annual demand into peak-hour demand, and while MOIRA2 is used in the industry as a demand forecasting tool, in EWR is used purely as a rail and route allocation tool. The parameters used are standard parameters from MOIRA2 and have been approved by the DfT.

2.2.4 The process for converting annual demand to a train level is:

- **Single day:** Day-of-week parameters allocate demand onto a single weekday. Seasons are weighted towards weekdays, while off-peak tickets are more weighted towards weekends.
- **Desired time of travel:** Time of day profiles allocate demand to various time of days. Commuters are more likely to depart at 07:30, while leisure travellers are more likely to travel at 09:30.
- **Single train**: MOIRA2 allocates each passenger onto a single departure opportunity (either a direct train or set of trains with connections), considering overtaken trains and the interval between trains. Fast trains with a large headway between them will attract more demand than slow trains that run immediately after other trains.
- **Combine total flows**: MOIRA2 adds up all the individual origin-destination flows on one train to calculate how many passengers are on a train at a given time. For example, a westbound train departing Cambourne may have passengers on board travelling from Cambridge to Tempsford-St. Neots, Cambridge to Bedford, but also Ely to Bedford (having changed at Cambridge).

2.2.5 Detailed assumptions for the EWR Modelling Suite can be found in the ‘East West Rail - Affordable Connections Record of Assumptions’ document.

2.2.6 The gravity model has four significant limitations from a strategic viewpoint.

- **Post-pandemic working patterns:** As it calibrated upon pre-pandemic working patterns in 2018-19, it does not reflect a likely reduction in commuting on one or more days of the week. This means that rail demand may be lower than modelled. This has been addressed by producing a DfT Covid scenario overlay as a sensitivity.

- **Employment:** The gravity model's employment forecasts are from conventional sources or derived from housing growth in the same location. Notably this means that significant employment growth in Cambridge is not a model input, and therefore, rail demand may be higher than modelled.
- **House price or other constraints**: The gravity model does not consider house price constraints or rail constraints from certain directions. The 'theory of change' suggests that that further commuting from the south of Cambridge is unlikely owing to high housing costs, and that significant growth from the north and east of Cambridge is unlikely to due rail capacity constraints. As a result, rail demand may be higher than modelled.
- **Modal constraints:** Since the gravity model does not consider rail-road competitiveness, constraints on the road network and the effect on rail demand is not considered. The 'theory of change' suggests that it is impossible for additional trips to arrive by rail and therefore rail demand may be higher than modelled.

2.2.7 The potential upside of these limitations can be explored through a trip-end modelling approach that follows the Theory of Change, by trading-off the assured and calibrated nature of the gravity model.

2.3 Trip-end modelling

2.3.1 The purpose of the trip-end model is to overcome limitations in the gravity model related to the Theory of Change for Cambridge, and to explain further why some of the changes in the gravity model may be expected to materialise in the real world.

2.3.2 The purpose of the trip-end modelling in Affordable Connections is not to calculate a precise forecast, but to provide a narrative of how demand could change in a transformational world where very different travel patterns could plausibly materialise. It cannot calculate an accurate demand forecast but can help to provide an upper bound.

2.4 Methodology

2.4.1 The demand modelling approach is a 'trip-end' model approach. This considers both where passengers are travelling from, and where they are travelling to. In our calculations, it also overcomes a gravity model limitation by considering mode share as a separate stage.

2.4.2 Trip-end modelling is a recognised modelling method by the DfT for the modelling of new stations, alongside gravity modelling. For East West Rail, benchmarking provides the input parameters rather than calibrated regressions.

2.4.3 The stages involved in trip-end modelling are:

- **Resident workers:** Assumptions of how many resident workers could live at a location. This could include a forecast after delivering dependent development, factoring in projected household size and employment rates.
- **Proportion travelling to the destination for work:** This is benchmarked against comparator flows for a similar distance or rail journey time from the 2011 census. Care is taken to consider alternative employment destinations. For example, Ely and Royston are both similar distances to Cambridge by rail with a comparative, but 19% of Ely commute to Cambridge compared to 9% for Royston. This is because there are significantly more employment alternative employment sites from Royston (including London) for a given travel time, compared to Ely. There is significant variability in this factor.
- **Proportion travelling to the destination by rail:** This is benchmarked against comparator flows for a similar distance or rail journey time from the 2011 census. There is less variability in this factor.
- **Converting to peak hour demand:** On a proportion of regular commuters will travel in the peak hour, while some peak-hour travellers will not be commuters. A factor is applied based on the relationship between commuting to Cambridge and observed rail counts in the 08:00-08:59 hour.
- **Amalgamating across trains:** The process is repeated for a limited number of origin-destination flows that could be expected to travel over the route section. Examining demand approaching Cambridge, this could consider commuting to Cambridge from Cambourne, Tempsford-St. Neots, Bedford, Ridgmont, and Woburn Sands.
- **Dividing a peak hour by trains:** The total expected number of passengers per hour is divided across the number of trains that run in the hour.

2.4.4 The key limitations of the trip-end modelling in Theory of Change trip-end modelling are:

- It does not consider the how the proportion of residents commuting to a location, or the mode share may be affected by the journey time or frequency of the transport link. For example, a 4tph service may be more attractive than a 2tph but the trip-end modelling in the ‘theory of change’ is unable to distinguish this.
- It cannot be expanded to the whole arc as it is built around the particular characteristics of one place.
- It can only reasonably handle a small number of flows and therefore is only useful at the end of a line such as approaching Cambridge where the number of discrete overlapping flows is likely to be lower than in the middle of the line. It cannot handle interchange dynamics effectively.
- It is prone to human bias when selecting benchmarks, particularly with a transformational scenario that cannot be calibrated against
- It cannot be used in appraisal as the it only considers a small number of flows and does not consider travel time savings impacts that form to user benefits.

3 Appendix 3: Theory of Change Transport Constraints

3.1 Cambridge rail capacity

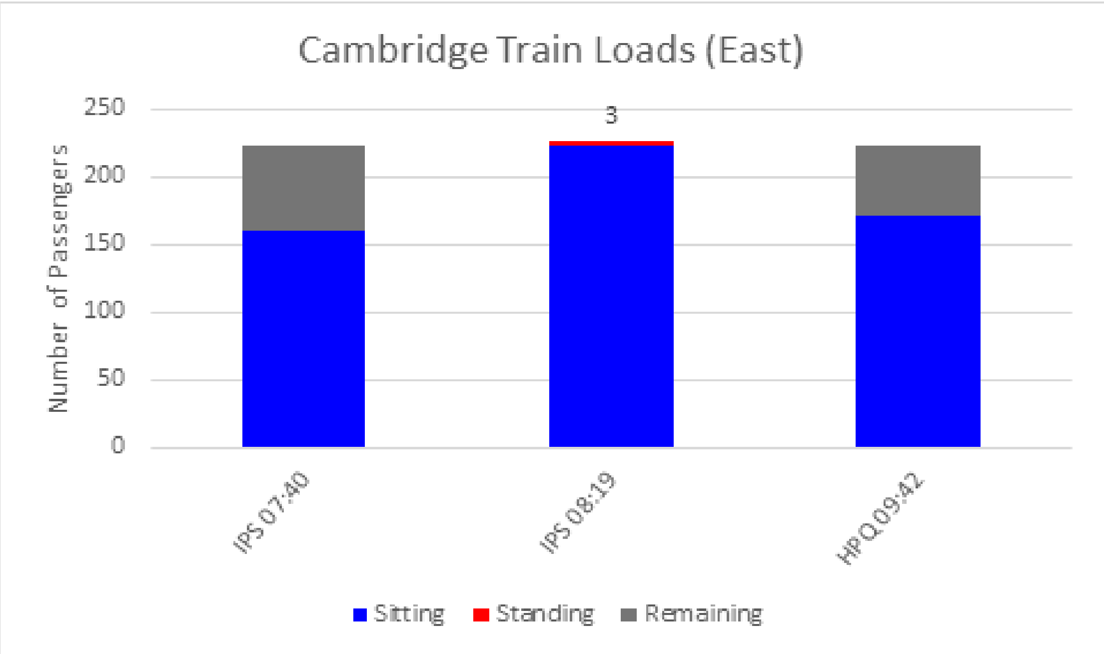
3.1.1 Table 3.1 below shows observed Count data for 2019, which suggests capacity constraints on trains arriving in Cambridge from the North and East of Cambridge.

Table 3.1: Observed Standing and Seated Passengers, DfT counts, Autumn 2019.

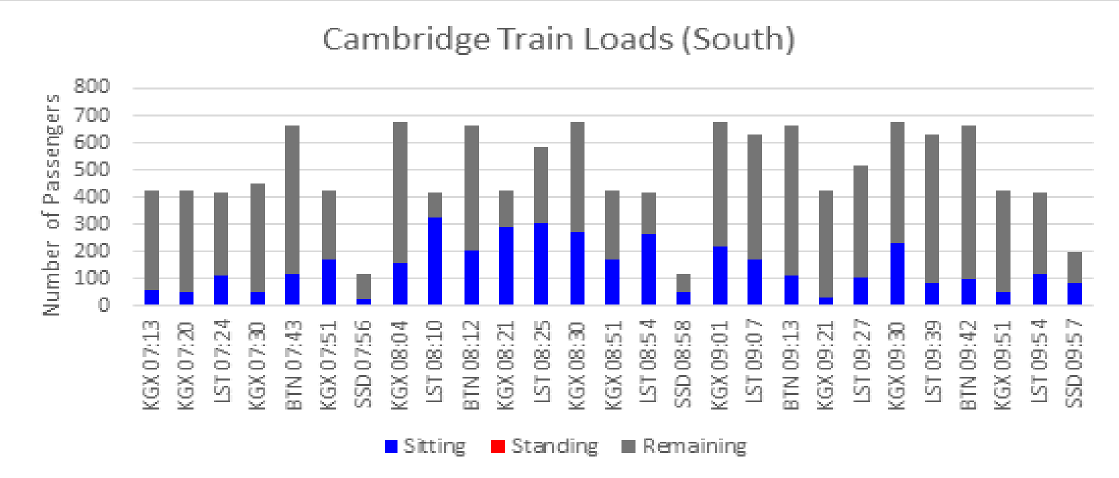
Direction	Total Seated	Total Standing	Total Remaining Seats	Passenger to Seat Ratio
North	1,013	632	64	153%
East	224	3	0	101%
South	2,044	0	2364	46%
Total North and East	**1,237**	**635**	**64**	**144%**
Total All Directions	**3,281**	**635**	**2428**	**69%**

3.1.2 Trains arriving in Cambridge from the North are full and have a significant number of standing passengers during peak travel time. The estimated passenger to seat ratio in the morning 1-hour peak (08:00 – 08:59) is 153%. This is above the Passengers in Excess of Capacity limit. That this includes commuters travelling *through* Cambridge to access employment in London.

Trains arriving from the East are also full but do not have as many standing passengers as those arriving from the North. These trains do not have space to absorb more demand with a morning 1-hour peak passenger to seat ratio of 101%.



On the other hand, trains arriving in Cambridge from the South appear to have capacity with plenty of empty seats during the morning 1-hour peak. The capacity is driven by a requirement of 12-car trains at the London end. This is not expected to grow due to higher house prices and competing sources of employment at London and Stansted Airport.

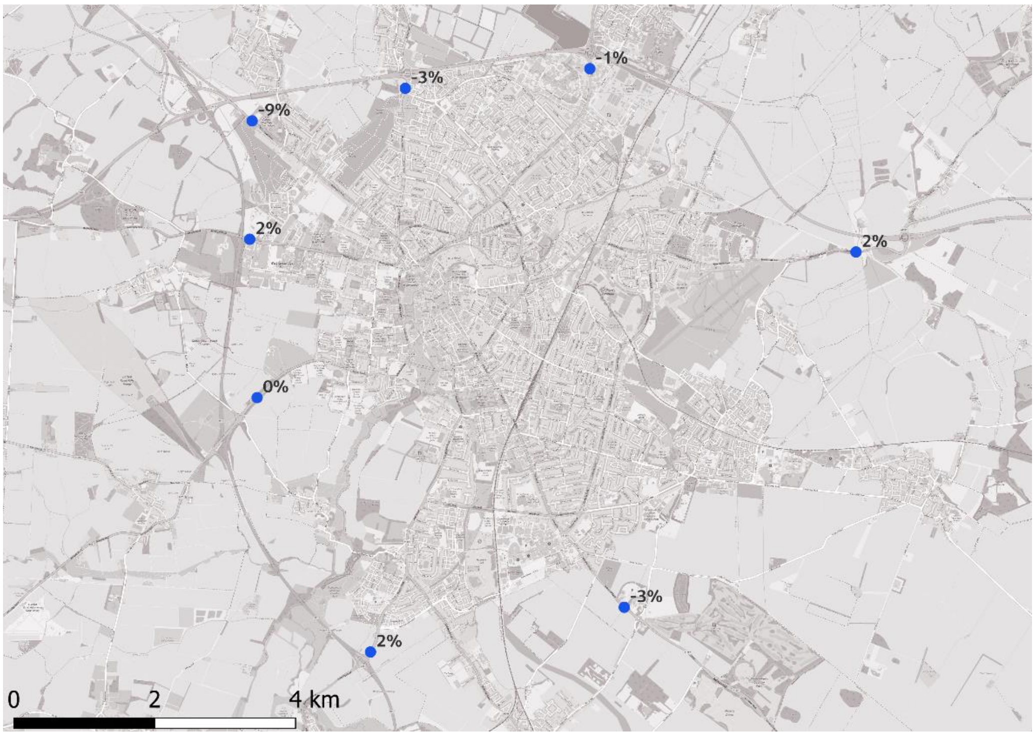


3.1.3 There is some limited opportunity to grow capacity from the North with Ely Area Capacity Scheme and recent power supply upgrade enables 8-car trains, rather than 4-car trains in the observed counts.

3.2 Cambridge Road capacity

3.2.1 Observed traffic count data suggests little growth in all-day traffic in Cambridge via the main radial roads into Cambridge.

Figure 3.1 12-hour Weekday Bi-directional count growth per year (CAGR %) 2016-2019 for Main radials[1]



3.2.2 The peak hour (08:00 – 09:00) traffic counts also suggest very little growth in traffic into Cambridge.

Table 3.2: Peak Hour Traffic Count (Uni-directional)[2]

Road	Name	Direction into Cambridge	Latest Value	Growth per year (CAGR %)	Survey years
B1049	Bridge Road	S	626	N/A	2018 only
A1309	Milton Road	S	340	-4%	2008 - 16
A1303	Newmarket Road	W	1242	-2%	2015 - 19
A1307	Babraham Road	N	823	-2%	2010 - 15
A1309	Hauxton Road	N	1,470	7%	2017 - 19
A603	Barton Road	E	407	-5%	2013 - 2018

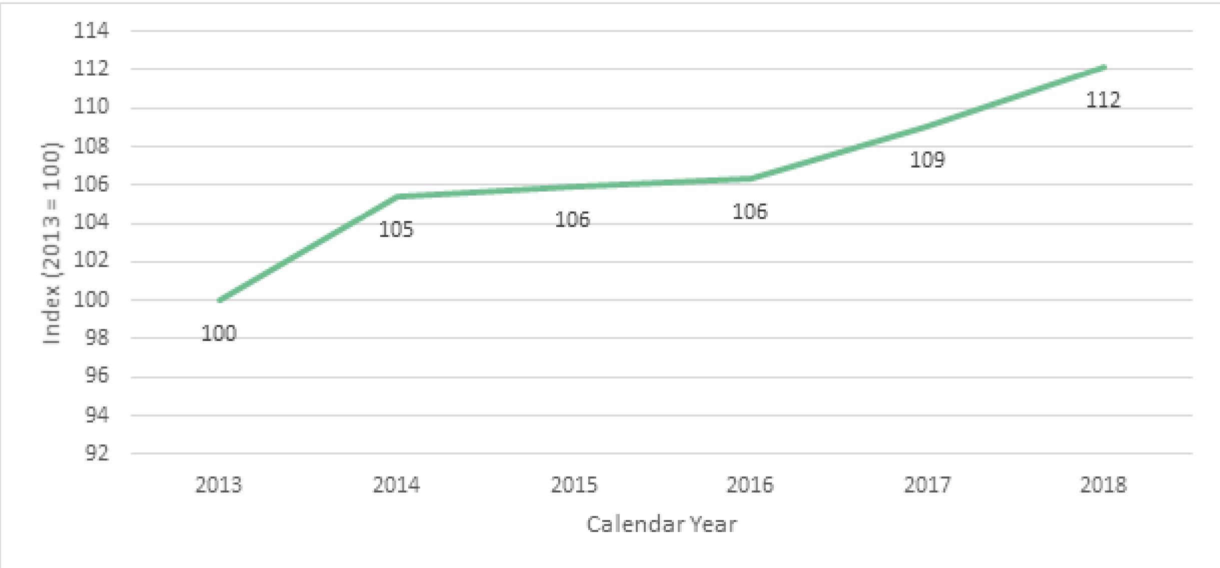
[1] Cambridgeshire County Council Traffic Count Data. Note that these are bi-directional counts, which includes travel into and out of Cambridge.

[2] Note that the data are taken at different dates between 2008-2018. As such, CAGR has been taken over different periods. Data from DfT Road Traffic Statistics

Road	Name	Direction into Cambridge	Latest Value	Growth per year (CAGR %)	Survey years
A1303	Madingley Road	E	756	(2%)	2003 - 2016
A1307	Huntingdon Road	S	1,108	(12%)	2004 - 2008
Total			6,772	-2% (Weighted average)	

3.2.3 Over the same time, jobs in Cambridge have grown but road traffic has not.

Figure 3.2 Employment Growth in Cambridge LAD[3]



3.2.4 The fact that traffic counts have not increased and that employment has continued to increase is highly indicative of the fact that there are road constraints.

3.2.5 Enhancing road capacity is not found in any local plans and not within government policy.

3.2.6 This suggests that increasing employment access will need to be facilitated by a non-car mode.

[3] Business Register & Employment Survey

3.3 Cambridge park and ride capacity

Figure 3.3 Cambridge Park and Ride Locations

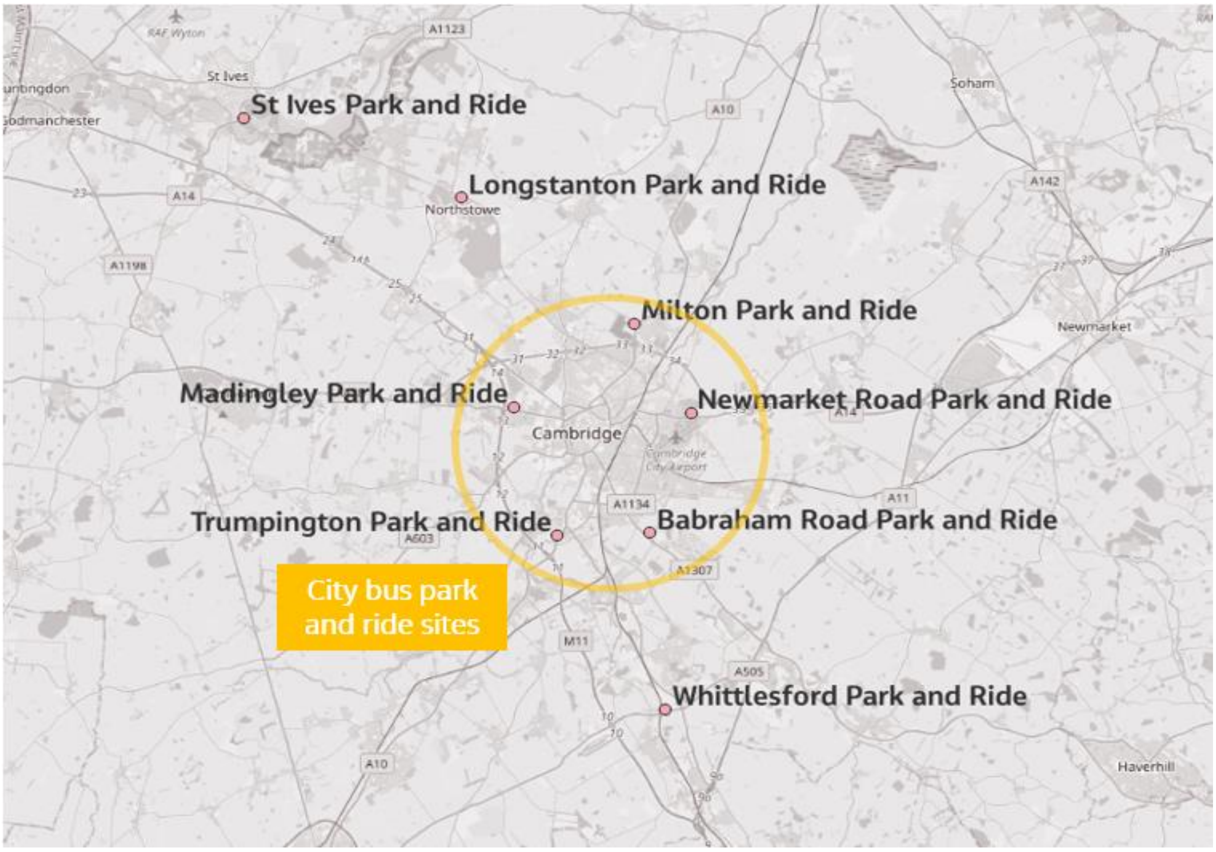


Table 3.3: Cambridge Park and Ride Capacity

Park & Ride	Type	Frequency per Hour	Implied hourly capacity[4]	Parking Spaces[5]
Milton	City bus	5	325	792
Newmarket Road	City bus	5	325	873
Babraham Road	City bus	6	390	1,458

[4] Assuming 65 seats for city bus; 50 for guided bus

[5] Note that parking spaces for some of these are implied parking spaces based on the live number of spaces and utilisation statistics provided by the Cambridge City Council live availability data. This the case for the following sites: Babraham Road, Milton and Newmarket Road. Data for Longstanton, St.Ives, Trumpington and Madingley was taken from the Cambridgeshire Busway website - Park & Ride | The Busway - connecting Huntingdon, St Ives & Cambridge. Data for Whittlesford Park and Ride was taken from the NCP website - Whittlesford Station (Greater Anglia) (ncp.co.uk)

Park & Ride	Type	Frequency per Hour	Implied hourly capacity[4]	Parking Spaces[5]
Trumpington	City bus	7	455	1,340
Madingley Road	City bus	5	325	930
St Ives	Guided bus	7	350	1,000
Longstanton	Guided bus	8	400	350
Whittlesford Parkway	Rail	3	371[6]	371
Total (City Bus only)			**1,820**	**5,393**
Total (All)			**2,941**	**7,114**

3.3.1 Park and Ride sites in Cambridge are not fully utilised with live utilisation statistics suggesting significant surplus capacity. It is likely that the lack of utilisation can be attributed to traffic constraints.[7]

Table 3.4: Park and Ride Utilisation[8]

Park and Ride Site	Remaining Capacity
Babraham Road	60%
Madingley Road	71%
Milton	80%
Newmarket Road	42%
Trumpington	77%

3.3.2 It is likely that the under-utilisation is driven by the access and interchange penalty incurred when using a park and ride side, and it is unlikely that additional park and ride sites would transformationally increase access to employment.

[6] Capped by parking spaces

[7] Note that the live utilisation statistics were checked at 09:30 on a Friday. It is likely that the utilisation would be slightly higher during a midweek day.

[8] Check 'live' availability at our multi-storey car parks - Cambridge City Council

3.4 Cambridge bus capacity

3.4.1 Buses have the similar road capacity challenges as cars when not operating on dedicated lanes.

3.4.2 Cambridge has two major dedicated busway corridors into Cambridge where guided buses operate. These provide more reliable services at higher speeds and has been inc. Demand on these services has grown into Cambridge (pre Covid) as the services have developed and supported local housing, particularly at Northstowe and Trumpington. Buses operating on the busway are operated on a commercial basis.

3.4.3 There are fewer physical constraints on operating more buses at present; it's a demand and cost effectiveness constraint rather than a supply constraint with further services may need additional subsidy. Greater Cambridge partnership is currently investigating increasing and revising bus services through its "City Access" which had a public consultation in Autumn 2021[9]. Increased funding would be required to support this which is also part of the consultation.

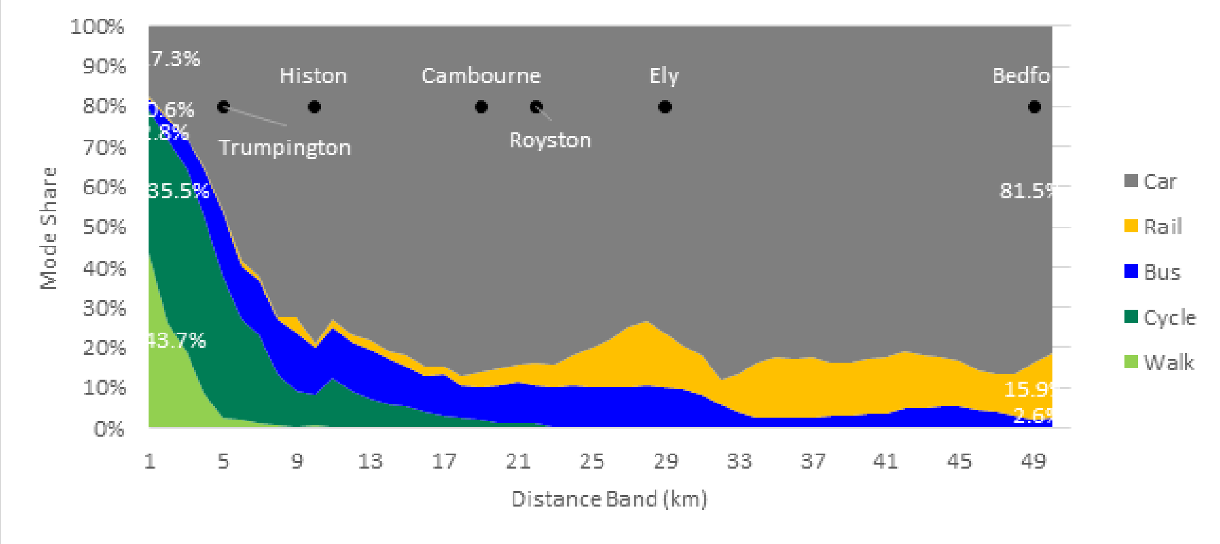
3.4.4 It is highly unlikely that operating more buses would not enable significantly more employment as it is not a more attractive mode over the existing congested roads for many users, or park and ride from those travelling from further outside. Demand for buses will likely support modal shift for shorter trips into Cambridge and will compliment rail improvements by providing a first and last mile solution for accessing jobs in the Cambridge area. Buses have also only unlocked dependant development when they provide fixed infrastructure such as a busway.

3.5 Cambridge walking and cycling

3.5.1 Walking and cycling are shorter distance modes. This is shown below in *Table* 3.*5*. Walking and cycling area a majority of mode share within 5km. Therefore, additional housing development within Cambridge is unlikely to present a capacity constraint for accessing employment.

[9] https://consultcambs.uk.engagementhq.com/making-connections-2021?preview=true

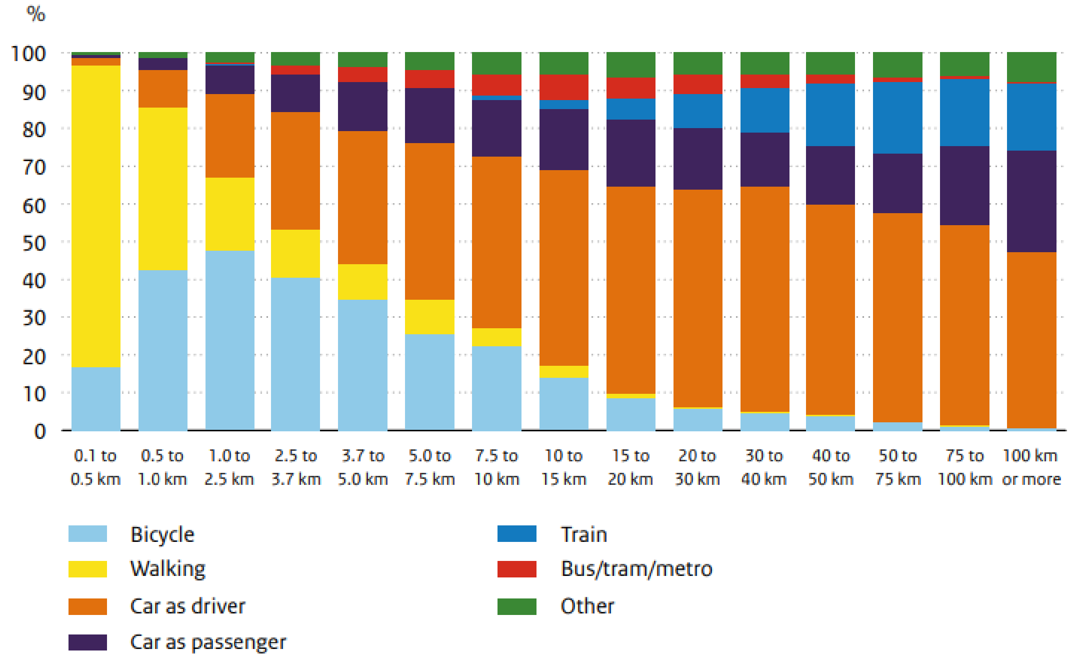
Table 3.5: Cambridge Travel to Work Mode Shares (2011)[10]



3.5.2 Walking and cycling are not a feasible options for commuting from nearby towns such as Cambourne due to distance. Taking the world's best practice example, the Netherlands, less than 10% of journeys are made by bicycle above 15km.

[10] 2011 Census Data

Figure 3.4 Mode Share by Distance - Netherlands[11]



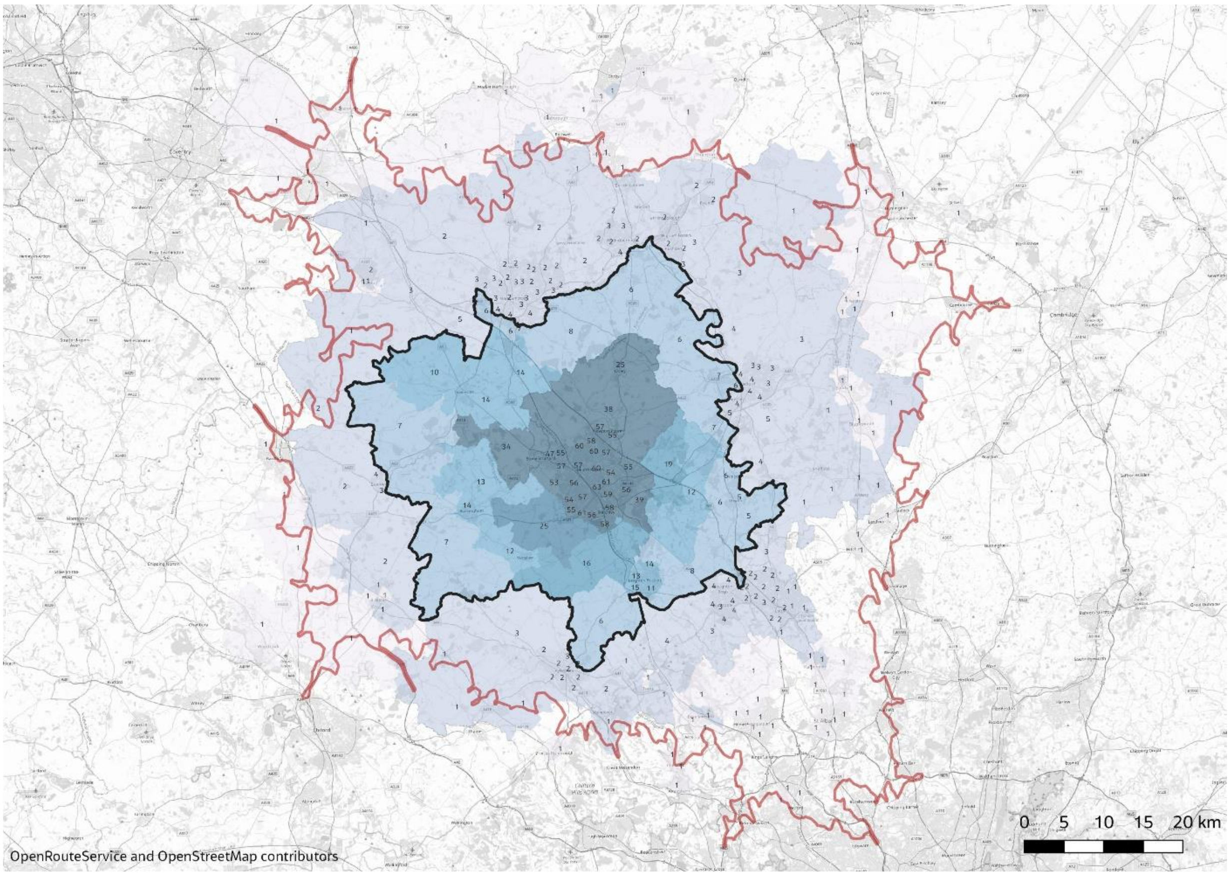
3.6 Time access

3.6.1 Shorter travel times are preferred. However, there is a strong drop-off with the propensity to commute to a destination above 45 minutes.

3.6.2 Evidence from Milton Keynes, a relatively uncongested city where traffic constraints are not a limiting factor, shows the 1% of people commuting boundary matches up with a 45-minute travel time catchment relatively well.

[11] https://s23705.pcdn.co/wp-content/uploads/2021/03/Netherlands-Cycling-Facts-2020.pdf

Figure 3.5 Correlation between 1% travelling to Milton Keynes and 45-minute travel time zone



3.6.3 Rail journey times in the Summer 2011 timetable were analysed against the 2011 census to determine whether 45 minutes travel time could also be applied to rail journeys. While there is slightly more variance, this also broadly aligns up with the catchment that 1% of commuters travel to work.

Figure 3.6 Rail journey time to Oxford in Summer 2011 timetable against commuting to work (by all modes) in 2011 timetable

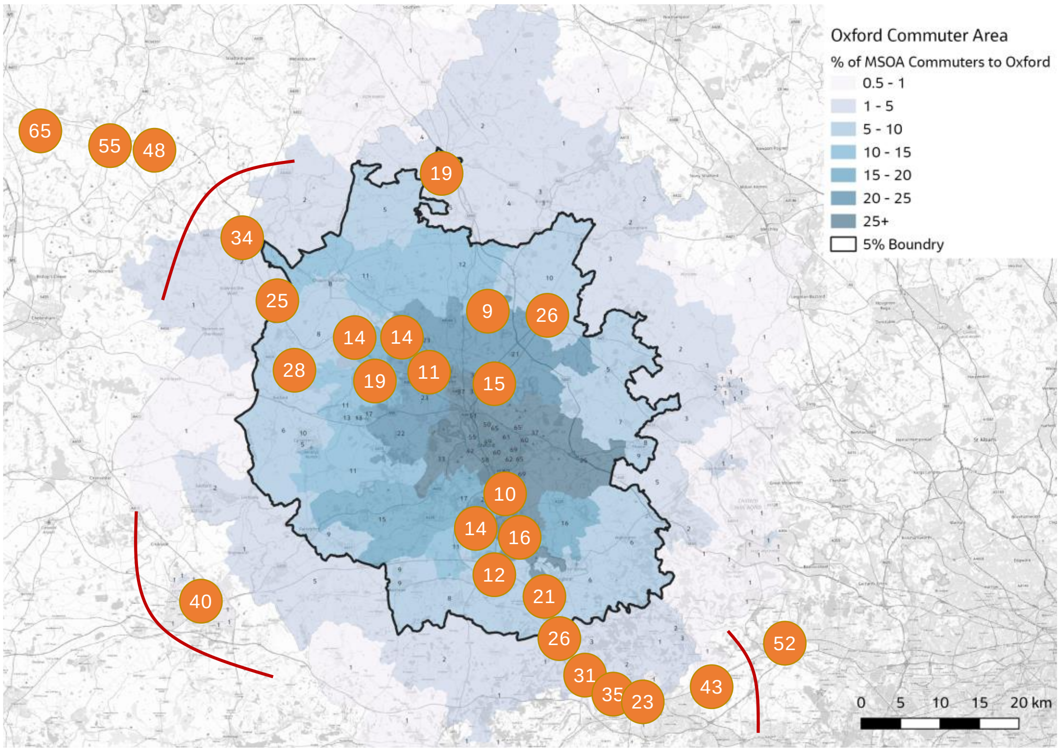
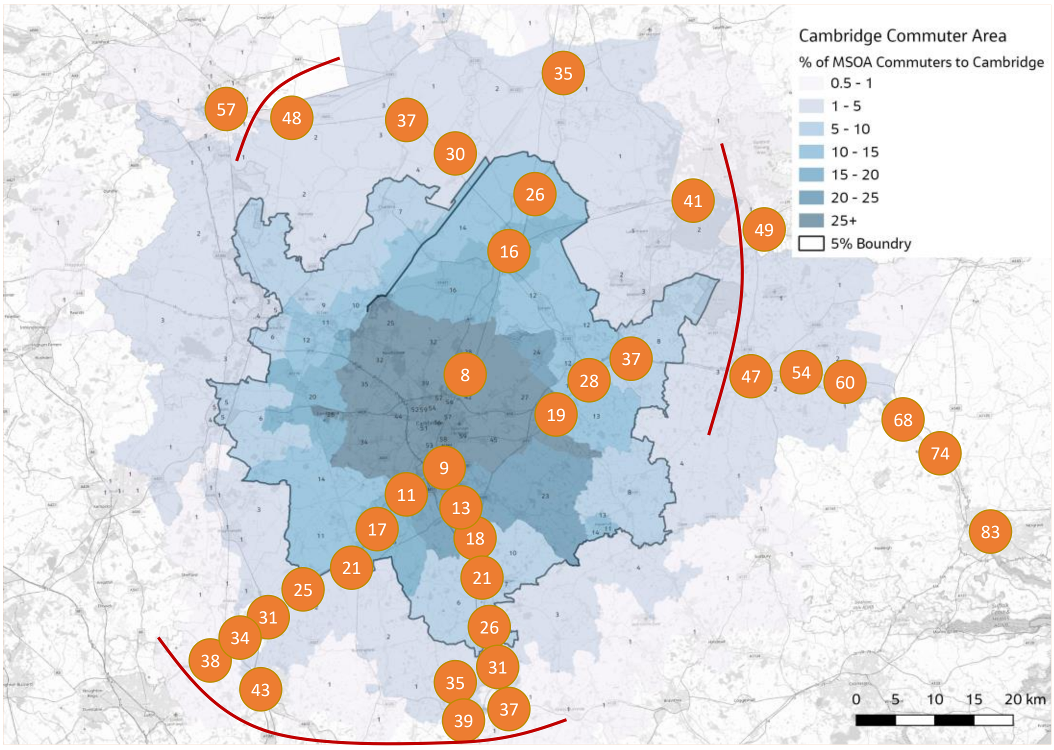


Figure 3.7 Rail journey time to Cambridge in Summer 2011 timetable against commuting to work (by all modes) in 2011 timetable



3.6.4 An access model was built for Cambridge to assess how many resident workers could access Cambridge within 45 minutes mode times considering:

- Trips could be made via direct car journey to Cambridge, rail heading from a station in the same MSOA as the passenger, or a rail heading via a station in a neighbouring MSOA to Cambridge.

- Congested travel times were used, with data sourced from Google Maps API with the 'pessimistic' option.

- A park and ride penalty of 15 minutes was added for the driving option as most new drivers to Cambridge would not be able to park in the city centre. This accounts for the time needed to diver to a Park and Ride site, park, wait for a bus, and additional time spent on the bus.

  A 10-minute park and access penalty was added for rail heading, where travel is routed via a station in a different MSOA.

3.6.5 The access model also considers the number of resident workers as an example of the size of the labour pool. It did does not consider the any increased population as a result of dependent development.

3.6.6 Current access times to Cambridge are constrained by congestion and park and ride. Overlaying the fastest modes, 45 minutes reaches north and south due to rail links but does not reach west.

3.6.7

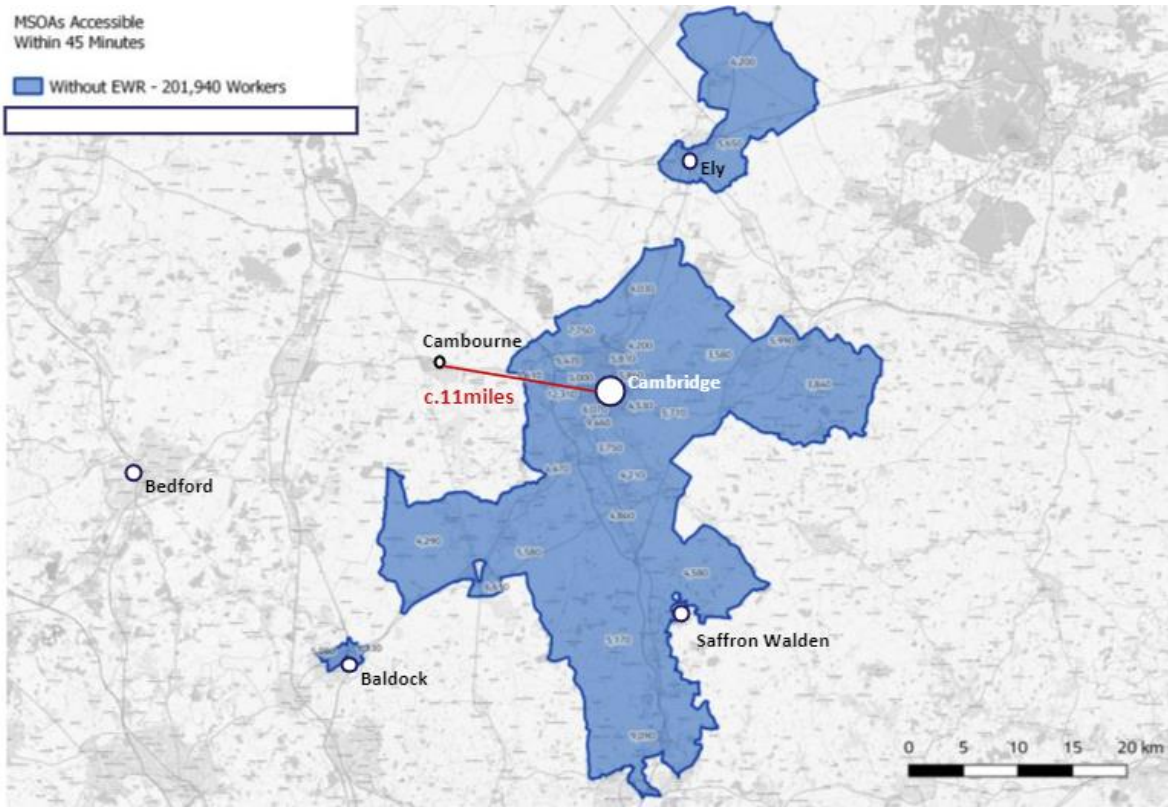
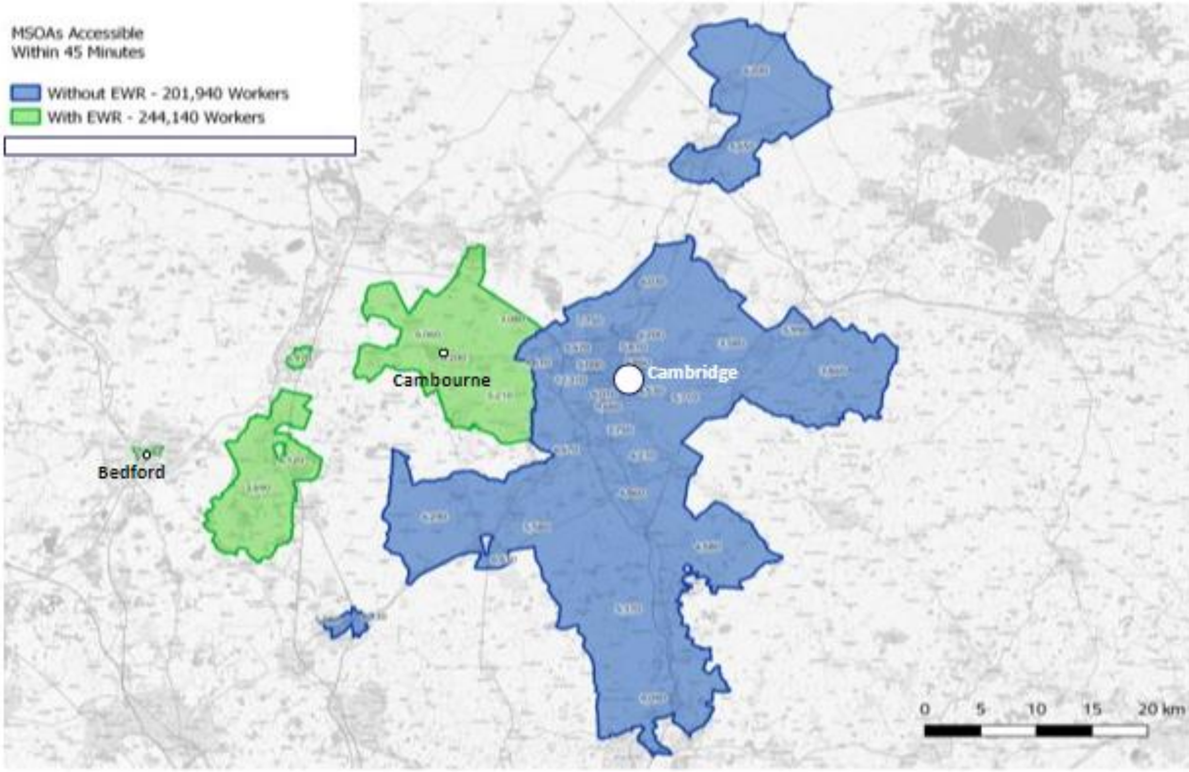


Figure 3.9 45-Minute Commute Boundaries (EWR options v no EWR)[12]

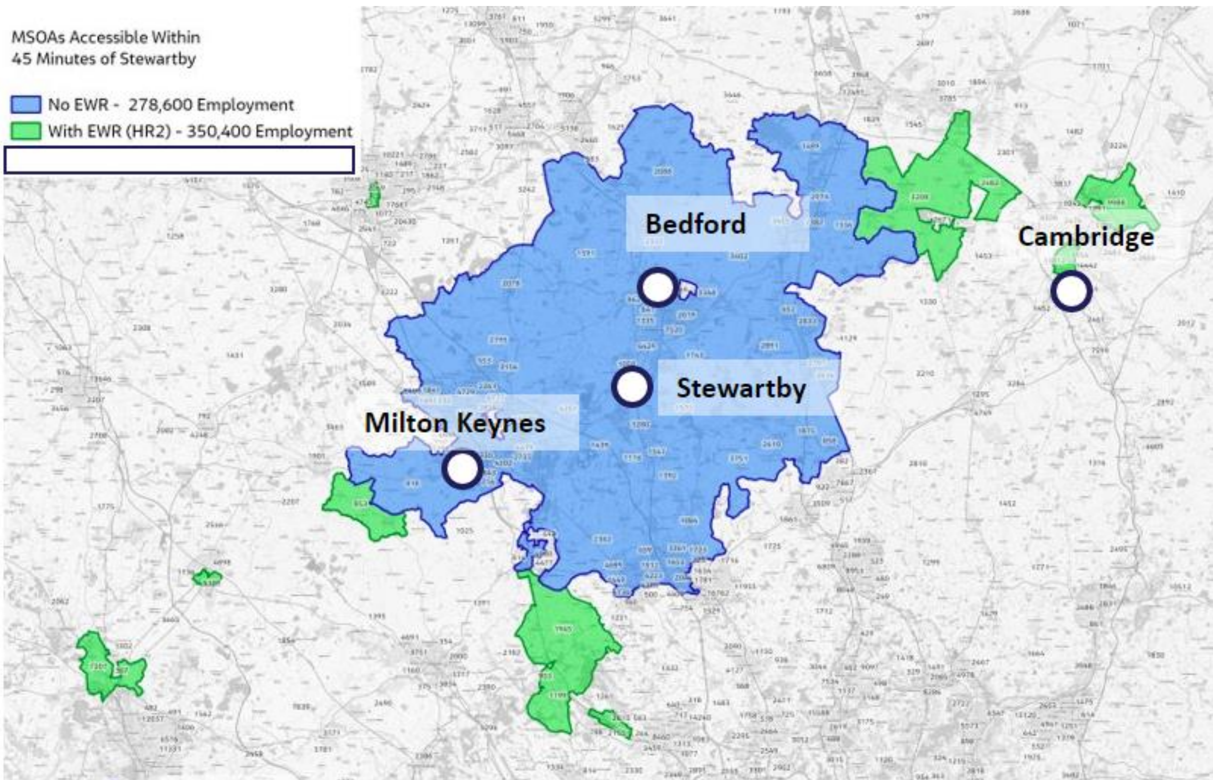


3.6.8 This could expand the zone and the number of resident workers by 40,000.

3.6.9 This exercise has been repeated for the Marston Vale Line to demonstrate the phenomenon in reverse; how many jobs are available to a resident within 45 minutes. Without a new transport link the zone is limited by driving distance, with 278,000 jobs within 45 minutes travel time. With a new transport link, this could expand to approximately 316,000 jobs.

Figure 3.10 Stewartby 45-Minute Boundary

3.6.10



4 Appendix 4: Theory of Change Trip-End Modelling

4.1 The need

4.1.1 There are many advantages of a gravity model for whole-scheme appraisal and planning, in particular being able to model tens of thousands of origin-destination pairs, and giving confidence for business planning in methodologies endorsed by TAG.

4.1.2 However, the gravity model has shortcomings. Firstly, it is calibrated purely on travel patterns observed today. It does not receive as an input any unevidenced yet aspirational patterns that a transformational scheme such as EWR aims to deliver.

4.1.3 Furthermore, the EWR Full Demand model is uni-modal due to two factors:

- Disparity of data: There is excellent rail data available from ticket sales. This data is not a sample, it's a full dataset. This expansive data is not available for other modes. For example, with driving, data is not available for a town or village level. There is at a LA-LA level but it's not detailed enough for local journeys.

- Proportionality: Rail constitutes 1% of travel in GB. it would be a waste of resources to model the remaining 99% to get the 1%. In a uni-modal model, we can focus all our attention on the mode that we're interested in.

4.1.4 The uni-modality of the model prevents it from fully representing detailed mode shift dynamics. In particular, as it does not separate out market size and mode share, it is limited for strategic considerations on a very local level.

4.1.5 In order to plan demand and capacity for strategic considerations, a trip-end approach was constructed to build up a demand forecast from first principles.

4.2 The approach

4.2.1 The first principles approach utilises two key assumptions per OD pair:

- **Market size**: percentage of commuters from the origin that travel from Place A to Place B by all modes.

- **Mode share**: proportion of these commuters that travel using given mode i.e. rail.

4.2.2 The number of working age population is estimated for each origin. This uses current population, planned housing development and dependant housing development. The factors to convert into resident workers are approximately 2.29 individuals per household, and 0.48

workers per population. This working population is then multiplied by market size and mode share to find the daily rail demand.

4.2.3 This approach can only reasonably consider up to 10 origin-destination pairs, and only at the end of a line where those flows are expected to comprise the majority of demand. It does not work well in the centre of a line where there would be many overlapping flows. For example, on the MVL, there are many overlapping flows and an extra layer of complexity of in both directions there being commutable access to a city, namely Milton Keynes and Bedford.

4.2.4 Within the model, two scenarios are built up which warrant different market size and mode share assumptions:

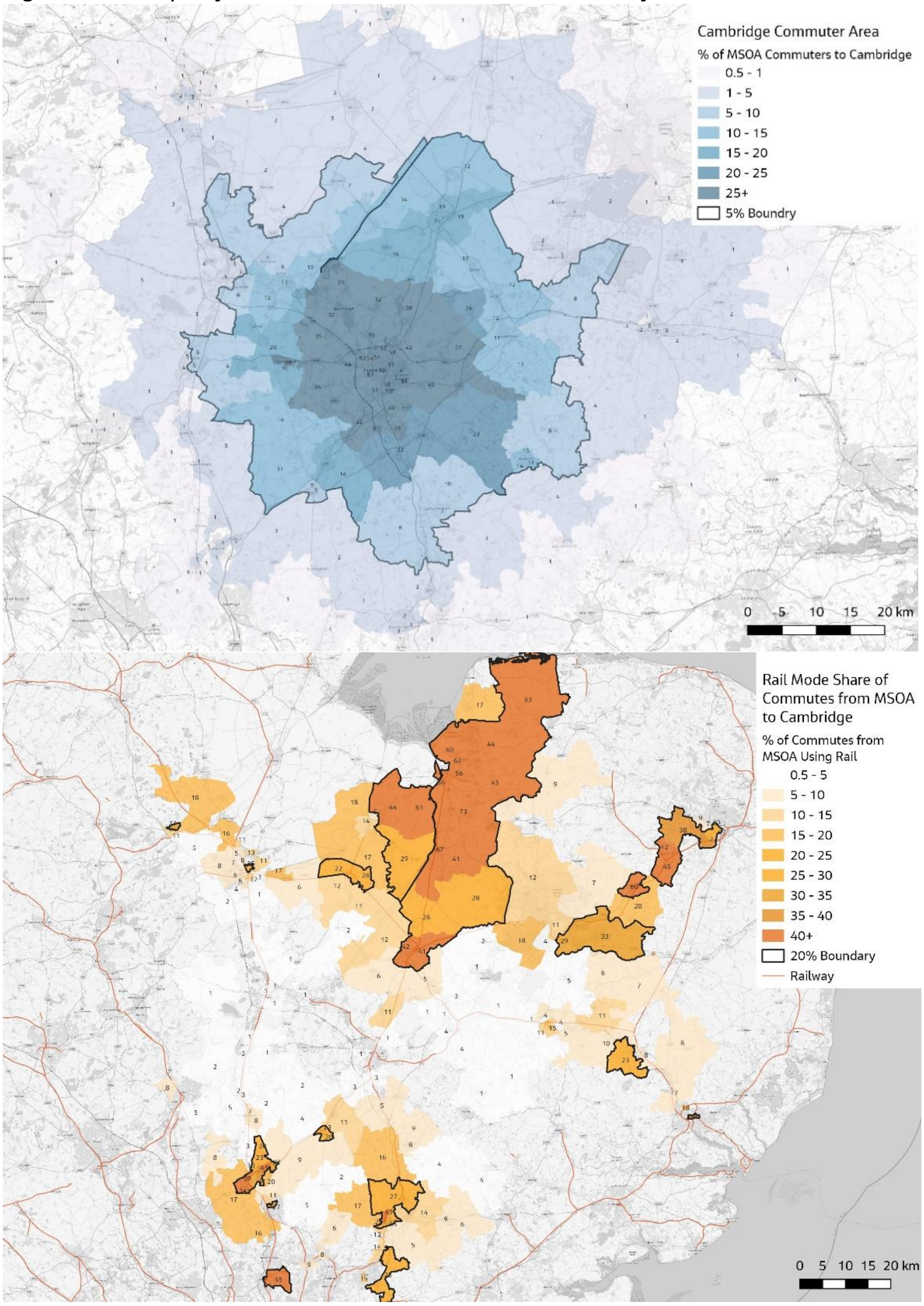
- **Conservative scenario:** Representing market sizes and mode shares experienced today, reflecting the range of nearby employment sites and similar journey times or distances;
- **Transformational scenario:** Representing a plausible but very aspirational world where market sizes and mode shares represent around the limits of what is observed today for a given mode share, which may not be transferrable between contexts.

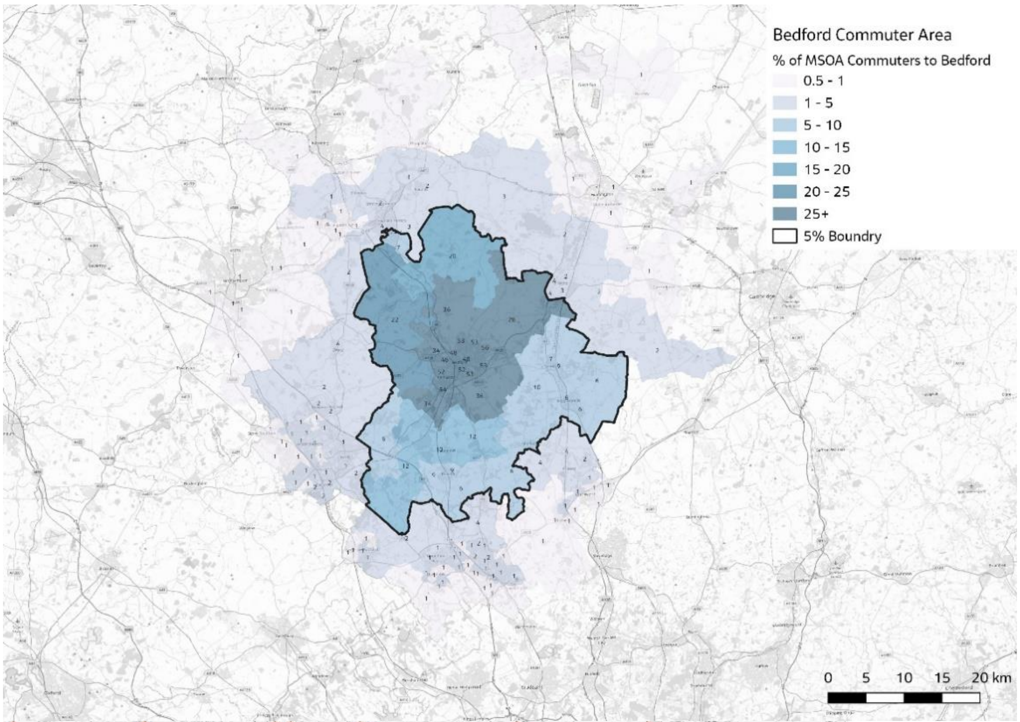
4.2.5 The source data for benchmarking is the Census 2011 travel to work dataset at the MSOA mode by mode (NOMIS ID: WU03EW). Despite its drawbacks in terms of recentness, this represents the best and most comprehensive data source for commuting only.

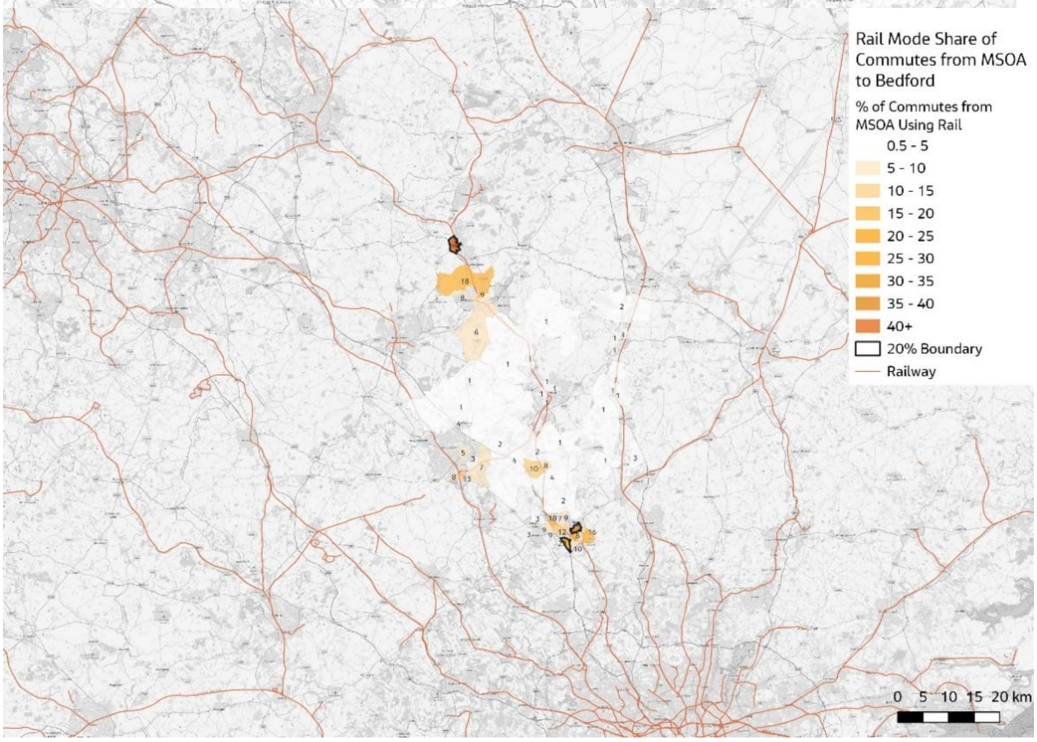
4.2.6 For EWR, the representative cities we have used for commuting destinations are: Cambridge, Bedford, Milton Keynes, Oxford, London.

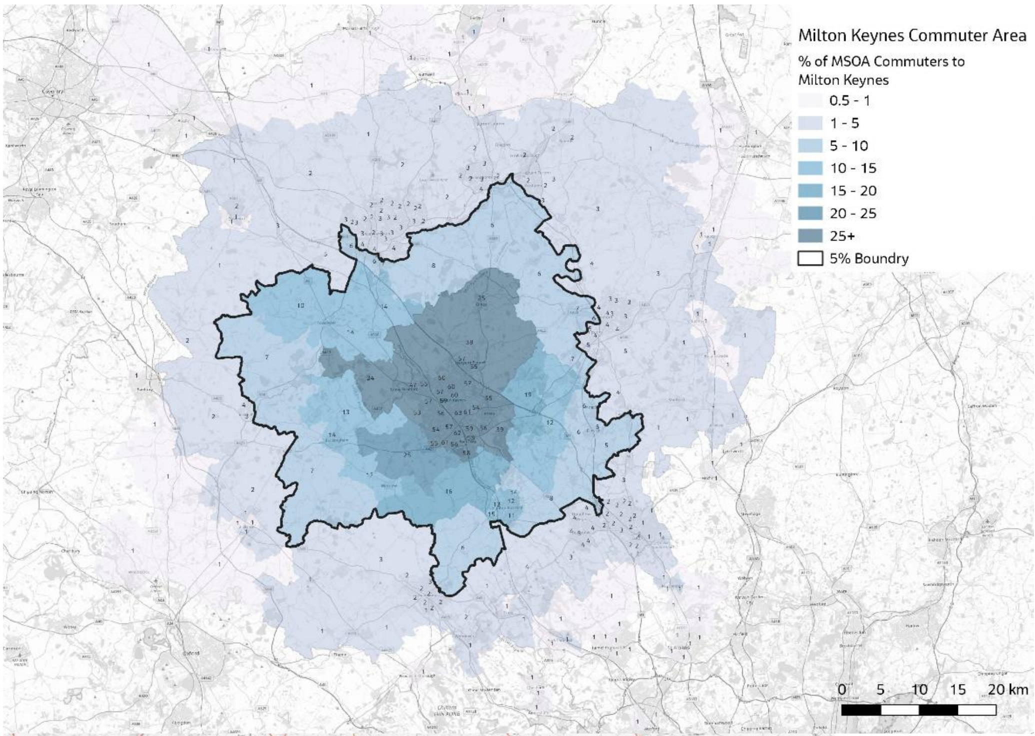
4.2.7 The following maps visualise the current market size and mode shares for the four key cities.

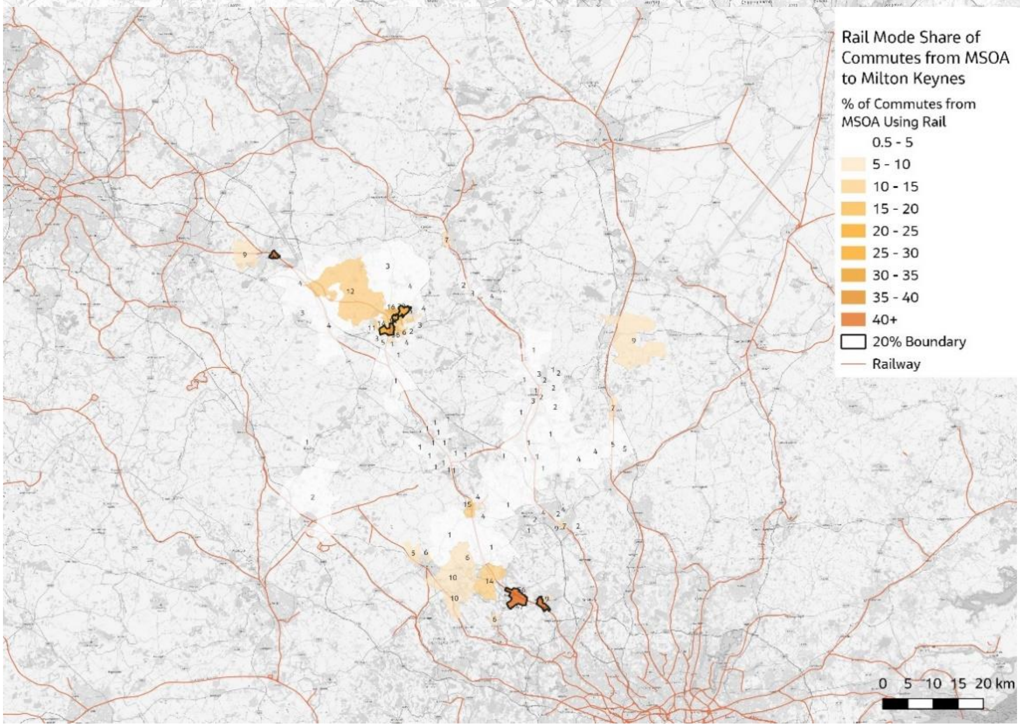
Figure 11 - Maps of market size and mode share across four cities

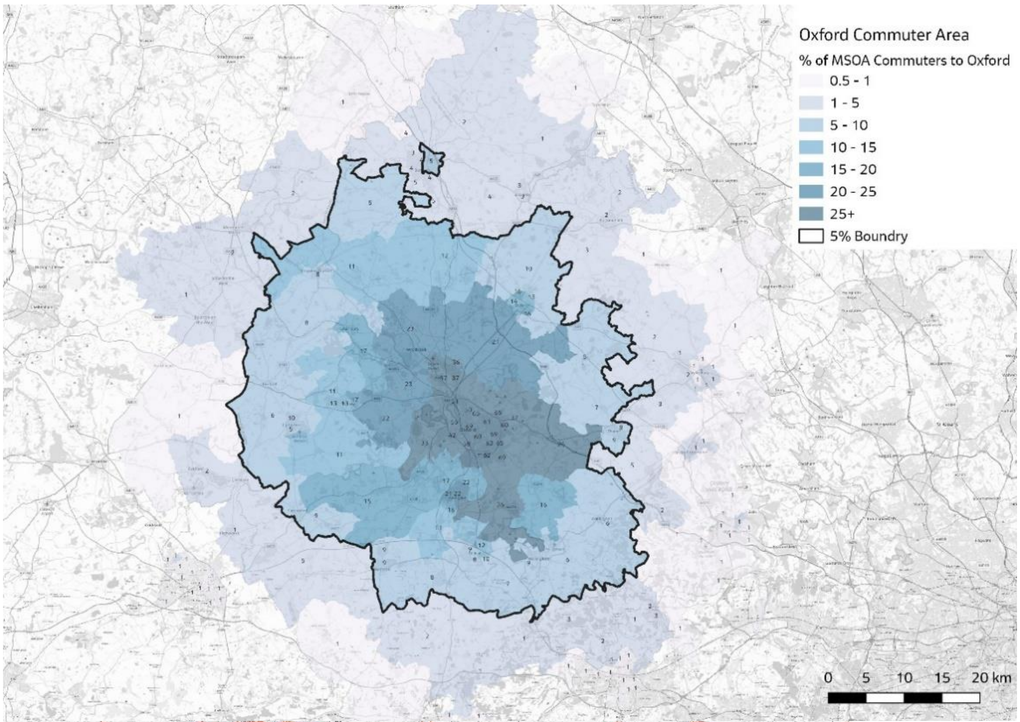


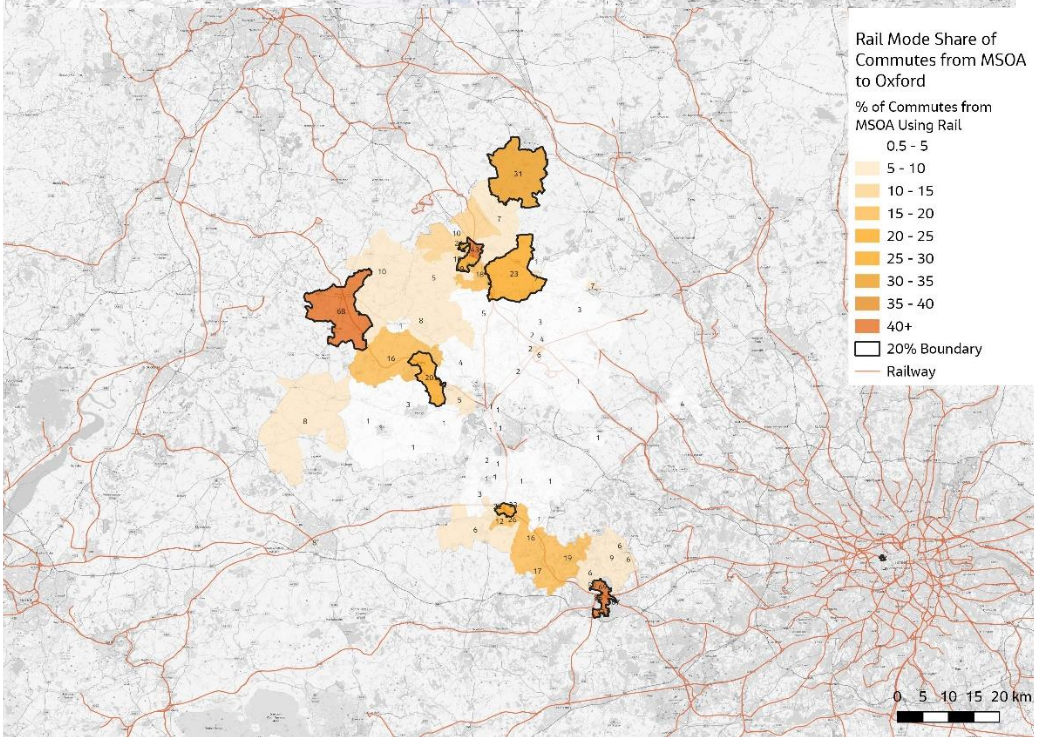

Bedford Commuter Area
% of MSOA Commuters to Bedford
0.5 - 1
1 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25+
5% Boundry
0 5 10 15 20 km


Rail Mode Share of Commutes from MSOA to Bedford
% of Commutes from MSOA Using Rail
0.5 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40+
20% Boundary
Railway
0 5 10 15 20 km


Milton Keynes Commuter Area
% of MSOA Commuters to Milton Keynes
0.5 - 1
1 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25+
5% Boundry
0 5 10 15 20 km


Rail Mode Share of Commutes from MSOA to Milton Keynes
% of Commutes from MSOA Using Rail
0.5 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40+
20% Boundary
Railway
0 5 10 15 20 km





4.2.8 This represents the number of people **regularly** commuting between locations. A conversion is needed to turn this to rail demand. We have multiplied the number of regular commuters by 58%, derived from $\frac{3500}{6000}$. This is made up of:

3,500 – estimate of the number of people arriving in Cambridge in the morning peak hour. This comes from:

- 4,000 – approximate number of people **on board trains arriving** in Cambridge in the high peak hour in the 2019 counts

- 500 – Jacobs estimate of the number of these people who would **not** get off the train at Cambridge

6,000 – estimate of the number of people regularly commuting into Cambridge in 2019, which comes from:

- 4,000 – number of people normally commuting by rail into Cambridge in the 2011 census

- 1.5 – factor to increase from 2011 to 2019 based on increase in sale of rail season tickets to Cambridge.

4.2.9 The results for the conventional and transformational scenarios are shown below. This implies 1,200 passengers per hour for the conventional scenario, and 4,000+ for the transformational scenario.

Table 4.1 ***Conventional*** *Scenario*

Station	Existing population	Increase in population **planned from dependent development**	**Produces a** employed working age population	Journey Time **to Cambridge (mins)**	% of Employed Population commuting to Cambridge	% Rail Mode Share	Regular Rail Commuters **Commuting demand per day**	Peak hour passengers per hour **Pre-pandemic observation**
Cambourne	9,200	53,400	30,800	15	30%	10%	920	540
Tempsford	500	44,000	21,900	24	5%	40%	440	250
Bedford	63,200	20,500	41,200	36	2%	55%	450	260
Stewartby	1,600	19,900	10,600	40	1%	55%	60	30
Ridgmont	2,800	19,200	10,800	44	1%	55%	60	30
Woburn Sands	7,700	40,600	23,800	46	1%	55%	130	80
M.K. / Bletchley	66,000	15,700	40,200	60	0%	65%	30	20
Total	**151,000**	**213,300**	**179,300**				**2,090**	**1,210**

Table 4.2 ***Transformational*** *scenario*

Station	Existing population	Increase in population **planned from dependent development**	**Produces a** employed working age population	Journey Time **to Cambridge (mins)**	% of Employed Population commuting to Cambridge	% Rail Mode Share	Regular Rail Commuters **Commuting demand per day**	Peak hour passengers per hour **Pre-pandemic observation**
Cambourne	9,200	53,400	30,800	15	40%	20%	2,460	1,430
Tempsford	500	44,000	21,900	24	20%	60%	2,630	1,520
Bedford	63,200	20,500	41,200	36	5%	65%	1,340	780
Stewartby	1,600	19,900	10,600	40	5%	65%	340	200
Ridgmont	2,800	19,200	10,800	44	5%	65%	350	200
Woburn Sands	7,700	40,600	23,800	46	5%	65%	770	450
M.K. / Bletchley	66,000	15,700	40,200	60	0%	75%	90	50
Total	**151,000**	**213,300**	**179,300**				**7,990**	**4,630**

4.3 Supported jobs

4.3.1 To align with the strategy of supporting job growth in Cambridge, the transformational scenario is used to infer how what proportion of new residents in an area would commute to Cambridge. There are four main categories considered.

4.3.2 **A: Business as usual.** An additional 17,300 jobs could be supported by 32,300 homes that are not dependent on a new transport link. In line with the High Growth approach to demand modelling in the Full Demand Model, since the housing development pipeline only considers data up to 2031, a further 50% housebuilding is considered to extrapolate growth to 2050. Additional jobs come from planned housebuilding of 32,300 homes across five main areas.

- Cambridge: There is significant planned housebuilding within the Cambridge Urban Area. Residents would be able to walk or cycle to work, and are not limited by current transport constraints.
- Cambridgeshire Guided Busway: There is significant planned development at locations like Northstowe, where residents would be able to take an uncongested guided bus to work in Cambridge.
- Stations north of Cambridge: A small amount of planned development in Ely and other towns.
- Stations east of Cambridge: A small amount of planned development in Kennett and other towns.
- Stations south of Cambridge: A small amount of planned development in Foxton and other towns.

4.3.3 **B: Expand.** The next 5,500 jobs could be supported by delivering a new transport link and allowing existing residents of locations like Bedford to commute to Cambridge and support additional jobs growth. Although some of these workers already commute to Cambridge, this would expect to increase from improved connectivity. The working age population is counted as within 2km of existing stations.

4.3.4 **C: Grow**. A further 7,900 jobs can be supported through planned 46,300 houses of the newly connected locations. In line with the High Growth approach to demand modelling in the Full Demand Model, since the housing development pipeline only considers data up to 2031, a further 50% housebuilding is considered to extrapolate growth to 2050.

4.3.5 **D: Strengthen.** The final 14,800 jobs can be supported by delivering 69,400 dependent development homes at newly connected locations, not currently in the planning pipeline. This would increase the workforce that could commute to Cambridge.

4.3.6 Dwellings are converted into additional labour force by applying ratio of workers to households (~1.13).

4.3.7 The proportion travelling to Cambridge from each station are derived from the trip-end model and contributing datasets including census.

4.3.8 This leads to 45,500 total jobs for Cambridge, supported by 199,900 homes. Of the additional jobs, 28,200 jobs (categories B, C and D) are supported by EWR. Other interventions are needed to achieve the full 80,000 jobs.

4.3.9 The tables below show how each category is calculated.

Table 4.3 A: Business as usual

Category	Stations included	Final number of dwellings (EEH) + 50%	Additional labour force	% of Employed Population commuting to Cambridge	Cambridge commuters
Rail stations to the East	Kennett, Dullingham	812	917	12%	110
Rail stations to the North	Littleport, Ely, March, Manea	1,536	1,736	15% (Littleport), 20% (Ely), 3% (March), 4% (Manea)	287
Rail stations to the South	Great Chesterford, Meldreth, Whittlesford, Foxton	2,816	3,182	10% (Great Chesterford, Whittlesford), 6% (Foxton, Meldreth)	297
Cambridgeshire Guided Busway	St Ives, Longstanton, Oakington Swavesey, Histon	15,678	17,716	15% (St Ives), 35% Longstanton), 40% (Oakington), 45% (Swavesey, Histon)	6,873
Cambridge Urban Area		14,411	16,284	60%	9,770
Total		**32,252**	**39,834**		**17,337**

Table 4.4 B: Expand

	Number of dwellings for existing population	Additional labour force	% of Employed Population commuting to Cambridge	Cambridge commuters
Sandy	5,544	6,265	35%	2,130

St Neots / Tempsford13	7,721	8,725	20%	1,321
Cambourne	3,731	4,216	40%	506
Stewartby (MVL)	695	785	5%	39
Ridgmont (MVL)	1,197	1,353	5%	68
Woburn Sands (MVL)	3,249	3,671	5%	184
Bedford	26,805	30,290	5%	1,212
Total	**48,942**	**55,304**		**5,460**

Table 4.5 C: Grow

	Final number of dwellings (EEH) + 50%	Additional labour force	% of Employed Population commuting to Cambridge	Cambridge Commuters
Sandy	149	168	35%	59
St Neots / Tempsford[14]	12,054	13,621	20%	2,724
Cambourne	7,953	8,987	40%	3,595
Stewartby (MVL)	2,979	3,366	5%	168
Ridgmont (MVL)	-	-	5%	-
Woburn Sands (MVL)	13,382	15,122	5%	756
Bedford	9,813	11,089	5%	554
Total	46,330	52,353		7,856

13 Both locations are considered, so results are combined

14 Both locations are considered, so results are combined

Table 4.6 D: Strengthen

	Number of dwellings	Additional labour force	% of Employed Population commuting to Cambridge	Cambridge commuters
Cambourne	19,300	21,809	40%	8,724
Tempsford	19,200	21,696	20%	4,339
Woburn Sands (MVL)	8,800	9,944	5%	497
Ridgmont (MVL)	9,300	10,509	5%	525
Bedford	3,800	4,294	5%	215
Stewartby (MVL)	9,000	10,170	5%	509
Total	**69,400**	**78,422**		**14,809**

5 Appendix 5: Detailed appraisal tables

5.1 Economic Appraisal

Economic Appraisals compare benefits against costs over the life of a project or for a defined period of time. As is typical for infrastructure projects, the monetised impacts of EWR are projected to a point 60 years from entry into service. Both the benefits and costs are discounted and presented in 2010 prices and values in line with TAG guidance. The 60-year value is known as the Present Value (PV).

5.2 Key appraised costs and benefits

5.2.1 Appraisal items are classified into either the Present Value of Benefits (PVB) or the Present Value of Costs (PVC). These costs are then offset by any generated revenue from EWR following DfT TAG to give a net cost to Government. Indirect Tax Impacts are considered a negative benefit. In this report, costs are shown as with a negative sign. The Net Present Value is the difference between Present Values Benefits and Costs. The Benefit Cost Ratio is the Present Value of Benefits divided by (negative) Present Value of Costs.

5.2.2 Appraised benefits fall into three categories under TAG, with increasing levels of uncertainty.

5.2.3 Level 1 impacts are conventional transport user benefits for any transport scheme that have a high degree of confidence. These are:

- Rail user benefits: travel time savings and user charge savings (from lower fares on a shorter route avoiding London).
- Non-user benefits: Reduction in the Marginal External Costs (MECs) of motoring driven by mode shift to passenger rail services, which is primarily congestion. A minor part of this is a reduction in DfT road budget spend. This also considers the environmental impacts of mode shift.
- Freight benefits: Reduction in the Marginal External Costs (MECs) of HGVs driven by mode shift to freight rail services.
- Indirect tax impacts: Impact upon Treasury receipts from a reduction in fuel tax, and VAT impacts of zero-rated rail fares.
- Revenue: Passenger fare receipts on all non-open access operators.
- Capital costs: Costs of delivering the scheme infrastructure including operating costs.
- Whole life costs: Costs of maintaining the infrastructure over the lifetime of the scheme.
- Operating costs: Costs of operating the railway over the lifetime of the scheme.
- Construction disbenefits: Costs of constructing the railway.

5.2.4 Level 2 ‘wider economic impacts’ are benefits that accrue to the broader economy, assuming that land use does not change. These are:

- Static agglomeration: In a transport appraisal, these are the benefits of bringing businesses [closer together] in terms of time and making businesses more productive.
- Labour supply impacts: the impact of the scheme upon national employment, enabling economically inactive individuals to enter the labour market.
- Output change in imperfectly competitive markets: Benefits of overcoming barriers to trade.

5.2.5 Level 3 'wider economic impacts' are benefits that accrue to the broader economy, assuming changes in the land use. These are:

- Land value uplift: The impact higher land values from building additional housing or development, accounting for any displaced development or rise in land values elsewhere, and the costs of delivering complementary interventions such as utilities and roads.
- Move to More or Less Productive Jobs: Accounting for higher levels of productivity as workers move between regions of different productivity.
- Revenue and Indirect Taxation impacts: Revenue and resulting indirect tax impacts from additional passengers who travel due to living in dependent development enabled by the transport scheme.

5.2.6 Benefit Cost Ratios (BCRs) can be calculated for Level 1 and Level 2 benefits. BCRs do not normally include Level 3 benefits but they may inform decisions about the value for money of a scheme. The indicative Level 3 "BCR" is shown for comparison for the high growth scenario only.

5.2.7 The DfT value for money framework (2017) sets out an approach to monetising the impact an infrastructure scheme has on landscape methods to determine the value for money categories. The framework fully recognises Level 3 wider economic impacts. Hence, relevant indicative monetised and/or non-monetised impacts are being considered and may result in a final decision on the preferred option differs from that implied solely by the BCR.

What did we appraise and why?

5.2.8 Appraisal is the procedure followed to assess the costs, benefits and risks of alternative ways to meet government objectives. During the appraisal process we have considered of a longlist of option choices, selecting a rational and viable set of options for shortlist analysis. At EWR we continue to review and update our appraisal methodology in line with updated guidance from the DfT, and develop our modelling framework, in order to enhance our ability to assess the impact of the scheme.

5.2.9 Our economic analysis has been carried out in accordance with HM Treasury's Green Book and the DfT's Web Based Transport Analysis Guidance (WebTAG). In line with that guidance, our economic appraisal continues to be based on a social cost benefit analysis, which attempts to place a monetary value on as many impacts as possible.

5.2.10 Our sifting and shortlisting exercise allowed us to focus our economic analysis upon four heavy rail Option Families via the Cambourne, the surviving options. We undertook conventional modelling and transport appraisal to better understand the costs and benefits of the heavy rail options HR 1,2,3&5. HR1&2 both take a northern approach to Cambridge, whereas HR3&5 take a southern approach. The economic appraisal for EWR captures the costs, benefits and changes in revenues for the whole of the rail network – not just those associated with the EWR infrastructure.

5.2.11 In line with the Department for Transport's guidance, we estimate the static welfare impacts of EWR including impacts on economic output to estimate the impact of EWR on the UK economy to produce the Level 2 BCR.

5.2.12 In addition to the standard WebTAG compliant wider economic impacts there are a number of other important effects, which are not currently assessed as part of the primary BCR measure in the business case. Some of these elements, such as land use change, have the potential to generate significant additional benefits. Hence, we have also produced a Level 3 BCR to account for changes in spatial patterns of economic activity as businesses and people cluster in areas with improved transport connectivity and the potential economic gains from development and regeneration along the EWR route. This does not capture the unmonetised strategic and indirect impacts of EWR and the individual options.

What did this tell us?

5.2.13 Standard approach to modelling and forecasting results showed us that, in conventional appraisal terms, the BCRs were 'poor' across all options, with little difference between each option for Level 1 and Level 2 benefits. We carried out a range of sensitivities, considering different levels of potential demand. The high growth scenario is presented in the table below for illustrative purposes.

5.2.14 The benefits are initially assessed in units of time before being converted to monetary values using DfT guidance. Whilst these monetisable benefits did not differ greatly between route alignments, the costs did differ explaining the differences between the BCRs calculated. These early estimates of costs were a key driver of the BCRs, which did not account for the transformational and strategic benefits considered later as part of the application of our Theory of Change.

Table - Appraisal Results for 4 tph Options, High Growth, 2010 PV (£m)

Heavy rail options, High, 4 tph	HR1	HR2	HR3	HR5
Level 1 Benefits (excl. WEIs)	£953m	£970m	£934m	£933m
Level 1 & 2 Benefits (incl. WEIs)	£1101m	£1122m	£1082m	£1081m
Total Costs	-£3851m	-£3407m	-£3764m	-£4308m
Revenue	£716m	£707m	£685m	£712m
Net Cost to Government	-£3135m	-£2700m	-£3079m	-£3596m
Level 1 BCR	**0.30**	**0.36**	**0.30**	**0.26**
Level 2 BCR	**0.35**	**0.42**	**0.35**	**0.30**
Land value uplift	£228m	£228m	£229m	£229m

DD Revenue	£1197m	£1193m	£1180m	£1194m
Indirect Tax Loss	-£164m	-£163m	-£161m	-£164m
Move to more/less productive jobs	£294m	£294m	£272m	£272m
Total Benefits	£1459m	£1481m	£1422m	£1418m
Net Cost to Government	-£1938m	-£1508m	-£1900m	-£2402m
Indicative Level 3 BCR	**0.75**	**0.98**	**0.75**	**0.59**

5.2.15 Further work was then undertaken applying EWR Assessment Factors – to help understand the benefits not captured in the BCR. See chapters 6-8 in the main report.

6 Appendix 6 Heavy Rail route options: Councils impacted and potential issues, concerns and benefits

Route	Council	Impact / Concern / Benefit
HR1	South Cambridgeshire District Council	Will impact new areas and villages, with potential environmental impacts. Potential for a new station at Bar Hill - would enable better connections for areas of new development. Avoiding southern route removes perceived negative impacts here.
	Cambridge City Council	Concerns: Impacts in north of City Loss of direct connection to new Cambridge South station. Potential benefits: Direct link to Cambridge North station (Science Park)
	Cambridgeshire Country Council	Same concerns as for South Cambridgeshire District Council and Cambridge City. Possible impacts on A14 and Guided Busway, including construction.
HR2	Bedford Borough Council	Reduced impact on areas at risk of demolition of homes. Concern that St Johns will have greater level of impact. Lack of direct link to MML.
	Central Bedfordshire	New route near Sandy had no previous consultation. Possible impacts on areas for new development.
	South Cambridgeshire District Council	Will impact new areas and villages, with potential environmental impacts. Potential for a new station at Bar Hill - would enable better connections for areas of new development. Avoiding southern route removes perceived negative impacts here.
	Cambridge City	Concerns: Impacts in north of City Loss of direct connection to new Cambridge South station. Potential benefits: Direct link to Cambridge North station (Science Park)
	Cambridgeshire Country Council	Same concerns as for South Cambridgeshire District Council and Cambridge City. Possible impacts on A14 and Guided Busway, including construction.
HR3	Bedford Borough Council	Reduced impact on areas at risk of demolition of homes. Concern that St Johns will have greater level of impact. Lack of direct link to MML.
	Central Bedfordshire	New route near Sandy had no previous consultation. Possible impacts on areas for new development.
HR4	Bedford Borough Council	Reduced impact on areas at risk of demolition of homes. Concern that St Johns will have greater level of impact. Lack of direct link to MML.
	Central Bedfordshire	New route near Sandy and to east had no previous consultation. Possible impacts on Sandy homes and new development areas. New station at Sandy – improved connections, possible local impacts. Impact on ECML and current Sandy station.

Route	Council	Impact / Concern / Benefit
	Huntingdonshire District Council	Loss of proximity to route and new station connections. Reduced direct impact of route on district.
	South Cambridgeshire District Council	Impact on many new areas and villages, with no previous consultation on this route. Potential environmental impacts. New stations at Gamlingay and Bourne – local impacts, new connections Loss of station and connections for Cambourne.
	Cambridge City Council	Impact on recently developed residential areas in Trumpington. New Trumpington station - Impact on Park & Ride and residential area. No link to Cambridge South station and hospital/biomedical campus. Impact on Guided Busway. Potential environmental impacts.
	Cambridgeshire Country Council	Same concerns as for South Cambridgeshire District Council and Cambridge City. Impact on other transport infrastructure.
HR5		Concerns as identified in NSC2 for main route options.
HR6	Bedford Borough Council	Reduced impact on areas at risk of demolition of homes. Concern that St Johns will have greater level of impact. Lack of direct link to MML.
	Central Bedfordshire Borough Council	New route near Sandy had no previous consultation. Possible impacts on areas for new development.
	South Cambridgeshire District Council	Will impact new areas and villages, with potential environmental impacts. Potential for a new station at Bar Hill - would enable better connections for areas of new development. Avoiding southern route removes perceived negative impacts here.Impacts around Harston/Hauxton and link to current rail line remain.
	Huntingdonshire District Council	Loss of proximity to route and new station connections. Reduced direct impact of route on district.
	Cambridgeshire County Council	New stations at Gamlingay and Bourne – local impacts, new connections. Loss of station and connections for Cambourne Potential environmental impacts.

7 Appendix 7: Light Rail Paper

7.1 Purpose of Paper

7.1.1 This Paper is an appendix to the Affordable Connection Project Report. It provides additional information and references to analysis carried out on light rail options. The aim is to define light rail as opposed to heavy rail, summarise the principal characteristics, communicate the constraints of applying light rail systems to the section of East West Rail between Bedford and Cambridge, and hence explain why LR1 and LR2 are the most appropriate configuration of a light rail scheme for EWR's circumstances in the Bedford-Cambridge section.

7.2 What is Light Rail?

7.2.1 The definition from the Office of Rail and Road of Light Rail says:

7.2.2 "Light rail is an urban transportation system that generally uses electrically powered rail guided vehicles along exclusive rights-of-way at ground level, on raised structures, in tunnels, and in streets. To allow greater flexibility in integrating systems into urban environments, light rail systems generally use lighter equipment that operates at slower speeds when compared to mainline or heavy rail metro/urban railways.

7.2.3 Tramways are a specific type of light rail system that have a significant element of the system operating in a highway environment or other public space. Tramways are typically built at street level, sharing roads with traffic, but most systems feature a variety of operating environments, including private rights of way, segregated, off street sections."

7.2.4 All rail systems, including variations of Light Rail, are regulated by the Railways and Other Guided Transport Systems Regulations 2006 (ROGS).

7.2.5 UK Railway Group Standards provide the specification for heavy rail network interoperability. Hence, they only apply to light rail where there is an interaction between a light rail network and the heavy rail network such that light rail vehicles operate on the heavy rail network .

7.2.6 Interoperability supports safe and technical compatibility of trains and infrastructure, allowing multiple different systems to operate as one network. Within UK Railway Group Standards, there are many types of vehicle and services typically characterised by phrases including: Intercity, Regional, Suburban/Commuter and Urban/Metro services. All those services are governed by standardisation of: signalling principles (either colour light or in-cab); traction power; platform height and offset; categorised loading criteria and gauge profiles; kinematic performance; minimum radii and maximum gradients. They do not constrain the frequency of service, combined vehicle length, seating capacity, or platform length.

7.2.7 Consequently, Light Rail systems are not ordinarily governed by UK Railway Group Standards, although they have to meet standards for health and safety purposes that are regulated by ROGS. Light Rail systems consequently have the greater freedom in specification to optimise their characteristics (signalling principles, vehicle dimensions, infrastructure gauge and loading, power supply etc) where a system is segregated, or provide compatibility to operate with systems other than heavy rail, such as highways. To be interoperable with heavy rail network requires compliance to Railway Group Standards as noted above.

7.3 What function does Light rail perform?

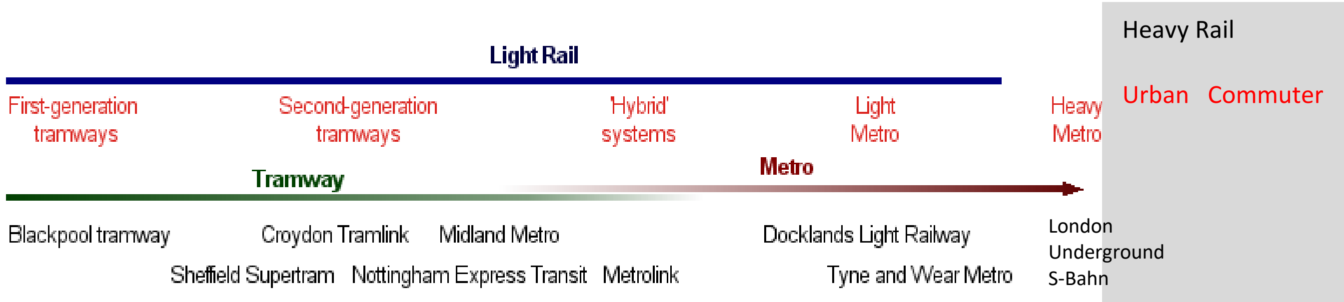


Figure 12 - Visualisation of rail systems by journey distance-capacity

7.3.1 Light rail systems typically provide the capacity to transport large numbers of people by providing higher frequency of services per hour, with shorter vehicles in comparison with heavy rail systems. As shown in Figure 12, the term "Light Rail" embraces systems with a variety of characteristics. These can be summarised as follows:

- *First generation tramways* are those historic tramways built in the 19th and early 20th centuries. In England, they are limited to the system in Blackpool;
- *Second generation tramways* are those built in the late 20th and early 21st centuries, characterised by modern, articulated vehicles and new formations, they embrace systems such as Nottingham Express Transit, Manchester Metrolink and the Croydon Tramlink.
- *Metro* systems tend to be segregated and in the UK include
- *Hybrid systems*, often using old Heavy Rail alignments such as the Tyne and Wear Metro and Sheffield Tram/Train; and
- *Light metro*, such as the Docklands light railway, which is an urban transit model characterised in many cases by segregated, elevated track.
- *Heavy metro* systems are largely distinct from light rail and embrace systems like the London Underground and Glasgow Subway, although it is technically classified as an underground light metro.

7.3.2 This paper principally addresses – and the ETR Report intends by the term "Light Rail", second generation tramway systems and Metro systems akin to the Hybrid systems listed above.

7.3.3 A Light Rail system compensates for its vehicles having a lower capacity by more frequent services and stops similarly being more frequent. Consequently, platforms can be shorter to match the vehicle, lowering the total cost of the system. Stations are typically be located closer together (typically 500m to 1km apart as opposed to a 10km station interval for EWR), as demonstrated by Table 1, last column. The effect of this, like buses, is to capture demand for journeys where the connecting mode is typically active travel, rather than driving to park at a station typical of commuter rail services. However, the German and Copenhagen S-Bahn systems represent Light Rail variations with a heavy rail specification, but with frequent stations only up to 5km apart, which also applies to Skytrain in Vancouver.

7.3.4 Light Rail is popular for short, but quick journeys. Information provided by UK tram[15] and leading transport planners suggestobjective of light rail systems is to create a 15 minute city, with most daily necessities accomplished by walking or cycling from homes and light rail serves longer journeys or 20 minute neighbourhood journey. Statistics from UK Tram show that that 90% of journeys on light rail are less than 10 miles in distance[16].

Table 7 - Examples of different light rail systems

Name	Light Rail Type	Miles of network	Vehicle design speed mph	Stations	Average distance between stations in miles
UK					
East West Railway Bedford-Cambridge	TBD	40	75	4	10
South Yorkshire Tram	Tram	22	55/60	50	0.4
Docklands Light Railway	Light Metro	23.5	50	45	0.5
Edinburgh Trams	Tram	11.3	50	24	0.5
Greater Manchester Metro	Tram	59	50	99	0.6
Nottingham Express Transit	Tram	20	50	51	0.4
London Tramlink	Tram	17.5	50	39	0.4
Tyne and Wear (Nexus) Metro	Light Metro	48	50	61	10.8
International					
Eglinton Crosstown (Toronto)	Tram	15.5	50	19	0.8
Finch West (Toronto)	Light metro	6.8	50	18	0.4
Skytrain (Vancouver)	Light metro	49.5	50	53	0.9

[15] UK Tram represents operators, promoters, manufacturers, contractors and consultants involved in tramways and metros and also the ultra and very light rail and personal rapid transit sectors.

[16] A light rail strategy for the UK uktram.org/DfT statistical release 25 June 2020 – Light Rail and Tram Statistics, England:2019/20

Metro Ligero (Madrid)	Tram	17.3	43	37	0.5
Kowloon, Hong Kong	Tram	22.5	50	68	0.3
Keihan Otsu Line, Japan	Tram/Light Metro	13.4	47	27	0.5

7.3.5 Most Light Rail systems only have need to operate at a top speed of around 50 mph as the normal short distance between stations characteristically makes higher speeds unnecessary. This is because there is little time spent at cruising at maximum speed.

7.3.6 A Light Rail variant is the Tram/Train, which has a slightly higher speed of 60 mph. A Tram/Train can be utilised when on street, on dedicated segregated alignments and on the national rail network infrastructure. However, the average speed across the tram network is often quite low due to the number of stops, an example of this being Tramlink where average speeds are around 21kph[17].

7.3.7 Light Rail provides greater transport capacity than road networks, and so are often retrofitted to cities when traffic congestion results in gridlock. Consequently, trams and other Light Rail systems sharing road space interface with highways or other public realm operate on a 'line of sight' principle to avoid collisions.

7.3.8 This means that operators and third parties have to act themselves to avoid collisions. There are also traffic signals which govern movements at junctions rather than railway-type signalling. This limits the speed in sections of Light Rail systems that share public realm so as to keep the braking distance short. A further disadvantage is that a Light Rail system with shared roadspace will link its performance of the service to traffic congestion levels. To mitigate this traffic segregation is often necessary and priority may be provided by way of traffic signalling, but this will still result in some time penalties for services.

7.3.9 On board, to maximise utility of the smaller vehicles used in Light Rail systems, the customer environment typically has limited seating and large standing areas. This is to enhance capacity, bearing in mind that journeys are typically short. It also provides passengers with mobility within the vehicle enabling lower dwell times at stops as they can move within and out of vehicles easily when boarding or alighting. At peak times this provides greater overall capacity, with proportionally more standing than seated journeys allowing higher density. Passengers are disposed to a higher tolerance of standing for the shorter journey durations[18].

7.3.10 As Table 1 demonstrated, Light Rail Systems are typically deployed in an urban environment with medium to high population density spread over a medium or large city size area. Where population densities are lower, bus services tend to be sufficient. For higher density population areas, with higher potential ridership, and where the value of urban land is higher, systems utilising tunnelling and more intensive longer trains, tend to indicate that metro service levels are justifiable. .

[17] FOI request FOI-0228-1819 Tfl 22-5-2018

[18] Average journeys are 4.3 miles DfT statistical release 25 June 2020 – Light Rail and Tram Statistics England 2019/20

7.3.11 The constrained urban environment, including city centres with historic buildings, often needs tighter radii to be traversed when following existing roads or aerial corridors, so the individual vehicle length is shortened and articulated to reduce the swept path.

7.4 EWR Characteristics

7.4.1 The route context for the Bedford to Cambridge section of EWR is a rural route of 40km between the two main settlements. There is currently a low population density in between the two centres except for few small towns or large villages. The cities are well connected by dual carriageways, including A428 upgrade which makes intercity travel possible by road at circa 60mph. Cambridge suffers significant road congestion in peak hours, being the 4th most congested city in the UK.

7.4.2 Other urban areas served by light rail systems are much more densely populated than the areas around Cambridge and Bedford at present. Even allowing for new settlements, the density of population in the Bedford-Cambridge section of the Oxford Cambridge Arc is unlikely to be like the conurbations currently served by light rail systems. The likely distance between stops in the Bedford-Cambridge section is about 10 miles.

7.4.3 To be competitive with the alternate mode of a car journey, a transport system preferably needs a higher speed than roads between stations typically spaced 10km apart. The options that performed best in the EWR sift process as set out in Chapter 4 of the ETR Report are those light rail systems that trend towards a heavy rail specification and hence resemble that sort of station pattern. Thus, the German and Copenhagen S-Bahn with a heavy rail specification, but with frequent stations only up to 5km apart and Skytrain in Vancouver have station dispositions on their route most closely analogous to the likely settlement and stopping pattern in the area that EWR would serve. This contrasts with the Light Rail descriptor set out above, which relies on frequent, intense service patterns.

7.4.4 Where this is not possible, whether because of constraints in other areas or otherwise, it is important to accommodate longer train sets to provide capacity. For EWR, constraints on the corridor within the Cambridge area limit the frequency of service, making this particularly important. These constraints are discussed below.

Figure 13 - Skytrain in Vancouver, Canada, showing a higher capacity vehicle, faster, longer distance light rail service

7.5 Constraints

7.5.1 In considering transport mode, whilst the available market is important (see comments on population density above), it is also necessary to consider constraints upon delivery, however imposed. EWR Co has good information about the area between Bedford and Cambridge for the purposes of the Affordable Connections Project. It has identified routeing possible in rural areas having regard to the more significant constraints identified such as settlements, other transport corridors and ecological designations.

7.5.2 It is the urban areas of Bedford and Cambridge that would most constrain any mode in reaching suitable destinations in the two main urban areas. Routes into Bedford and Cambridge are most likely to be viable when using existing transport corridors (as opposed to acquisition of extensive areas of residential and business property or tunnelling). However, these carry limitations, which are described below:

Roads

7.5.3 Roads provide a potential route for Light Rail. They can either be shared or priority can be given to the rail vehicles, such as at traffic lights and level crossings, as for a tram system, or road space can be re-purposed as segregated space. Cardington Road in Bedford, which has potential space for corridor widening, leading to the east of the town, but a segregated route is potentially available using the alignment of the former Varsity railway line, which would afford a less constrained alternative. Therefore, on the assumption that the Varsity line alignment could be used, road space availability is not considered to affect the use of light rail in Bedford.

7.5.4 Conversely, in Cambridge the main A428, A1303, A603 and A10 roads do not have enough space to create segregated space; shared space would negatively affect current road capacity and compromise performance of light rail. There would be concurrent delays between the rail system and the road traffic.

Busways

7.5.5 Bedford does not have an existing busway system, so there are no such alignments available to a Light Rail system in the Bedford area.

7.5.6 Cambridgeshire guided busways utilise old railway alignments and present potential existing corridors that could serve desirable destinations in the Cambridge city centre. Despite the likelihood of a significant negative impact of the capacity of the existing bus network, the use of busway alignments has been considered for Scheme Option families LR1 and LR2. However, both Scheme Option families are constrained by available land area for their terminus stations (Assumed to be at Cambridge Station Plaza and Cambridge North station plaza). Constraints at termini limit vehicle length and number of platforms assuming a surface terminus as opposed to a much more expensive underground Light Rail terminus. This affects the maximum capacity of a Light Rail system because of the shorter vehicle length, and reduced frequency owing to turnaround times.

Rail

7.5.7 There are two means by which rail corridors can serve for access to urban areas: common use of the Heavy Rail tracks, and segregated Light Rail tracks within the Heavy Rail corridor.

7.5.8 In Bedford, use of the railway alignment to the North provides no advantage over a Heavy Rail solution. The railway is already among the most congested infrastructure in England, meaning that a shared solution would be very difficult to achieve. The expansion of the railway corridor is also difficult because it would entail acquisition of the same land as for a heavy rail solution. Leaving Bedford to the East would favour reuse of the former Varsity Line alignment or on-street running using Cardington Road as described above. Never-the-less, this was studied and documented in the Bedford Light Rail Presentation in the Data Room, including using only a single track along the corridor running bi-directionally.

7.5.9 Use of the existing rail corridors with segregation in Cambridge either to the north or the south incurs very similar 4-tracking costs as heavy rail to bring dedicated lines into Cambridge Station. However, it does not provide the same collateral network advantage of infrastructure resilience.

7.5.10 Shared use of railway lines by Light Rail causes reduced network capacity. The TPWS (Train Protection Warning System) protected block sections must be modified by introducing additional block sections to facilitate additional protection caused as a result of the lack of robust crashworthiness[19]. The Sheffield Supertram has achieved shared running as a pilot Tram/Train project but suffers from this limitation. EWR Co has considered and applied these principals to signalling schemes plans for Light Rail Scheme Option families running into Bedford North, Bedford Varsity and Cambridge South. These show that the shared use of railway lines has negative impacts on capacity and signalling systems, which would require costly mitigation. Cambridge North was not studied due to the reduction of mainline services the capacity reduction would create, in the order of 40% to 60% reduction, which is greater than would apply to a Heavy Rail solution because the insertion of Light Rail Vehicles into the timetable would remove train paths that in a Heavy Rail solution are still occupied by passenger trains.

Not entering the City

7.5.11 It will be noted that the principal constraints upon the adoption of a Light Rail solution to Bedford-Cambridge links lies in the Cambridge area, as opposed to Bedford. Therefore, instead of entering Cambridge with Light Rail, a terminus at Trumpington or at Bar Hill was considered. This removes the constraint to frequency of service imposed by sharing another transport corridor, and so lifts the theoretical capacity. However, when services arrived at such a terminus supporting feeder/dispersal transport journeys could not provide continuity of journey. By comparison, existing park and ride schemes at Trumpington, Maddingley and Newmarket Road are fed by a bus service that is at capacity at peak hours, and constrained by traffic congestion, which would affect onward journeys in the same way for an out-of-centre Light Rail terminus. Stopping services at a terminus outside the city centre to avoid urban constraints also results in an interchange time penalty as well as increasing load on existing

[19] Light rail vehicle structures and crashworthiness standards Stuart Brown, 7 February

transport systems (which are the current limit to growth potential), so is unattractive to users and does not meet the strategic need.

Affordability -construction differences

7.5.12 Any Light Rail alignment design would be dominated in the rural, interurban area, by a need for a high attainable speed. Higher speed requires larger radius curves, both vertical and horizontal. Consequently, the opportunity to realise savings from a light rail specification compared to heavy rail are proportionately less significant than in urban areas – the alignment has more common characteristics with Heavy Rail for a given line speed.

7.5.13 Similarly, the Light Rail system must address the same geographical obstacles exist regardless of the heavy or light rail specification of the rail system, so bridges, viaducts and earthworks are needed and these are a function of alignment choice. Savings can be made with higher maximum gradient, but these are mostly in the marginal differences in the approach embankment lengths to intersection bridges achieving grade separation.

7.5.14 The relief around Bedford is flat when associated with the River Great Ouse valley, and low rolling hills to the North side. In Cambridgeshire the fens of Anglia predominate in the North, with some rolling hills around Harston, with Cambourne sitting atop the highest elevation of the potential routes.

7.5.15 Alignments to the North of Bedford and South of Cambridge onto the West Anglia Main Line (Route Alignment 1) may also benefit from reduced cutting depths because of the higher permissible light rail gradients due to lower speeds. However, water courses and flood levels tend to dictate embankments heights.

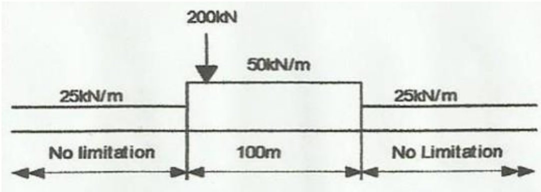
7.5.16 Imposed loading differences between light and heady rail do not tend to reduce width of the embankments and cuttings as these are driven the stability of the ground and the materials used in their construction.

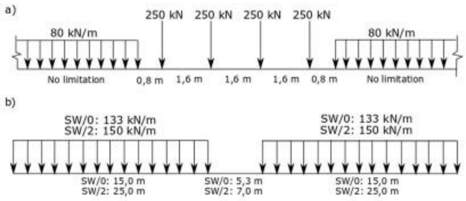
7.5.17 Imposed loading differences between light and heavy rail do reduce the structural element of underbridges and viaducts, but only by approximately 10% in materials.

Load Case Light and Heavy Rail

Light Rail = 200kN Axel load

Heavy Rail = 250kN Axel Load





On structures the governing case is the serviceability limit state (stiffness) to control deflection, twist or vibration, so typically 10% saving in material. EG Pier spacing increases. This effect has limited impact to cost on short span structures.
Earthwork volumes are driven by stability criteria, so not significantly impacted by load case

4 East West Railway Company

Figure 14 - Shows the difference between light and heavy rail imposed loadings

7.5.18 Based on the above, the advantages of Light Rail over Heavy Rail are limited in terms of construction and hence affordability.

7.6 Summary

7.6.1 The different variations of Light Rail system were applied to East West Rail at concept level and set out in the Long List. Using the evaluation criteria set out in the Affordable Connections Project Report, those options were assessed. Only LR1 and LR2 are scored highly enough to progress to be assessed against the Theory of Change. Those other Light Rail system concepts that did not survive to be assessed against the Theory of Change are set out here outlining the principals that caused limitations to their success as viable option.

7.6.2 Geographical constraints within Cambridge and Bedford limit the capacity, length, frequency or journey time of different types of light rail systems.

7.6.3 Trams get caught in traffic, and space is constrained on the road network in Cambridge, the journey time is too slow to be attractive.

7.6.4 Tram-Trains significantly negatively impact on the capacity of the West Anglia Mainline (if run along through multiple block sections), to the detriment of all other rail services., that would require reduction in the order of 40% to 60%. The exception is the throat of Cambridge station on a Varsity alignment. The journey time is too slow to be attractive, (see the demand analysis varying by journey time).

7.6.5 The table below shows the journey times in minutes for heavy rail and light rail journeys between Bedford and Cambridge:

Table 8 - journey times in minutes for heavy rail and light rail journeys between Bedford and Cambridge

Bedford to Cambridge	Light Rail	Heavy Rail HR
Via Cambourne and Cambridge North*	43 (LR1)	38 (HR2)
Via Varsity Line	37 (LR2)	31 (HR4)

*Journey times to Cambridge North only

7.6.6 Segregated light rail adjacent to West Anglia Mainline and Midland Mainline has most if not all the cost and none of the benefit (like speed, freight capability) of a heavy rail specification and integration (heavy rail has higher availability by diversity of infrastructure e.g. operational platform).

7.6.7 Stopping services at a terminus outside Cambridge city centre to avoid urban constraints results in an interchange time penalty and increasing load on existing transport systems (which are the current limit to growth potential), so is unattractive to users and does not meet the strategic need.

7.6.8 The remaining options are to re-purpose the Cambridge guided busway corridors to a light rail solution, to provide a terminus at Cambridge North or Cambridge Station; hence LR1 and LR2.

7.6.9 The cost saving benefits of a light rail system apply well for a transport system in an urban environment. In a greenfield environment where the target speed is higher there is less proportional cost saving impact when building an alignment compared to a Railway Group Standard railway specification.

8 Appendix 8: Cost Estimates

Context

The report demonstrated that there are potentially affordable, viable transport Option Families which can provide connectivity between Oxford and Cambridge and satisfy the demand requirements established using the ToC (Section 5). This section of the report shows how the cost of the viable infrastructure options (Oxford to Cambridge heavy rail solutions derived from the four shortlisted Option Families) was estimated and how these cost estimates compare with those developed in connection with the 2021 alignment options consultation.

These estimates were developed from the very preliminary route alignment design work which has been undertaken as part of the Affordable Connections Project (ACP) and are based primarily on the length and profile of each route along with the physical characteristics of that solution.

Options Considered

EWR Co has considered the various ways in which the strategic case for improved transport connectivity in the Oxford to Cambridge Arc can be achieved. 170 possible solutions were considered including heavy rail, light rail, guided bus, and conventional (on-road) bus schemes.

As described in previous sections of this report, a process of shortlisting and sifting led to the identification of eleven Option Families, comprising six heavy rail solutions, two light rail solutions and three guided bus solutions. EWR Co concluded that only heavy rail solutions can satisfy the predicted demand requirements resulting from its Theory of Change along the route and of the six Option Families, four emerged as viable. The cost analysis was focused on these four heavy rail options (listed in paragraph 8.11.5), based on the infrastructure solutions required to deliver the initial phase of the Option Families, when the railway initially enters service.

Between Bedford and Bletchley, only one route option was considered to simplify the assessment, following the existing Marston Vale Line. The approach taken in seeking a more affordable solution was to minimise the scope of work on this section of the railway and to reduce the line speed from 100mph (in the scheme presented at the 2021 consultation).

Estimating Principles

The very preliminary nature of the design of the alignment options between Bedford and Cambridge meant that the focus was on developing indicative costs per kilometre of railway, adjusting for stations and other known features and characteristics along the routes. An assessment was made of the potential costs for full electrification of the route, but these costs were separated from the other costs as a decision on traction power has yet to be made. Costs were baselined to Quarter 2, 2021. All costs are expressed as a value range, which reflects the level of confidence in the estimates, and which is appropriate at this stage of development.

Base cost estimates were developed for the four shortlisted heavy rail options to understand the relative costs of options. Estimates were also made of risk and uncertainty and of inflation. Base costs include all direct construction, manufacturing and assembly costs, construction preliminaries, contractors' overheads and profits, design costs, project management costs, land and property costs, and the client's management costs, including the costs associated with gaining the necessary permissions to build the railway.

Estimates of risk, uncertainty, and inflation were made using the latest available information. EWR Co recognises that the current global situation makes these estimates difficult to define with confidence, but to give a sense of the total cost of each scheme option they are expressed as a likely range of values within which it is believed the costs will fall.

Base Construction Costs

Over 80 percent of the direct construction costs of a railway are typically made up from five three main categories of work:

- Civil Engineering (c.55-60 percent)
- Permanent Way (c.18-20 percent)
- Buildings and Property (c.10-12 percent)

Unit rates were derived from a tender and outturn costs for a variety of historical projects, together with the EWR Alliance scheme (EWR2), which will construct the railway between Bicester and Bletchley (CS1). Additionally, EWR Co has drawn upon the detailed analysis of earthworks costs on EWR2, carried out by EWR Co in 2021. It should be noted that where benchmarking has been carried out, care was taken to ensure like-for-like comparison.

The cost of stations was estimated from other similar structures including those on the Marston Vale Line. Winslow Station has a target cost of approximately £5m and Bletchley High Level station is £3.5m, both part of CS1. However, at this stage of development the actual station building costs have not been disaggregated from the surrounding, associated works so the estimates are somewhat higher in capital cost.

Indirect Costs

Indirect costs are costs which enable construction and include the contractors' construction preliminaries plus the other costs. The combination of direct and indirect costs provides base costs for the scheme.

- Contractors' overheads and profits were estimated at 10 percent of direct costs plus preliminaries.
- Design costs were estimated at 10 percent of direct costs plus preliminaries. Project management costs have been estimated to be 8.3 percent. Other costs have been estimated at 5 percent of direct works costs and indirect construction costs.
- Land and property cost estimates are prepared based solely on desktop information rather than surveys and visits. The estimates include the cost of securing property interests and settling compensation claims in accordance with the legislation and the 'Compensation Code'[20].
- Allowances were made for environmental works, utilities related costs and off-route works at Oxford Station and Bicester Level Crossing as 'below the line' items, which means that the sums are deemed to be at Base Construction Cost equivalent, i.e. inclusive of and not subject to uplifts for contractors' preliminaries, overheads, profits, or other factors. There is insufficient scope, design or engineering input available at this stage on which to base anything other than a very high-level indication of potential cost.

An indicative allowance for environmental works comprises £1,250,000 per route kilometre for the section of new railway between Bedford and Cambridge. Included within this is an allowance of £85,000 per kilometre to support specific measures needed to achieve a 10 percent increase in biodiversity, in line with the Environment Act (2021). A further lump sum allowance of £33 million is added for undefined low carbon materials/low carbon construction methods to support the net zero carbon objective, where it is too early in the project to assess the exact scope of these activities.

Risk and Uncertainty

Risks and uncertainties associated with the route options were excluded from the base cost estimates but were considered in developing total cost ranges for the shortlisted options. Risks are defined as events or activities which may or may not happen and would have cost implications if they do; uncertainties are defined as events or activities which are expected to happen, the costs of which are difficult to estimate at this stage.

[20] The national Compensation Code is a body of law, policy and practice, which informs and governs the principles on which land is valued in the context of compulsory acquisition or under the shadow of compulsory acquisition.

Risk and uncertainty remain difficult to estimate at the current time. The combined impact of trade restrictions and labour shortages caused by Brexit, the war in Europe, the high demand on plant, labour, and materials resources for other major infrastructure projects, and the unstable costs of raw materials and fuels means that the past is no longer a reasonable predictor of future trends.

In line with the sensitivity analysis and given the quality of the heavy rail options cost estimates and the definition of their infrastructure, EWR Co selected a 33%-59% risk range uplift percentage for the cost of these options, which reflect P60 confidence level, as a lower bound, and P70 confidence level, as a higher bound in line with the Transport Analysis Guidance.

Inflation

Inflation was excluded from the base cost estimate for each of the route options. Inflation had increased significantly during the 12 months prior to this estimating exercise and, although it was forecast to reduce during 2023 and 2024, the future impact on the economy and the construction industry remains difficult to predict with any degree of certainty.

However, in developing the cost estimates consideration was given to the "Market View Summer 2022" view produced by Arcadis which suggests that there will be higher levels of inflation in construction than in the general economy. The National Infrastructure Construction Tender Price Index also anticipated significantly high levels of inflation than the RPI index.

The Cost Estimates for Shortlisted Heavy Rail Options

The four shortlisted heavy rail options (HR1, HR2, HR3, HR4) were costed as follows (rounded to nearest £10million Costs are shown for scenarios that enable the operation of 4 tph between Bedford and Cambridge, in line with the train service to satisfy demand arising from the ToC.

Table 9 - Summary of relevant costs of the scheme options for 4 tph (rounded to nearest £10m)

	Cost (£m)			
Description	**HR1**	**HR2**	**HR3**	**HR5**
Direct Construction Cost	£1,400	£860	£1,060	£1,530
Indirect Construction Cost	£670	£390	£490	£730
Total Construction Cost	**£2,070**	**£1,250**	**£1,550**	**£2,260**
Other Indirect Cost	£980	£730	£820	£1,090
Base Cost	**£3,050**	**£1,980**	**£2,370**	**£3,350**
Lower Bound Risk Range	**£4,080**	**£2,630**	**£3,150**	**£4,460**
Upper Bound Risk Range	**£4,970**	**£3,150**	**£3,770**	**£5,340**

These cost estimates are based on the following assumptions:

Updated Costs (December 2022)

- HR1 is based on 6 tracking North of Bedford. 4 track Northern approach into Cambridge
- HR5 is based on 6 tracking North of Bedford. 4 track Southern approach into Cambridge

Initial ACP Costs (Aug 2022)

- HR2 is based on Bedford Varsity route. 3 track Northern approach into Cambridge
- HR3 is based on Bedford Varsity route. 4 track Southern approach into Cambridge

Option Family	Mode	Route Option	Bedford approach	Cambridge approach
HR1	Heavy rail	Via Cambourne	Northern approach	Northern approach
HR2	Heavy rail	Via Cambourne	Southern approach	Northern approach
HR3	Heavy rail	Via Cambourne	Southern approach	Southern approach
HR5	Heavy rail	Via Cambourne	Northern approach	Southern approach

9 Appendix 9 – EWR Co Assessment Factors

Id	Assessment Factor	Definition	Supporting Considerations	Description of how Factor is applied at this stage of design development
Business Case and Customers				
1	Transport user benefits	Benefits to transport users. This includes elements that drive 'generalised journey time': origin to destination journey times, access times to stations, number of interchanges. Also consider crowding and quality compared to current journey. Include benefits of mode shift (i.e. decongestion and environmental benefits where people are attracted to rail rather than use of other modes due to shorter generalised journey times).	1. Time savings 2. Mode shift benefits	Qualitative, not monetised. Benefits to existing users rather than those attracted to developments which is captured in the housing and economic growth Assessment Factor. High level consideration of estimated overall journey time. At this stage modal shift assessments are based on a high-level qualitative assessment of the proximity to existing users to capture the ability of the station to attract new local patronage
2	Contribution to enabling housing and economic growth including best serving areas benefitting from developable land	Potential for wider employment and productivity benefits of improved east-west connectivity and the opportunity for stations served by EWR to support housing growth within their catchment areas.	1. Wider economic impacts 2. Total potential houses enabled 3. Regeneration	Indicative qualitative assessment using available evidence in advance of modelling. Potential for wider employment and productivity benefits due to improved connectivity. Potential for stations served by EWR to support housing growth.

Id	Assessment Factor	Definition	Supporting Considerations	Description of how Factor is applied at this stage of design development
				Potential for stations served by EWR to support local regeneration.
3	Capital costs	Cost to bring the project to full service, including land acquisition, construction and any adaptation and mitigation works, including risk.	1. Up front cost to implement scheme 2. Cost risk 3. Programme risk	A quantitative estimate of the cost range appropriate to the design maturity of the options being assessed. A qualitative assessment of cost and programme risks at this stage.
4	Operating costs	Ongoing costs incurred in the delivery of the train service	1. Service operating costs e.g. staff, stations, signalling & electrical control centre, rolling stock lease, energy	A qualitative assessment of the scale is used where relevant at this stage of assessment
5	Overall affordability	Consideration of the financial implications of the options in terms of costs and incomes for EWR and other parties, over the whole life of the railway. Whilst incomes are considered here, other non-financial benefits such as those considered in factors 1 & 2 are weighed against this factor of Overall Affordability and all other factors when determining which option represents best Value for Money.	1. Whole Life Cost: a. Capital costs b. Operating costs c. Maintenance costs d. Renewal costs e. End of life costs 2. Fare revenue 3. Non-fare revenue 4. Wider / non-EWR costs and incomes 5. Likelihood of obtaining third party funding contributions	Only capital costs are estimated quantitatively at this stage of assessment. The other considerations are considered qualitatively.
Network Capability				

Id	Assessment Factor	Definition	Supporting Considerations	Description of how Factor is applied at this stage of design development
6	Short distance connectivity to support commuting travel into key employment hubs (current and future)	Journey time between housing centres and employment hubs	Trips appropriate to the infrastructure being considered are used e.g. where relevant, for the new railway between Bedford and Cambridge the following are considered: Cambourne to Milton Keynes Cambourne to Cambridge St Neots South / Tempsford to Milton Keynes St Neots South / Tempsford to Cambridge	
7	Short distance passenger services	Journey time between EWR stations (station to station only)	Trips appropriate to the infrastructure being considered are used e.g. where relevant, for the new railway between Bedford and Cambridge the journey time between Bedford and Cambridge is considered	
8	Rail passenger connectivity to existing mainlines	Ease of interchange e.g. platform-to-platform distance, level change/accessibility, stopping frequency, timetable alignment	Trips appropriate to the infrastructure being considered are used e.g. where relevant, for the new railway between Bedford and Cambridge the ease of interchange with ECML is considered.	
9	Long distance passenger services	Strategic consideration of the extent to which EWR facilitates long distance passenger services beyond Oxford to Cambridge	Trips appropriate to the infrastructure being considered are used e.g. where relevant, for the new or modified railway on the approach to Cambridge the impact of options on the potential for future extension of services east of Cambridge is considered	

Id	Assessment Factor	Definition	Supporting Considerations	Description of how Factor is applied at this stage of design development
10	Satisfying existing and future freight demand	Potential to meet freight demand, as anticipated by the freight industry, through active provision for freight paths	1. Travel time 2. No. of paths 3. Waiting time 4. Time of day	Generally this level of detail is not yet developed and modelled at this stage but the capability of the existing network i.e. number of paths is considered where relevant
		Railway Operations		
11	Performance	The ability of the railway to provide a service that meets or exceeds customer expectations	1. Maintainability 2. Rolling Stock Reliability 3. Infrastructure Reliability 4. Operational Resilience of EWR service 5. Operational Resilience of Wider Rail Network	Qualitative assessments at this stage. Maintainability – the ease of undertaking routine inspections and maintenance of the infrastructure without affecting service to customers and the frequency of maintenance activities which are likely to affect service to customers. Rolling stock reliability – likelihood of failure occurring Infrastructure reliability – likelihood of failure occurring Operational resilience of EWR to unplanned events Operational resilience of Wider Rail Network to unplanned events
12	Alignment with wider railway strategy / infrastructure	The extent to which the railway takes account of potential future change	1. Technology and customer expectations 2. Wider rail network strategy	High level qualitative considerations at this stage.

Id	Assessment Factor	Definition	Supporting Considerations	Description of how Factor is applied at this stage of design development
			3. Climate 4. Passenger demand 5. Freight demand	Extent to which the option enables latest and emerging technology, enables new and emerging strategic changes in the rail sector and provides flexibility to adapt to future changes in climate and demand if different to the scenarios used as the basis for design.
13	Safety risk (construction and operation)	The risk (likelihood and consequence) of harm to workforce and public during construction, operations and maintenance	1. Safety risk (construction) 2. Safety risk (operations and maintenance)	No options being considered are unsafe. These considerations relate to levels of risk associated with build and operation. Safety risk (construction) - risk (likelihood and consequence) of harm to workforce and public during construction, based on the expected residual risk in the final design. Safety risk (operations and maintenance) - risk (likelihood and consequence) arising from all in-service hazards, including the unplanned events considered when assessing operational resilience.
		Environment		
14	Environmental impacts and opportunities	Impacts on and opportunities to improve local, national and global environment, and local and regional socio-economic conditions not considered in other factors	Environmental Statement topics for DCO application: 1. Agriculture, Forestry and Soils 2. Air Quality 3. Climate 4. Community	

Id	Assessment Factor	Definition	Supporting Considerations	Description of how Factor is applied at this stage of design development
			5. Ecology and biodiversity 6. Electromagnetic interference 7. Equalities 8. Health 9. Historic Environment 10. Land quality 11. Landscape and visual 12. Major accidents and natural disasters 13. Noise and vibration 14. Planning 15. Socio-economics 16. Traffic and transport 17. Waste and materials 18. Water resources and flooding Social Impact topics as per DfT TAG: 19. Physical activity, health and well being 20. Accessibility 21. Severance 22. Option and Non-Use Values 23. Distributional Impacts 24. Community benefits from station facilities for non-rail passengers	
Local Plans				

Id	Assessment Factor	Definition	Supporting Considerations	Description of how Factor is applied at this stage of design development
15	Consistency with Local Plans	Impacts on and opportunities to support the Local Plans prepared by the Local Planning Authority	Local Plans are considered at this stage of design development	

10 Appendix 10 – AVRT Report

East West Rail

Advanced Very Rapid Transit Report

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	Name	Role	Signature	Date
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Revision history

Change date	Version/revision	Section	Change
29-07-22	V0.1 (Work in Progress)	NA	NA
30-01-23	V0.2 (Review)	All	Restructure and response to DfT and company wide comments, update to reflect new ACP7 position.

Glossary

AVRT
Advanced Very Rapid Transit
An automated guided segregated busway system

CAM
Connected and Automated Mobility. An emerging range of technology concepts that create mass transit solutions to transport needs

CCAV
Centre for Connected and Autonomous Vehicles

DCO
Development Consent Order as described within the Planning Act 2008

MVL
Marston Vale Line described by the Engineer's Line Reference system for UK railways

TWAO
Transport and Works Act Order is a permission given by Secretary of State under the Transport and Work Act1992

1. Executive Summary

1. This paper defines what an Advanced Very Rapid Transit concept system is, applies it to the East West Rail scenario, assesses the characteristics of it with regards benefits and cost in comparison with heavy rail and light rail options and makes a sifting decision following the Affordable Connections Project Terms of Reference.
2. Advanced Very Rapid Transit (AVRT) is a system concept comprising a fleet of automated vehicles that travel on a dedicated guideway which would carry passengers between stations. The key differentiator to Guided Busways is that it is automated, narrower and faster.
3. AVRT has been assessed to be less beneficial (defined as benefits minus costs) than heavy rail in achieving the outcomes of East West Rail's Theory of Change, so is not recommended for application to East West Rail.
4. The key limitations of an AVRT scheme for East West Rail are: it generates compulsory interchange at Bedford and Cambridge, whereas rail can serve with through services on MVL and potentially call at all three stations of Cambridge (Cambridge North, Cambridge and Cambridge South) to serve the catchment areas of high value jobs; it does not support freight; significant technology concept development is needed to de-risk and prove in order to make it worthy of investment, (that adds at least 2 years programme time) leading to a high opportunity cost of time for UK economic growth. The maturation of autonomous technology would not change the limitations to connectivity these AVRT options incur.
5. Within the limitations of the study, a position of agreed cost of the scheme options between the promoter of the system and East West Rail was not achieved. Both positions represent optimism and pessimism respectively. The uncertainty and broad range of cost outcomes have been modelled. In the best case scenario for AVRT it may be up to 50% cheaper in Base Construction Cost than heavy rail, but in the worst case (for AVRT) scenario may cost more than the best case heavy rail scenario if risks are realised. AVRT is likely to be lower cost than other options, but with significantly lower benefit. When assessed with the MVL upgrade and an electric timetable, AVRT Benefit Cost Ratio is less than Heavy Rail.
6. It is suggested to UK Government to sponsor the promotion, research, development and trials of connected and autonomous guided busway technology, as there is potential for this emerging transport system concept to be desirable given the right circumstances. This will allow future transport planners and enterprises undertaking options sifting a better developed understanding of the outcomes it may achieve and design parameters.
7. Whilst assessing the potential AVRT has, the team has found that for other applications or scenarios this mode (and Automated Guided Busways more generally) could be competitive as a transport system against Light Rail and Heavy Rail. This may be particularly applicable to some of the following environments; denser urban areas, urban areas with high relief features, and urban areas with disused railway lines or other legacy transport corridors.

2. Introduction

1.1 Affordable Connections Context

8. Following the change in Government policy in 2021 regarding the Oxford-Cambridge Arc, East West Railway Company (EWR Co) was asked by the Department for Transport (DfT) to determine how best to support local growth ambitions for the East West Rail (EWR) project, and the level of associated benefits which can be achieved at a lower initial. The Affordable Connections Project (ACP) was established by EWR Co to achieve the purpose set out in the Terms of Reference as: 'How to enable connections across the Arc to be delivered to ensure new well-paid jobs, homes and simpler transport systems can be co-created – affordably and sustainably'.

9. The ACP Draft Report was submitted to DfT in June 2022 (Document reference: EWR-EWR-ZZ-XX-RP-Z-000001), concluding that a shortlist of four heavy rail options appeared to be worthy of further consideration and recommended that further development work should be undertaken. The ACP Draft Report considered a range of potential technical and engineering solutions, including; heavy rail, light rail and guided busways.

10. During a longlist stage, where a wide range of potential engineering solutions to the Terms of Reference were considered, other modes of transport and alternative technologies were identified in addition to heavy rail. One preliminary concept was Advanced Very Rapid Transit (AVRT). This engineering solution has been advocated by Professor John Miles 1with the Cambridge region in mind. The concept is at the desktop study stage of development and has consequently not been deployed elsewhere. The Cambridge Autonomous Metro scheme studied various modes to solve the transport challenges of Cambridge and the AVRT concept has been developed from that to suit this scheme. Although AVRT is a novel and untested transport concept, it was felt that it offered sufficient potential to warrant further investigation.

11. At the time not enough was known about Connected and Automated Mobility technologies (and AVRT in particular) to allow comparison with other modes. Time and resources were limited so a decision was taken to defer its assessment as part of the ACP work and to generate a separate report once it was better understood.

12. To understand the concept and enable its assessment on a comparative basis, EWR Co engaged with the proponent of a form of the technology to develop understanding to a testable level in the context of ACP.

13. Since Summer 2022 a revised position has been presented by EWR Co to the Department for Transport under the updated project Affordable Connections - Objective 7. See the updated report EWR-EWR-ZZ-XX-RP-Z-000001 V0.4. This AVRT report is based upon the working assumptions of Summer 2022 Affordable Connections V0.3 where 4 options for heavy rail were shortlisted. The best performing option in the Summer 2022 report based on cost assessment (HR2) was chosen as a comparison for AVRT. Subsequent work undertaken

[1] Professor John Miles is the Proponent of the AVRT Concept. http://www.eng.cam.ac.uk/profiles/jcm91 and Chairman of Automotive Council Working Group on Intelligent Mobility

(including for example on Assessment Factors, Environmental Appraisal and Operational analysis of timetable implications) has revisited the order of preference of the emerging option(s). At the time of writing this was the exclusion of the Bedford Varsity approaches, reverting to a Northern exit to Bedford, primarily on the basis of environmental impact. The sifting decision is thus against HR2 and without consideration of environmental impact, which would be considered if the AVRT concept is shortlisted.

1.2 Purpose and structure of the report

14. The purpose of the report is to explore the potential of the AVRT concept , apply the concept to the East West Rail Theory of Change, appraise the option(s) developed in relation to other strongly performing options studied within Affordable Connections Project in order to achieve a sifting decision.

15. The structure of this report is:

- “What is AVRT?” Defines the proposed AVRT concept generically, agnostic of geography.
- “What needs to be true for AVRT to become an operational transport mode?” Identifies what development and integration work is necessary to make the generic AVRT concept a reality.
- “The Optimum Circumstances for AVRT” Provides an assessment of the optimum circumstances in which AVRT could be a viable investment or advantageous in comparison to other transport modes .
- “AVRT applied to East West Rail” Applies the AVRT concept to EWR and generate credible options.
- “The Costs of the AVRT Options” Values the estimated costs of the options, considering capital and operational cost with ranges and risk.
- “Assessment of AVRT Business Case” Assesses the AVRT concept in terms of journey experience and economic appraisal. The reference case of the Heavy Rail 2 option is used for comparison, and conclusions drawn on its benefits and opportunity costs.
- “Affordable Connections Sifting Process” Compares AVRT business case to other options using the Affordable Connections Project assessment criteria, achieving a sifting decision.
- “If deployment on EWR is not viable, where could AVRT or similar concept be installed successfully?” identifies the potential of the concept, lessons learned from EWR and indicates other use cases, schemes or locations worth studying.

2 What is Advanced Very Rapid Transit?

16. This Chapter provides the main characteristics and assumptions on the generic Advanced Very Rapid Transit system in concept. It provides the general description and definition of what AVRT is, so that in later chapters the alignment options and appraisal can be conducted based upon the generic concept. In system engineering terms, this is the System Definition and the Concept of Operations.

17. The goal of the generic AVRT system concept is to move people efficiently and reliably between stations, creating a means of transport of humans around or between urban conurbations for journeys of between 1km and 50km in length. Above 50km distance higher speed trains may be more competitive in terms of speed and networked journeys, below 1km active transport modes would better serve local journeys.

18. Advanced Very Rapid Transit (AVRT) is a system concept comprising a fleet of automated vehicles that travel on a dedicated guideway which would carry passengers between stations.

19. AVRT is a subset of the Bus Rapid Transit (BRT) system concept. AVRT differentiates itself to in-service BRT by being faster, narrower and automated. BRT is a high frequency bus service with dedicated infrastructure, scaled to meet the demand from urban areas.

20. BRT systems can run on segregated infrastructure to bypass road congestion or create direct connections. BRT can also run on existing or upgraded roads that allow the creation of a service network with a core corridor, however this is not currently part of the AVRT concept.

21. Typically the AVRT concept deployment may be best suited to service medium to densely populated areas, including small to medium sized cities and urbanised areas. It should be competitive against Light Rail, regional rail and bus systems. Lower population densities would not generate a traffic congestion problem to justify investment, and higher density conurbations would need a high frequency high capacity mass transit solution, like a metro train service. The AVRT concept uses stations instead of stops, as the interchange onto AVRT is multimodal, the infrastructure is segregated and the facility provides infrastructure for the safe crossing of the line, boarding, alighting, waiting and interchanging. System capacity for all transport modes to move passengers per hour is the product of vehicle (or convoy) frequency and vehicle (or convoy) occupancy. AVRT capacity is achieved by high frequency of service with small convoys of vehicles (typically one to three) to meet demand, as opposed to less frequent higher capacity vehicles like an 8 car train at 4 trains per hour. The system is limited in capacity by the alighting and boarding time at the termini that constrains the turnaround.

22. AVRT is narrower in cross section than a standard bus, in order to reduce the cross section of the infrastructure and allow cheaper tunnelling. This should reduce the capital costs of the infrastructure, but at the penalty of reduced volume of the vehicle for passengers.

23. The system concept is for autonomous vehicles to be driven by machine, saving on having a driver of the vehicle. The autonomous nature allows the vehicles to combine into convoys running closely together digitally coupled. As demand increase or decreases, vehicles are automatically activated from storage and join the operational network.

24. AVRT aims to be cost competitive to other transport modes. It aims to be as fast as a conventional light rail train. It aims to be cheaper than rail by having a narrower infrastructure cross section, with simpler systems on the line of route including no switches and crossings, a road surface. It aims to have lower operating costs by using automation to replace humans. AVRT differentiates itself from a BRT System which maintains the normal width of a bus and standard highway dimensions.

25. The network could be configured as a line connecting two primary centres or a hub and spoke serving a single city or a combination for a larger metropolis.

26. Customers would have a multi-modal journey from Origin to Destination, with connecting journeys typically being more local in nature. This is because the system prioritises connectivity time between nodes of transport with a direct route, which is different to a bus line which tends to be more tortuous in collecting journeys from residential stops. Connecting journeys anticipated may be walking, cycling, personal electric mobility, bus, private vehicle, train or taxi. Stations should enable interchange between modes, with storage or waiting areas for those modes. In rural areas, this would normally include car parking. This differs from a regional or city wide bus service, that has limited infrastructure and is designed to collect people making journeys who are pedestrians only, with a sometimes ponderous route selection though urban areas.

27. An AVRT Concept vehicle has been developed and is used in this analysis, with the following particular characteristics and key dimensions: Laden Weight = 18 tonnes; Length = 17m; Height = 2.5m; Width = 2.20m; Max Speed 160kph; 8-wheel drive; 8-wheel steer; Bi-Directional Operation; All-electric powertrain; Battery Capacity = 600kWh; Energy Consumption (at max speed) = 2kWh/km Max; Power = 500kW. For visualisation see Figure 2-1 and Figure 2-2.

Figure 2-1 AVRT Concept vehicle visualisation in elevation

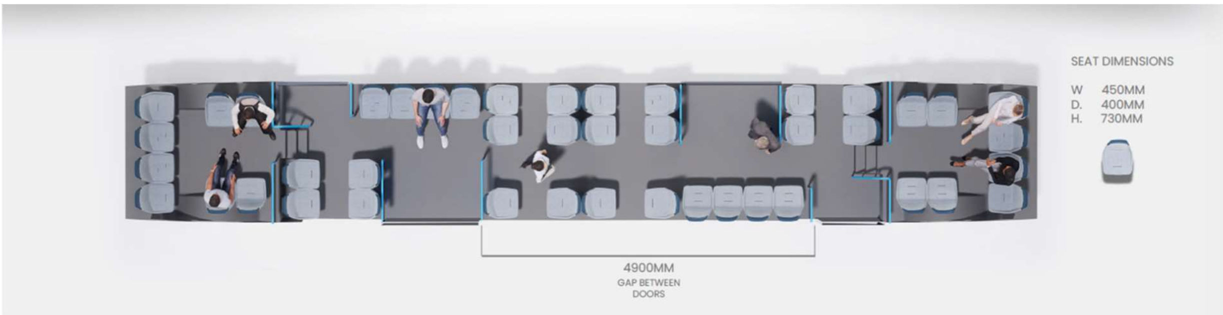


Figure 2-2 AVRT Concept vehicle floor plan, example layout option

28. Current and emerging automotive technology would be utilised to automate the vehicles individually and as a system. Low headway could be attained, which is the distance between vehicular convoys, in the same way as buses can be driven close together. Vehicles are driven by machine at the headway of the braking response of the coupled system, IE the convoy of vehicles can be as close together as it takes the convoy behind to stop without crashing into the convoy in front. Convoying of vehicles could take place, through digital coupling, where the stopping distance is longer than the gap between vehicles, if both are digitally linked. The advantage of digital coupling for convoying over mechanical is that This is theoretically unlimited in number of vehicles, but would be limited in practise by the cost trade off of longer platforms or more frequent services to achieve the same capacity. The level of automation is linked to the technology development required, as a segregated infrastructure safety case can be made more easily where foreign objects are more tightly controlled on the network.

29. The limitation on the capacity of an AVRT system is governed by the boarding and alighting times at the rush hour peak flows. This is tightly linked to the headway that can be achieved as this is the clearance time at the platform of the vehicle.

30. The vehicle capacity is circa 50 Persons, with variations of standing and seating space and density, that can vary occupancy between 35 and 50. This includes passengers standing by necessity to assume 50 person loading per vehicle. As the vehicles can convoy, the capacity of one timetabled movement can be in multiples of vehicles, i.e. 100 or 150 persons for 2 and 3 vehicle convoys.

31. AVRT is proposed to run faster than conventional guided busways, allowing it to outperform a traditional BRT, car journey on parallel roads that may suffer congestion, and be comparable to rail systems.

32. The speed of the vehicles could be higher than the speed limit of public highways for coaches, which is 60mph, if using dedicated infrastructure to control the risk of collision. Higher speeds of 75 or 100mph could be attainable depending on technology readiness, a structured design and risk assessment process that identify adequate control measures and demonstrate them to a Regulator (such as the Office for Rail and Road). See the following Chapter on concept development for more information.

33. The use of segregated infrastructure with the guideway separated from other transport modes increases reliability of the service for on-guideway portions of journeys. Being able to run at a consistent speed makes the mode competitive to road transport, especially where road networks in urban areas have reached capacity and congestion reduces the average speed.A typical cross section is shown at Figure 2-3. Thus, high speed is not necessarily a key feature of AVRT if deployed with short duration hops across a city, but over longer distances (10km plus) between stations the average speed becomes proportionally more important. The AVRT concept can thus be flexible, but different features become proportionately more important.

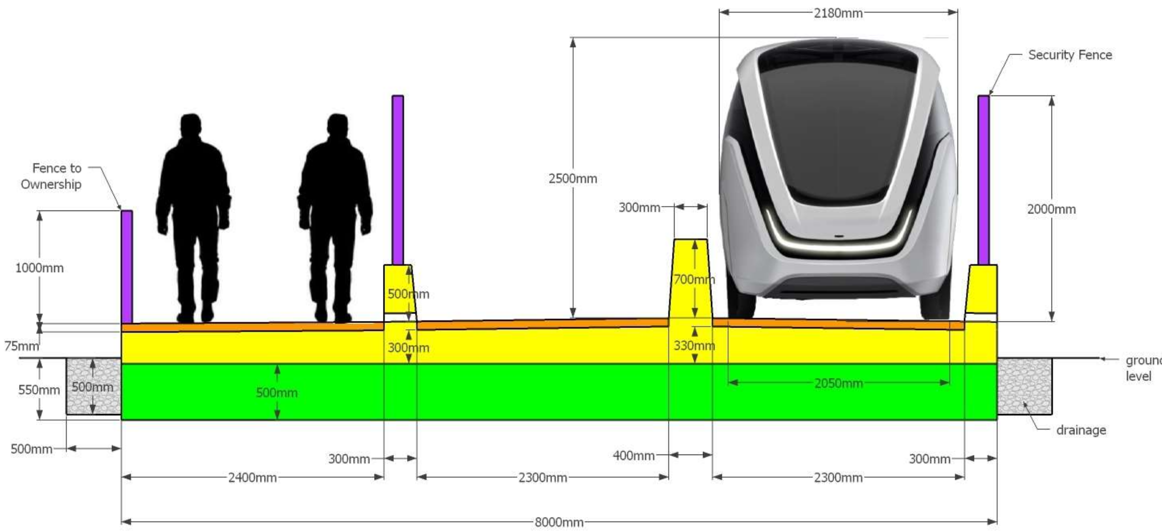


Figure 2-3 Cross Section through rural AVRT guideway. No appraisal is made by EWR of the emergency condition.

34. Electric charging of on-board batteries is achieved through existing electric bus charging technology. The vehicle would be recharged whilst stationary per duty cycle (return trip) over longer distance networks (20km+). In a lower energy demand application, such as city limit only networks, the vehicle battery may have sufficient capacity to run a whole shift (multiple duty cycles), before being recharged. No line of route infrastructure is provided for charging, IE Overhead wires. Intermediate opportunity chargers may be necessary at some stations or laybys. Either scenario places different demands on the energy and battery system, which is optimised to the application to reduce lifecycle costs.

35. The internal diameter of a tunnelled section is circa 4.3m, similar to the Jubilee Line Extension at 4.4m. This utilises the reduced cross section of the AVRT vehicle to achieve a reduced diameter compared to heavy rail, which may require tunnelled dimensions of up at 6.2m (Crossrail). Included is the dedicated escape footpath for Mobility Impaired Persons. EWR is not yet satisfied that the dimensions shown in the figure meet UK Standards for tunnels and evacuation measures that are applied to road and rail tunnels. Standards would need to be determined and verified with a Regulator.

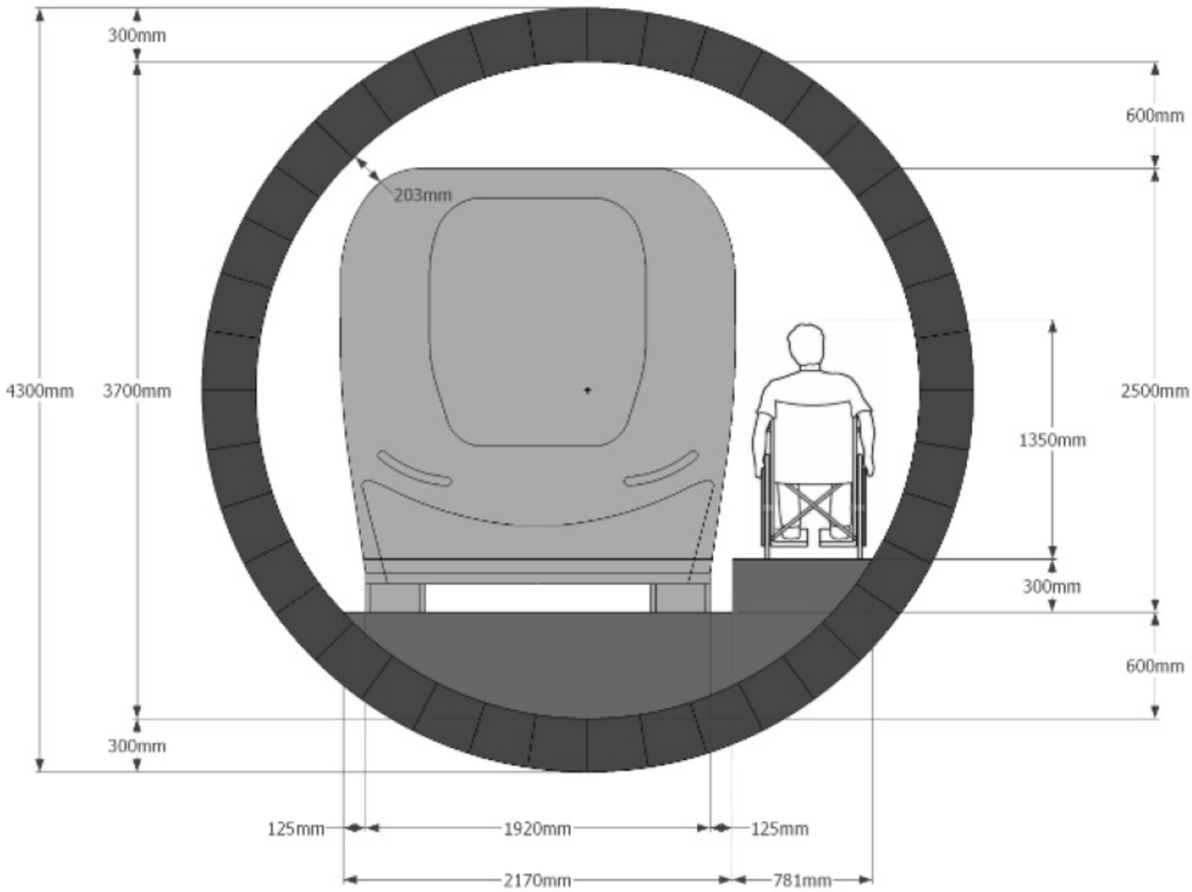


Figure 2-4 Cross section of AVRT tunnelled section, single direction only shown for clarity. Correction to diagram is the Inner diameter is 4.3m.

36. A typical underground station is similar to Glasgow metro in size – circa 40m long and 12m deep. The design would be subject to the same fire risk mitigations as any other UK underground station, to comply with Fire Precautions (Sub-surface Railway Stations) (England) Regulations 2009.

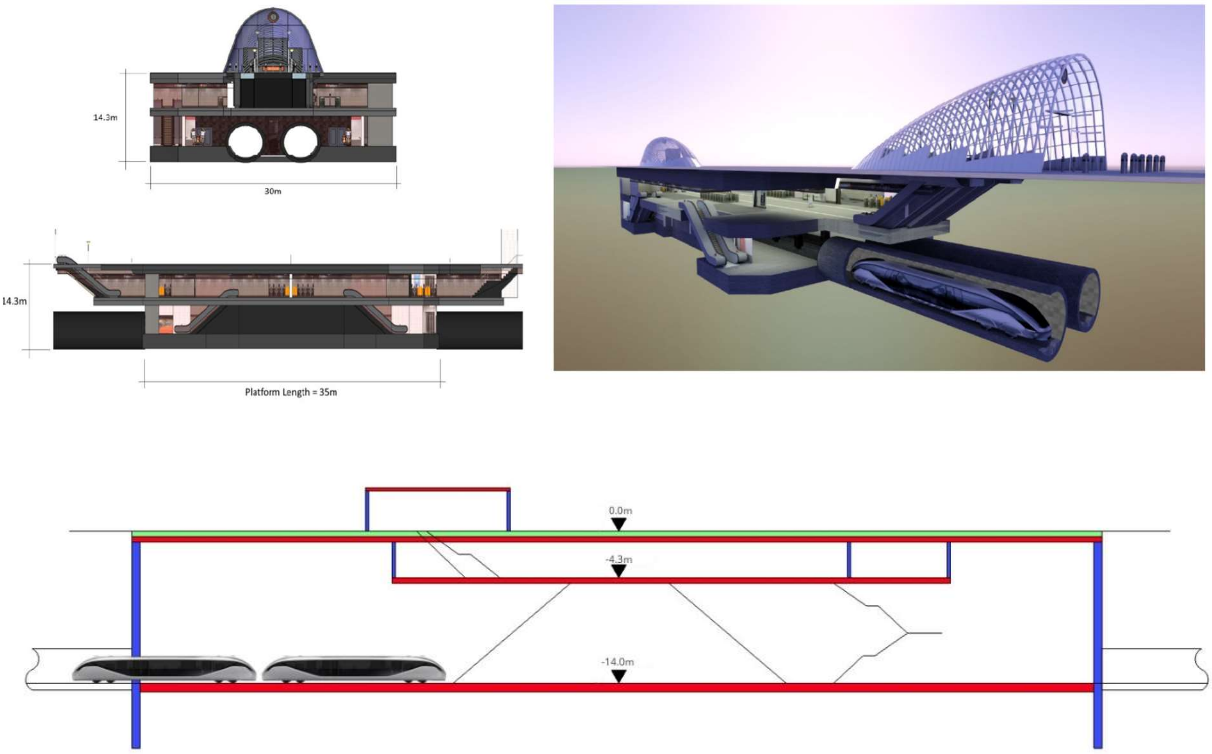


Figure 2-5 AVRT Underground Station visualisation

37. The system achieves high capacity through high frequency services. High frequency service means that waiting periods are typically limited to 3 minutes in peak periods, so significant waiting facilities are not necessary. The platform could be configured to separate pedestrian movement from vehicular, like a railway station without level crossings. Overbridges are thus provided, and these would need step free access. A bypass loop could be provided, to allow regulation of service through staggered arrivals and departures, and bypassing moves for Empty Carriage Stock moves.

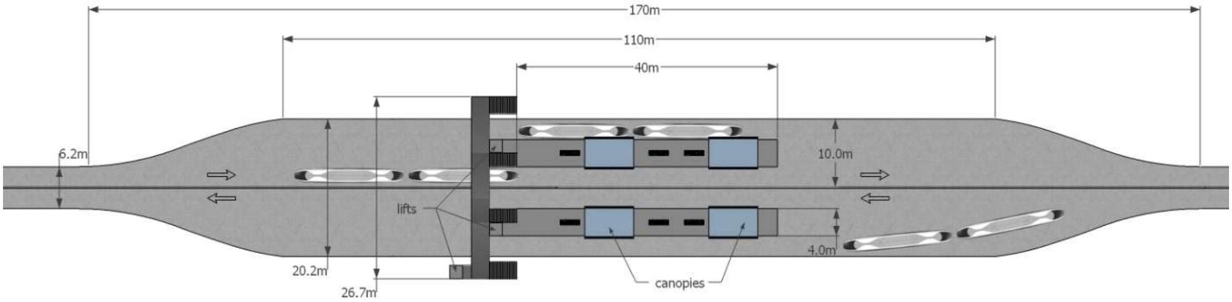


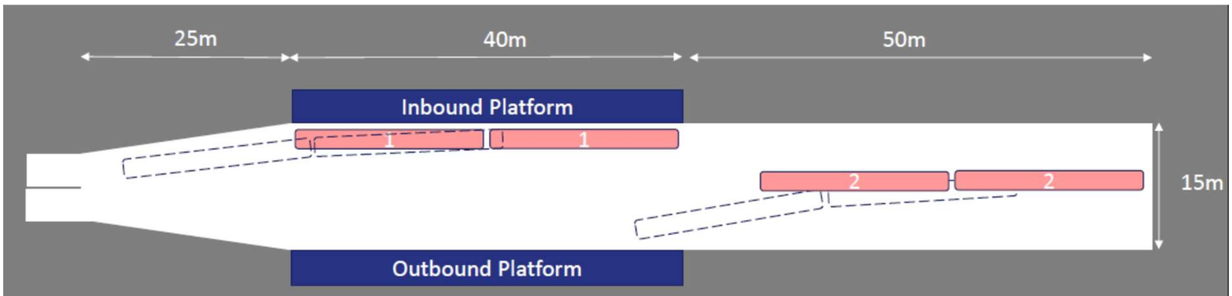
Figure 2-6 Typical layout of an above ground surface station. Plan diagram shows island platforms with loops allowing Depart-Arrival overlap of vehicle moves

38. The user groups of the system are: Passengers or Customers, Customer Service Agents, Drivers (potentially for the first iteration until Level 4 Automation by Society of Automotive Engineer achieved), Vehicle Maintenance, Infrastructure Maintenance, System Owner, System Control Room Operatives, Mobile Operations Managers. All these have been built into the cost model.

39. Stations are staffed with Customer Service Agents whose primary role is the safe operation of the station by assisting alighting and boarding of the vehicles, crowd control and revenue protection. It is not intended to normally have staff on board the vehicle, whose occupants could be managed remotely by CCTV. On vehicle passenger to passenger interaction thus has risks around assault that are not mitigated by an on board Customer Service Agent. Potentially roving security agents may be needed, but these are not priced.

40. A human driver could operate the vehicle, (especially in the first iteration vehicle technology), in the same way as the Dockland Light Railway has a “train captain” providing limited override capability in the event of degraded working, whilst also being available on board for Customer Service. The reaction times of the human may necessitate slower operational speeds, given the line of sight driving.

41. At terminus stations a cross-over area is needed to allow the vehicles to switch between the up and down line for each direction. Stations can be above or below ground. A marshalling area allows the regulation of the service by stabling the vehicles in case of perturbation events, which allows buffering of minor time variations in arrivals and departures as vehicle sets can be parked up allowing a layover between service departures. In normal operation the slow speed crossover manoeuvre would be undertaken empty of passengers. The turnaround time would be governed by boarding and alighting times. To maintain passenger flows at peak hours, separation of the boarding and alighting passengers is suggested. Two platforms are thus proposed to simplify ergonomics within the station and is compatible with the need for vehicle marshalling.



Time (Seconds)	Event	Comment
0	AVRT No 1 stops at in-bound platform	
0	AVRT #2 departs manoeuvring area	
5	AVRT #1 Doors open	
35	AVRT #1 Doors close	
40	AVRT #1 leaves in-bound platform	
60	AVRT #2 stops at out-bound platform	

Figure 2-7 Typical terminal station layout

42. A depot would need to be provided for storage of out of service vehicles, maintenance of the vehicles, and vehicle charging.

43. Degraded working of the network may occur in cases of vehicular failure, fire or accident, communications failure between vehicles and centralised control, guideway blockage, failure of safety critical underground systems, inclement weather that limits the range of the on board sensors. With a bus network overtaking can take place on any part of a two way road, and thus the service is resilient to perturbation and needs limited network control, as the timetable effectively regulates the service. The network is designed to be sterile, without being open to egress by third parties or foreign objects. With AVRT the guideway is effectively a single path with overtaking only possible at nominated built areas. At the higher service frequency of AVRT proposed some degree of traffic regulation would be necessary by a centralised network control, for example by providing speed regulation instruction to vehicles to absorb time differences. Some comparable emergent properties of railway systems could be present, for example network congestion and propagation of disruption.

3 What needs to be true for AVRT to become an operational transport mode?

44. This Chapter identifies how one could make AVRT concept a reality by quantifying the development and integration work necessary.

45. To receive investment, the Treasury Green Book asks the business case of any scheme to demonstrate it is worthy of investment, typically with a Benefit to Cost Ratio of greater than 1. The scheme must also demonstrate to stakeholders it is the most advantageous against other transport modes. Generating a business case to receive funding for the development is an activity in itself. IT may be possible to separate the technology development on a speculative basis though CCAV, but ultimately a location must be found with a transport need.

46. The assumptions on which the business case is founded must be tested robustly to provide assurance, including proving the key concepts. The high-capacity scenario of AVRT needs a high frequency of service, with multiple vehicles in independent operation compared to a multiple unit train. The key success factor in this scenario of the AVRT system is to achieve automation of the vehicle movements, otherwise the operational expenditure of staffing each vehicle with a driver or supervisor would make it non-competitive.

47. The maturity of a concept system can be described by using Technology Readiness Levels, defined in Table 1

Table 1 Technology Readiness Levels

Technology Readiness Levels, taken from UK Research and Innovation
TRL 1: basic principles observed and reported
TRL 2: technology concept or application formulated
TRL 3: analytical and experimental critical function or characteristic proof-of-concept
TRL 4: technology basic validation in a laboratory environment
TRL 5: technology basic validation in a relevant environment
TRL 6: technology model or prototype demonstration in a relevant environment
TRL 7: technology prototype demonstration in an operational environment

TRL 8: actual technology completed and qualified through test and demonstration
TRL 9: actual technology qualified through successful mission operations.

48. AVRT is a proposal which has yet to be developed beyond concept feasibility stage. AVRT is based upon utilising existing and emerging technologies in a new use case and configuration. Different elements of the technology that make up the AVRT system are individually at different levels of maturity. The vehicle structure and physical running equipment, predominantly based on bus and rail technology, will be at TRL9 but the narrower vehicle profile and dual end control generate new challenges to stability and control that may move back the readiness level. The automation achieved by the technology stack will be between TRL2 to 8 for different grades of automation. For example, technologies like lane keep assist and adaptive speed cruise control are in service in private vehicles at TRL9, but self-drive automation is only at TRL6. The AVRT concept is only as advanced as the lead time for the least developed technology. Integrating all the technology together into the vehicle and system relies upon aligning the technology readiness and this process itself takes time, see below for more. Figure 3-1 below indicates that AVRT is at Stage 2 of a 9-stage technology readiness process, reflecting the current concept stage of the mode.

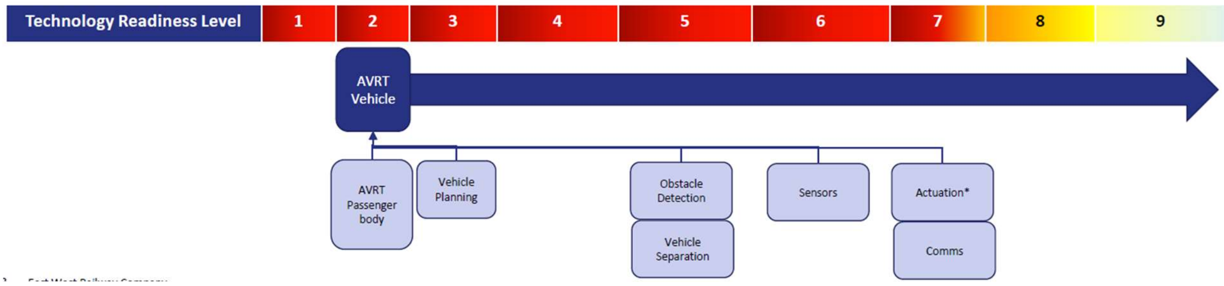


Figure 3-1 Current status of AVRT development, and functional systems

49. EWRCo suggest that the minimum TRL for an investment decision at Strategic Outline Business Case would be a Technology Readiness Level 3 Proof of Concept. Outline Business Case may need a TRL4 Demonstrator Vehicle. To achieve Final Business Case approval, scale and testing should be at Technology Readiness Level 6 Large Scale as a minimum.

50. A survey of current status of technology is provided in the next few paragraphs along with key facts and observations about in service technologies. This highlights the development needed to bring a 100mph to 70mph service into operation.

51. ZhuZhou in Hunan Province China operates Autonomous Rail Rapid Transit; a 43mph autonomous optically guided BRT system. An on-train passenger assistant is present for manual override functions. It runs on the highways network and dedicated bus lanes. It serves the dense urban area of Zhuzhou. The vehicles are mechanically coupled, otherwise know as “Bendy-Buses”, but it is unknown if they are independently steered, or tractor-trailer configuration.

52. Adelaide runs O-Bahn Busway, a conventional sized Bus Rapid Transit system that is 12 km long, on dedicated guideway using mechanical guidewheels and is restricted to 53mph.

53. Cambridgeshire Guided Busway is 25km long, the longest guideway path in the world. It runs at 55mph. It cost £152M in 2010 to build on the redundant track bed of an old railway line. It was piled and has longitudinal concrete beams to cope with weak ground conditions and control differential settlement, giving it a ride across concrete beam joints at regular intervals. It is a hybrid system that is segregated from highway traffic for rural high speed travel and at grade in town where it merges to existing roads and travels at ambient speeds.

54. Any consenting process(es) needed for delivery of a transport scheme must be able to demonstrate the concept is understood sufficiently to demonstrate viability, absence of impediment to delivery and the impacts of the scheme. AVRT is thus disadvantaged in this regard to other transport modes that utilise mature technology and can be modelled with high degrees of certainty. The consenting process may thus drive further development and demonstration separate from information needs for an investment decision. For example, the dynamic simulation of the vehicle could need to be developed to validate the guideway design and geometry to confirm the route alignment design. The scheme may thus need TRL 6, 7 or higher to satisfy a Transport and Works Act 1992 (TWA) application or similar planning application. In this regard, a TWA Order is the most likely consenting route with a Development Consent Order (DCO) under the Planning Act 2008 also being a possibility if it was possible to show that AVRT was nationally significant.

55. EWRCo propose that it is a prerequisite that upfront investment is necessary to develop, test and integrate the technologies needed in order to de-risk, consent and provide confidence to select the concept and invest.

56. As a new concept the Regulation, Licencing and Governance model might need to be established. Factors to consider include the applicability of The Railways and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS), or Highways legislation. The officials from the Centre for Connected and Autonomous Vehicles (CCAV – a joint unit between Department for Business, Energy & Industrial Strategy and Department for Transport) are further investigating the regulatory framework with colleagues from the Office for Rail and Road and the Health & Safety Executive.

57. To prepare AVRT to become an operational transport mode, the whole systems development lifecycle processes defined by IEEE Systems Engineering Standards could be followed as programme guidance, as it is recognised as best practise. This could include, but not be limited to, the following activities:

- Establish an AVRT development organisation and build capability
- Making a Strategic Outline Business Case.
- Definition of a target state, including the Operating Concept
- Definition and implementation of a procurement strategy for vehicular and system development
- Building and testing of a prototype "demonstration vehicle"
- Validation of a system-wide control concept
- Guideway test length would need to be constructed and integration testing between infrastructure and vehicle to prove kinematics and safety systems
- Establishment of a legal and regulatory framework
- Creation of a production-ready design from the vehicle concept
- Homologation and delivery of production vehicles
- Construction of an infrastructure of the scheme
- System integration testing and Trial Running
- Trial Operations and emergency procedure rehearsals

3.1 Programme Implications of becoming Operations Ready

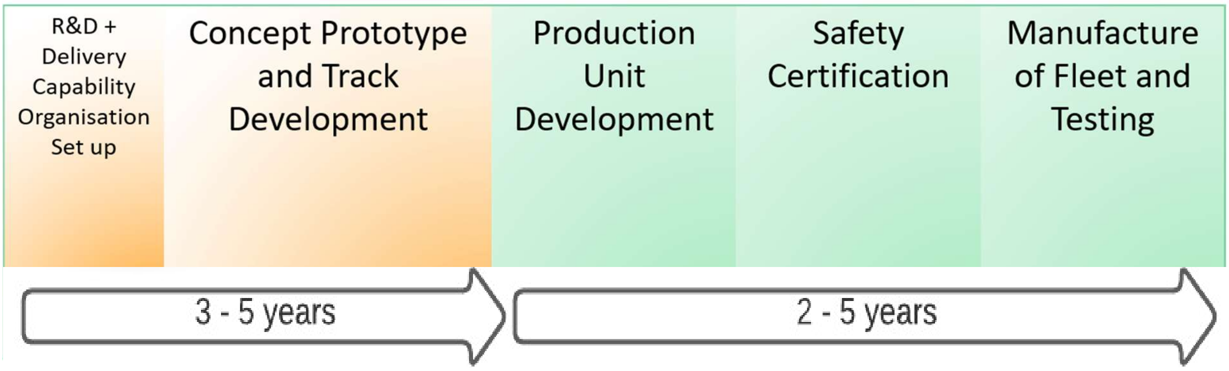
58. The development and production of the AVRT vehicles will take a number of years (explored below) before the fleet can be ready for service operation. Although some of this time will be in parallel to the business case, infrastructure design and consents processes, some of it will necessarily be sequential as it may be that proof of concept is necessary to enable approval of Outline Business Case. It is expected that sufficient information will need to be known for the vehicle to be able to assess land requirements and environmental impacts prior to Statutory Consultation and DCO application. Consenting a transport system requires powers of compulsion. They in turn require there to be an absence of impediment to the delivery of the

project. The vehicle and concept would need to be fully proven by DCO inquiry, otherwise there is a risk that the order may be delayed based on lack of proof.

59. Tests at scale using production vehicles would be necessary to determine if the concept is validated. It will add time to achieve entry into service above the baseline programme of heavy rail deployment when compared to EWR's programme. There are existing vehicles, such as the Aurrigo Auto-Shuttle, in service at test locations in Cambridge and the NEC Birmingham. This vehicle has a seated capacity of 10, and a top speed of 30mph. This demonstrates the extent of development from the current state of the art needed. As a new vehicle class, the standards and certification methods would need to be worked out, verified and validated. This is additional activity to the construction of rail carriages, with established standards to is easy to procure a serviceable set of vehicles.

60. In the estimation of the timescales full production and safety certification was considered as the Figure 3-3 shows. Rail rolling stock can already have safety certification or be accessible to a low risk programme of testing depending upon which stock we procure, and so the safety certification is longer in AVRT.

61. It is estimated that the total lead time for the production of the vehicle fleet would be 5 to 10 years from commencement of research and development, which would make this the critical path for any project. This is in excess of the current EWR programme of DCO submission and subsequent construction. That would mean that the opening date for the service may in a best case scenario 2032 or out to 2037 allowing for variation in risk. This is circa 2 years additional time over and above that to deploy a heavy rail solution to East West Rail, including a period of trial running and operations.



3.2 Development and Production Start-up Costs

62. Development and production start-up costs would be incurred due to the novel nature of the mode. Specific moulds and tooling may be needed to produce the vehicles. Many of the elements of the overall system would be like existing transport networks, for example, the Cambridge to Huntingdon Guided Busway, and Leigh to Manchester Guided Busways for the roadway and the modern smaller metro stations. Neither of those infrastructures are configured for high speed running, so pavement design and the geometry of the road would

need a set of design rules to be determined. Key dimensional limits could be determined for curvature and superelevation for different design speeds.

63. The cost of research and development and production to enable services to commence is estimated at £120m, as a typical number. It is noted that EWR Co is not experienced in automotive development, and the uncertainty is high. The composition of this estimate is summarised in Table 2 below.

Table 2 AVRT Development and Production Investment Summary

Item	System	Prototype Concept	Production Ready	Risk	Total	Comments
1	Vehicle	£6M	£42M	Estimated at 102% of costs £48M	£96M	Prototype vehicles can be built by established specialist vehicle builders (eg ProDrive; Delta-Cosworth; Williams Advanced Engineering etc)
2	System Wide Control	£1M	£5M	Estimated at 102% of costs	£12M	Agent simulation of vehicles and customers and hardware in loop
3	Test Facility	£1M for hire and use of vehicle proving facilities	£5M for hire and use of vehicle proving facilities	Estimated at 100%	£12M	Assumes use of MIRA/Milbrook proving grounds plus (possibly) use of Cambridge or Manchester Guided Busways, airport or section of motorway for high speed trials
Total					£120M	

4 Optimum Circumstances for AVRT

64. This chapter provides an assessment of the optimum circumstances in which AVRT could be a viable investment or advantageous in comparison to other transport modes.

65. AVRT may have potential as a transport mode in the UK to provide capacities speed and reliability higher than typical UK Bus Rapid Transit schemes and at a lower cost than conventional rail-based systems. Transport systems generally can be ranked by capacity in ascending order, serving increasing population density as follows: Minor road network; bus network; bus rapid transit; light rail, heavy rail and metro (EG London Underground) systems. The dimensions that vary the mode choice by the transport planner can include; property prices, historic and environmental constraints, town planning and distances between population centres. The mode itself generates different levels of demand depending on the service provided for example infrequent heavy rail services, whilst capacity may be present, may not be well populated, especially if those journeys are served by the road network.

66. The vehicles are proposed to be substantially smaller than for conventional heavy rail rolling stock (EG Crossrail at 6.2m diameter), with a cross-section akin to Glasgow Underground (3.7m diameter) or Jubilee Line rolling stock (at 4.3m diameter). It is worth noting that modern standards for the evacuation of mobility impaired persons now require more space. This means that any tunnels would be proportionally less expensive to construct than a heavy rail tunnel because of the reduced tunnel diameter, but similar to modern metro tunnels. Above ground the reduced cross section and structural loadings should be cheaper than railways.

67. Passenger demand varies according to the level of service provided. A better service means people switch away from other modes and more people make the trips concerned. The choice individuals make between different transport modes is primarily determined by:

- the overall attractiveness of a travel alternative in equivalent travel time (including interchange penalties),
- the monetary cost of the trip,
- journey time and
- waiting time.

68. AVRT can be more frequent than other public transport modes, operating up to 27 services per hour. A higher frequency of service benefits passengers by reducing the average waiting time and therefore attracting more demand. The effect of an improvement in frequency is more impactful on short distance trips where waiting time makes a larger proportion of the total end-to-end journey time. When an interchange to access a less frequent service is required as part of a trip, the overall end-to-end journey frequency will be limited by the least frequent service. However, when the interchange takes place to access a more frequent service, passengers will benefit from accessing to that service. For example, the high frequency of the London Underground does not improve the frequency of trains to Leeds, but it does allow passengers alighting from heavy rail trains at Kings Cross to board a tube immediately.

69. A lower journey time attracts more passenger demand. AVRT could offer a significant advantage compared to buses, as AVRT vehicles can run faster on dedicated alignments (buses are often mixed in with general traffic congestion). However, AVRT does not offer a general advantage compared to rail since both alignments are always segregated from cars and other road users. Figure 4-1 below shows the improvement on end-to-end journey times through increasing the service frequency from every 15 minutes to every 3 minutes. This reduces the average wait time from 7.5 minutes to 1.5 minutes. For a 10-minute journey, this would represent a 34% improvement. However, for a 60-minute journey, this would represent only a 9% improvement. Very high frequency modes are best suited to serve trips that have short journey times (15 minutes or lower).

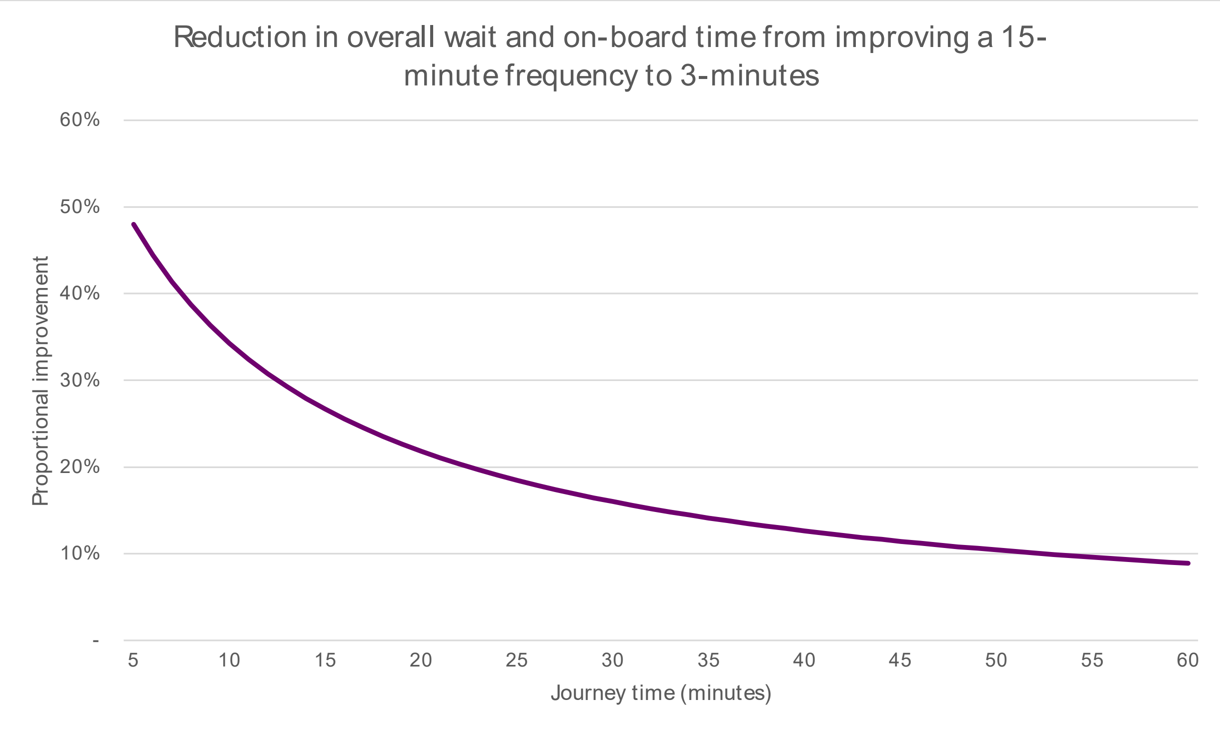


Figure 4-1 Graph showing reduction in journey time impact from high frequency

70. AVRT, when compared to railway, could serve denser locations such as town or city centres if the mode is able to tunnel lines and stations underneath urban areas in an affordable way. More frequent stops serving desirable destinations would attract more passenger demand with less connecting journeys by serving a higher catchment area. Therefore, urban geographies that have high relief of hills with easy tunnelling conditions would suit AVRT, maximising the differentiation to other modes. Another scenario is one of medium density, not requiring metro demand, with historic and environmental constraints that limit new above ground corridors being constructed that favour a low-cost tunnelled solution.

71. Above ground, AVRT could be competitive for retrofit to existing redundant linear infrastructure. For example, intact Beaching era abandoned lines and their railway alignments. For cities well connected by regional rail, then star network deployments of AVRT serving the city centres may be candidates, where trams or metros are not already deployed. The use case or scenario may be rapidly growing conurbations where road network is at capacity and limits the bus service expansion. It should be noted that redundant above ground infrastructure is often in alternative uses or subject to environmental designations.

72. AVRT is unlikely to differ from other public transport modes in fares. Lower fares can encourage more demand. It is unlikely that AVRT fares would be set at a significantly different level to other modes, since fares are largely determined by market position and/or public policy, rather than cost structure. If AVRT services were legally classified as "bus services of a class specified in an order made by the Secretary of State", then AVRT would be obliged to convey large levels of concessionary travel free of charge.

73. The context with the greatest advantages would be as follows:

- Passengers making short distance trips within an urban area, where a high frequency service is an advantage over less frequent (but higher capacity) rail vehicles as the wait time is lower for comparable modes;
- Moderate or low numbers of passengers making end-to-end trips, so the high capacity offered by a longer train is not required. At the same time, a spread of passengers over time is required to justify a high frequency service, (for example, shift changes at a factory or lecture times at a university would not be appropriate);
- Lengthy sections of tunnelling, to exploit the cost advantage of AVRT over heavy rail and conventional buses;
- existing redundant land transport corridors IE Beaching report closed rail corridors; and
- Where the network can service the majority of the journey need from origin to destination. There are limited potential benefits from integration with existing services as an AVRT service cannot provide a through service using existing infrastructure (whereas a bus or a train service could continue its journey along existing roads or tracks).

5 AVRT applied to East West Rail

74. This chapter presents options for AVRT to be deployed between Bedford and Cambridge. The key parameters are defined for the application of the generic concept, generating options specific to the requirements of East West Rail. The appraisal of the options follow in subsequent chapters.

75. The Theory of Change is set out in the Affordable Connections Main Report. The key points of this are summarised in this chapter. Growth at Cambridge is constrained due to road congestion that is limiting access from outer settlements into the city from residential areas, allowing high value knowledge economy jobs to be connected to a larger more accessible housing stock, particularly East-West into and out of Cambridge. This is the most significant portion of the benefits. Connectivity benefits from Oxford to Cambridge are significant, particularly for the opportunity of journey time improvement around and through Marston Vale Line. Journeys are not typically end to end but distributed across the line, with distribution in order of value as commuting, work journeys and leisure. Within the Bedford to Cambridge section, serving and facilitating housing growth in the Tempsford area and Cambourne generates most value. Within Cambridge value is gained from serving the North science park, interchange at central Cambridge stations for London connections and the Southern bio medical campus. The growth assumptions within this theory of change then generate the anticipated demand for services and hence the required service levels relative to the growth assumptions. The AVRT scheme must therefore address these needs as best possible.

76. Professional judgement has been to identify options from among a range of possible scenarios. This analysis is not a search for an optimised AVRT solution in the Cambridge area, but an application of AVRT to the East West Rail business case that allows comparison with other options to assess the potential performance of the mode. It has not been possible to verify or validate the assumptions, as the concept is new and has few other comparable reference systems. Some performance claims have been taken at face value, and not proven. No operational model of the network (for proving reliability and operability),) or assessment of the ride characteristics of the vehicle (maybe including physics modelling) has been undertaken. The level of information developed is appropriate to allow sufficient comparison with heavy rail solutions.

77. The scheme has not and does not need to be developed to allow a full appraisal of the options using assessment factors, as the principal sifting criteria of Affordable Connection Project sit in advance of the Assessment Factors process that is applied to Shortlisted options only. Consequently no appraisal of environmental factors has been made.

78. Some system dimensions in the concept remain unresolved between EWR and the promoter. These include the following, in particular:

- Emergency conditions and access to the routeway (whether a footpath or vehicular access may be needed)
- The limiting conditions of the geometry of the alignment that determine the earthworks required for a smooth alignment. Uncertainty exists with regard to design

speed, jerk rate, the comfort of standing passengers and sensor visibility requirements, that leads to variance in capital cost, journey time and passenger comfort.

- The need for depots at either end due to start of service timing
- Maintenance regime
- The width of the seat in the vehicle and its ability to accommodate the distribution of average people comfortably, and hence the capacity of the vehicle.
- The gap between infrastructure and vehicle travelling at 70mph is 125mm, this requires the hysteresis to be controlled to prevent contact and accident

79. The range of demand scenarios from the Theory of Change predicts somewhere between 2000 and 4000 passengers per hour at peak. Two different capacity options have been considered for AVRT – a service which would accommodate 2000 passengers per hour and a higher-capacity service which would accommodate 4000 passengers per hour. The dimensions determined are set out in the Table 3 below.

Table 3 Demand scenarios and how AVRT meets that with capacity provision

Passengers per hour (peak capacity)	2000	4000
Growth scenario for demand above base	Low	High
Headway time	3 min	2 min 14s
Convoys per hour	20	27
Vehicles per hour	2	3
Persons per convoy	100	150

80. By comparison with heavy rail, 2 trains per hour with 4-car trains could carry 855 passengers per hour, whilst 4tph with 8-car trains would accommodate 3420 passengers per hour. Based on a reference of a Class 323 train (normally a 3 car unit) which represents 3+2 seating modified for some standing at moderate density.

81. Two concept alignments for AVRT were considered and named alignments AVRT1a and AVRT2a. See Figure 5-1 below. The best performing shortlisted alignments from the document Affordable Connection Project Main Report at the time of analysis in Summer 2022 by mode were Light Rail 2 and Heavy Rail 2. See the main report for these alignment descriptions, and the Common Data Environment for the route alignment modelled in the Geographical Information System. For comparison purposes it was decided to adopt these alignments as far as possible to allow the least change in variables between modes to allow as systematic comparison as possible (IE to change the minimum number of variables). The assumptions of those alignments (HR2, LR2, AVRT1a and AVRT2a) were carried forward (as of Summer of 2022); namely that the old Varsity line route that runs East from Bedford is available as a transport corridor. EWR chose alignment AVRT1a to closely match LR2 and HR2. The variation is at the Northern approach into Cambridge, where LR2 and AVRT1a use the guided busway, and HR2 takes a new alignment to get onto the mainline railway network. AVRT2a is a variation of AVRT1a that utilises a tunnelled section into central Cambridge to maximise the assumed benefits of the mode.

82. Tunnelled alignments for other modes were discounted on the basis of larger tunnel diameter making tunnelling cost inefficient and a lack of ability to integrate the services into the wider railway network, therefore there is no equivalent other alignment to compare AVRT2a to. These are depicted in Figure 5-1 below.

83. As described in respect of customer experience and demand in the chapter below, pulsing (the arrival of high numbers at low frequencies) of customers at interchange locations is likely to occur and will result in queuing and congestion at those peak hours and services, due to mismatch between high frequency, lower capacity, and higher capacity lower. This may have implications for the design of stations, and sufficient space may need to be provided to accommodate peak passenger flows and avoid congestion, safety risks and provision for suitable passenger comfort. Therefore, capital costs for interchange stations may be higher than for through services or where interchange is between the same mode.

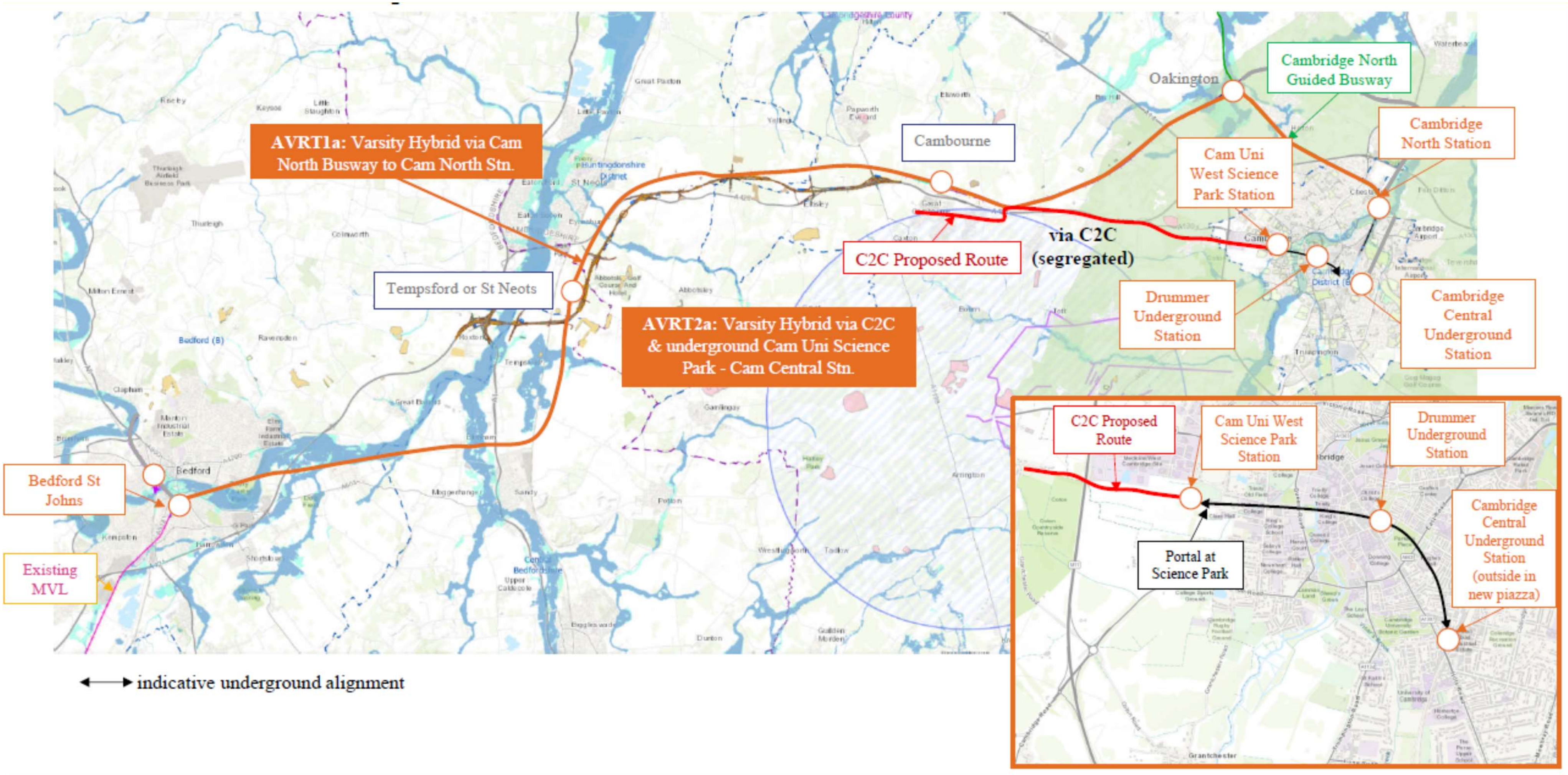


Figure 5-1 AVRT Options considered in the Assessment

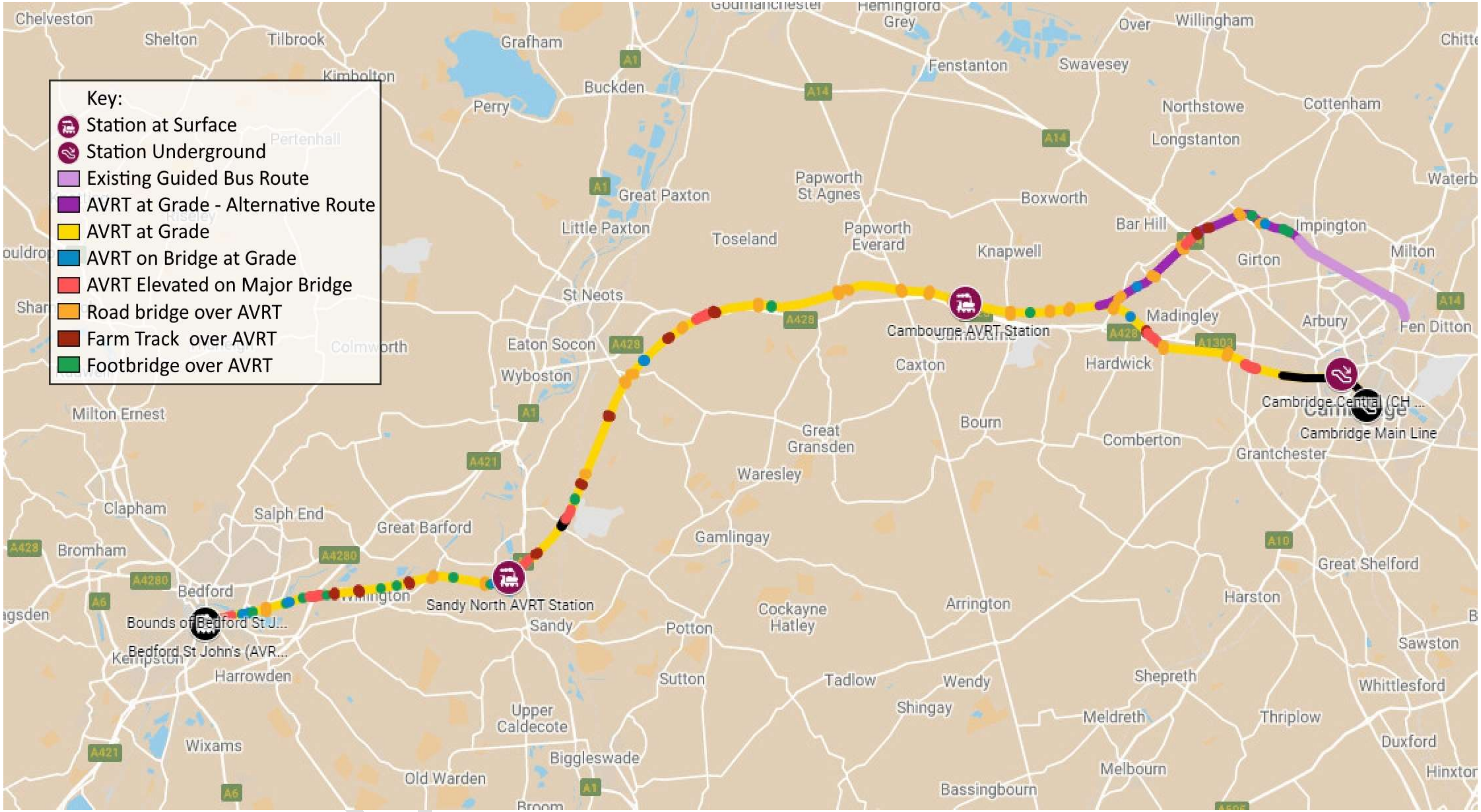


Figure 5-2 Map showing the deployment of infrastructure

84. Both AVRT1a and AVRT2a options would operate from Bedford St Johns (space constraints would preclude AVRT services reaching Bedford Midland Main Line station at grade), leaving Bedford via the old Varsity Line alignment to the East, then via Sandy North and the new A428 corridor to Camborne. Alignment 1a thereafter is above ground and uses the existing Cambridge North Guided Busway to terminate at Cambridge North Station. There is insufficient space to extend AVRT to Cambridge Station or the City Centre and therefore passengers would need to change to Heavy rail services at Cambridge North for onward travel.

85. AVRT2a would follow the heavy rail route out of Cambourne but would then access Cambridge City Centre along the proposed C2C scheme route and then enter via a tunnel under Western Cambridge with underground stations. This is segregated from the highway network. See Figure 5-2.

86. The difference between the vehicle widths in order is AVRT (2.18m wide), then a normal bus or coach at (2.55m), then rail (2.80m wide). However, the infrastructure corridors are not similarly scaled as highway design rules requires a carriageway in excess of the width of the vehicle, to allow for the accuracy of the driving of the vehicle. IE Public highways must accommodate buses and HGVs to varying degrees. AVRT is a single vehicle class guideway, so the gauge can fit the vehicle parameters closely. Railway carriages overhang their sleepers, but may be sited as close together as their kinetic envelope with maintenance tolerances allow (at slow speeds/low curvature where ballast shoulders are not required).

87. The following Figure 5-3, Figure 5-4, Figure 5-5, Figure 5-6, Figure 5-7, and Figure 5-8 describe the level of detail and explain what the dimensions of key assets look like. They are direct from the Proponent and East West Rail have not undertaken to assure the validity of the dimensions or suitability.

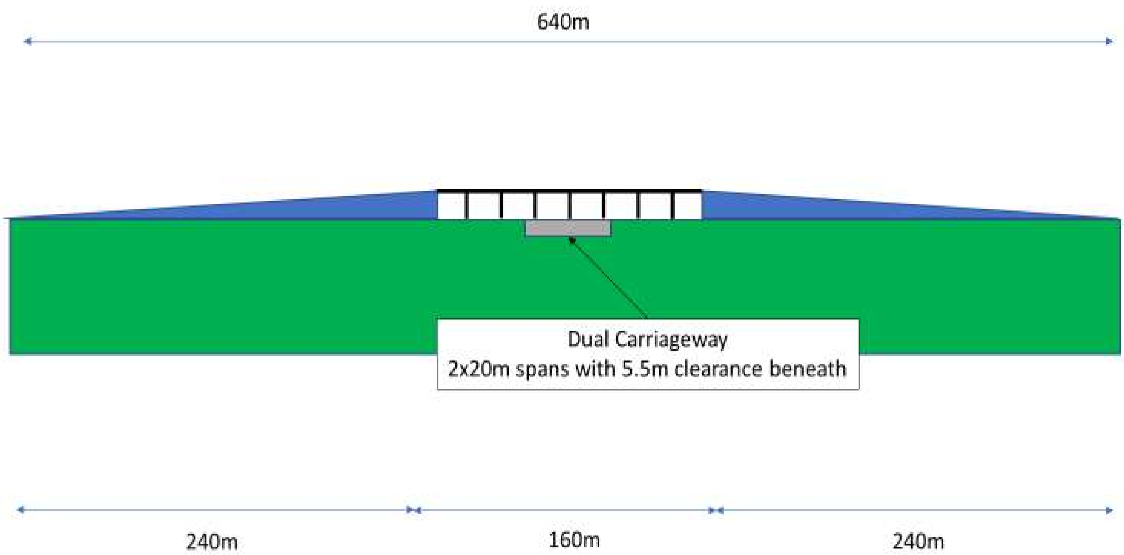


Figure 5-3 Indicative design for AVRT bridge over a highway

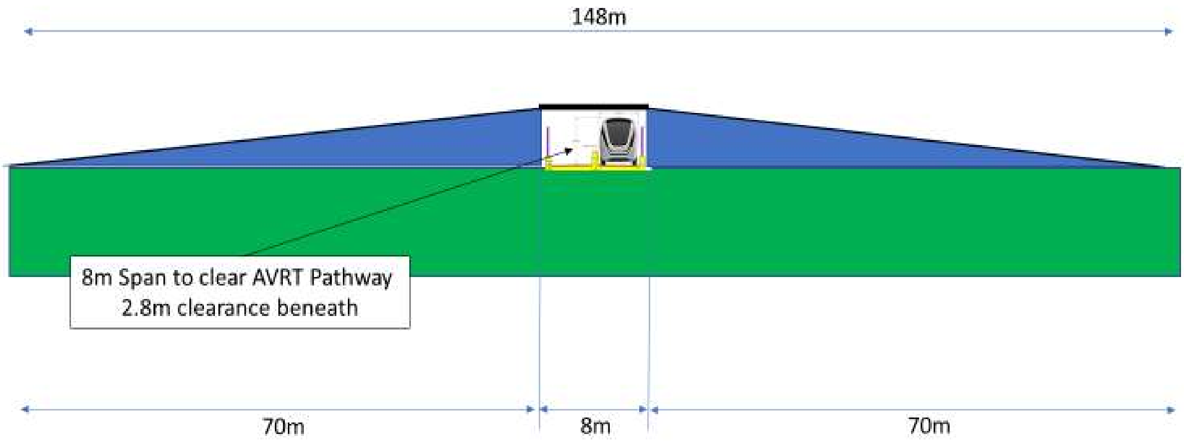


Figure 5-4 Indicative design for highways bridge over AVRT. The significant advantage of this arrangement is the low rise necessary in comparison to railways. Railways need 4.4m clearance as a minimum, normally 5.6m for electrification. AVRT is not electrified with overhead wires.

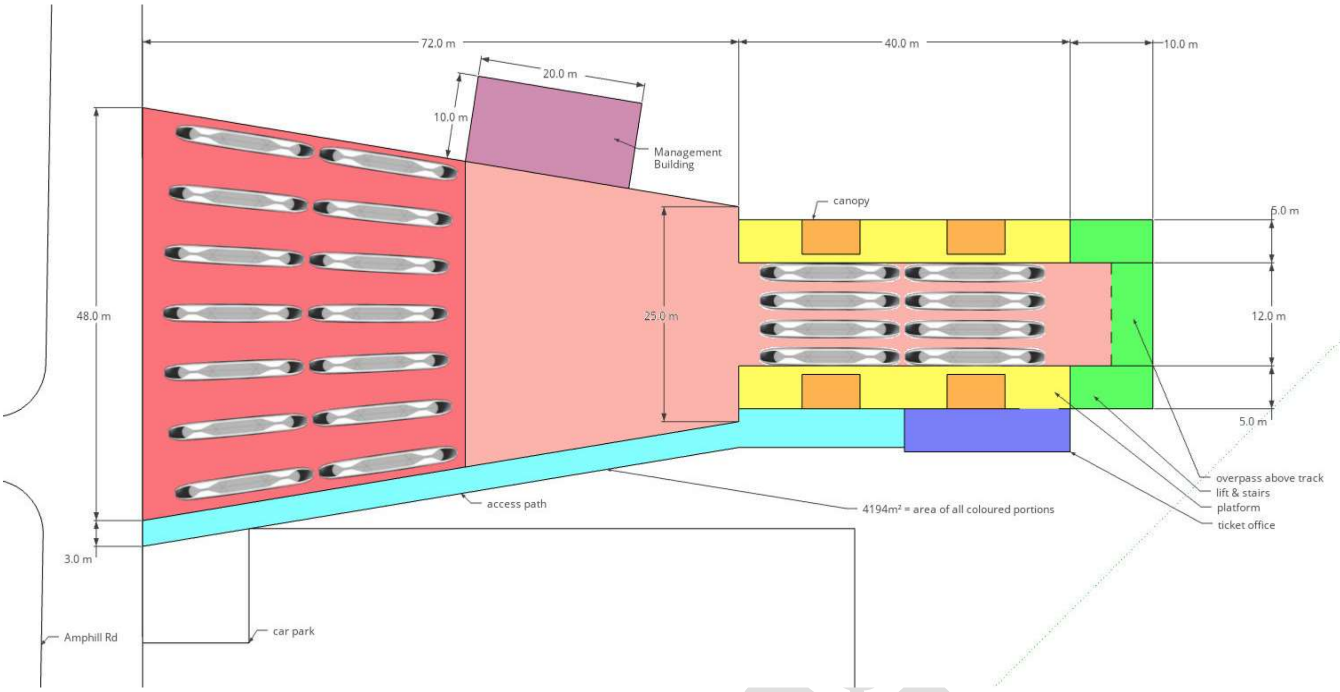


Figure 5-5 Bedford St Johns Station indicative plan layout; used for pricing and checking it fits into the land parcel

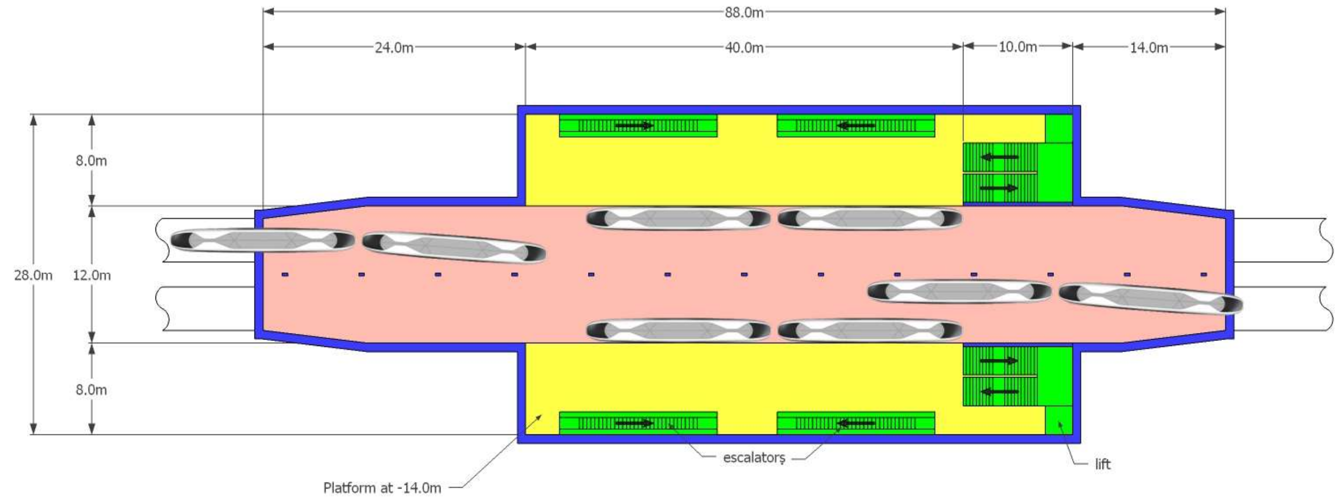


Figure 5-6 Cambridge West Underground Station indicative plan layout

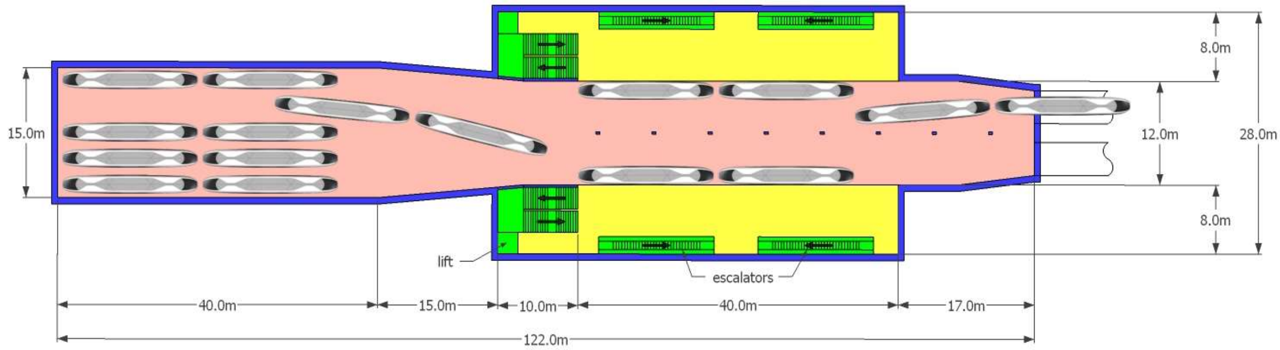


Figure 5-7 Cambridge Central Underground Station indicative plan layout

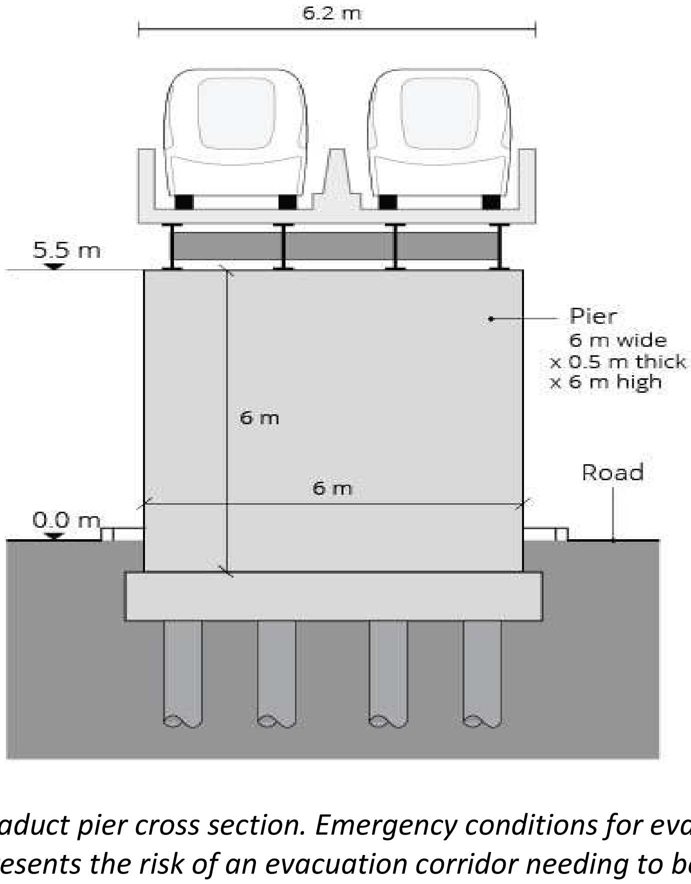


Figure 5-8 Elevated viaduct pier cross section. Emergency conditions for evacuation have not been assessed, this presents the risk of an evacuation corridor needing to be added to the cross section.

6 The costs of the EWR AVRT options

88. This Chapter provides cost estimates for all elements of the scheme; capital investment costs, fleet costs and operating expenditure. The uncertainties of the concept and risk treatment are described.

6.1 Capital Cost Estimates

89. Within the team authoring this report, two teams were asked to undertake cost analysis of the infrastructure works with two different views and hence results; EWR's in house estimating team with a conservative view and separately the promoter contracted by EWR to develop the concept with an optimistic view. The two views represent one conservative, and one optimistic. This provides a range representative of the estimating uncertainty associated with the uncertainties of the principles of the concept. This is different from the risk and uncertainty treatment, which is reference class forecast based. EWR's estimating team have no prior knowledge of the scheme and developed a cost based on the assumptions within this report. Cost metrics from Configuration State 1 EWR Alliance contracted works were used as the basis. This cost estimate was assured by an independent team from our supply chain. The alternative estimate by the Proponent used metrics from the building and highways sectors.

90. Different risk profiles to that of heavy rail were used on the AVRT cost as the preliminary nature of the concept places it in a different category within the DfT Reference Class Forecasting guidance.

91. The analysis has considered selected scheme options for comparison. They are first; the best performing Heavy Rail alignment at two service levels, 2 trains per hour and 4 trains per hour. Second; The Light Rail alignment that serves the Northern approach to Cambridge with 4 trains per hour. These have been costed as follows in Table 4 (rounded to the nearest £10m) using the conservative methodology. A more detailed breakdown of these costs is provided in Annex A.

Table 4 Summary of Base Construction costs plus risks, electrification and rolling stock ranked in order of cost

Route Option Costs: Low/High (£m)														
Description	**Option LR2 4tph**		**Option HR2 2tph**		**Option HR2 4tph**		**Option 1a AVRT 2,000pph**		**Option 1a AVRT 4,000pph**		**Option 2a AVRT 2,000pph**		**Option 2a AVRT 4,000pph**	
Direct Construction Cost:	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Bletchley to Bedford (MVL)	90	100	90	100	90	100	90	100	90	100	90	100	90	100
Bedford to Cambridge	600	770	740	830	760	850	750	850	780	890	980	1,110	1,020	1,170
Total Direct Cost	**690**	**870**	**830**	**930**	**850**	**950**	**840**	**950**	**870**	**990**	**1,070**	**1,210**	**1,110**	**1,270**
Preliminaries	230	290	260	310	270	310	280	320	280	330	350	400	370	420
Overheads and Profits	90	110	110	130	110	130	110	130	120	130	140	170	150	170
Total Construction Cost	**1,010**	**1,270**	**1,200**	**1,370**	**1,230**	**1,390**	**1,230**	**1,400**	**1,270**	**1,450**	**1,560**	**1,780**	**1,630**	**1,860**
Other Indirect Costs	350	450	400	460	400	470	420	490	430	500	490	570	510	590
Base Construction (For MVL and CS3)	**1,360**	**1,720**	**1,600**	**1,830**	**1,630**	**1,860**	**1,650**	**1,890**	**1,700**	**1,950**	**2,050**	**2,350**	**2,140**	**2,450**
Risk Provision (MVL and CS3)	450	1,020	530	1,080	540	1,110	970	2,290	1,000	2,360	1,210	2,840	1,260	2,960
Base Construction plus Risk (MVL and CS3)	**1,810**	**2,740**	**2,130**	**2,910**	**2,170**	**2,970**	**2,620**	**4,180**	**2,700**	**4,310**	**3,260**	**5,190**	**3,400**	**5,410**
Base Cost - For Electrification Only	300	360	470	550	470	550	300	360	300	360	300	360	300	360
Base Cost + Risk - Electrification Only	400	570	630	870	630	870	480	800	480	800	480	800	480	800
Inflation - Electrification Only	90	130	150	200	150	200	140	230	140	230	140	230	140	230
Total Cost Electrification Only	**490**	**700**	**780**	**1,070**	**780**	**1,070**	**620**	**1,030**	**620**	**1,030**	**620**	**1,030**	**620**	**1,030**
Inflation, Excluding Electrification	420	630	490	670	500	690	740	1,180	760	1,220	920	1,470	960	1,530
Base Construction plus Risk (MVL and CS3) plus Electrification	**2,720**	**4,070**	**3,400**	**4,650**	**3,450**	**4,730**	**3,980**	**6,390**	**4,080**	**6,560**	**4,800**	**7,690**	**4,980**	**7,970**
Rolling Stock (Design & Development)	0	0	0	0	0	0	63	63	63	63	63	63	63	63
Rolling Stock (Vehicle Purchase)	0	0	0	0	0	0	34	34	70	70	34	34	70	70
Rolling Stock risk provision	0	0	0	0	0	0	194	194	266	266	194	194	266	266
Inflation, Excluding Inflation	0	0	0	0	0	0	80	80	110	110	80	80	110	110
Rolling Stock	**0**	**0**	**0**	**0**	**0**	**0**	**370**	**370**	**510**	**510**	**370**	**370**	**510**	**510**
Base Construction plus Risk (MVL and CS3) plus Electrification plus Rolling Stock	**2,720**	**4,070**	**3,400**	**4,650**	**3,450**	**4,730**	**4,350**	**6,760**	**4,590**	**7,070**	**5,170**	**8,060**	**5,490**	**8,480**

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92. Table 4 above shows that the total upper bound Base Construction costs range from £1,720m at the lower end for LR02 to £2,440 at the higher end for AVRT2a (4,000 pph).

93. Within this range Base Construction Costs are similar across both Heavy rail options and both AVRT1a Surface options ranging from £1,830m to £1,950m.

94. AVTR2a Tunnel options are significantly more expensive than other options due to higher costs associated with tunnelling and underground stations.

95. When comparing point estimate values of the conservative estimate, it is evident that the base construction costs excluding risk, electrification and rolling stock. This is shown in **Error! Reference source not found.**.

Table 5: Base Construction Costs for all Options Ranked in Order of Cost

Scheme Option	Base Construction Cost £m £m
Light Rail Option 2 4tph	1,460
Heavy Rail Option 2 2tph	1,660
Heavy Rail Option 2 4tph	1,690
AVRT Option 1a (2,000 pph)	1,710
AVRT Option 1a (4,000 pph)	1,750
AVRT Option 2a (2,000 pph)	2,110
AVRT Option 2a (4,000 pph)	2,190

96. When comparing the cost differences between AVRT1a and Heavy Rail the key points have been summarised in **Error! Reference source not found.**6.

Table 6 Comparison of Direct Construction Costs / Key Cost Drivers of HR vs AVRT1a

HR2 Bedford Varsity – Varsity Hybrid & RA1 – Cam via the North [4tph]					Option 1 AVRT (2,000ph) Point Estimate £m					Extra works over and above HR2		
Description	Qty	Unit	Total	% to Direct	Description	Qty	Unit	Total	% to Direct	Description	Variance	Commentary
Earthwork	4,958,000	m3	£160M	21%	Earthwork	2,556,245	m3	£90M	12%			AVRT has a 50% Earthwork Assumption
Pway	62	Route km	£130M	17%	Pathway	53	Route km	£220m	25%	Pathway Pathway - Oakington to Cambridge North	85,000,000 40,000,000	AVRT and Heavy Rail have different construction types, as such AVRT requires more resource to construct then HR and as such is priced higher in it's unit rate. Include Oakington to cambridge north
					Pathway Lighting	53	Route km	£30M	6%	Pathway Lighting	30,000,000	AVRT requires specific pathway lighting on the route, Heavy Rail has less lighting specification and included within the rate
					LoR Fibreoptic Cable & Control centre	53	Route km	£20M	2%	LoR Fibreoptic Cable & Control centre	15,000,000	AVRT requires specific control centre to be built along with fibreoptic cable, Heavy Rail would use the existing control centre
Station	5	nr	£85M	11%	Station	5	nr	£80M	10%			AVRT is lower in cost
					Stabling, Charging & Drivers Accom	2	nr	£60M	9%	Stabling, Charging & Drivers Accom	60,000,000	AVRT requires stabling to be built in two locations, Heavy Rail utilises existing stabling locations
Viaduct	32,440	m2	£70M	9%	Viaduct	8,400	m2	£40M	5%			Heavy Rail has a lower unit rate for viaduct, this is due to more efficiency has been applied via cost engineering with designers and more efficiency due to a much higher volume
Overbridge	28	nr	£70M	9%	Overbridge	39	nr	£180M	25%			1) Quantity of overbridge is higher on AVRT, the quantity was taken from John Miles as what AVRT would require, Heavy Rail taken from design . 2) Heavy Rail rate is lower as this has been built up based on geographical bridges we have priced whereas AVRT route is on per bridge benchmark rate
					Other Civil			£15M	2%			Culverts, Access points, Footbridge
Rail MEP - Signalling	113	STK	£65M	9%	Rail MEP - Signalling		STK	£0M				No signalling cost requred so saving for AVRT
Total Cost of Key Elements			**£580M**	**75%**				**£730M**	**96%**	Total Additional Scope	230,000,000	
Overall Total of the Option			**£770M**					**£760M**				

AVRT	760
Additional works	-230
Adjusted total	**530**

HR2 Vs AVRT 1A (Exclude additional scope) £760m Vs £530m
AVRT cost is lower than HR2 when extra works are excluded

97. Comparing beyond base construction costs, points of significant difference include electrification costs for Heavy rail which equate to £1,070m, compared to £1,030m for AVRT and £700m for light rail.

98. AVRT is a mixture of some relatively well-known civil engineering costs (cost of building a trackway, similar to the heavy rail schemes) and some items requiring significant development work (AVRT vehicles and control systems). Optimism Bias (OB) accounts for a significant difference in costs across the options with 200% OB being applied to the new AVRT vehicles given their level of novelty, design development cost, cost of driverless new technology as well as risk of increased cost due to supply chain scarcity / niche market. 200% is based on Table 4 from the Green Book: Supplementary Green Book Guidance – Optimism Bias, Online [Accessed on 1 April 2022], *Microsoft Word - GreenBook_optimism_bias.doc (publishing.service.gov.uk)*

99. 90% optimism bias has been applied to capital cost of AVRT Infrastructure based on an average of 59% and 121% OB as per WebTAG values for a Rail Scheme with a 70% and 80% certainty level accordingly. This equates to between £2,290m to £2,360m on the AVRT1a options and £2,840m to £2,960m for AVRT2a depending on pph. By comparison the upper bound OB for LR2 and HR2 are £1,020m and £1,080m respectively.

100. Vehicle purchase is not applicable to either Light Rail or Heavy Rail options as these are treated as annualised operating expenditure costs as per the current franchising and financing arrangement for UK railways. Capex is for vehicular purchase is £97m and £133m to AVRT1a and 2a options respectively. This is split into £63m for design development (pre-risk treatment), and then either £34m for vehicle purchase for AVRT1a or £70m for AVRT2a vehicle purchase due to the additional number of vehicles required.

101. Rolling stock risk provision is another point of difference with no provision being required for either light rail or heavy rail but AVRT1a and 2a attracting £194m in estimate costs for the 2,000 pph options and £266m for the 4,000 pph options.

102. Inflation has been taken to the mid-point of construction. AVRT differs from other forms of transport due to the length of time for vehicle concept to be completed. For Light rail and heavy rail the overall percentage uplift is 23.1 percent to 4Q30. By comparison AVRT is 28.3 percent to 4Q32. These allowances have been applied against base construction cost and risk.

6.2 Fleet Costs

103. The 20bph 2-vehicle 2,000 pph option requires 68 AVRT vehicles, while the 27bph 3-vehicle 4,000 pph option requires 140 vehicles. This includes a 12% allowance for spare vehicles above the peak vehicle requirement. AVRT vehicles are assumed to be purchased outright once every 10 years, rather than leased. (AVRTs do not exist yet so it may be unfair to suggest that their lifespan is 10 years - even if we compare them to traditional buses, the comparison is not entirely fair as traditional buses operate in a different environment (roads) with different kind of components (engine, transmission, etc). Some components on buses are likely to be subject to more uneven wear and tear (breaks, suspension, body frame etc) which AVRT are unlikely to face due to running on segregated track like surfaces. However the maintenance regime and specification of the AVRT route is to be determined.) This reflects

the likely lifespan of an AVRT vehicle and is similar to regional bus companies, who purchase rather than lease vehicles. This is unlikely to make a material difference to the appraisal results compared to leasing. As a result, the cost of AVRT vehicles is allocated under capital expenditure in the appraisal summary tables, rather than operating expenditure.

104. Once production is established, AVRT fleet cost is estimated to be lower than for heavy rail . That is based upon the cost assumption that AVRT is akin to bus prices, not rail and draws on historic costs of buses and rail carriages. However, the vehicles have a shorter life span and less passenger space than heavy rail vehicles. The vehicle fleet production costs are determined by the number of vehicles required to accommodate the forecast demand over the 60-year appraisal period.

105. The vehicle fleets required for the scenarios of 2,000 and 4,000 passengers per hour per direction between Bedford and Cambridge are summarised in the table below. In Table 7 it can be seen that AVRT vehicles provide the same number of seats for a lower up-front cost, but the overall lifetime cost is higher due to the shorter service life.

Table 7 Comparison of Vehicle Fleet Production Costs for AVRT and Heavy rail

Mode	Cost per car	Peak hour capacity (minimum)	Service interval	Departures per hour	Capacity per car (seat+ stand)	Capacity per departure (required)	Cars per departure (required)	Convoy sets required (1.5 hr cycle time)	Cars	Total fleet cost	Fleet life	Total fleet cost 30 years
AVRT	£0.6m	2000	3.0	20	50	100	2	30	60	£36m	10 years	£108m
AVRT	£0.6m	4000	2.2	27	50	148	3	41	123	£74m	10 years	£221m
Rail	£1.5m	2000	15.0	4	120	500	5	6	30	£45m	30 years	£45m
Rail	£1.5m	4000	7.5	8	120	500	5	12	60	£90m	30 years	£90m

106. The deductions from Table 7 are, for the given assumptions, seat for seat (or passenger space for passenger space), AVRT vehicles are not cheaper than heavy rail vehicles. This is sensitive to the fleet life assumption driven by the variables of battery life technology and the incurred maintenance costs.

107. What is modelled in the costs is the Electrification from Oxford to Bedford and the upgrade of the MVL to generate the demand that feeds the Bedford end of the AVRT scheme. An alternative scenario; the implementation of the AVRT scheme on itits own, with no further costs associated with railway upgrades, has been produced but the corresponding Benefits have not been assessed for this scenario. This scenario does not align with the Theory of Change and hence is not considered within the Affordable Connection Project sifting criteria.

108. The Proposer of the concept has identified an AVRT1a 2,000 pph infrastructure cost of £365M Direct Construction Cost between Bedford and Cambridge. This estimate is not assured by East West Rail, due to the time it arrived and the changing parameters of the application of AVRT. See the Appendix for a break-down of the differences in position. What is modelled in the table below is the lower bound of the estimate, by both the Optimistic (unassured) estimate and the Pessimistic (but assured) estimate teams. This gives an indication of the cost ranges that the scheme may achieve.

Table 8 Comparison of Optimistic and Pessimistic estimates

Serial	Item estimated	Optimistic, £M	Optimistic without Electrification and MVL £M	Pessimistic £M
1	Bletchley to Bedford (MVL) direct cost	£90	-	£90
2	Bedford to Cambridge direct cost	£365	£365	£750
3	Total Direct Cost (1 + 2)	£455	£365	£840
4	Preliminaries (33% of 3)	£152	£122	£280
5	Overheads and Profit (13% of 3)	£60	£48	£110
6	Total Construction Cost (3 + 4 + 5)	£666	£534	£1,230
7	Indirect costs (34% of 6)	£228	£183	£420
8	Base Construction (for MVL and CS3) (6 + 7)	£894	£717	£1,650
9	Risk Provision (% of 8)	£525	£421	£970
10	Base Cost plus Risk (8 + 9)	£1,419	£1,138	£2,620
11	Base cost for electrification only	£300	-	£300
12	Base cost + risk electrification only (11 + 60 % of 11)	£480	-	£480
13	Inflation - Electrification only (29% of 12)	£140	-	£140
14	Total cost of electrification only (12 + 13)	£620	-	£620
15	Inflation, Excluding Electrification (28% of 10)	£401	£322	£740
16	Base Construction plus Risk (MVL and CS3) plus Electrification (10 + 14 + 15)	£2,440	£1,460	£3,980
17	Rolling Stock (Design and Development)	£63	£63	£63
18	Rolling Stock (Vehicle Purchase)	£34	£34	£34
19	Rolling Stock Risk Provision (200% of 17+18)	£194	£194	£194
20	Rolling Stock Inflation (28% of 17 + 18 +19)	£80	£80	£80
21	Rolling Stock total (17 + 18 + 19 + 20)	£ 371	£371	£371
22	Base construction plus risk (MVL and CS3) plus electrification plus rolling stock (16 + 22)	£2,811	£1,831	£4,351

109. We can see from Table 8 that the optimistic estimate is between 42% and 65% of the pessimistic estimate accounting for all costs (serial 22). The Base Construction Cost (serial 2) is 50% simply less.

110. We now compare this to HR2 which is £1.6Bn to £1.83Bn Base Construction Cost in the Summer 2022 estimate. At all costs including electrification it is £3.45Bn to £4.73Bn. Shown in the Figure 6-1 Range of cost estimatesbelow.

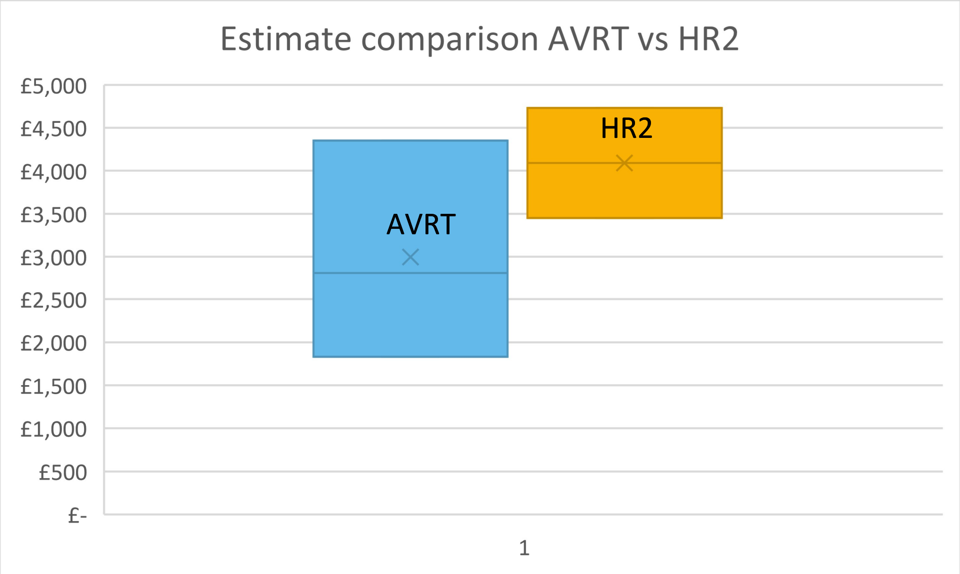

Figure 6-1 Range of cost estimates

6.3 Operating costs

111. The operating costs for AVRT have been calculated in the context of an end-to-end transport Oxford-Cambridge link, as the marginal additional costs required beyond CS1, the committed section. Hence, enabling full comparison with the Affordable Connections Heavy rail 'Adult' options, the operating costs for AVRT options include:

- increasing Marston Vale Line (MVL) heavy rail services from 1tph to 3tph between Bletchley and Bedford (of which 2tph are fast Oxford-Bedford trains, and 1tph is an MVL stopping service);
- increasing Oxford to Bedford rail services from 2tph to 4tph by adding in 2tph between Oxford and Bletchley.

112. The operating cost forecast for the AVRT appraisals has been developed using the same model as used for Affordable Connections Main Report as of Summer 2022. The model for AVRT includes information from the November 2021 version of TAG, which is the same basis of analysis as the rest of Affordable Connections that are comparable.

113. The key assumptions followed to estimate the operating cost of the AVRT options are:

- Service frequencies are assumed to reduce to 12 buses per hour (every 5 minutes) in the off-peak to better match capacity with demand, and reduce unnecessary operating costs.

- Energy consumption is 2kWh per vehicle kilometre, which is approximately 3.2kWh per vehicle mile (including hotel power). Electricity costs use 'rail' costs based on 'industrial' prices, rather than higher 'road' costs based on 'domestic' prices from the TAG data book.

- AVRT vehicle maintenance cost is estimated at £20,000 per vehicle per annum.

- The core assumption in our analysis is that AVRT will operate without a driver. A sensitivity has been undertaken to understand the cost impact of requiring one driver per convoy. Drivers make the scheme significantly non-competitive to heavy rail, so proving the automation is key to underpinning the business case for AVRT.

- Staff costs per year are estimated at £1,410,000 for a central team, £640,000 for a system maintenance team, and estimates for the station staff which are dependent on whether the station is located overground or underground. Station staff costs for Bedford St John's station is £420,000, the cost of a surface station is £200,000, and the cost for an underground station is £720,000. These staff costs are further uplifted by 35% to include the estimated cost of pensions and National Insurance.

- Infrastructure maintenance includes a cost of re-laying the tarmac (£13.4m in 2021/22 prices) every 10 years. There is a separate allowance for capital renewals.

114. Optimism bias for operating costs is 41%, which is the same as used for heavy rail within ACP. The cost of vehicles, which is included in capital costs, is subject to 200% optimism bias for each purchase.

115. **Error! Reference source not found.Error! Reference source not found.** and Table 9 show the total operating costs required above CS1. Including the cost of purchasing vehicles and excluding optimism bias, AVRT is cheaper to operate than Heavy rail over the 60-year appraisal period for 3 out of the 4 AVRT options; it is marginally more expensive for the AVRT2a 27bph option. These figures represent a potential minimum cost.

Table 9 Lifetime operating costs over 60 years. £ 2010 real prices, undiscounted, before optimism bias, excluding costs for CS1. 'pph': passengers per hour

	AVRT1a 20bph (2000pph)	AVRT1a 27bph (4000pph)	AVRT2a 20bph (2000pph)	AVRT2a 27bph (4000pph)	HR2 4tph (2000pph)
Staff	929	929	1,078	1,078	1,362
Rail vehicle lease charges	122	122	122	122	275
AVRT vehicle purchase	250	416	250	416	-
Rolling stock maintenance	203	280	203	280	365
Traction power costs	361	538	375	563	272
Infrastructure maintenance	66	66	66	66	155
Total	**1,931**	**2,351**	**2,094**	**2,526**	**2,429**

116. The key conclusions when comparing AVRT operating costs against Heavy rail are listed below:

117. Staff: AVRT staff costs are lower than heavy rail on the assumption that the AVRT convoys would not be staffed (whereas heavy rail services would be operated with a driver). This figure includes the costs of control room, a dedicated head office for AVRT, and platform staff where required. Proving Automation for AVRT services is thus necessary before investing in

deploying the system at scale. The heavy rail comparator (and the heavy rail section west of Bedford) assumes 'driver only operation'; there is provision for some customer service (not safety critical) staff but not on every train service and fewer platform/station staff than for AVRT.

118. Vehicle lease and purchase costs: Fleet costs are significantly higher for AVRT, as up to 5 times more vehicles per hour would operate per hour between Bedford and Cambridge. A 4tph 4-car heavy rail service requires 16 vehicles per hour, while a 27bph 3-vehicle AVRT service would require 81 vehicles per hour. AVRT vehicles cost similar amounts per seat as heavy rail carriages and AVRT vehicles require replacement every ten years.

119. Vehicle maintenance costs: Costs are significantly lower for AVRT based on estimates provided by Professor John Miles. This is still consistent with the requirement for more frequent vehicle replacements.

120. Traction power costs: The costs of energy consumption are significantly higher for AVRT. This is because AVRT requires up to 5 times as many vehicles per hour, and the assumed energy consumption is similar per vehicle at 3.5kWh/mile for heavy rail, compared to 3.2kWh/mile2 for AVRT. Rubber tyre on tarmac produces higher friction than steel wheel on steel rail, and does not benefit from aerodynamic savings of trailing close coupled units not attracting form drag.

121. Infrastructure maintenance: Costs are significantly lower for AVRT as the maintenance cost included is for analogous to road maintenance whereas rail infrastructure is more mechanically complex and requires more maintenance. So the running costs year on year are lower. Both AVRT and heavy rail costings include the same allowance of 30% of the initial capex in 30 years' time to reflect renewals of the infrastructure (re-railing or re-surfacing, and re-cabling).

[2] Originally provided as 2kWh/km. 28

7 Assessment of AVRT business case

122. This Chapter assesses the AVRT concept in terms of journey experience and economic appraisal. The reference case of the Heavy Rail 2 option is used for comparison, and conclusions drawn on its benefits and opportunity costs.

7.1 Journey experience

123. AVRT would provide a different transport offering to customers, particularly in the context of an end-to-end Oxford-Cambridge transport route. The key differences against a heavy rail solution are:

- More frequent services
- The introduction of an interchange
- The absence of on board toilets, and a narrower more confined journey compared to trains

124. Figure 7-1 and Table 10**Error! Reference source not found.** shows a table of journey times, comparing HR2 (Heavy Rail) against AVRT1a and AVRT2a.

125. Journey times on AVRT1a are higher than Heavy Rail to access Cambridge station. This is primarily due to the connection time required at Cambridge North to continue a journey to Cambridge station.

126. Journey times on AVRT2a are lower than HR2 between Bedford St. Johns and Cambridge. This is primarily due to AVRT2a taking a shorter and more direct route alignment between Cambridge and Cambourne, travelling through the centre of Cambridge rather than around the north of Cambridge. The fastest Heavy Rail alignment – HR5 via Cambridge South and Bedford Midland – is 1 minute slower than AVRT at 35 minutes.

127. Journey times beyond Bedford are slower than Heavy Rail for both AVRT1a and AVRT2a. This is due to requiring an interchange time at Bedford St. Johns to change vehicle.

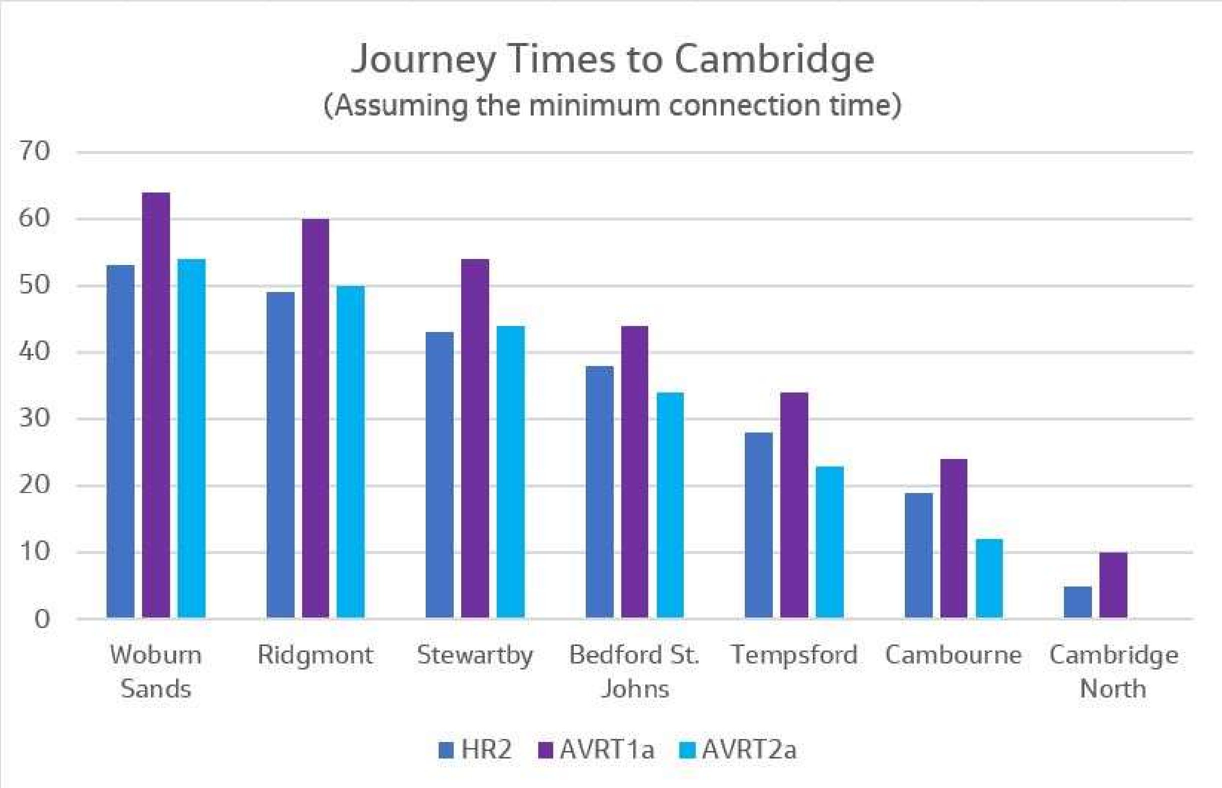

Figure 7-1 Journey times to Cambridge station, assuming a connection time of 5 minutes.

Table 10 Journey times to Cambridge station, assuming a connection time of 5 minutes. minutes. Direct journey opportunities highlighted.

Origin station	HR2 *Heavy Rail*	AVRT1a *AVRT*	AVRT2a *AVRT*
Woburn Sands	53	64 (change at Bedford St. Johns)	54 (change at Bedford St. Johns)
Ridgmont	49	60 (change at Bedford St. Johns and Cambridge North)	50 (change at Bedford St. Johns
Stewartby	43	54 (change at Bedford St. Johns and Cambridge North)	44 (change at Bedford St. Johns)
Bedford St. Johns	38	44 (change at Cambridge North)	34
Tempsford-St. Neots	28	34 (change at Cambridge North)	23
Cambourne	19	24 (change at Cambridge North)	12
Bar Hill / Oakington	12	12 (change at Cambridge North)	-

Origin station	**HR2** *Heavy Rail*	**AVRT1a** *AVRT*	**AVRT2a** *AVRT*
Cambridge North	5	5 (change at Cambridge North)	-
University West Science Park	-		5
Drummer Underground Station	-		2

128. Heavy rail does not require an interchange to travel between the Marston Vale Line and Cambridge station. However, both AVRT1a and AVRT2a would require an interchange at Bedford St Johns for trips beyond that station (Table 11**Error! Reference source not found.**).

129. An AVRT service between Bedford St Johns and Cambridge would result in combination of different types of service across the Oxford-Cambridge Arc:

- a conventional Heavy rail service between Oxford, Milton Keynes and Bedford with 2 or 4tph;
- an AVRT service between Bedford and Cambridge, with vehicles every two to three minutes.

130. AVRT services would terminate at Bedford St Johns. This impacts interchange journeys in two ways:

- **Continuing journeys on East West Rail**. Passengers would need to change at Bedford St. Johns between AVRT and Heavy Rail services. Costs for the construction of this have been included.
- **Continuing journeys onto the Midland Main Line.** Midland Main Line services call at Bedford Midland station, which is a different station to Bedford St. Johns. Passengers would either need to take a 20-minute walk across Bedford Town Centre, or change trains twice: once at Bedford St. Johns, and then again at Bedford Midland.

131. AVRT1a terminates at Cambridge North and does not serve Cambridge. This impacts interchange journeys in two ways:

- **Continuing to Cambridge station.** Passengers would need to change trains to continue to Cambridge station.
- **Continuing to London and other destinations.** Cambridge North station has fewer connection opportunities. Therefore, journeys to destinations like Ely would require two changes; once at Cambridge North and another at Cambridge. The half-hourly fast service to London Kings Cross is unaffected as it calls at Cambridge North twice an hour.

132. Research in the UK has demonstrated that rail customers value a direct seat between ‘origin to destination’, and hold a high psychological ‘interchange penalty’. This is demonstrated by the value passengers hold of Thameslink despite very high frequencies on the London Underground on parallel routes. As AVRT would require more interchanges than heavy rail, this reduces the attractiveness to passengers and reduces passenger demand.

133. PDFH research in the table below suggests that passengers treat the interchanging at least 10 minutes in on-train time equivalent for a 15-mile journey, which rises according to distance. This is in addition to the time required to interchange. For Bicester to Cambridge - 70-mile journey – a passenger on an Off-Peak ticket would treat interchanging as equivalent to 31 minutes of travel time.

Table 11 Interchange penalties (from Table B4.13, PDFH v6.0)

Distance (miles)	Passengers on Anytime, Off-Peak and Advance tickets, minutes	Passengers on Season tickets, minutes
15	15	10
30	19	12
50	25	16
70	31	20
100	40	26

134. The high frequency of AVRT does not mitigate or outweigh the psychological 'interchange penalty' as a direct seat will always be more attractive, and a high-frequency connection would not improve end-to-end frequency.

135. Due to the relatively low capacities of AVRT vehicles compared to heavy rail vehicles, connecting passengers would not expect to always be able to board the first departing AVRT vehicle. For example in the evening peak, at Tempsford-St Neots a 12-car Thameslink train with 666 seats would arrive from London every 30 minutes with a substantial level of connecting passengers for Cambourne. With 80 seats on a two-vehicle AVRT service (2,000 pph option), passengers may need to wait for subsequent departures (see section 8 for a worked example). This is partly mitigated by high frequency but could lead to lower customer satisfaction if there is uncertainty as to whether passengers would be able to board.

8 Demand and capacity

8.1.1 Approach

136. Demand is calculated using the EWR Full Demand Model (FDM), part of the EWR modelling suite. This incorporates an econometric gravity model to calculate passenger demand between two locations, given certain economic characteristics. This is in line with previous economic cases in the IOBC (September 2021) and Affordable Connections (June 2022). This may be referred to as 'conventional demand modelling' and is not a 'theory of change' trip-end approach. See the Affordable Connections Main Report and Appendices on the Business Case Modelling and Appraisal.

137. The FDM is designed for assessing inter-urban demand between stops with 2km catchment areas, across the EWR geography from Oxford through to Cambridge. The model geography is identical to those considered for Heavy Rail, Light Rail and Guided Bus modelling. This includes potential stations at Cambourne, Bar Hill (used for Oakington as a proxy), and Cambridge North. The model is therefore capable of adequately representing trips from nearby towns into Cambridge, as these were designed into the model for the Heavy Rail runs within Affordable Connections.

138. The model does not include stops that were proposed at the proposed University Science Park West Station or the proposed Drummer Underground Station and doesn't not include the benefits of the trips within Cambridge. Due to project timescales, there was not adequate time to rebuild, calibrate and assure the model to consider these two locations. Cambridge North – with its population catchment that represents north Cambridge and employment catchment that covers the Cambridge Science Park – is used as a proxy for the two central Cambridge stations. This is a modelling simplification. The key limitation of this approach is the inability to model very local journeys within Cambridge. Any benefit arising from this connectivity is not assessed as material to the analysis, and is akin to a new inner city road or bus service, as opposed to inter-urban connectivity between substantial new housing and jobs markets. As the strategic objectives of EWR as per the document Affordable Connections Terms of Reference concern inter-urban travel between Oxford, Milton Keynes, Bedford, Cambourne and Cambridge, it was not deemed a strategic priority to model very local journeys that a different scheme may accommodate more appropriately.

139. An adjustment is made to peak-hour timetables fed into the FDM to reflect that passengers may not always be able to board the first available service. The aggregate demand generation purposes only, headways are modelled as if passengers are able to board the second departing service. When the aggregate level of demand is allocated to individual services, this is distributed across the full operating timetable with services operating every 3 minutes for the 2,000pph option and every 2 minutes 13 seconds for the 4,000pph option.

140. There is cost reduction benefit to a system that can reduce service frequency to match demand dynamically or respond to surge in demand. However, the infrastructure is scaled to meet a peak demand scenario. This demand response feature has been approximated to an off-peak assumption for the purpose of analysis by taking a 50% assumption of the vehicles being in service compared to peak.

8.1.2Demand by flow

141. Table 12 shows selected origin-destination pairs for different distances for the 20bph option.

Table 12 Selected journey pairs with passenger demand per year on selected flows (2050, high growth with dependent development). Percentage change in demand compared to heavy rail in brackets.

Between		HR2	AVRT1a (20bph)	AVRT2a (20bph)
Cambridge	Cambourne	485k	523k (+8%)	1,292k (+166%)
Cambridge	Tempsford-St. Neots	106k	93k (-12%)	172k (+62%)
Cambridge	Bedford (a town centre station)	271k	220k (-19%)	400k (+48%)
Cambourne	London	570k	595k (+4%)	667k (+17%)
Cambridge	Bletchley	57k	28k (-51%)	40k (-30%)
Cambridge	Oxford	80k	59k (-26%)	61k (-24%)
Cambridge	Luton	50k	11k (-78%)	20k (-60%)

142. AVRT1a consistently produces less demand than AVRT2a. This is a combination of not serving Cambridge central station, interchanges with other modes to reach other destinations in Cambridge and slightly longer journey times.

143. The high frequency of AVRT produces the most significant response on the shortest distance journeys. This is in line with section **Error! Reference source not found.**, which notes that the reduced wait time proportionately has the largest impact on shorter distance journeys. This generates significantly more short-distance demand, with AVRT2a producing over 150% more demand between Cambourne and Cambridge, and approximately 50% more demand between Bedford and Cambridge.

144. For journeys where interchange with heavy rail is required to continue a trip (whether the Bedford-Cambridge link is heavy rail or not) then AVRT does not represent a significant frequency improvement as passengers' journey opportunities are constrained by the least frequent leg. For journeys such as Cambourne to London that require an interchange on both Heavy Rail and AVRT, AVRT delivers a modest demand increase (+17% for AVRT) as it reduces the wait time at Cambridge or Tempsford-St. Neots stations.

145. For cross-Bedford journeys, AVRT – along with other non-heavy rail modes – represents a less attractive mode as passengers would need to interchange between AVRT and heavy rail at Bedford St. Johns to reach their destination. In the base growth scenario with heavy rail scheme HR2, passengers travelling across Bedford represent 50% of EWR passengers using the service east of Bedford; in the high growth scenario there is significant development east of Bedford, but also on the Marston Vale Line and 32% of passengers east of Bedford have

travelled from west of Bedford. The interchange adds both actual additional journey time, and a psychological 'interchange penalty' to passengers (see section 121). This results in a reduction of demand for cross-Bedford journeys with Cambridge to Bletchley reducing 30% with AVRT2a, and Cambridge to Oxford decreasing 24%.

146. AVRT would serve Bedford St. Johns but not Bedford Midland. Any journeys between Midland Main Line destinations and the Eastern Section – such as Luton Airport Parkway to Cambridge –would require two interchanges (at both Bedford Midland to catch a MVL service and Bedford St. Johns) or a circa 15 minute interchange walk across Bedford. This severely reduces the attractiveness of these journeys for passengers, reducing numbers of trips across Bedford. Demand between Cambridge and Luton, which requires an interchange at Bedford Midland, reduces by 60%. It could be possible for AVRT to serve Bedford Midland station at additional cost, which would involve tunnelling. However, this has not been costed or modelled.

8.1.3Demand by route section

147. Table 13 shows annual demand travelling across some key route sections. This includes all journey travelling over a specific cordon point.

Table 13 Annual modelled demand (2050) travelling over EWR route section (High Growth with Dependent Development) . Percentage difference to HR2 shown in brackets.

Cordon point	HR2	AVRT1a (20bph)	AVRT2a (20bph)
West of Bedford St. Johns	3.6m	2.4m (-33%)	2.5m (-31%)
East of Bedford St. Johns	4.7m	3.0m (-36%)	3.4m (-28%)
East of Cambourn e	4.0m	3.2m (-20%)	4.7m (+18%)

148. AVRT results in less demand on the sections of route west of Bedford, as there are significantly fewer cross-Bedford journeys. The number of passengers making journeys on the eastern end of the Marston Vale Line as it approaches Bedford St. Johns is over 30% lower for AVRT compared to Heavy Rail, as all passengers crossing Bedford would need to change vehicle, which would add a psychological 'interchange penalty' and time needed to interchange.

149. The demand reduction is lower for AVRT on the section immediately east of Bedford St. Johns. This is primarily because many passengers travelling west of Tempsford St. Neots are crossing Bedford, and the higher frequency of AVRT does not mitigate the psychological 'interchange penalty' and additional connection time.

150. AVRT results in a greater level of demand on the eastern section of the route, with AVRT2a producing 18% more demand east of Cambourne. This is because AVRT generates many very

short distance trips around Cambridge. This is partly offset by a reduction in longer-distance trips from Cambridge.

8.1.4Cambridgeshire Guided Busway

151. AVRT Option 1a would take over the Cambridgeshire Guided Busway alignment between Histon and Cambridge North.

152. This means that existing bus services on the Cambridgeshire Guided Busway would be unable to operate. The six buses per hour (as at June 2022) would either need to terminate at Histon for interchange with AVRT, with passengers incurring an interchange penalty and only if AVRT provided additional capacity to meet this demand, or the buses would need to continue on local roads with an approximate 20-minute journey time penalty.

153. It is unlikely that changing on to AVRT1a would provide a materially better service than a diverted busway service. As AVRT1a terminates at Cambridge North station, passengers travelling to central Cambridge would have a quicker journey by staying on the bus as it leaves the Guided Busway early at Histon. Passengers travelling to the Science Park or around Cambridge North station are unlikely to experience a materially improved journey time considering that the Cambridgeshire Guided Busway already operates at 55mph.

154. This will result in quantified loss of benefits of £128m PV in 2010 prices due to the valuation of extended journey times and loss of revenue due to reduced demand.

8.2 Capacity

155. To assess capacity, it would not be appropriate to assess hourly demand against hourly capacity. This is because demand is expected to ‘pulse’ at key interchanges, where a heavy rail – a lower-frequency, high-capacity per service mode – meets AVRT – a higher-frequency, low capacity per service mode.

156. The demand modelling shown below represents a ‘mean weekday’ in 2050 with dependent development. This does not represent the busiest day; mid-week, Autumn and Spring are all expected to be busier than the ‘mean’ average.

157. To assess capacity fairly against heavy rail, we have assumed the same standing densities as specified by the DfT for use regional rail services, of 0.45m2 per standing passenger. This results in approximately 9 standees per vehicle, or 18 standees of a two-vehicle service. We have not measured standing passengers at ‘crush loading’.

158. Passengers travelling entirely within the eastern section – served by AVRT – will distribute evenly across an hour. For example, there will be a steady arrival of passengers arriving at Cambourne intending to travel to Cambridge.

159. Passengers interchanging off heavy rail (a less frequent mode with more capacity per service) will arrive in ‘pulses’. For example, a 3tph service on the Marston Vale line will create 3 main ‘pulses’ of connecting passengers with AVRT services at Bedford St Johns. This means that only few of the 20 services in the hour are likely to be far busier than the rest. This also applies in reverse; AVRT passengers intending to interchange onto heavy rail will board an

AVRT service at a time that minimises the connection; well-timed arrivals are likely to be very busy as passengers will not intend to wait at their interchange.

160. Figure 8-1 Eastbound simulated service loads at Bedford St. Johns during the AM peak (07:00-09:59). AVRT2a, 20bph 2-vehicle ('2000 pph'). Includes heavy rail departures from Oxford or Bicester. 2050 high growth with dependent development.below shows train loadings at Bedford St. Johns heading eastbound with 20bph AVRT services during the morning peak (7-10am). The second AVRT service (due to the transfer time) after each Heavy rail arrival is more crowded than the other AVRT services. Except for one arrival in the AM peak that would require passengers to wait for the subsequent departure, the first service is able to accommodate demand.

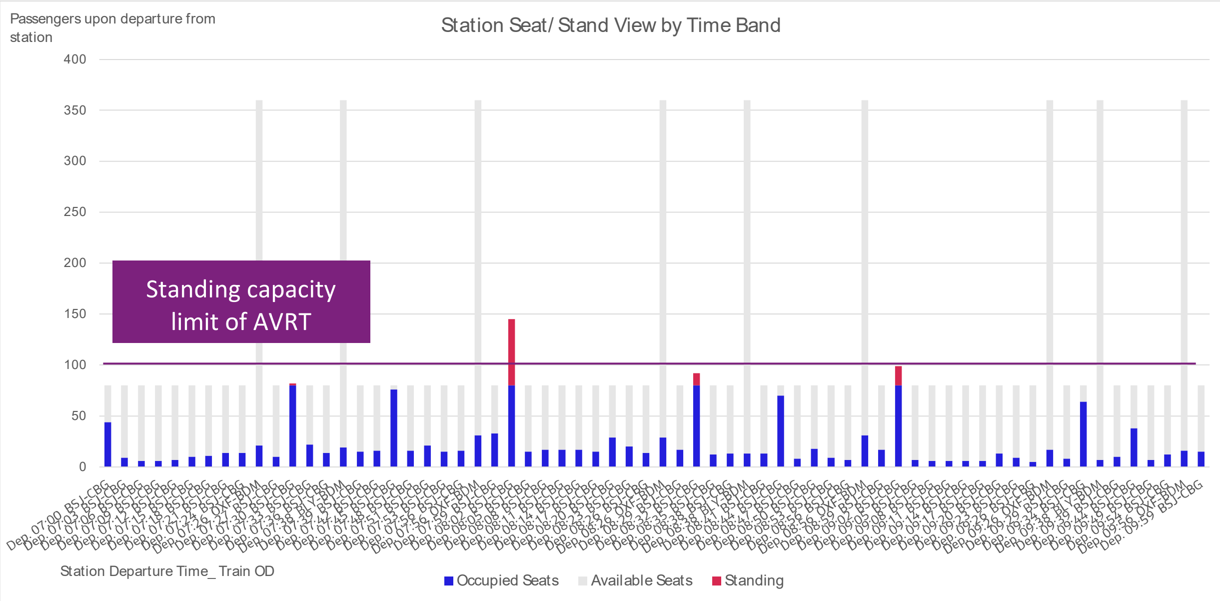

Figure 8-1 Eastbound simulated service loads at Bedford St. Johns during the AM peak (07:00-09:59). AVRT2a, 20bph 2-vehicle ('2000 pph'). Includes heavy rail departures from Oxford or Bicester. 2050 high growth with dependent development.

161. Pulsing also happens in the middle of the eastern section, as passengers interchange onto AVRT at Tempsford-St. Neots, Cambridge North, and Cambridge. Passengers may be connecting off an interchange (such as morning commuting journeys from Huntingdon to Cambridge, changing at Tempsford-St. Neots), or boarding an AVRT with the intention of connecting further down the line (such as a journey from Cambourne to London King's Cross, changing at Cambridge). This is less prominent than at Bedford St. Johns with demand more efficiently spread throughout each hour, but results in peaks of demand.

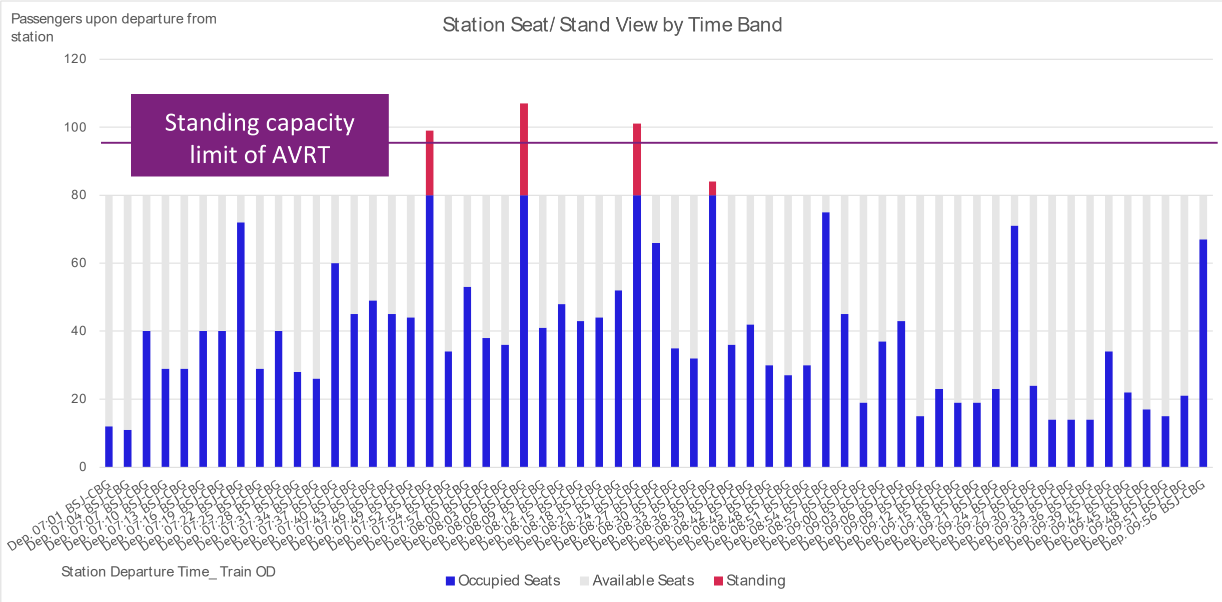

Figure 8-2: Eastbound simulated service loads at Cambourne during the AM peak (07:00-09:59). AVRT2, 20bph 2-vehicle ('2000 pph'). 2050 high growth with dependent development.

162. The demand modelling in this section suggests that on aggregate, AVRT produces less demand to the west of Bedford and immediately east of Bedford, but more demand on the eastern section of the Eastern section approaching Cambridge. The level of pulsing – although resulting in peaks and troughs throughout the hour – does not appear to overload the system, but may at times require passengers to wait for the following service.

8.3 Economic appraisal

163. In line with the Affordable Connection Project Main Report methodology, we have conducted an economic appraisal on a consistent basis to compare the likely quantified benefits of the scheme against the costs to assess the value for money of the scheme. This considers the demand considerations raised in the sections above – including journey time, frequency, and interchange – and monetises them in terms of the valuation of time saved in addition to other factors.

164. The economic appraisal is based on the EWR 'Full Demand Model'. FDM is a model that incorporates industry best practice and DfT Transport Planning and WEBTAG guidance. FDM is a hybrid of an elasticity-based forecasting model and a regression-based gravity model. It does not consider a demand scenario or economic impacts that are derived from the 'Theory of Change', but provides assessment against which the additional third order benefits can be appraised.

165. The economic appraisal for AVRT compares benefits in monetary values using DfT guidance and costs in 2010 prices. The appraisal of AVRT options follows the same methodology as the Heavy Rail appraisals within Affordable Connections. The economic analysis considers four AVRT options: AVRT1a and AVRT2a routes with a '2000 pph' (20bph, 2-vehicles) and '4000

pph' (27bph, 3-vehicles) capacities. The results have been benchmarked against HR2 4tph 'Adult' option for comparison purposes. We have not compared AVRT appraisal results against Light Rail or Guided Bus options as these appraisals were not produced for the purposes of the ACP analysis and because those options were discounted without the need for such appraisals.

166. The purpose of this appraisal, aligning with the 'Terms of Reference' for Affordable Connections (as for other modes considered in ACP at this stage), is to consider AVRT in the context of an inter-regional transport link connecting Oxford, Milton Keynes, Bletchley, Cambourne, and Cambridge. The modelling – including capital costs, operating costs, passenger demand, and transport economic benefits – considers AVRT in the context of an end-to-end transport Oxford-Cambridge link. This does not consider opportunities outside this scope, including very local travel within Cambridge over a 1-2km distance. The value for money recommendations are specific to the requirements of East West Rail; there may be further opportunities for AVRT as a standalone scheme in the same area that meets a different transport requirement.

167. The key modelling assumptions followed in the appraisals of AVRT options are:

- No demand and benefits have been included for local trips within the three stations in the city of Cambridge (for option AVRT2a).
- Treatment of passenger revenues and costs are identical to Heavy rail. All revenues and costs are assigned to the publicly funded Broad Transport Budget, rather than the Private Sector. This reflects the likely funder (not financier) being from a public grant, rather than private funds.
- Fares are assumed to be identical to the treatment of Heavy rail. There is no Bus Service Operators Grant or concessionary travel assumed other than the average for Heavy rail in the Southeast. AVRT fares are assumed to increase at RPI+1% per year in line with TAG guidance. This is lower than the assumption for buses.
- Fares are assumed to be integrated with Heavy Rail. An additional 'boarding fare' is not applied for a change of mode between AVRT and Heavy rail. IE having to buy an AVRT ticket in addition to a train fare, as opposed to a train ticket from Oxford to Cambridge.
- Passenger journey purpose splits are assumed to be identical to Heavy rail as the journeys carried by AVRT in this circumstance are more representative of rail flows than bus flows, which are more short distance in nature.
- Wider economic impacts are included with an identical methodology to heavy rail. This is because AVRT is a segregated mode that overcomes traffic congestion and can support dependent development.
- No freight benefits have been included for AVRT options. This reflects the inability to divert trains between Felixstowe and inland freight terminals onto East West Rail if AVRT is the mode selected.
- The disbenefits of truncating the Cambridgeshire guided busway services at Histon are included for AVRT1a.

168. Further information on key appraisals assumptions is included in the EWR Record of Assumptions.

169. Table 14 and Table 15**Error! Reference source not found.** shows the high-level economic appraisal results of the four AVRT options for base growth and high growth scenarios respectively, in a format specified by the Department for Transport and consistent with the main ACP report.

Table 14 Appraisal results for AVRT options, Base growth, 2010 PV (£m)

AVRT options, Base growth	HR2 4tph 'Adult' (for comparison)	AVRT1a '2000pph'	AVRT1a '4000pph'	AVRT2a '2000pph'	AVRT2a '4000pph'
Level 1 Benefits (excl. WEIs)	£826m	£206m	£196m	£265m	£254m
Level 1 & 2 Benefits (incl. WEIs)	£958m	£269m	£260m	£337m	£326m
Total Costs	-£3431m	-£3154m	-£3704m	-£3697m	-£4291m
Revenue	£579m	£352m	£357m	£443m	£449m
Net Cost to Government	-£2852m	-£2803m	-£3347m	-£3254m	-£3841m
Level 1 BCR	0.29	0.07	0.06	0.08	0.07
Level 2 BCR	0.34	0.10	0.08	0.10	0.08
Inclusion of Level 3 Impacts					
Land value uplift	-	-	-	-	-
DD Revenue	-	-	-	-	-
Indirect Tax Loss	-	-	-	-	-
Move to more/less productive jobs	-	-	-	-	-
Total Benefits	£958m	£269m	£260m	£337m	£326m
Net Cost to Government	-£2852m	-£2803m	-£3347m	-£3254m	-£3841m
Indicative Level 3 BCR	0.34	0.10	0.08	0.10	0.08
Implied VfM (Incl. Level 3 Impacts)	Poor	Poor	Poor	Poor	Poor

*Table 15 Appraisal results for AVRT options, **High** growth, 2010 PV (£m)*

AVRT options, High growth	HR2 4tph 'Adult' (for comparison)	AVRT1a '2000pph'	AVRT1a '4000pph'	AVRT2a '2000pph'	AVRT2a '4000pph'
Level 1 Benefits (excl. WEIs)	£973m	£319m	£310m	£404m	£393m
Level 1 & 2 Benefits (incl. WEIs)	£1130m	£399m	£391m	£497m	£487m

AVRT options, High growth	HR2 4tph 'Adult' (for comparison)	AVRT1a '2000pph'	AVRT1a '4000pph'	AVRT2a '2000pph'	AVRT2a '4000pph'
Total Costs	-£3431m	-£3154m	-£3704m	-£3697m	-£4290m
Revenue	£705m	£439m	£446m	£555m	£563m
Net Cost to Government	-£2726m	-£2715m	-£3258m	-£3142m	-£3728m
Level 1 BCR	0.36	0.12	0.10	0.13	0.11
Level 2 BCR	0.41	0.15	0.12	0.16	0.13
Inclusion of Level 3 Impacts					
Land value uplift	£281m	£281m	£281m	£281m	£281m
DD Revenue	£1282m	£1242m	£1251m	£1209m	£1214m
Indirect Tax Loss	-£174m	-£177m	-£178m	-£172m	-£173m
Move to more/less productive jobs	£454m	£454m	£454m	£454m	£454m
Total Benefits	£1692m	£958m	£948m	£1060m	£1049m
Net Cost to Government	-£1444m	-£1473m	-£2007m	-£1934m	-£2514m
Indicative Level 3 BCR	1.17	0.65	0.47	0.55	0.42
Implied VfM (Incl. Level 3 Impacts)	Low	Poor	Poor	Poor	Poor

170. The table below summarises the costs and benefits for the AVRT option 1a, 2000 pph scheme (including a version with an optimistic cost estimate) compared to heavy rail option 2 (HR2) 4tph. Appendix B presents the 4 main AVRT options considered with a further detailed breakdown of benefits and costs. Most of the benefits and revenues estimated for AVRT are lower than for heavy rail. This is due to AVRT generating less demand on longer distance journeys as a result of the interchange penalty at Bedford St Johns, in addition to the additional time to change vehicles. AVRT produces a higher level of demand for short-distance journeys around Cambridge. However, the overall effect of is a net reduction in monetised impact.

171. If we reference the optimistic estimate position into this analysis, including the upgrade to MVL and Electrification, then the result is improved, but still not competitive relative to Heavy Rail.

*Table 16 Appraisal results for AVRT options, **High** growth, 2010 PV (£m) alonside the optimistic estimate*

	High Growth 2010 PV		
	HR2 4tph lower bound	AVRT 1a 2000pph	AVRT 1a 2000pph Optimistic Estimate
Level 1 & 2 Benefits (incl. WEIs)	**£1,130**	**£399**	**£399**
Total Costs	**-£3,431**	**-£3,154**	**-£2,811**

Revenue	**£705**	**£439**	**£439**
Net Cost to Government	**-£2,726**	**-£2,715**	**-£2,372**
Level 1 BCR	**0.36**	**0.12**	**0.14**
Level 2 BCR	**0.41**	**0.15**	**0.17**
Inclusion of Level 3 Impacts			
Land value uplift	**£281**	**£281**	**£281**
DD Revenue	**£1,282**	**£1,242**	**£1,242**
Indirect Tax Loss	**-£174**	**-£177**	**-£177**
Move to more/less productive jobs	**£454**	**£454**	**£454**
Total Benefits	**£1,692**	**£958**	**£958**
Net Cost to Government	**-£1,444**	**-£1,473**	**-£1,130**
Indicative Level 3 BCR	**1.17**	**0.65**	**0.85**

172. The Level 1 Benefits of the AVRT are lower than for heavy rail. This is a combination of lower business user benefits, and the absence of freight benefits.

173. AVRT introduces an interchange penalty at Bedford St Johns. This results in fewer journeys on flows such as Woburn Sands to Cambridge, as well as significantly lower journey time saving benefits for passengers that continue to travel across Bedford. For a 50-mile journey, this interchange penalty is equivalent to 25 minutes for a passenger on an 'Anytime' ticket, in addition to time spent interchanging. This is a significant reduction in benefit compared to heavy rail for cross-Bedford journeys.

174. Business valuation of journey time increases with distance. As a result, it could be up to 5 times higher than commuting, and up to 10 times higher than leisure travel for journeys beyond 200 km. Businesses highly value journey time reductions on long distance journeys as it reduces the costly elements of business travel including overnight accommodation and evening meals. By introducing an interchange, long-distance journeys are less attractive, which reduces business valuation of time. This reduces the business user benefits by approximately half (see detailed appraisal results).

8.4 Freight

175. AVRT does not accommodate rail freight. Heavy rail provides an opportunity for 2 additional freight trains per day in each direction on the GB rail network without any additional infrastructure off the EWR network. This has a modelled benefit of £268m PV. Emerging work in partnership with Network Rail suggests that there is the potential to operate up to 15 additional freight trains per day in each direction on the GB rail network with additional off-EWR network interventions, with a modelled benefit up to £1,800m PV for approximately £384m of capital costs for freight interventions off-network.

176. Freight benefits derive from operating additional trains from the Port of London and the Port of Tilbury to freight distribution centres in the West Midlands, East Midlands, Lancashire, and Yorkshire. These trains can operate in paths on the North London Line vacated by diverting trains from the Port of Felixstowe to these destinations via East West Rail.

177. This requires a continuous rail connection between Cambridge, Bedford, and Bletchley, where trains can then join the Midland Main Line and West Coast Main Line. AVRT would not provide this opportunity.

178. AVRT does not deliver rail freight benefits as freight trains cannot share the same alignment as AVRT. This produces a reduction in Marginal External Costs compared to a heavy rail option, which also contributes to lower Level 1 Benefits.

179. AVRT1a truncates the Cambridgeshire Guided Busway at Histon. This results in a £128m reduction in Level 1 Benefits due to a longer journey time into Cambridge or requiring a change onto AVRT.

180. AVRT options generate lower revenue than Heavy Rail because of fewer long-distance trips with high yields (fares), while producing more short-distance trips with low yields (fares). The overall impact is large reduction in revenue, from approximately £700m PV to approximately £450-£550m PV.

181. Agglomeration and Output Change in Imperfectly Competitive Markets, which are both 'Level 2' Wider Economic Benefits, are approximately half when compared to heavy rail. This is because they are linked to long distance inter-regional connectivity.

182. Level 1 benefits do not include dependent development. This is because residents who live in houses built by the railway cannot experience a travel time saving if they didn't exist before the railway intervention, and do not result in road congestion impacts if the car journeys did not exist before the railway intervention. The higher accessibility is instead represented in the land value uplift as a "Level 3" Wider Economic Benefits. The Core section where AVRT generates the most demand compared to heavy rail is very weighted towards dependent development, which does not have transport benefits associated. Dependent Development revenue is marginally lower than for heavy rail. Trips associated with dependent development in Winslow on the Western section are unaffected, while those associated with Winslow and Ridgmont on the Central MVL section are slightly reduced as through journey opportunities to Cambridge are not so attractive due to the interchange at Bedford. On the Bedfrod to Cambridge section, Dependent development revenue from Tempsford to London is unaffected as neither HR2 nor AVRT would impact this flow. Cambourne to London is marginally improved by AVRT.

183. The total appraised costs of AVRT are lower than HR2 for AVRT1a '2000 pph' and higher than HR2 for all other options. Although capital costs and operating costs are broadly comparable to or slightly cheaper than HR2, the Optimism Bias applied to AVRT is higher. The higher level of Optimism Bias reflects that Heavy Rail is over a 150-year-old technology with operational deployments in a Southeast England environment, where challenges are well known. We have used a capital cost optimism bias of 90% for the infrastructure elements of AVRT, and 200% for the AVRT vehicles, the riskier elements of the appraisal. A sensitivity test has been undertaken to understand the impact of lower optimism bias for vehicles purchases once the technology has been proved (still assuming a 200% for the first purchase of vehicles but a reduction for subsequent purchases).

8.5 AVRT economic results.

184. HR2 has an indicative Level 3 BCR of 1.17 including wider economic impacts, which suggests 'low' value for money on the DfT Value for Money Guidance. AVRT has a lower BCR for all heavy rail options. The best performing AVRT option in a high growth scenario– AVRT1a '2000 pph' has an indicative Level 3 'BCR' of 0.65 suggesting 'poor' value for money.

185. AVRT1a has a higher BCR than AVRT2a, with Level 3 'BCRs' of 0.65 and 0.47 respectively. AVRT2a has a slightly higher level of benefits as it is quicker and serves Cambridge station, although it also has higher capital and operating costs due to the need to tunnel underneath Cambridge and the higher staff requirements of underground stations.

186. The '2000pph' (20bph, 2-vehicle) options have higher BCRs than the '4000pph' (27bph, 3-vehicle) options. This is primarily driven by operating costs of purchasing and operating a greater number of AVRT vehicles.

8.6 Sensitivity testing

187. Modelling assumptions around AVRT are particularly uncertain due to novelty of the approach, specifically around costs. Therefore, we have undertaken several sensitivity tests on AVRT1a 20bph covering variations in:

- *On-board staff.* AVRT vehicles are assumed to be driverless under the baseline scenarios, without a member of on-board staff. With this sensitivity we tested having onboard staff with a £35,000 salary per year, benchmarked against DLR Customer Service Assistants without a London salary weighting. This reflects the absence of a system in the UK that does not have any on-board staff presence, regardless of whether vehicles themselves are computer-driven.
- *Vehicle cost optimism bias*. The baseline assumption for OB applied to vehicles cost in capex is 200% for each generation of AVRT vehicles. Under this appraisal run, we have tested a lower OB of 61% for the 2nd through 6th purchase of vehicles to represent a potential future where subsequent generations of vehicles are less risky than the first generation.
- *Earlier Entry into Service*. The baseline assumption is that the CS2 electrified services run from December 2028 with the first phase of the AVRT entering into service in December 2035. Under this test, we assumed AVRT would start straight away from December 2028. This represents the possibility of an accelerated development of AVRT as a new technology that could be delivered at the same time as a comparative heavy rail solution.

188. Table 17 summarises the results of the sensitivity testing on AVRT 1a 2000pph under base growth. Table 18 illustrates the same sensitivities run on high growth scenarios. The impact on both growth scenarios is similar.

- Driver sensitivities impact on the total cost of the AVRT options as drivers' salaries are incorporated in the operating costs increasing the total costs by circa £240-300m and hence leading to a slight NPV deterioration.

- Lower vehicle cost OB for second purchase of vehicles onwards mainly leads to a reduction in capex by £52m, and improves construction disbenefits dependent on capex by £4m.
- Earlier entry into service of AVRT results in a lower level of discounting on both costs and benefits. The effect on the benefits is slightly lower for costs than benefits which reduces NPV slightly.

*Table 17 AVRT1a 2000pph Sensitivities, **Base** growth, 2010 PV (£m)*

AVRT options, Base growth	AVRT1a '2000pph' Baseline	On-board staff	Lower Vehicle cost OB	Earlier EiS
Level 1 Benefits (excl. WEIs)	£206m	£206m	£210m	£215m
Level 1 & 2 Benefits (incl. WEIs)	£269m	£269m	£273m	£283m
Total Costs	-£3154m	-£3455m	-£3102m	-£3583m
Revenue	£352m	£352m	£352m	£398m
Net Cost to Government	-£2803m	-£3104m	-£2751m	-£3184m
Level 1 BCR	0.07	0.07	0.08	0.07
Level 1 NPV	-£2596m	-£2897m	-£2541m	-£2970m
Level 2 BCR	0.10	0.09	0.10	0.09
Indicative Level 3 BCR	0.10	0.09	0.10	0.09
Implied VfM (Incl. Level 3 Impacts)	Poor	Poor	Poor	Poor

*Table 18 AVRT1a 2000pph Sensitivities, **High** growth, 2010 PV (£m)*

AVRT options, Base growth	AVRT1a '2000pph' Baseline	On-board staff	Lower Vehicle cost OB	Earlier EiS
Level 1 Benefits (excl. WEIs)	£319m	£319m	£323m	£328m
Level 1 & 2 Benefits (incl. WEIs)	£399m	£399m	£403m	£414m
Total Costs	-£3154m	-£3455m	-£3102m	-£3582m
Revenue	£439m	£439m	£439m	£490m
Net Cost to Government	-£2715m	-£3016m	-£2663m	-£3093m
Level 1 BCR	0.12	0.11	0.12	0.11
Level 1 NPV	-£2396m	-£2697m	-£2340m	-£2765m
Level 2 BCR	0.15	0.13	0.15	0.13
Indicative Level 3 BCR	0.65	0.54	0.68	0.53
Implied VfM (Incl. Level 3 Impacts)	Poor	Poor	Poor	Poor

189. The sensitivities demonstrate that the implied Value for Money rating is unlikely to change with each of the uncertain scheme elements, and heavy rail remains higher value for money than AVRT.

8.7 Risks and limitations of the study

190. There are several risks associated with the application of AVRT to EWR, described in the following paragraphs.

191. The concept solution may not work to achieve the outcomes proposed. The concepts proposed may work individually, but there is not yet an integrated design concept that proves all the attributes are attainable. For example, fitting all the necessary equipment and people into the vehicle in the size claimed, making it work as a system, with the footprint claimed for the cost and time promoted. Much more work by a dedicated team would be necessary to model the system and verify it.

192. This would be a first of a kind project to develop both a technology solution and an application of that to create a transport network. The technology solution needs research, development, prototyping and testing prior to an investment case being sustainable. The learning points from several major programmes is that combining technology development risk and major programme delivery is highly risky by the Infrastructure Project Authority guidance. Normally technology development should be sponsored offline of a major programme, proven, and then deployed once the risk is reduced.

193. The accuracy and redundancy of the guidance system determines the width of the infrastructure footprint. This has not been studied, nor a Failure Modes Effects Analysis undertaken, therefore the validity of the concept is uncertain.

194. The system reliability in inclement weather conditions is indeterminate. Given the narrow carriageway, snow conditions would quickly lead to compacted ice forming, which would impact guidance, braking distances and hence safe speeds.

195. The processes and activities required to stand up a new transport mode are novel so may be subject to additional activities not identified by the authors of this report, as there is a natural limitation on the knowledge and experience of EWR Company and its supply chain configured for developing a railway.

196. Whilst it is heuristically true that a narrower vehicle and infrastructure must be proportionally cheaper, this may not be offset by the reduction in passenger experience, comfort, and corresponding usable space within the vehicle. This would require ergonomic assessment and mock-ups to test.

197. The chosen alignment for AVRT that connects into Bedford is the old Varsity Line. Given the time that has passed since the existing Varsity Line was decommissioned and its transition to amenity space and habitat, there are significant environmental considerations if it were to return to being an active railway line or AVRT route. Primarily, the key constraints associated with this area are the protected status of open space land in and surrounding Priory Park, the proximity to and extent of route within flood zone areas, the presence of scheduled ancient

monuments along and nearby to the route and the extent of potentially priority and high value habitat which could be lost. In addition, parts of the existing line around Blunham have had been subject to residential development, which could be at risk of demolition or require diverting the railway around this area. The environmental impacts have not been appraised for AVRT. It is noted this risk only applies if AVRT is a preferred mode, and further development maintains this alignment as preferred. This risk also affects a heavy rail alignment approaching Bedford from the east.

198. Although AVRT is a new transport mode, with elements akin to heavy rail and guided busway, it seems likely that it would be promoted under the Transport and Works Act 1992. The presence of open space on alignments 1a and 2a, which is potentially subject to restrictions on acquisition that are more stringent under the 1992 act than under the Planning Act 2008. Other application means may also be possible, and this would require consideration in due course. Those alignments also carry the same risk as for other modes.

199. AVRT Option 2a will involve tunnelling under Cambridge, a sensitive area for heritage and archaeology, which carries the risk of discerning ancient artefacts and therefore a significant delay to the construction programme. In addition, there will need to be access ground level for stations, emergency egress and ventilation shafts, which may attract objections to the scheme.

200. Legislative changes may be required in relation to permitted guideway technology. This concerns the application of Railways or Other Guided Transport Systems Regulations or the Transport and Works Act that may require amendment to enable guidance by non-physical means. This may result in programme delays and a subsequent potential impact on the pace of dependent development. We have assumed these changes do not impact the entry into service date which is driven by the technology development programme.

9 Affordable Connections Sifting Process

201. This Chapter applies the Affordable Connection sifting process (as set out in the main report) to the AVRT options generated to achieve a decision.

202. To ensure consistency with the process undertaken to select shortlisted options for ACP, we have applied the same sifting processes to AVRT.

203. The initial longlisting sift was to apply a credibility test, followed by an affordability test. As stated in the introduction to this report, the novel nature of AVRT as a new transport mode would otherwise have discounted it as a viable option at this stage. However, given its asserted potential to deliver high-capacity services at a lower capital cost than heavy rail, the decision was to develop the concept and subject it to assessment, in this report. Therefore, AVRT was assumed to have passed both the credibility and affordability tests for the purposes of this report.

204. The next stage was the Strategic Sift which considered the following parameters

- Strategic Need – Does it connect the right places?
- Strategic Need – Does it attract enough demand?
- Strategic Need – Does it have enough capacity to meet that demand?
- Is it attractive to users?

205. Assessment factors have not been used, as there are applied to shortlisted options only at the later stage.

206. It is expected that an AVRT system could be constructed to connect Cambridge and Bedford and enables onward journeys with an interchange at Bedford. It could also be capable of attracting demand, particularly for the shorter journeys within the eastern section, and it demonstrably has sufficient capacity to meet demand.

207. As we have noted above, the service could be attractive to passengers for shorter journeys on the eastern section, but less so for through journeys to and from the central section, due to the interchange penalty and queuing issues at Bedford St. Johns. Option 1A would also require an interchange at Cambridge North to access central Cambridge. There are similar heavy rail issues with approaching Cambridge from the north.

208. AVRT has been assumed to pass the Strategic Need Sift and the Attractiveness Sift for journeys on and within the eastern section but would arguably fail on both counts when considering connectivity along the entire EWR route. This is consistent with the conclusion in Chapter 3 that AVRT performs best on short journeys with high demand and high frequencies, but less well over longer distances and where there is a requirement to interchange with a high vehicle capacity-lower frequency service.

209. It has been demonstrated in the Economic appraisal above, in comparison to other best performing modes and options, that AVRT does not outperform other options. The demand is weaker and [hence?] the benefits are weaker than Heavy Rail as a mode. Other AVRT

alignment options may be proportionally more expensive to construct or have slower journey time and hence even [fewer/lower] benefits. Within the framework of the Affordable Connection Project terms of reference and assessment criteria AVRT does not progress to the shortlisted Option stage of the Affordable Connections Main Report.

210. Notwithstanding the range of cost estimate, with AVRT probably being cheaper than heavy rail, the benefits are not as significant as heavy rail options. As such, it is concluded that Heavy Rail options are preferred and AVRT does not progress past the sift as an option for EWR. Hence AVRT is not Shortlisted.

10Development opportunities for AVRT

211. In this Chapter the opportunities are identified for adding value to the concept development, aside from application to East West Rail's scenario. This may apply to Connected and Autonomous Vehicles Mass Transit Solutions (CAM), as well as AVRT. It aims to answer the question: "If deployment on EWR is not viable, where could AVRT be installed successfully?" This Chapter is speculative and does not represent a considered view of other applications. It uses our learning from this study and indicates the circumstances that may suit CAM deployment.

10.1 General

212. The content of this chapter are not considered to be relevant to the decision as to whether to progress AVRT further for EWR. Whatever the benefits of AVRT that might accrue as a result of its deployment in another context, these are not material to EWR, in respect of which the benefits of AVRT have to be compared with those of other modes.

213. The Centre for Connected and Autonomous Vehicles, the Department for Transport and its partners are investing in feasibility studies of non-rail Connected and automated mass transit on segregated routes. The Future of Mobility Strategy published on www.gov.uk sets out the aspiration, and subsequent work is ongoing developing the policy, strategy and its implementation.

214. UK Government should consider sponsoring the promoted, researched, developed, and trialled of Connected and Autonomous Vehicles Mass Transit Solutions. This will allow future transport schemes (such as East Wet Rail, or local authorities) a better developed understanding of the potential for this emerging transport system, enabling feasibility and option selection.

215. This appraisal has identified that AVRT (and by inference automated faster Bus Rapid Transit systems) may provide a capacity with competitive features to light rail and some heavy rail applications in the domain of shorter distance sub-regional and rural-urban transport. There may be a sweet spot of application of this concept. This may be a new transport network development, or an upgrade of an existing Bus Rapid Transit Systems that has the following features:

- A dedicated guideway as a central core of a route.
- A network of routes, through medium dense urban areas, or small to medium nucleus cities and their suburbs that act as feeders of demand, collecting people and moving them through the central core efficiently
- The optional ability to run on roads to collect passengers and lower the total cost of the system, whilst integrating the network and reaching centres of employment and residence.

216. This study did not consider the Use Case of running automated buses on the highway network, as the scenario was to create high reliability and frequency and this required independence of the network, not being impacted by traffic delays. This was considered as a separate scheme in Affordable Connection Project sifting.

217. The business case of AVRT relies on automation of a system reducing the operational expenditure, as capacity is generated by high frequency multiple vehicles. This is only economic if they are without a driver (or other full time on board staff), , assuming revenue protection is assured. Developing and proving the automation is necessary before scaling up investment in a scheme. The technologies of automated driving and digitally coupling vehicles into convoys could be developed that can be fitted to regular width buses as well as AVRT narrow types.

218. Whilst assessing the potential AVRT has, the team has found that for other applications (geographical or scenario), this mode (and Automated Guided Busways more generally) could be competitive as a transport system against Light Rail and Heavy Rail. This may be particularly applicable to some of the following features:

- A concentrated population provides a high level of demand that can be met with a frequent and high-capacity transport solution;
- That urbanised area may have constraints that favour tunnelling (mountainous or environmentally constrained) that enables direct connections enabled by AVRT’s narrower cross section; this has a significant cost advantage over other modes;
- Higher attainable speeds of 75-100 mph are necessary between more spaced-out stations (typically greater than 2 km apart) than a typical Bus Rapid Transit scheme;
- A service where using AVRT does not mean many more passengers need to interchange with low frequency high capacity transport modes (IE Heavy rail) to complete the journey;
- There is no requirement for container and aggregate freight;
- An implementation timeline that can accommodate a 10-year timeline to establish a production-ready vehicle fleet

219. Several opportunities, summarised below, have been identified where AVRT (or Automated Guided Busways) may be suitable for deployment on a currently planned rail re-opening.

10.2 Wisbech to March, Cambridgeshire

220. This is not a strong candidate for serving journey demand, as the demand is low. However, this could be a potential test site for the technology and systems integration, that leaves a legacy and re-habilitates a disused railway line.

Table 19 Assessment criteria for AVRT for Wisbeach to March

Passengers making short distance trips within an urban area, where a high frequency service is an advantage over longer rail vehicles	✖ 10 mile journey through a rural area
A spread of passengers over time that justifies a high frequency service, so shift changes at a factory or lecture times at a university would <u>not</u> be appropriate	✖ train connections at March
Moderate numbers of passengers making end-to-end trips, so the high capacity offered by a longer train of rail vehicles is not required	✔ 36k people in Wisbech but only 22k in March so may only be a low volume
Low numbers of passengers likely to make intermediate trips, so not having intermediate stations is not a disadvantage	✔
Lengthy sections of tunnelling, to exploit the cost advantage of AVRT over heavy rail and conventional buses	✖
Limited potential benefits from integration with existing services	✖ people in Wisbech would probably like a direct service to Peterborough (181k people) or Cambridge (162k) rather than March only (22k)

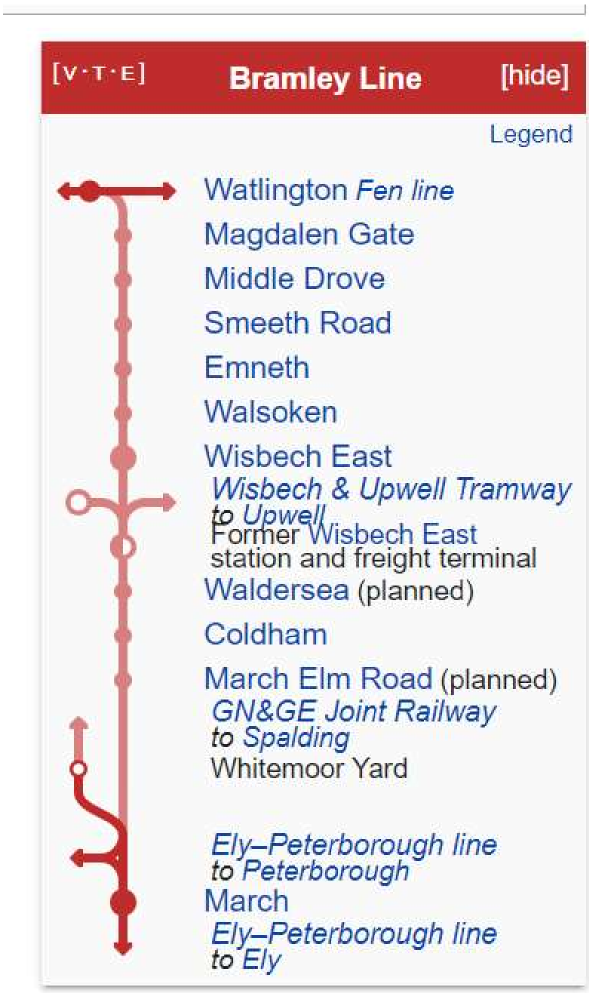

Figure 10-1 The old Wisbeach to March Bramley Line

10.3 Haverhill to Cambridge

Table 20 Assessment criteria for AVRT for Haverhill to Cambridge

Passengers making short distance trips within an urban area, where a high frequency service is an advantage over longer rail vehicles	✘ 20 mile journey through a rural area
A spread of passengers over time that justifies a high frequency service, so shift changes at a factory or lecture times at a university would not be appropriate	✔ potentially some train connections but okay for local trips
Moderate numbers of passengers making end-to-end trips, so the high capacity offered by a longer train of rail vehicles is not required	✔ 27,000 people in Haverhill, 162k people in Cambridge
Low numbers of passengers likely to make intermediate trips, so not having intermediate stations is not a disadvantage	✔
Lengthy sections of tunnelling, to exploit the cost advantage of AVRT over heavy rail and conventional buses	✘ a rural area; a heavy rail service could use the rail alignment instead

Limited potential benefits from integration with existing services	✔

Figure 10-2 Schematic conceptual service, from Cambridge Autonomous Metro study

10.3 Leek to Stoke

Table 21 Assessment criteria for AVRT for Leek to Stoke

1.1 Passengers making short distance trips within an urban area, where a high frequency service is an advantage over longer rail vehicles	1.2 ✘ 12 miles
1.3 A spread of passengers over time that justifies a high frequency service, so shift changes at a factory or lecture times at a university would not be appropriate	1.4 ✔ potentially some train connections
1.5 Moderate numbers of passengers making end-to-end trips, so the high capacity offered by a longer train of rail vehicles is not required	1.6 ✔ 20,000 people in Leek, 385k in Stoke
1.7 Low numbers of passengers likely to make intermediate trips, so not having intermediate stations is not a disadvantage	1.8 ✘ Stoke-on-Trent is a dispersed urban area (of five towns) and you would probably want to serve some trips within the city
1.9 Lengthy sections of tunnelling, to exploit the cost advantage of AVRT over heavy rail and conventional buses	1.10 ✘ the railway line did not have tunnels but Stoke is quite hilly
1.11 Limited potential benefits from integration with existing services	1.12 ✔

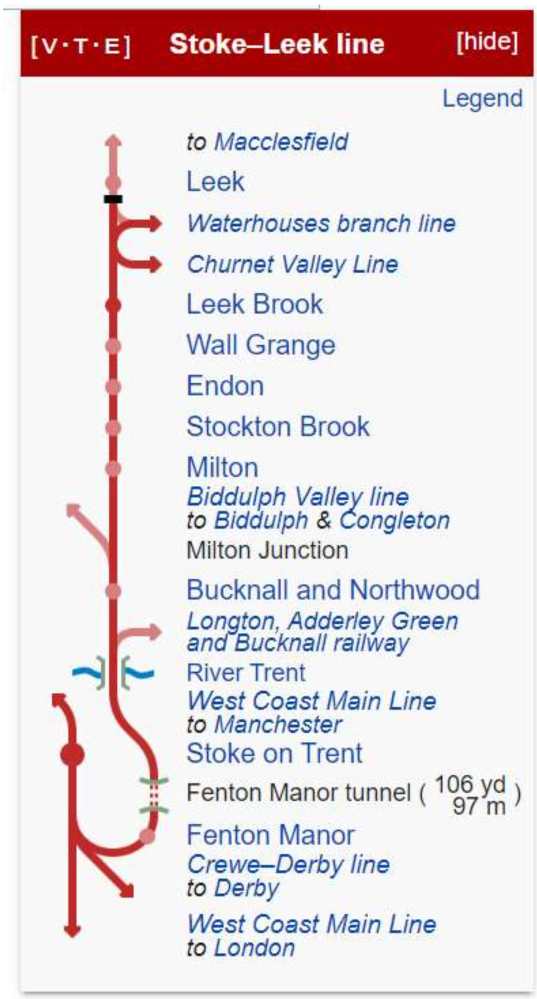

Figure 10-2 Leek to Stoke Line reducndant railway schematic

10.4 UK wide Bus Rapid Transit schemes

221. Retro fit could potentially be undertaken to any of the existing Bus Rapid Transit systems in use in the UK with automation. This would depend on individual scheme undertaking benefits analysis. See Figure 10-3 Bus Rapid Transit schemes in UK.

Figure 10-3 Bus Rapid Transit schemes in UK

222. The Cambridge Autonomous Metro has been investigated by the Cambridgeshire and Peterborough Authority, and reported elsewhere, EWR offers no comment on this study. The AVRT concept was considered for the scheme within an option selection report. Readers are referenced to that report on Greater Cambridge Partnership website.

10.5 Scheme for Milton Keynes

223. See Figure 10-4 for the concept service

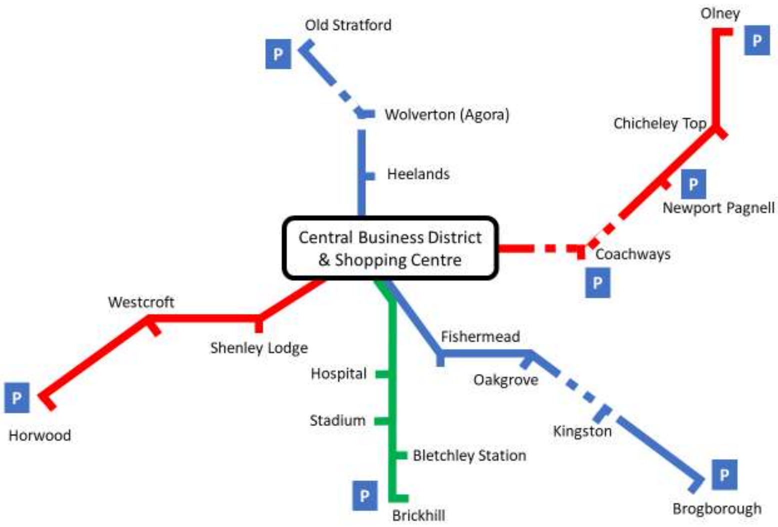

Figure 10-4 Indicative AVRT Layout for Milton Keynes (tunnelled sections shown dotted)

10.6 Scheme for Oxford

224. See **Error! Reference source not found.**for the concept service

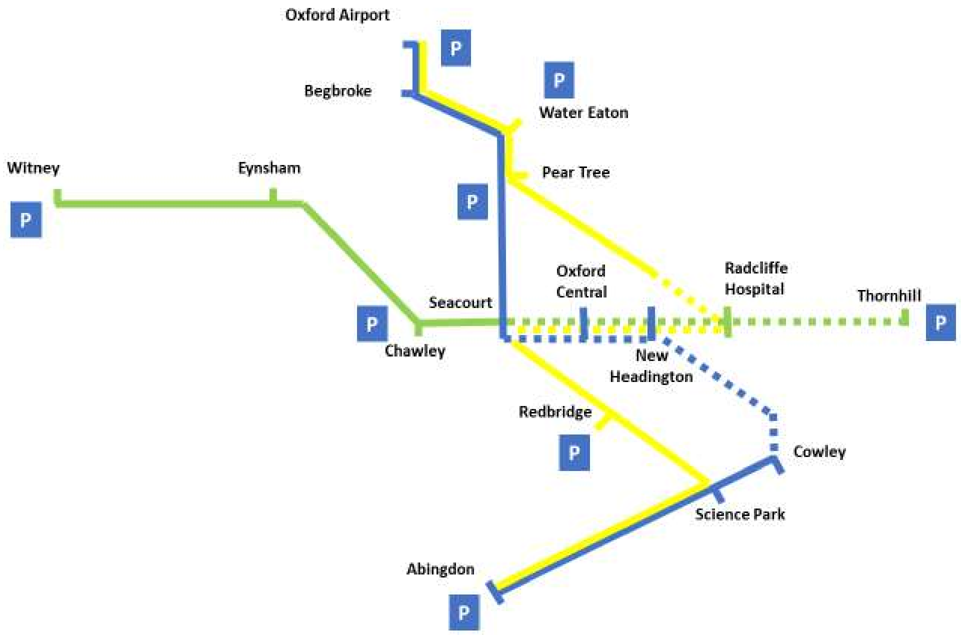

Figure 10-5 Indicative AVRT Layout for Oxford (tunnelled sections shown dotted)

11 Findings and Conclusions

225. This paper defines what an Advanced Very Rapid Transit system is, assesses the characteristics of it and what circumstances suit the concept. Advanced Very Rapid Transit (AVRT) is a system concept comprising a fleet of automated vehicles that travel on a dedicated guideway which would carry passengers between stations. The concept is applied to the East West Rail scenario and appraised for the service it may provide, the journeys it may generate as demand, and hence the possible range of benefits and costs.

226. AVRT may have the potential to be an effective high-capacity transport mode in particular conditions. It may be particularly suited to an urban environment, providing a rapid transit system with high frequencies over short journeys. In constrained urban environments, where the impact of new route creation is high, such as EWR, it offers the cost effectiveness of narrow diameter tunnelling, which in some circumstances may offer advantages over other modes of transport; namely rail.

227. The lead times to establish a production ready vehicle fleet and operations ready system is between 5 to 10+ years. Investment prior to this would take significant risk on the automation being proven safe (not requiring drivers) and thus validating the business case. Stakeholder expectations in the Arc are high and the Cambridge economy is already overheating, suppressing growth potential of the local economy. This time risk to delivery (which is additional to heavy rail) appears not to meet the aspirations for unlocking transformative growth post Brexit.

228. Four different scenarios of AVRT were developed against normal and high growth scenarios along two alignments, AVRT1a and AVRT2a.

229. Within the limitations of the study, a position of agreed cost of the scheme options between the promoter of the system and East West Rail was not achieved. Both positions represent optimism and pessimism respectively. The uncertainty and broad range of cost outcomes have been modelled. In the best case scenario for AVRT it may be up to 50% cheaper in Base Construction Cost than heavy rail, but in the worst case (for AVRT) scenario may cost more than the best case heavy rail scenario if risks are realised.

230. AVRT is not found to be a more advantageous transport solution for the requirements of the Oxford to Cambridge Theory of Change, which values easier, faster journeys over longer distances. A mixed mode system would create imbalance between service frequencies and the disincentive of interchange penalties making longer distance journeys less attractive. The creation of an interchange with Heavy Rail services at Bedford St Johns station would act as a disincentive for passengers due to the additional inconvenience, passenger congestion and longer journey times, which is quantified in the modelling method, and reflected in the valuation of the benefits.

231. AVRT could perform better over shorter distances but less well than Heavy Rail across the entire EWR route. The economic appraisal for both options indicates a lower Benefit Cost ratio than Heavy Rail, with materially lower benefits. This is because the significant generation of shorter distance journeys around Cambridge does not mitigate the loss in longer distance journeys across the Ox-Cam arc.

232. AVRT1a is likely to be lower cost than other options, but with significantly lower benefit. When assessed with the MVL upgrade and an electric timetable, AVRT Benefit Cost Ratio is less than Heavy Rail. An appraisal of the AVRT scheme in isolation of an upgrade of the MVL was not conducted, as this does not achieve the growth potential and connections that are the aim of East West Rail.

233. The lower appraised costs of AVRT1a do not outweigh the materially reduced benefits from terminating short at Cambridge North station. AVRT1a has significant impact on the existing guided busway operation, which reduces the benefits to Cambridge, and which would be where cost savings could be made relative to new corridor construction.

234. AVRT2a has higher appraised costs (capital and operating costs combined) than Heavy Rail because Heavy rail can access Cambridge without the need for tunnelling, at proportionally lower cost. The costs and benefits of tunnelling into central Cambridge are not justified by the alternative of connecting into the railway corridors.

235. AVRT is unable to provide for ISO container and aggregate freight.

236. Any further work on developing a refined proposition of AVRT falls outside the Terms of Reference of Affordable Connections, and the Sponsons Requirements for East West Rail. There may be other imperatives from the Department for Transport to investigate transport innovation, utilising this Use Case as a study.

12Appendix A: AVRT operating costs

Table A.1 Table of cost assumptions

Assumption	AVRT1a 2,000 pax	AVRT1a 4,000 pax	AVRT2a 2,000 pax	AVRT2b 4,000 pax
Infrastructure optimism bias	Low: +59% High: +121%			
Vehicle requirement	68	140	68	140
Vehicle cost point estimate (2021 prices)	£500,000			
Vehicle capital cost optimism bias	Core: 200% for all purchases throughout appraisal period Sensitivity: 200% for 1st purchase, 61% for 2nd-6th purchase			
Vehicle operating cost optimism bias	41%			
Vehicle lifespan	10 years			
§Service length in number of vehicles	2	3	2	3
Service start time	05:30			
Service end time	23:30			
Driver salary (2021 prices)	£0 £28,000 (low) + NI and pensions £35,000 (high) + NI and pensions			
Non-driver staff costs per year (2021 prices)	£4,310,000 + 35%			
Traction power per AVRT vehicle	2kWh/km			
Vehicle maintenance costs	£20,000 per vehicle per year			
Infrastructure maintenance costs	Not provided. Cost of re-laying tarmac on road, once every 10 years treated as recurring capex.			

More information on cost assumptions and estimates can be found in the AVRT Cost Estimate record. All pertinent information is in this report in summary.

13Appendix B: Detailed appraisal results

Table B.1: Detailed appraisal results for AVRT options, **Base** growth, 2010 PV (£m)

	HR2 4tph 'Adult' (for comparison)	AVRT1a '2000pph'	AVRT1a '4000pph'	AVRT2a '2000pph'	AVRT"a '4000pph'
Revenue	£579m	£352m	£357m	£443m	£449m
Capex	-£2112m	-£2268m	-£2691m	-£2704m	-£3163m
Opex	-£973m	-£659m	-£755m	-£713m	-£813m
Whole life costs	-£358m	-£229m	-£259m	-£281m	-£315m
Road Infrastructure	£12m	£1m	£1m	£1m	£1m
Broad Transport Budget	**-£2852m**	**-£2803m**	**-£3347m**	**-£3254m**	**-£3841m**
Congestion	£434m	£113m	£115m	£145m	£148m
Indirect taxation	-£138m	-£59m	-£60m	-£74m	-£75m
Rail Greenhouse Gases	£20m	£21m	£21m	£21m	£21m
Accident	£22m	£12m	£12m	£15m	£16m
Local Air Quality	£3m	£2m	£2m	£2m	£2m
Noise	£5m	£1m	£1m	£1m	£1m
Car Greenhouse Gases	£55m	£11m	£12m	£15m	£15m
Energy Fixed Cost Savings	£27m	£33m	£47m	£34m	£49m
Construction disbenefits	-£150m	-£162m	-£192m	-£193m	-£225m
Air Quality: NOx	£12m	£12m	£12m	£12m	£12m
Air Quality: PM	£3m	£3m	£3m	£3m	£3m
Terminated busway disbenefits	-	-£128m	-£128m	-£128m	-£128m
Total VoT impact	£431m	£294m	£298m	£338m	£342m
Commute	*£181m*	*£139m*	*£141m*	*£162m*	*£164m*
Business	*£84m*	*£40m*	*£40m*	*£43m*	*£44m*
Leisure	*£166m*	*£115m*	*£117m*	*£132m*	*£134m*
User Charge benefits	£101m	£54m	£54m	£74m	£74m
Commute	*£30m*	*£17m*	*£17m*	*£23m*	*£23m*
Business	*£7m*	*£3m*	*£3m*	*£5m*	*£5m*
Leisure	*£65m*	*£34m*	*£34m*	*£46m*	*£47m*
L1 Benefits	**£826m**	**£206m**	**£196m**	**£265m**	**£254m**
L1 NPV	**-£2026m**	**-£2596m**	**-£3150m**	**-£2989m**	**-£3587m**
L1 BCR	**0.29**	**0.07**	**0.06**	**0.08**	**0.07**
Category	Poor	Poor	Poor	Poor	Poor

	HR2 4tph 'Adult' (for comparison)	AVRT1a '2000pph'	AVRT1a '4000pph'	AVRT2a '2000pph'	AVRT"a '4000pph'
Agglomeration	£121m	£58m	£59m	£66m	£67m
OCIICM	£9m	£4m	£4m	£5m	£5m
Labour Supply Market	£1m	£1m	£1m	£1m	£1m
L2 Wider Economic Benefits	£132m	£63m	£64m	£71m	£72m
L2 Benefits	**£958m**	**£269m**	**£260m**	**£337m**	**£326m**
L2 NPV	**-£1894m**	**-£2533m**	**-£3087m**	**-£2918m**	**-£3515m**
L2 BCR	**0.34**	**0.10**	**0.08**	**0.10**	**0.08**
Category	Poor	Poor	Poor	Poor	Poor
Revenue from dependent development	-	-	-	-	-
L3 Broad Transport Budget	**-£2852m**	**-£2803m**	**-£3347m**	**-£3254m**	**-£3841m**
Indirect taxation from revenue	-	-	-	-	-
L2 Wider Economic Benefits	£132m	£63m	£64m	£71m	£72m
L3 Move to More Productive Jobs	-	-	-	-	-
L3 Land Value Uplift	-	-	-	-	-
L3 Benefits	**£958m**	**£269m**	**£260m**	**£337m**	**£326m**
L3 NPV	**-£1894m**	**-£2533m**	**-£3087m**	**-£2918m**	**-£3515m**
Level 3 "BCR"	**0.34**	**0.10**	**0.08**	**0.10**	**0.08**

Table B.2: Detailed appraisal results for AVRT options, **High** growth, 2010 PV (£m)

	HR2 4tph 'Adult' (for comparison)	AVRT1a '2000pph'	AVRT1a '4000pph'	AVRT2a '2000pph'	AVRT"a '4000pph'
Revenue	£705m	£439m	£446m	£555m	£563m
Capex	-£2112m	-£2268m	-£2691m	-£2704m	-£3163m
Opex	-£973m	-£659m	-£755m	-£713m	-£813m
Whole life costs	-£358m	-£229m	-£259m	-£281m	-£315m
Road Infrastructure	£12m	£1m	£1m	£1m	£1m
Broad Transport Budget	**-£2726m**	**-£2715m**	**-£3258m**	**-£3142m**	**-£3728m**
Congestion	£472m	£140m	£142m	£181m	£184m
Indirect taxation	-£158m	-£73m	-£74m	-£92m	-£93m
Rail Greenhouse Gases	£20m	£21m	£21m	£21m	£21m
Accident	£26m	£15m	£15m	£19m	£19m
Local Air Quality	£4m	£2m	£2m	£3m	£3m

	HR2 4tph 'Adult' (for comparison)	AVRT1a '2000pph'	AVRT1a '4000pph'	AVRT2a '2000pph'	AVRT"a '4000pph'
Noise	£6m	£1m	£1m	£1m	£1m
Car Greenhouse Gases	£59m	£14m	£14m	£18m	£18m
Energy Fixed Cost Savings	£27m	£33m	£47m	£34m	£49m
Construction disbenefits	-£150m	-£162m	-£192m	-£193m	-£225m
Air Quality: NOx	£12m	£12m	£12m	£12m	£12m
Air Quality: PM	£3m	£3m	£3m	£3m	£3m
Terminated busway disbenefits	-	-£128m	-£128m	-£128m	-£128m
Total VoT impact	£533m	£377m	£382m	£439m	£443m
Commute	*£225m*	*£177m*	*£180m*	*£208m*	*£210m*
Business	*£100m*	*£50m*	*£51m*	*£57m*	*£58m*
Leisure	*£208m*	*£149m*	*£151m*	*£173m*	*£175m*
User Charge benefits	£119m	£63m	£64m	£85m	£86m
Commute	*£35m*	*£20m*	*£20m*	*£26m*	*£27m*
Business	*£8m*	*£4m*	*£4m*	*£5m*	*£5m*
Leisure	*£76m*	*£40m*	*£40m*	*£54m*	*£54m*
L1 Benefits	**£973m**	**£319m**	**£310m**	**£404m**	**£393m**
L1 NPV	**-£1753m**	**-£2396m**	**-£2948m**	**-£2738m**	**-£3334m**
L1 BCR	**0.36**	**0.12**	**0.10**	**0.13**	**0.11**
Category	Poor	Poor	Poor	Poor	Poor
Agglomeration	£145m	£74m	£75m	£86m	£87m
OCIICM	£11m	£5m	£6m	£6m	£6m
Labour Supply Market	£2m	£1m	£1m	£1m	£1m
L2 Wider Economic Benefits	£157m	£80m	£81m	£93m	£94m
L2 Benefits	**£1130m**	**£399m**	**£391m**	**£497m**	**£487m**
L2 NPV	**-£1596m**	**-£2316m**	**-£2868m**	**-£2645m**	**-£3241m**
L2 BCR	**0.41**	**0.15**	**0.12**	**0.16**	**0.13**
Category	Poor	Poor	Poor	Poor	Poor
Revenue from dependent development	£1282m	£1242m	£1251m	£1209m	£1214m
L3 Broad Transport Budget	**-£1444m**	**-£1473m**	**-£2007m**	**-£1934m**	**-£2514m**
Indirect taxation from revenue	-£174m	-£177m	-£178m	-£172m	-£173m
L2 Wider Economic Benefits	£157m	£80m	£81m	£93m	£94m
L3 Move to More Productive Jobs	£454m	£454m	£454m	£454m	£454m

	HR2 4tph 'Adult' (for comparison)	AVRT1a '2000pph'	AVRT1a '4000pph'	AVRT2a '2000pph'	AVRT"a '4000pph'
L3 Land Value Uplift	£281m	£281m	£281m	£281m	£281m
L3 Benefits	**£1692m**	**£958m**	**£948m**	**£1060m**	**£1049m**
L3 NPV	**£248m**	**-£515m**	**-£1059m**	**-£874m**	**-£1464m**
Level 3 "BCR"	**1.17**	**0.65**	**0.47**	**0.55**	**0.42**

14Appendix C Key differences in AVRT pricing between EWR and Concept Proposer

Item	AVRT 1a 2,000pax (Arcadis)	AVRT 1a 2,000pax (B.E. Cons.)	AVRT 1a 2,000pax (B.E. Cons.)	Comment
Route Length (km)	53	51 (45)	51 (45)	BE estimate assumes use of Cambridge Guided Busway infrastructure for the last 6 km.
Earthworks	£90M	-	£47M	BE estimate for AVRT = earthworks associated with bridge embankments (£32M) & pathway construction (£15M)
Pathway - Civils Works - Lighting - Control Centre & Fibre Cabling	 £220M £27M £17M	 £160M Nil £17M	 £145M Nil £17M	BE estimate for AVRT now excludes excavation (550mm), pathway lighting and footpath/cycleway (reduced width of pathway =6.5m)
Stabling & Maintenance	£62M (2 No)	£20M (1 No)	£20M (1 No)	Arcadis have allowed for 2 No facilities
Stations	£76M (5 No)	£41M (4 No)	£41M (4 No)	Earlier BE estimate for AVRT surface stations uplifted include larger car parks
Viaduct	£62M	£38M (4km)	£38M (4km)	Unclear on length of Arcadis viaduct
Bridges	£181M	£89M (55 No)	£57M (55 No)	BE estimate now excludes earthworks for bridge ramps Unclear on number & type of Arcadis bridges
'Other' Civils	£15M	-	-	Not sure what Arcadis costs refer to.
Balance of Misc. Additional Costs	£31M	-	-	Not sure what Arcadis costs refer to.
DIRECT CONSTRUCTION COST	**£757M**	**£365M**	**£365M**	

11 Appendix 11 - Case Studies

11.1 Silicon Valley Case Study

11.1.1 Known as the tech capital of the world, Silicon Valley is home to thousands of high-tech companies including several high performing large businesses such as HP, Intel, Google, Apple, Cisco, PayPal, Netflix and Adobe. Having raised a significant amount of capital[21], these companies employ over 1.6 million people[22] who earn more and are more productive than the state and US averages.

11.1.2 Like Silicon Valley, the Oxford-Cambridge Arc has a highly skilled workforce, high employment rates and is rooted in academia. With Stanford University in the heart of Silicon Valley, the Oxford-Cambridge Arc is anchored by two world leading universities. These institutions have played a vital role in the growth and prosperity of the respective regions, connecting people with resources to facilitate collaboration and innovation.

11.1.3 However, despite the similarities, Silicon Valley has nearly double the Arc's GVA per employee[23] and the venture capital raised in Silicon Valley remains unrivalled. In 2019 alone, Silicon Valley raised £34.6bn in venture capital and £149.2bn in total capital. The Oxford-Cambridge Arc raised £1.1bn venture capital and £27.4bn total capital in 2019[24] (although due to the pandemic venture capital increased to almost £2.4bn in 2020[25]). As a result, Silicon Valley is more innovative in terms of patents per 100k people, with 693 in 2019[26] compared to 309 in Cambridge, 91 in Oxford and 26 in Milton Keynes[27]. According to the Silicon Valley Innovation Center, as of February 2020 there are 174 unicorns in the San Francisco Bay Area[28], compared to just 11 in Oxbridge[29]. What is special about Silicon Valley is the intense entrepreneurial spirit, the abundance of high-skilled, well-paid talent, combined with ease of access to both funding and knowledge which together creates new ideas that materialise into profitable, high-growth businesses. This allows them to compete internationally.

11.1.4 Silicon Valley's success is challenged by high living costs and the rise of homeworking, which is leading to increasing numbers of staff being recruited from outside the Bay Area. According to

[21] Savills Research (2019). The Oxford-Cambridge Innovation Arc. Savills. Total venture capital investment in Silicon Valley 2019.

[22] Total Number of Jobs and Percent Change Over Prior Year (siliconvalleyindicators.org). Q2 2021 Total Number of Jobs in Silicon Valley.

[23] In 2019, employment (16 and over) in the Arc was 1,930,400 (NOMIS (2021). Annual Population Survey. T01 Economic activity by age. 12 months to December 2004-2020 and Jul 2020-Jun 2021. https://www.nomisweb.co.uk/datasets/apsnew) and the Gross Value Added was £117,316 (ONS (2021). Regional gross domestic product: enterprise regions. Table 1: Enterprise Regions: Gross Value Added (Balanced) [note 1,2] at current basic prices https://www.ons.gov.uk/economy/grossdomesticproductgdp/datasets/regionalgrossdomesticproductenterpriseregions), meaning GVA per employee was £60,772. In Silicon Valley, GVA per employee in 2019 was $250,000 (~£199,000 IN 2022 prices). Source: Value Added Per Employee (siliconvalleyindicators.org)

[24] Savills Research (2019). The Oxford-Cambridge Innovation Arc. Savills.

[25] Bidwells (2022). Radical Capital. Supercharge the Arc.

[26] Patents Per 100,000 People (Table) (siliconvalleyindicators.org)

[27] Centre For Cities: Outlook Data Tool

[28] Silicon Valley Innovation Center (2020). Infographic: Who are the Unicorns of Silicon Valley? https://siliconvalley.center/blog/infographic-unicorns-of-silicon-valley

[29] Dealroom.co (2020). 2019: A record year for VC investment in the UK. https://dealroom.co/uploaded/2020/01/2019-A-record-year-for-VC-investment-in-the-UK.pdf?x84402

Coinbase, it is for these reasons that in the last quarter of 2021 89% of the company's hiring was from outside the Bay Area, compared to just 30% in the first quarter of 2019[30]. Economists at the University of Chicago estimate that roughly 50% of Silicon Valley jobs can be carried out remotely leaving many people to question why they should continue to pay a premium for housing in San Francisco[31]. However, this movement of talent and businesses away from Silicon Valley to cheaper areas such as Austin, has meant that California now underperforms its competitors in many sectors and the share of venture capital in Silicon Valley is falling[32]. Housing problems have also led to worsening inequalities and social tensions in Silicon Valley[33].

11.1.5 To mirror the success of the Silicon Valley and avoid its decline, the Oxford-Cambridge Arc needs to bring talent and resources together to nurture a culture of entrepreneurship and innovation, whilst addressing housing affordability issues to ensure the talent is attracted in the first place, and stays for the long-term. This will enable the Oxford-Cambridge Arc to go from a national leader to an international leader.

"When we survey comparative innovation centres across the world, not least in the U.S., the scale of Oxford and Cambridge is really small. These two cities cannot compete on the world stage in isolation, and so the Arc is needed to bridge these leading clusters to elevate the region's international standing…The Arc benefits from huge inward investment, and an extraordinary number of new enterprises; we can do more with the ingredients we already have"[34].

11.2 Tel Aviv

11.2.1 Tel Aviv is a "beta+" world city – a global city that is a primary node in the global economic network. It has the largest economy per capita in the Middle East and the highest cost of living in the world.[35] Israel's only stock exchange and 40% of the country's finance and banking industry is found in Tel Aviv.[36] The city is the beating heart of Israel's high-tech and information-based industries, home to most of the country's start-ups.

11.2.2 However, poor transport infrastructure in Tel Aviv is a cause of Israel's low productivity when compared to other countries[37]. As in the Oxford-Cambridge Arc, Tel Aviv experiences road congestion, which has become a barrier to agglomeration of businesses and has resulted in GDP loss. On average, road users in Israel lose an hour a day due to traffic, costing 1.5% of annual GDP which equates to approximately $5 billion[38]. Until 2018, the only train connecting Tel Aviv and Jerusalem still used a track built during the Ottoman Empire, with the 35-mile

[30] The Financial Times (2022). San Francisco is scaring away the tech crowd.

[31] Kotkin (2022). The Flight of Big Tech. The Scroll.

[32] Kotkin (2022). The Flight of Big Tech. The Scroll.

[33] Financial Times (2022). San Francisco is scaring away the tech crowd. Financial Times

[34] Bidwells (2022). Radical Capital. Supercharge the Arc.

[35] https://en.wikipedia.org/wiki/Tel_Aviv#:~:text=Tel%20Aviv%20has%20the%20third,2.5%20million%20international%20visitors%20annually.

[36] https://english.tau.ac.il/tel_aviv_global_city

[37] https://www.runi.ac.il/media/yc5nbvol/economic_effects_of_investment_in_a_metro_system.pdf

[38] https://www.reuters.com/article/us-israel-infrastructure-idUSKCN1NX1AI

journey between Israel's two largest cities taking nearly two hours. Such long journey times between major cities also remains a reality in the Arc.

11.2.3 The Arc can learn lessons from Tel Aviv's response to this issue which includes plans for Tel Aviv Metro light rail project and improvements to the rest of the public transport system. Israeli policymakers recognise the importance of prioritising transport infrastructure investment, as the country is becoming increasingly reliant on the service industry, which by nature requires agglomeration benefits to achieve high levels of productivity.[39] In 2020, the government sped up the delivery of numerous infrastructure projects, such as furthering the amount of electrification along the rail-line linking Jerusalem and Tel-Aviv, and speeding up construction of the Tel Aviv Metro.

11.3 The Randstad Case Study

11.3.1 The Randstad is one of the largest metropolitan regions in Europe, comprising four of the largest Dutch cities: Amsterdam, Rotterdam, The Hague and Utrecht. It has a large infrastructure system that is pivotal to the Dutch railway network, with most intercity connections terminating in one of its cities. In addition to excellent rail connections, the Randstad is home to the Port of Rotterdam, and Amsterdam Airport Schiphol.

11.3.2 The Randstad shares sector specialisms with the Arc – Utrecht has the largest concentration of hospitals, life science companies and medical supplies in the Netherlands. Health and well-being is the second-largest economic sector here, employing 37,000 people, or 15% of total employment in Utrecht[40].

11.3.3 Due to its seaport, Rotterdam is the foundation of the Dutch economy, and is also a centre of education, housing internationally renowned universities and the Willem de Kooning Academy art school. With 620,000 inhabitants of over 170 nationalities, Rotterdam has a rich culture. It is attempting to combat high unemployment rates by endorsing a more knowledge-based local economy, aiming to attract and retain more skilled workers to strengthen its economic foundations.

11.3.4 The Hague's status as International City of Peace and Justice is responsible for 40,000 jobs, with 11% of employment[41] in the Hague being directly or indirectly related to the international organisations located there. It is also home to intergovernmental organisations, non-governmental organisations and regional headquarters of companies such as Huawei and T-Mobile.

11.3.5 Amsterdam is one of Europe's most attractive and competitive regions, thanks to its affordability and excellent transport infrastructure. A huge influx of start-ups and international corporations has boosted employment in Amsterdam and created of new types of jobs, knowledge and skills.

[39] https://www.brookings.edu/wp-content/uploads/2020/04/FP_20200407_israel_economy.pdf
[40] https://utrechtcityinbusiness.com/en/sector/ict/
[41] https://www.denhaag.nl/en/municipality-of-the-hague/the-hague-in-numbers.htm

11.3.6 In the Netherlands, most distance travelled by public transport is by rail. The Randstad contains some of the most heavily used routes, with these routes being serviced up to 8 trains per hour[42]. It is a prime example of how rail infrastructure improves mobility and access to high-value jobs. The success of these respective cities can all be attributed to excellent transport infrastructure – something the Arc should look to mimic.

11.4 Canary Wharf

11.4.1 Canary Wharf business district has developed from the former docks located on the north side of the Isle of Dogs. Employment in the area reaches 120,000 people, up from 27,000 in 2002, with the district now employing more people than the city of London. Public Transport has played a key role in enabling the rapid jobs growth and economic success story.

11.4.2 From the outset the need for public transport was identified, with the Docklands Light Railway the linking the city to the first phase of office development to the city of London, a network which now connects across East and South East London with 117 million passenger journeys in 2020.

11.4.3 Subsequently the DLR required both extension and train lengthening, however, with the need to increase capacity further a new solution was needed if Canary Wharf was to continue to grow. This was delivered with Jubilee Line opening in 1999 which provided faster connections and better interchanges to the tube network and more recently with the opening of the Elizabeth Line 2022, providing both better connections to Heathrow and West London. Each transport capacity upgrade has enabled more commercial space, higher employment density, and economic growth. Improved connectivity, in particular through the Jubilee line and now Elizabeth Line, has also enabled Canary Wharf to attract workers from across London and the South East, with over 90% commuting from outside Tower Hamlets.

11.4.4 Remarkably over the last 20 years the number of people driving to work in Canary Wharf has not increased significantly despite the number of jobs increasing fourfold and today over 85% of people arrive by public transport. Transport has also played a significant role in enabling the diversification of the area away from reliance on finance, with the area achieving significant housing delivery only possible through the very high use of public and active transport and excellent connections to other parts of London.

11.5 Manchester Metrolink – Linking an economy

11.5.1 Manchester Metrolink first opened between Bury and Altrincham in 1992. It has played a key role in the role in the growth of Greater Manchester into a strong city region economy.

[42] https://www.itf-oecd.org/sites/default/files/docs/stead.pdf

Greater Manchester's GVA has increased in real terms by 99% from 2000 to 2020[43] enabled by a 27% increase in total employment over the same period[44].

11.5.2 Metrolink is one of the biggest transport projects completed in the United Kingdom in recent decades. Its expansion has served to triple the size of the network, adding 65 km of new tramway, along with 380 new structures, including 160 bridges and tunnels[45].

11.5.3 Its success has supported expansion in a phased way, with significant expansions between 2010 and 2020 to new sites such as Media City, Rochdale, Manchester Airport, and the Trafford Centre. The service has enabled significant growth in high density housing and has connected and enabled important economic hubs of the city such as Trafford Park, Salford Quays and Kingsway Business Park, along with improving public transport between the airport and the city.

11.5.4 Metrolink has demonstrated strong performance in supporting local economic growth through improving access to more productive jobs[46] and supporting job growth in the productive central Manchester economy in addition to supporting modal shift[47] and therefore, a reduction in transport carbon emissions and improving access to key services in health and education.

11.6 HS1 – Supporting growth in London and Kent

11.6.1 High Speed 1 domestic services have played a significant role in supporting economic growth in Kent and London. The domestic service on HS1 has grown significantly from 11m passengers in 2010 to over 15m by 2017[48]. Its economic impact has been estimated at £457m per year from a combination of journey time savings, reduced crowding, improved productivity and carbon and air quality benefits.

11.6.2 The improved journey times have supported increased commuting into highly productive jobs in London, as large areas of Kent are now less than an hour's journey to London. This trend has helped support "aspiring homeowners" – with a significant number of young families (26-35-year-olds)[49] moving to the HS1 catchment area. It has also played a role in housing delivery, with the rail link supporting the development of 15,000 new homes. Of particular

[43] https://www.gmtableau.nhs.uk/t/GMCA/views/GreaterManchesterEconomyFactbook/Economy?%3Aembed=y&%3Aiid=2&%3AisGuestRedirectFromVizportal=y

[44] https://www.gmtableau.nhs.uk/t/GMCA/views/GreaterManchesterEconomyFactbook/Economy?%3Aembed=y&%3Aiid=2&%3AisGuestRedirectFromVizportal=y

[45] https://www.wsp.com/-/media/Campaign/New-Zealand/Documents/Manchester-Metro-Case-Study.pdf

[46] http://www.hydeparkandwoodhouseonline.com/wp-content/uploads/2013/06/Metrolink_report_final_31-Jul-08-copy.pdf

[47] https://highspeed1.co.uk/media/vemkxmot/delivering-for-britain-and-beyond-the-economic-impact-of-hs1-march-2020.pdfhttps://assets.ctfassets.net/nv7y93idf4jq/6Tk9r9ATVS8zTQfyi4vFD2/f67f3087b19d46fb8d4f2c290ec2fef0/Metrolink_Phase_3_evaluation_second_report.pdf

[48] https://highspeed1.co.uk/media/vemkxmot/delivering-for-britain-and-beyond-the-economic-impact-of-hs1-march-2020.pdf

[49] Economically Active (16-64), Annual Population Statistics, Office for National Statistics

note is the development of Ebbsfleet Garden City, which is expected to generate 1.4m journeys into London on completion.

11.6.3 Regeneration has also been a key benefit of HS1, with 5% of businesses citing high speed rail as having played a role in the decision to locate close at St Pancras International[50]. Beyond central London HS1 is supporting the growth of Stratford[51] as a business and cultural hub building on the Olympic legacy and has improved connections within Kent supporting modal shift in local travel.

11.6.4 Leisure travellers have also flocked to HS1 with an average of 15,000 trips per day, with over 50% of passengers indicating that high speed rail has played a role in the decision to visit Kent by rail[52]. These visitors have supported the growth of leisure-based regeneration on the Kent coast in towns such as Margate and Whitstable.

11.7 Borders Railway supporting new commuting patterns

11.7.1 The borders railway re-opened in 2015 providing a passenger service on a line previously closed in 1969. The reopening on the line aimed to support access to Edinburgh and onward connections for people living in the Scottish Borders and Midlothian.

11.7.2 The business case for re-opening had relatively poor benefit cost ratio of only 0.5[53] in the final business case. The case for the scheme was primarily based on enabling increased housing and supporting areas with high level of unemployment by better connecting into the stronger Edinburgh economy.

11.7.3 Passenger demand has outperformed initial estimates, particularly at the southern end of the line at Galashiels and Tweedbank[54] (partially offset by lower than forecast demand closer to Edinburgh). Overall, the higher than expected number of users would have significantly improved the business case and indicates strong demand for longer distance rail commuting and leisure travel[55]. Prior to the Covid-19 pandemic, evaluation of the scheme has demonstrated that the new rail line was delivering against its key objectives through improved access to Edinburgh, improving social cohesion, reducing population decline and creating modal shift[56]. An estimated 40,000 car journeys have been saved reducing congestion and supporting carbon savings[57].

[50] An Impact Analysis of the International HighSpeed Rail Link between London and Paris, Leeds Business School (2019)

[51] https://www.newham.gov.uk/regeneration-1/regeneration-project-stratford

[52] The Impact of HS1 on the Visitor Economy in Kent, Visit Kent and Destination Research (2017)

[53] https://www.gov.scot/binaries/content/documents/govscot/publications/foi-eir-release/2020/07/foi-202000050758/documents/foi-202000050758---information-released---borders-railway-final-business-case/foi-202000050758---information-released---borders-railway-final-business-case/govscot%3Adocument/FOI-202000050758%2B-%2BInformation%2Breleased%2B-%2BBorders%2BRailway%2BFinal%2BBusiness%2Bcase.pdf

[54] http://www.demand.ac.uk/wp-content/uploads/2017/03/14-EC1-Jim-Steer-01.pdf

[55] https://www.transport.gov.scot/media/39388/borders-railway-1-year-evaluation.pdf

[56] https://www.transport.gov.scot/media/41659/sct02189915561.pdf

[57] https://www.transport.gov.scot/publication/borders-railway-year-2-evaluation-survey-of-users-and-non-users-february-2018/

12 Appendix 12 – North of Bedford 4-track Operational Impact Assessment

See separate document "Appendix 12 - North of Bedford 4-track Operational Impact Assessment".

ARUP

East West Rail

East West Rail Engineering Partner

North of Bedford 4-track Operational Impact Assessment

Reference: EWR_PGM-ARU-OP-XX-RP-Z-000003

P04 | 24 February 2023

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1. Executive Summary

This study reports the operational implications of a 4-track design at Bedford compared to a segregated six track design. This was initially suggested for a reduced 2tph service level rather than the 4tph originally included in the requirements. Further analysis on the anticipated demand impact of reducing to 2tph has resulted in the removal of the 2tph option from the scope of the study as too much demand was lost. The study has since only looked the viability of a 4tph service. A best-case design for Bedford 4-track includes a new Up Fast Platform which avoids EMR services running on the Slow Lines.

Whilst there is no direct interaction between Thameslink and EWR services on the four-track design the inclusion of freight services links the structure of the timetables together. To optimise the timetable at Bedford the Thameslink and EWR services need to arrive and depart Bedford at similar times to maximise the number of parallel moves; if the services cannot be coordinated this way there is a sequence of conflicting moves which erodes the available capacity and creates a performance risk. Even with an optimised timetable the number of freight paths is limited to 2ftph in most hours.

There is limited scope to flex the Thameslink timetable due to the crossing moves at flat junctions on the Midland Main Line, Blackfriars Junction and across the Southern network. In addition, freight is tightly pathed between the Thameslink services due to the difference in running times and limited passing locations on the MML This fixes the freight path through Bedford and forms the constraint that EWR must work around.

In terms of performance, due to the number of constraints and interactions Thameslink services have on the existing network it is anticipated that both the Thameslink and freight services will be given regulation priority to minimise overall network disruption. This would leave EWR vulnerable to disruption on the Midland Main Line and potentially spread it along the EWR route to Cambridge, Oxford and the West Coast Main Line.

The modelling shows the enhanced Bedford layout offsets the performance risk to existing Midland Main Line services introduced with EWR, however EWR services themselves have an increased performance risk with the enhanced Bedford layout.

If the level of freight stipulated as necessary according to the Output Specification in previous assessments is reduced, it is theoretically possible to timetable a 4tph EWR service around the other services looking at Bedford in isolation on a four-track layout. However, this would constrain the EWR timetable in the middle of the route leading to compromises on performance and journey time that cannot be fully assessed without a full route timetable that factors in the wider route constraints. This could potentially impact the level of benefits associated with the scheme. Further there may be conflicts outside the Bedford area analysed that are impossible to overcome. These issues would be removed under a six-track layout. The level of freight services operating is detailed in Appendix C.

The report has provided additional analysis insights using early-stage performance modelling to outline the comparative differences between a 6-track and 4-track EWR solution north of Bedford. The performance analysis is limited to indicating trend differences between options and does not provide detailed insights into the performance due to the limitation of input data such as signalling scheme designs. The conclusions of the analysis are considered reasonable at this stage of development, when comparing different options and service assumptions.

Figure 1 below illustrates how the constraints at Bedford act together to form a significant constraint on the network for EWR services.

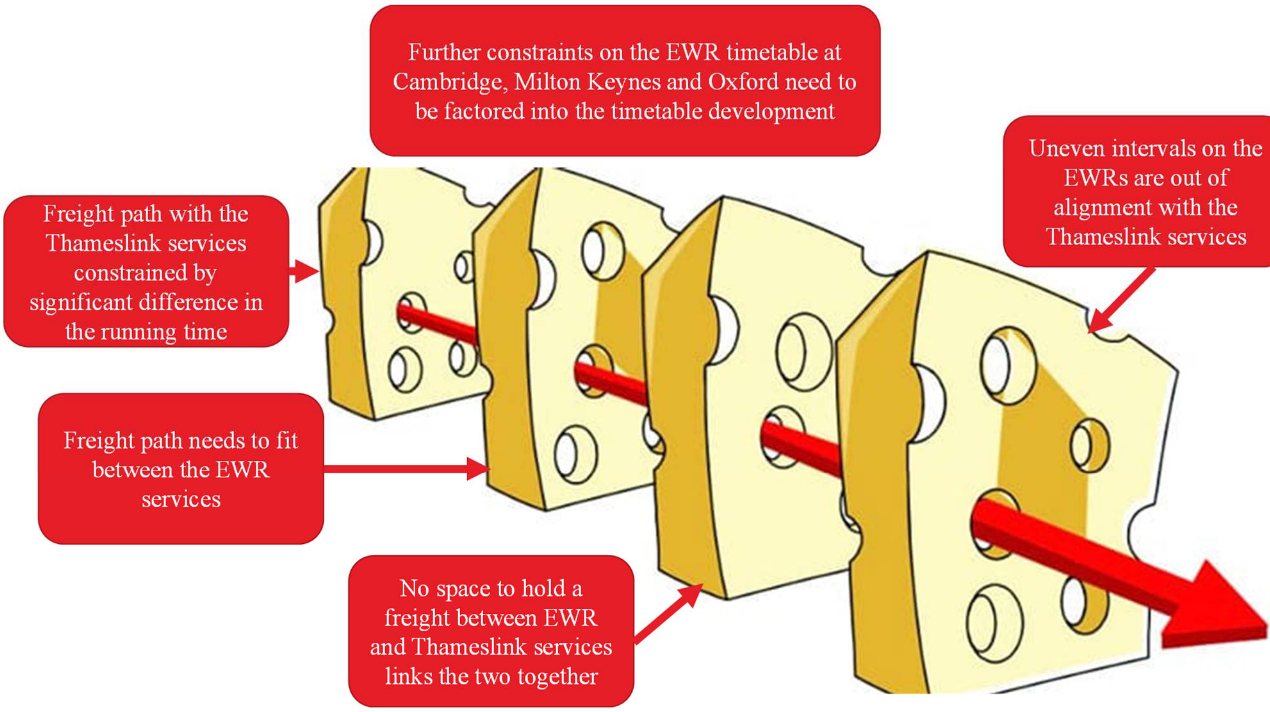

Figure 1 Constraints at Bedford

2. Introduction

This report outlines the operational findings from an early-stage capacity and performance modelling assessment of the implications in operating East West Rail (EWR) on the Slow Lines north of Bedford station in comparison to the 6-track option previously developed.

The operational assessment has been completed within the context of the EWR Programme Wide Output Specification (PWOS). However, since commencement of the assessment, EWR has developed new proposals following the completion of the Affordable Connections Programme (ACP). ACP reviewed the overall objectives of EWR with a focus on reducing the costs of the scheme, this included moving away from some of the PWOS requirements and reviewing corridors and modes of transport. In the context of Bedford, some of the ACP proposals included running on the Slow Lines north of Bedford and considered a reduced service level of 2tph which is no longer being considered due to the detrimental impact on demand.

The ACP proposals also include limiting services on the Marston Vale Line (MVL) potentially requiring services to terminate at Bedford, although not considered in this assessment. Once the new project objectives and proposals are outlined, further operational assessments are likely to be required to reflect the changes, outline the feasibility, and inform detail design development.

2.1 Background

Under the current Design Freeze 2 (January 2022) the EWR scheme includes an additional 2-tracks alongside the existing Midland Main Line (MML) through the Bedford north area. The 6-track alignment requires additional land alongside the existing railway, impacting on properties adjacent to the railway. The design for 6-tracking north of Bedford has emerged as a response to the PWOS Version 01 Revision 02 which acts as the basis for informing the design requirements for EWR. Key extracts from the PWOS and the Sponsors Requirements which the PWOS is derived from are included in Appendix A.

Due to the significant impact of 6-tracking north of Bedford the scope for the operational assessment aims to outline the operational implications of a 4-track design, whereby EWR merges with the existing 4-track layout north of Bedford station prior to diverging away from the MML towards Cambridge. The implications will be assessed against the PWOS requirements of the scheme for EWR passenger services, assessing both capacity and performance though timetable performance modelling. Figure 2 on the following page, outlines schematically the track design for EWR from Design Freeze 2 extracted from EWR_CS3-ARU-OP-XX-SK-Z-000007_P04, refer to source document for key, alongside a concept design for a 4-track option.

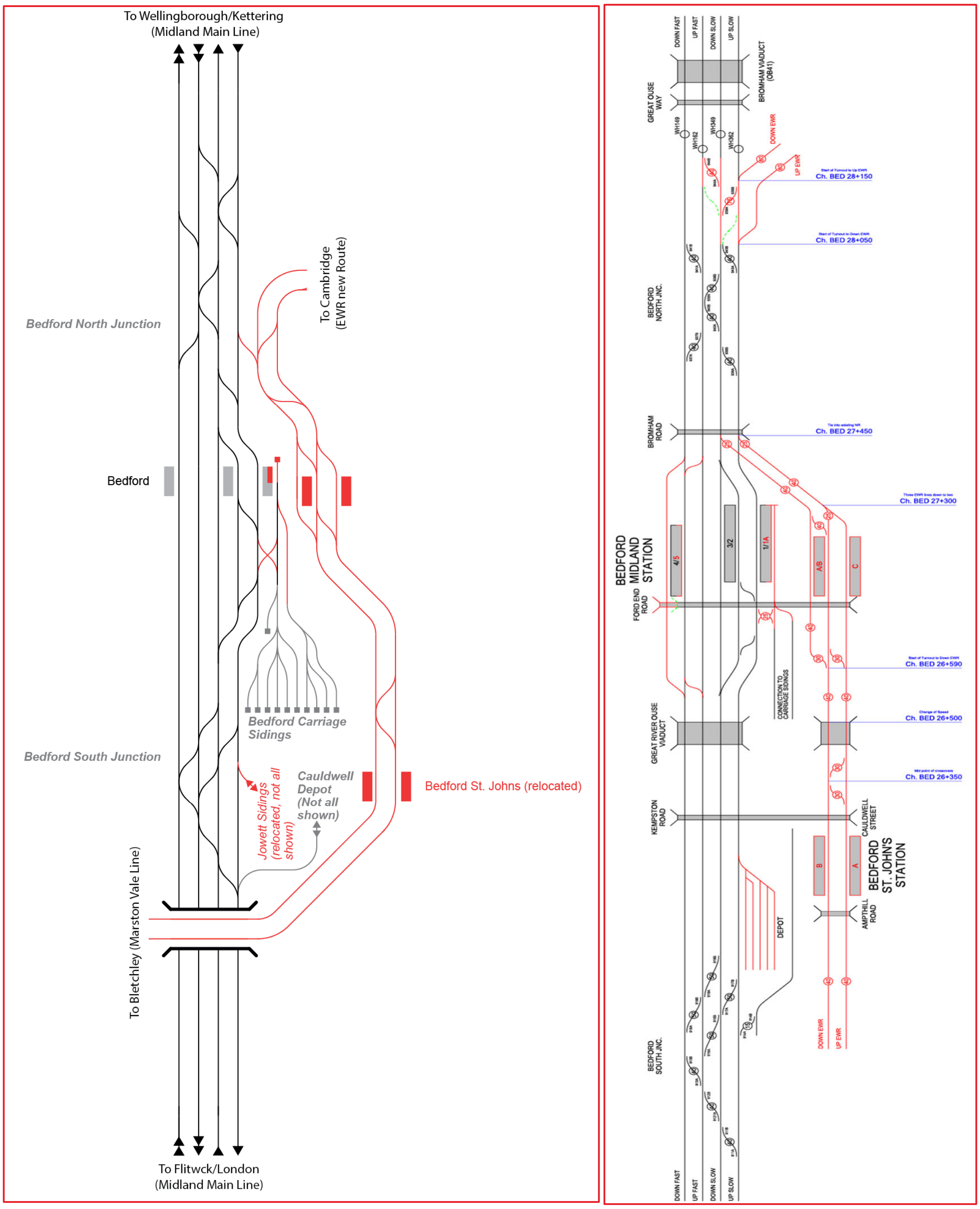

Figure 2 Schematic Track layouts

2.1.1 Previous Assessments

Since the first Non-Statutory Consultation for EWR which outlined Route E as the preferred EWR corridor between Bedford and Cambridge, Arup has supported EWR as their Engineering Partner, which has included the development of route-designs to support the EWR PWOS. Operational assessments have been completed to provide design requirements that aim to meet the PWOS, this includes the identification of requiring 6-tracks north of Bedford as outlined in EWR second Non-Statutory Consultation. The following Figure 3Figure 3 outlines a timeline of the operational assessments completed alongside key project milestones, including the recent ACP changes to the project requirements.

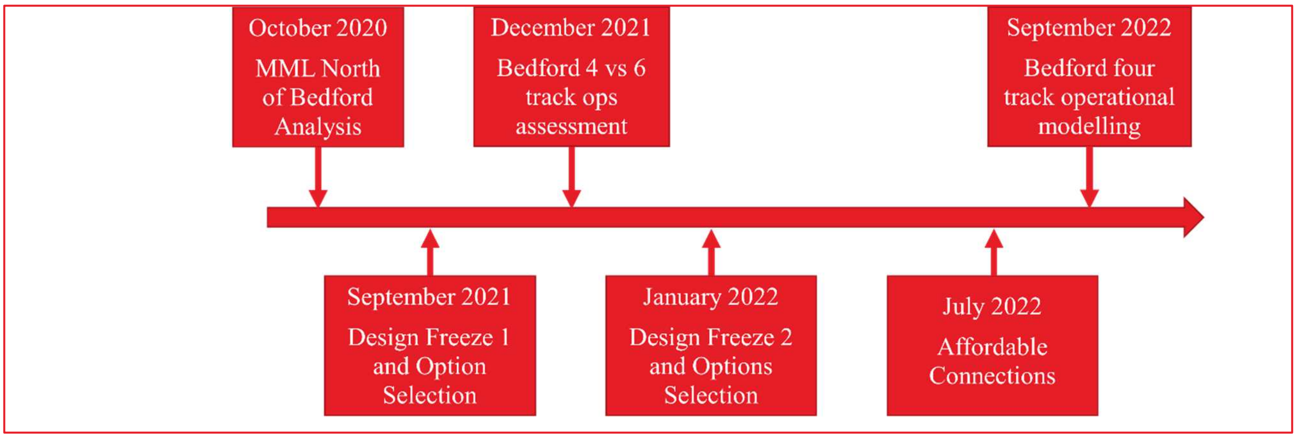

Figure 3 Previous operational assessments focused on Bedford.

MML North of Bedford Capacity Analysis (EWR_CS3-ARU-OP-XX-RP-Z-000002_P03)

The MML North of Bedford Capacity Analysis report in combination with the **North of Bedford CS3 Initial Optioneering (EWR_CS3-ARU-OP-XX-RP-Z-000001_p01*)*** report where the initial capacity assessments were to outline the requirements to accommodate EWR on Route E through the north of Bedford. At the time, Bedford station was excluded from the scope of works, although as a necessity is covered in the operational analysis. These reports review the potential options alongside engineering feasibility assessments to support the EWR through Bedford station and to the north, and in terms of meeting the PWOS objectives (Appendix A). Whilst the analysis was high-level it indicated that a 4-track solution north of Bedford would not likely robustly support EWR's PWOS objectives, and the assumed level of service required on MML, in addition, several PWOS requirements would not be met.

Design Freeze 1 and Non-Statutory Consultation

The outputs from the initial operational analysis at Bedford support the 2nd Non-Statutory consultation for EWR, whereby the potential option for 6-track through Bedford was outlined. The supporting technical documentation outlined why 6-tracking was being considered by EWR and what the impacts of potential designs are in the Bedford area.

Bedford 4 vs 6 track Ops Assessment (EWR_PGM-ARU-XX-XX-RP-Z-000005_P05)

This report followed up from feedback received from the 2nd Non-Statutory Consultation, reviewing further the implications of 4 tracking and 6-tracking. The analysis demonstrates that EWR services cannot be operated in accordance with the project objectives as specified in the PWOS, due to the operation of freight services on the route section being reviewed, even with the infrastructure layout changes suggested by a high-level assessment completed for Bedford Borough Council (BBC). The BBC assessment did not appear to consider the EWR PWOS requirements and applied different project service assumptions than that made between EWR and Network Rail (NR).

Design Freeze 2

Design Freeze 2 represented a second iteration of the designs for EWR, within Bedford the scope remained in the preferred solution to develop a 6-track design.

Affordable Connections Programme

Since the conclusion of DF2, EWR undertook an Affordable Connections Programme (ACP) to assess the overall project affordability, scope, and specification. ACP included reviewing the modes, routes, and options in delivering an East-West transport scheme between Oxford and Cambridge. One conclusion emerging from ACP included the option of operating EWR through Bedford station and on the existing Slow Lines north of Bedford, but with a reduced level of service (2tph) and relaxing of the output specification requirements. The ACP proposals also include limiting services on the Marston Vale Line (MVL) potentially requiring services to terminate at Bedford.

Whilst the ACP proposals are not considered in this study, the findings to an extent will provide indications on further service proposals developed where running on the existing Slow Lines north of Bedford is considered. It will be necessary however to consider operational impacts for future service proposals, including what is considered in this study given early-stage of development in design and operations.

3. Scope & Key Assumptions

The scope and assumptions of this assessment are set out in a detailed remit agreed with Network Rail Capacity Analysis: EWR_PGM-ARU-OP-XX-BF-Z-000001_P04. The following provides an outline of the Key Scope and assumptions.

An operational timetable and performance assessment of the 4-track design will be undertaken to assess the impact of this design in achieving the EWR project requirements.

Regardless of 4-track or 6-tracking north of Bedford, the EWR designs south of Bedford potentially impact on the operations of the MML due to changes to MML stabling sites, namely relocating Jowett sidings to a site adjacent to Cauldwell. As the impact of this has not been assessed in detail, the first step of the assessment will be revising the base MML timetable to understand the implications of the proposals prior to assessing the impact of a 4-track option. In addition, the assessment will also consider recent work undertaken to support the development of Wixams station to the south of Bedford which has operational implications at Bedford, potentially further impacting to the feasibility of a 4-track design for EWR.

The operational assessment will be completed in 2 phases: a timetable assessment and a performance assessment.

3.1 Timetable Assessment

The timetable assessment will consist of two parts, the first is to outline the impacts of the proposed relocation of Jowett Sidings to Cauldwell Depot and the closure of the EMU siding and extension of Platform 1a at Bedford, for both the base MML timetable, and base Wixams MML timetable. These timetables will be referred to as “Base Case Plus” and “Wixams Plus”.

The second part of the timetable assessment will overlay the latest EWR development timetable on to the 4-track design for the Base Case Plus timetable and Wixams Plus timetable options.

Additional sensitivity tests will be completed for these timetables, looking at the impact of changes to freight assumptions both on the MML and new freight flows on EWR, and the impact of including provision of an Up Fast Platform at Bedford.

The timetable assessments will also include the calculation of indicative Timetable Planning Rules and Sectional Running Times for the new 4-track design, for EWR services using RailSys. Given the nature of the design these are at best indicative but likely to change once a detail design has been developed.

The timetable assessments have been completed in respect to achieving the EWR project requirements (see PWOS) and impacts to exist operations.

3.2 Performance Assessment

The second phase will consist of an early-stage timetable performance assessment using an industry standard timetable modelling tool, RailSys, applying Network Rail standards for modelling. The performance modelling is at an early stage of project design and therefore does not represent a validation of option robustness, it is more provided to indicate comparative differences between options assessed.

The RailSys performance assessment for each option, and sensitivity test will follow a standard performance modelling process, this is illustrated in Figure 4Figure 4 below. The base case and calibration performance model will be sourced from the recent Wixams operational assessment, as this provides a recent model of the area and will reducing industry effort to support this assessment, by avoiding the need to establish a new base model. A high-level review of the model will be performed.

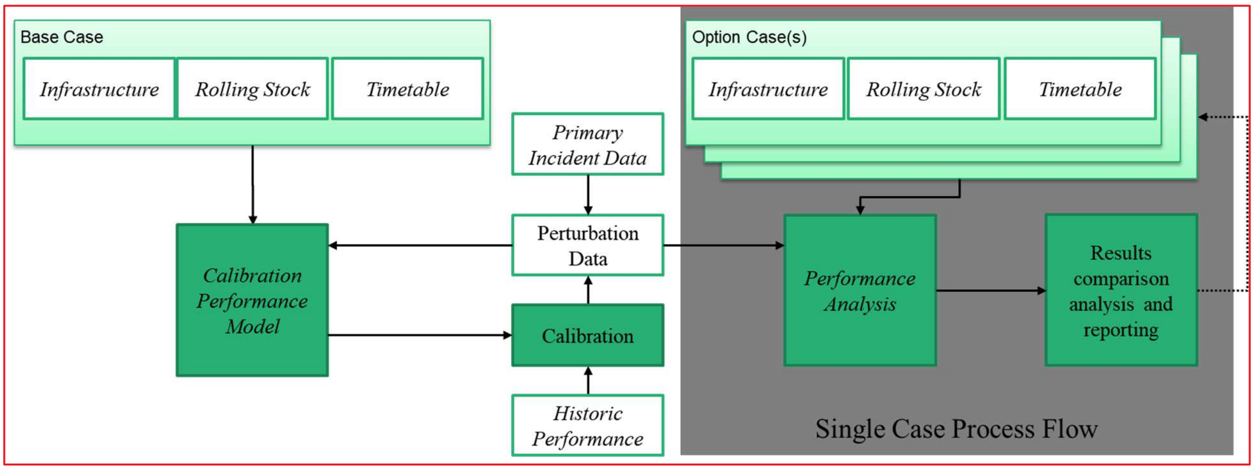

Figure 4 An illustration of a standard timetable performance modelling process.

3.3 Train Service Scenarios

All of the assessments are based on EWR running four trains per hour all day on even interval principles.

The initial operational assessment consists of the following options:

1. **Base Case:** used as the comparison to current MML operations (adopting the previous model created for the latest Wixams assessment).
2. **Wixams Case:** used for comparison to the base Wixams option performance assessment. (Adopting the previous model created for the latest Wixams assessment).
3. **Base Case Plus:** Used as a step from the Base Case to compare the impacts of the EWR scheme designs changes to the MML south of Bedford (i.e., Jowett relocation) independent of 4 or 6-tracking.
4. **Wixams Plus:** Used as a step from the Wixams Case to compare the impacts of the EWR scheme designs changes to the MML (i.e., Jowett relocation) independent of 4 or 6-tracking.
5. **4-track Option:** EWR 4-track scenario; overlay of EWR services onto a 4-track scenario north of Bedford on top of the Base Case Plus.
6. **Wixams 4-track Option;** EWR 4-track plus Wixams scenario; overlay of EWR services onto a 4-track scenario north of Bedford on top of the Wixams option timetable.

The initial modelling study found the performance risks associated with the removal of Jowett sidings were adequately mitigated with the provision of alternative stabling and enhancing platform 1A but the route would struggle to support 3 freight trains an hour alongside EWR. The freight assumptions were amended to a reduced level with the six-track option introduced as a comparator.

In addition to the six options outline above, four sensitivity cases where originally included in the scope, the following Table 1 outlines these sensitivities against the 6-options.

Table 1 Option Cases and Sensitivity Tests.

	MML Base Timetable freight	MML EWR Freight Assumption (x̄3ftph)	EWR Freight (1ftph)	Bedford Up Fast Platform
Base Case	✓			
Wixams Case	✓			
Base Case Plus	✓	✓		
Wixams Plus	✓	✓		
Base 4-track	✓	✓	✓	✓
Wixams 4-track	✓	✓	✓	✓

Each sensitivity scenario will be completed for the Base Case Plus and Wixams Plus. This is visually outlined in the following Figure 5:

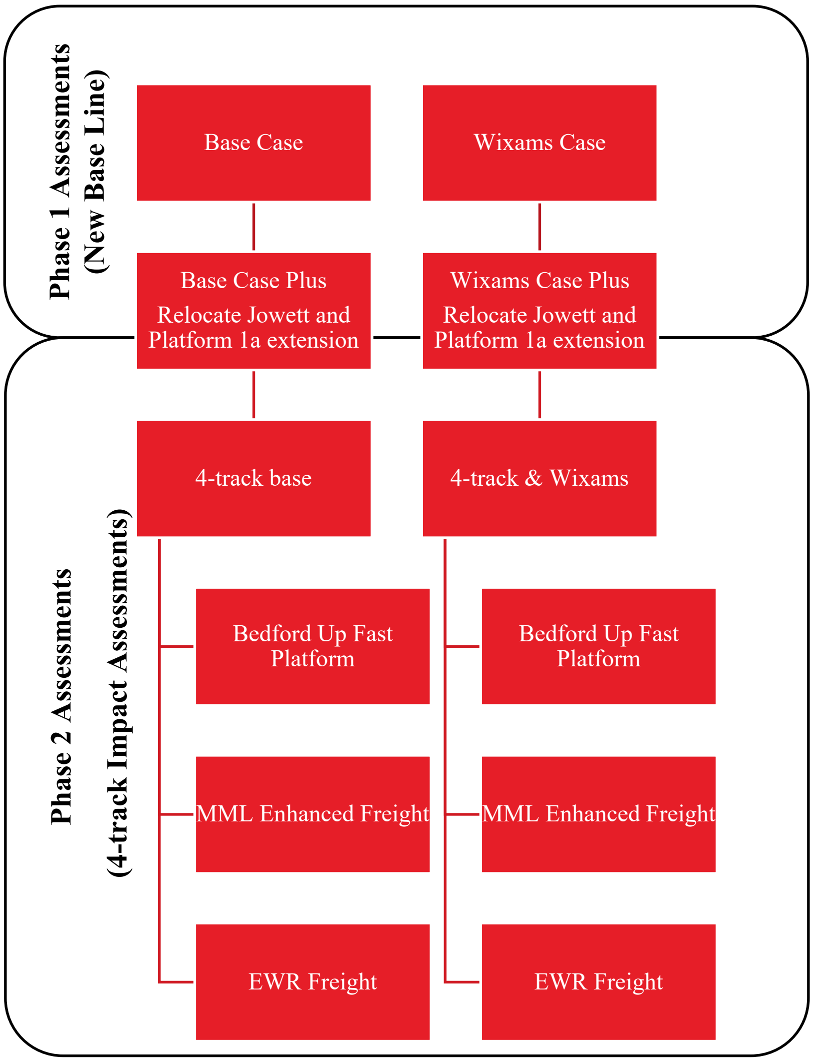

Figure 5 Overview of Option Cases and Sensitivity Cases

3.4 Geographic Scope

For both the timetable and performance assessments the geographic scope is the same, Figure 6 Figure 6 below outlines the overall geographic scope. For the Marston Vale Line (MVL) there are two current infrastructure and service options, under this study Concept 1 is assumed as it includes 5 passenger trains per hour (tph) in total. The full TSS is outlined in the detailed remit (EWR_PGM-ARU-OP-XX-BF-Z-000001_P04). The following outlines the key geographic boundaries:

- East West Rail Route:
  - Western extent: Bletchley
  - Eastern extend: Hauxton Jn (EWR route tie-in to Shepreth Branch Railway)
- Midland Main Line:
  - Southern Extent: St Albans
  - Northern Extents: Market Harborough & Corby

Figure 6 Operational assessment geographic scope. East West Rail Route as per Concept 1.

3.5 Changes to Scope and Assumptions

The following outlines changes to the assumptions & scope of works from the remit.

3.5.1 EWR Performance Distributions Changes

As noted in the remit the expected performance and reliability of EWR services is not currently known and provided a suggested starting position for a generic distribution to be applied to EWR services at entry and all stopping locations. Distributions are used within performance modelling to derive primary delay events. The initial distributions as specified in the remit; through iteration of the modelling the EWR distributions were updated as follows to drive a higher level of interaction between services.

Two distributions where set-up for EWR services:

- EWR Distribution 1
  - Applies to non-interchange locations where EWR services stop.
  - 15% proportion of services impacted
  - 0.5-minute average lateness.
  - 5 minutes maximum lateness.
- EWR Distribution 2
  - Applies on entry at the model boundary to EWR services and as a dwell delay at Bedford, Bletchley and ECML Interchange.
  - 75% proportion of services impacted
  - 2-minute average lateness
  - 10 minutes maximum lateness

3.5.2 Additional Freight Scenario (Best Case 4-track)

In addition to the four sensitivity tests completed a further freight sensitivity was considered whereby alterations are made to both MML and EWR freight service assumptions, reducing the overall number of paths in the timetable compared to the EWR assumed level of freight. This additional scenario has been tested including the MML Up Fast Platform option, to test a best-case scenario for a 4-track option. The following Table 2 outlines the freight assumptions:

Table 2 Additional Freight Scenario TSS.

Route	Average Number of Paths
MML (North-South flows including diversions to MVL)	1.5ftph (alternating hours of 2ftph and 1ftph)
EWR (East-West flows between Cambridge and Bletchley and in-addition to MML-MVL flows)	0.5fpth (alternating hours of 0ftph and 1ftph)

4. Timetable Capacity Assessment Findings

4.1 Implications of Relocation of Jowett Sidings and Platform 1A

The EWR alignment to approaching Bedford from the South requires the land that is currently used for stabling 12 car units at Jowett. As the Thameslink Class 700s are fixed formation units these cannot be accommodated on shorter stabling roads nearby. As such the removal of Jowett sidings represents a significant loss of network capability which needs mitigating. Alternative stabling has been proposed adjacent to Cauldwell along with extending platform 1A to hold a train going out of service until a path is available out of Bedford.

Relocating the stabling from Jowett to a new site adjacent to Cauldwell increases the number of movements on the slow lines to the south of Bedford. It also has the potential to increase congestion in the platforms at Bedford with trains to and from the depot needing a path between the existing services. To mitigate this risk, it is proposed to extend Platform 1A to hold a Thameslink train that is waiting for a path to the depot. The enhanced Platform 1A also enables the replatforming of Thameslink services to free up paths through Bedford for freight traffic and the East Midlands semi-fast service. The new layout at Bedford is illustrated schematically in Figure 7Figure 7 below.

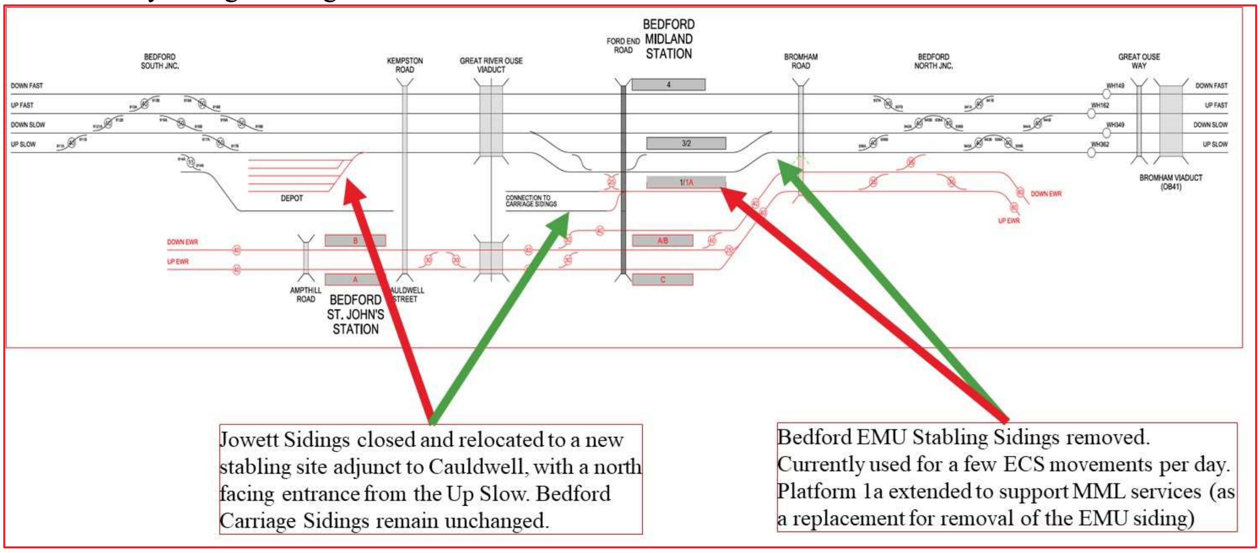

Figure 7 Proposed infrastructure changes common to all Bedford options

Within both the base and Wixams' timetables all the Empty Coaching Stock (ECS) movements currently planned between Bedford and Jowett, could be re-planned to the new stabling site at Cauldwell. All ECS movements are planned to use the Up Slow in both directions, accessing the new Cauldwell site via a new Up facing crossover. Within both timetables it was essential to make use of Platform 1A to increase turnround times in order to find paths between Bedford and the new Cauldwell stabling site.

As the solution requires use of Platform 1A to re-plan the Jowett ECS moves to Cauldwell, it was also possible to re-plan the Govia Thameslink Railway (GTR) services to optimise both platforming and approaches into Bedford. This has been applied to all timetables. In providing the additional Platform 1A and without impacting on GTR timings to the south of Bedford, a reduction from the reliance on bi-directional working between Bedford South Jn and Bedford has been achieved, improving the potential robustness of the timetable. Figure 8 outlines typical routings of GTR services in the base timetable, which requires frequent 'wrong-line' running between Bedford and Bedford South Jn due to the Platform and S&C arrangement at Bedford station. For example, a depart from Platform 3 in the Up direction can only be via the Down Line to Bedford South Jn. The base timetable also has departures from Platforms 1 & 2 running 'wrong-line' to enable some arrivals into Platforms 1-2 due to timing constraints. While the use of 'wrong-line; running in the timetable is TPR compliant, under perturbed scenarios it creates conflicts between services requiring routing interventions to be made.

Under the new station design with Platform 1a extended, it is possible to reduce the majority of these 'wrong-line' routings as GTR services are shifted over to from Platform 1-3 to Platforms 1a-2. This reduces routing complexity, and under perturbed running potentially simplifies routing decisions. The optimisation of Platforming at Bedford has been completed for all timetable options including the EWR 6-track solution in order to provide fair comparison to the 4-track scenarios.

This is illustrated in Figure 8Figure 9 below.

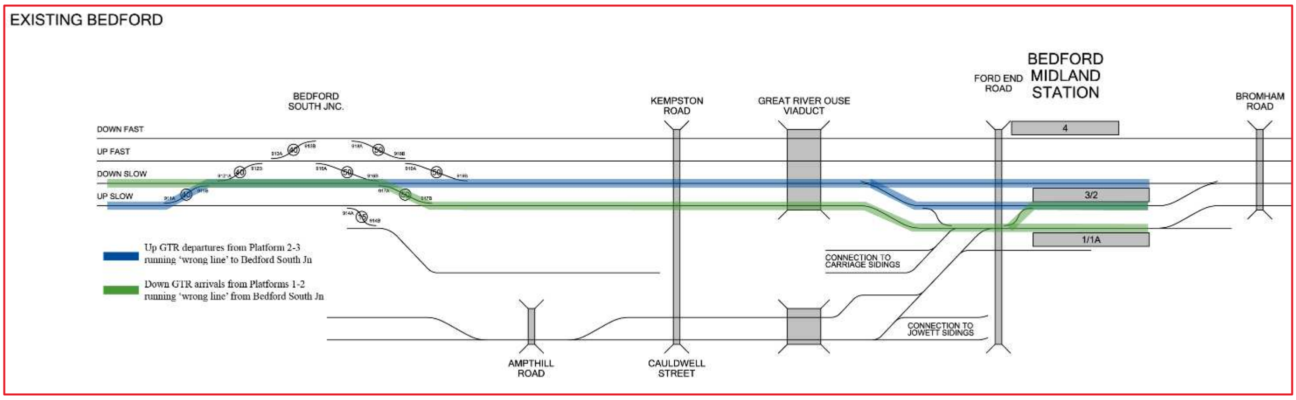

Figure 8 Current bi-directional working at Bedford

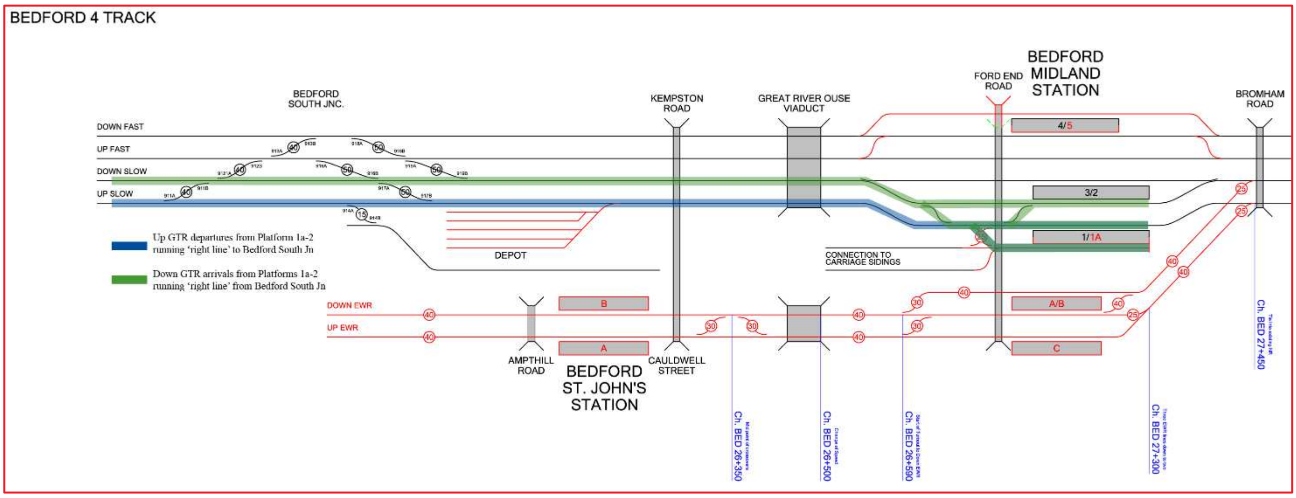

Figure 9 Simplified operation with Platform 1A

4.2 4-Track Timetable Implications Base Case Plus & Wixams Plus Case

There is insufficient capacity to route EWR through the existing platforms at Bedford. Under the 4-track design, EWR services are required to be routed onto the MML Slow Lines to the North of Bedford station, from the additional EWR platforms provided. EWR services then remain on the Slow Lines for approx. 800m before diverging at Bedford North Jn to/from Cambridge. Whilst a signalling scheme design has not being developed at this stage of development, a concept signalling solution was outlined by EWR. The implications of which are potentially significant on the operations of the timetable. The following Figure 10 outlines the illustrative signalling design completed by EWR. Note the design slightly differs in this figure whereby Platform 1a is an EWR Platform, the signalling implications are however considered the same for the assumed track design with Platform 1a used for GTR services.

The proximity of Bedford station and Bedford North Jn where EWR diverges towards Cambridge means that there are no signalling sections between the two-timing points. This means for example, a departure from EWR Bedford Platforms requires a clear route over the Up and Down Slow Lines and onto the EWR lines, blocking any other services on the Slow Lines. A Up direction EWR service can however be routing in parallel with a Down direction MML or EWR service.

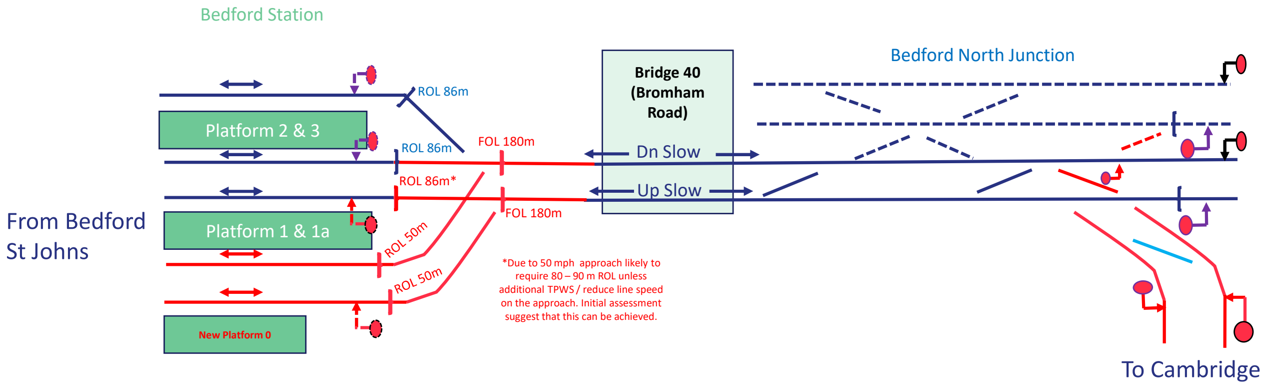

Figure 10 Indicative signalling design concept developed by EWR north of Bedford

4.2.1 Arrivals into Bedford

The key change illustrated in Figure 10 is the requirement to include Reduced OverLaps (ROL) at the north end of platforms which access the Slow Lines. The ROL are required to avoid conflicts at the junction where EWR merges with the MML Slow Lines after Bedford station. These have been indicatively modelled in RailSys as a detailed scheme design has not been developed. GTR services arriving on platforms 1-3 will require the use of reduced overlaps with a slower approach speed. This in turn leads to potentially extended journey times for GTR services arriving at Bedford of up to 1 minute. It is recommended that validation of this is carried out should a 4-track design be taken forward. It is also noted with the assumed designs that accessing Platform 1a may also increase journey times compared to the existing platforms as it is a terminal bay, this has not however been assessed in this study due to the lack of scheme design. The design also means EWR services arriving at Bedford in the Down direction will likely require arrivals on ROL.

Concerns have been raised on the level of reliance on reduced overlaps and a signalling design has been commissioned by EWR for future assessment

4.2.2 EWR Up Direction

Due to the potential significant speed differentials in the Up direction (from Cambridge) it is likely the signalling design will require use of Approach Controlled routes. Providing Approach Control here could introduce issues with standage for freight trains and a signalling design has been commissioned to understand how the route would be operated. The speed differentials come about due to the low-speed S&C included in the concept design which are constrained by the road bridge. While we have modelled the implications of the lower line speeds of the 4-track route compared to 6-track route, we have not modelled any implications from requiring approach control. Further assessment is required if a 4-track option is taken forward to confirm any implications both in terms of journey times and performance. There are further implications of the signalling design on operations that will need to be considered as the detail of the design is developed.

4.2.3 EWR Journey time implications

Both options allow the sectional running time to be met but the 6-track option has nearly a minute recovery time built into the running time.

4.2.4 Timetable Feasibility – Base Case and Wixams Case

The proposed station at Wixams has an aspiration for 4 train per hour to call; this increases the running time between Bedford and the Thameslink Core. To retain the paths through the Thameslink Core the arrivals at Bedford are later and the departures earlier. In the peak the turnround time has been reduced to not increase the rolling stock required; in the off-peak the stock working has been changed to step-back the service at Bedford to mitigate the performance risk.

There is a minimal direct impact on EWR from Wixams in the base timetables with the low level of freight as the Thameslink services needs to come into Bedford on reduced overlaps. Both the base and Wixams timetable restrict the available slow line capacity for through freight services with most down freight crossing to the fast line for a path through Bedford. The EMR semi-fast services need to cross to the slow lines at Bedford for a platform and they need a suitable path within the Thameslink and EWR services

4.3 MML EWR Freight Assumption (3ftph)

As part of the completed London to Corby enhancement scheme the Transport and Works Act Order (TWAO) included the requirement to support up to 3ftph on average on the MML. Through discussion with Network Rail the EWR project assumption adopted this as a project requirement as necessitated by the PWOS. Details of this are outlined in the technical documentation as part of EWR 2nd Non-Statutory Consultation. A base timetable that demonstrates the feasibility of this assumption has not been provided, and therefore as part of this assessment, indicative freight paths have been sought on the MML in addition to that provided in the base to attempt achieve 3ftph on average. The remit assumption for the additional freight paths assumed an 1800t freight load, it was found however existing SRTs in B-PLAN did not exist for this timing load. Indicative timings were developed for the assumed timing load (not validated) to maintain the remit assumption, although it was found as part of the study the timing load results in potential challenges in obtaining an average of 3ftph. This is because the assumed timing load was likely heavier than the majority of freight that typically operates on the route resulting in a worst-case outcome for the journey times of these freight paths and in turn having an impact on capacity along the wider MML route. In terms of compliant paths through Bedford however the constraints are the same in terms of feasible paths around EWR and MML services on the Slow Lines.

The following Table 3 outlines the number of freight paths within the base timetables and the number of additional paths achieved on the MML (North-South) against the objective of 3ftph as a total of the inter-peak period and an average number of paths per hour for that period. While 1000-1600 is the normal interpeak period Bedford operates a wide peak as it provides a peak towards London and absorbs the peak coming up from the south with associated depot movements which restricts freight growth. The full detail of freight paths over a 24 hour period is shown in Appendix C – Freight Paths.

Table 3 Numbers of freight trains in the inter-peak period

Direction	Up Freight Paths (Total/hourly average 1000-1600)		Down Freight Paths (Total/hourly average 1000-1600)	
Base Timetable	1	0.1	3	0.4
Wixams Timetable	1	0.1	3	0.4
Base Timetable 4-track	9	1.1	14	1.8
Wixams Timetable 4-track	7	0.9	12	1.5

A number of capacity challenges were presented when attempting to accommodate the additional freight paths within the timetable due to the limited availability of paths through Bedford. A number of paths have been provided through routing services onto the Fast Lines at Bedford North Jn, although this is likely to have detrimental impacts to performance on the MML. A path on the fast lines is possible but the single ladder junctions either side of Bedford restrict this to being in one direction. The limited availability of paths on the Slow Lines is restricted at Bedford due to GTR services turning round on through platforms 1-3. This is mitigated in part by the enhanced platform 1A which allows the Thameslink services to be replatformed to free up capacity for through freight traffic on the Slow Lines.

However, freight paths still need to hit a specific slot through Bedford to ensure viable paths to the south on the MML, in addition, this increases the need for EWR and GTR paths to be timed together to maximise paths on the Slow Lines. This means EWR paths need to be timed around the remaining spare paths through Bedford on the Slow Lines effectively linking the EWR timetable to the MML timetable, limiting flexibility of the EWR timings. The freight paths need to pass through Bedford in the window between a GTR service departing and before the next one arrives in both directions requiring two of the through platforms to be free.

South of Bedford Up direction freight paths typically are required to follow at headway behind the GTR service that departed ahead of it at Bedford to Sundon Loop where it is held in the loop and overtaken by the following GTR service at minimum margins, before proceeding to Harpendon Jn where the next following GTR catches up before it crosses over to the Fast Lines. The tonnage assumed under this assessment of 1800t for the additional freight paths results in minimum headways at Bedford, Sundon Loop and Harpenden Jn. This means the additional paths added have very limited flexibility from Bedford and to the south. The following Figure 11Figure 11 demonstrates this in a distance-time timetable graph, with the timetable represented graphically and paths moving in distance and time.

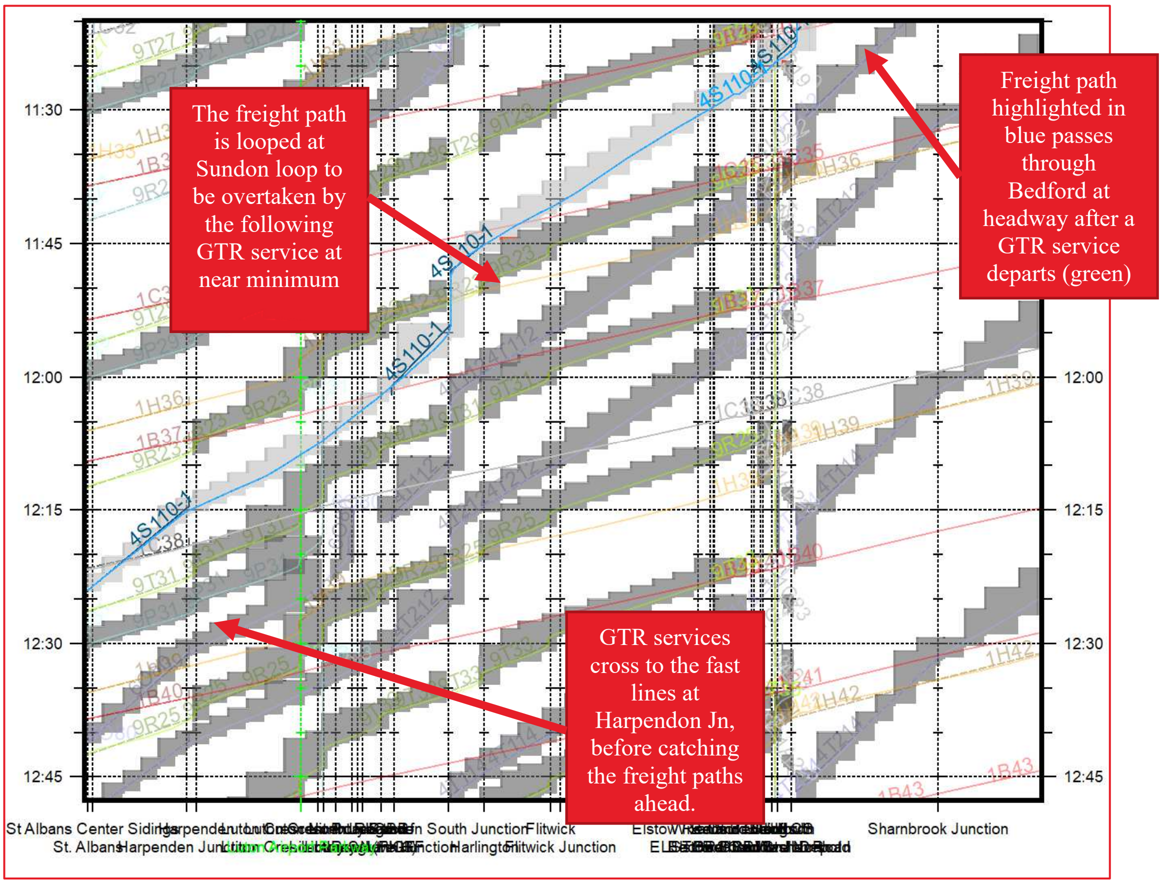

Figure 11 Train graph MML South

4.3.1 Wixams Timetable Option

The extra time required between the Thameslink Core and Bedford for the call at Wixams removes most of the recovery time from the turnround at Bedford. To build resilience into the service the trains are stepped back. The consequence of this is significantly longer turnrounds at Bedford on Thameslink services which restricts the ability to path freight services through Bedford.

As a result, as shown in the table of paths, there are less freight paths running north south through Bedford. The introduction of the additional stop does however reduce the journey time differential between Thameslink and freight services, potentially increases the resilience of freight paths south of Bedford.

4.4 EWR Freight

In addition to future growth on the MML, the assessment has considered the potential for new hourly freight flow on the EWR route. As with the EWR passenger services these paths would be required to route onto the MML Slow Lines between Bedford and Bedford North Jn with Down direction (towards Cambridge) EWR freight paths blocking paths in both directions when passing through this location. In addition, paths for freight on the EWR route are constrained around the assumed infrastructure and base timetable. Effectively EWR freight paths run between passing loops before being overtaken by a following EWR service. Prior to Bedford, freight is looped at EWR Ravensden Loop and after on the MVL (location depending on timetable/assumptions). This means the timings for the EWR freight through Bedford are largely fixed around the EWR timetable and have little flexibility without further implications on the location and potentially the number of passing loops provided on EWR. EWR timetable Concept 1 potentially further limits EWR freight paths. Concept 1 in additional to 4tph to Cambridge includes an all-stopping service between Bedford and Bletchley, this path operates largely in one half hour between EWR services and an overtake at Ridgmont. This leaves the second half hour only for potential EWR freight paths.

As outlined above, to support EWR on the MML Slow Lines the structure of the passenger timetable for both EWR and GTR must reflect each other with similar arrival and departure times at Bedford and the south or westbound freight service following close behind a passenger service. This means that a MML freight path is competing for the same path as an EWR freight path through Bedford. This means, after considering future freight requirements on the MML, there are few paths remaining for EWR, especially during the inter-peaks. The paths that have been provided are either during the MML peaks where there are limited North-South MML freight, or late evening where MML freight paths are less constrained in the timetable. The following table outlines the additional EWR freight paths included within the timetable (excluding existing MML to MVL freight).

Timetable Option (1000-1600)	Up Direction	Down Direction
Base Timetable 4-track	4	3
Wixams Timetable 4-track	5	4

Table 4 Total Number of additional EWR freight paths within the timetable.

4.5 Bedford Up Fast Platform

This option only tests the performance implication of moving EMR and does not further increase the number of freight paths.

As outlined previously, Bedford station currently lacks an Up Fast Platform and with the current timetable requirement to call EMR London St Pancras – Corby services at Bedford, this means these services are required to cross from the Fast Lines to the Slow Lines between Bedford North and South Junctions, further consuming capacity on the MML Slow Lines. The assessment has re-timed these services to indicatively call on the Up Fast Line, which indicates a potential journey time improvement. Though it should be noted that a design for an Up Fast Platform was not included in the assessment. By removing the EMR services from the Slow Line Platforms this provides opportunities to further optimise the platforming of GTR services, including using Platform 1a. The performance implications of this option are considered in section 5.

4.6 EWR Best Case 4-track Scenario

As the assessment proceeded and the early findings were reported to EWR, an additional sensitivity option was requested, with a reduced level of freight assumed during the inter-peak hours, and additional freight in the late off-peak (overnight) hours. The general assumption of this option has been to provide 1.5 freight paths per hour on the MML and 0.5 freight paths per hour on EWR, giving a maximum potential of 2 freight paths operating on the Slow Lines north of Bedford. This option is also developed on the full-scale 4-track infrastructure assumption including.

- Platform 1a to optimise GTR platforming and support the relocation of Jowett sidings
- An Up Fast Platform at Bedford to remove EMR services from operating on the Slow Lines through Bedford.

The following Table outlines the total number of additional paths provided in the Base-Case timetable interpeak period. The assumed approach has led to a reduction in paths provided on the MML, and an increase in EWR freight paths using either the paths freed up on the MML, or as a result of providing additional over-night paths as requested for the scenario.

Base Case	Up Direction	Down Direction
Base Additional Freight Paths	7	10
EWR Additional Freight Paths	4	3
TOTAL	**11**	**13**

Table 5 Total number of daily additional paths provided on the MML North-South and EWR East-West.

4.7 Timetable Capacity Assessment Summary

Figure 12 below shows how the individual constraints combine with a four-track layout at Bedford to become a significant constraint and performance risk to the EWR route.

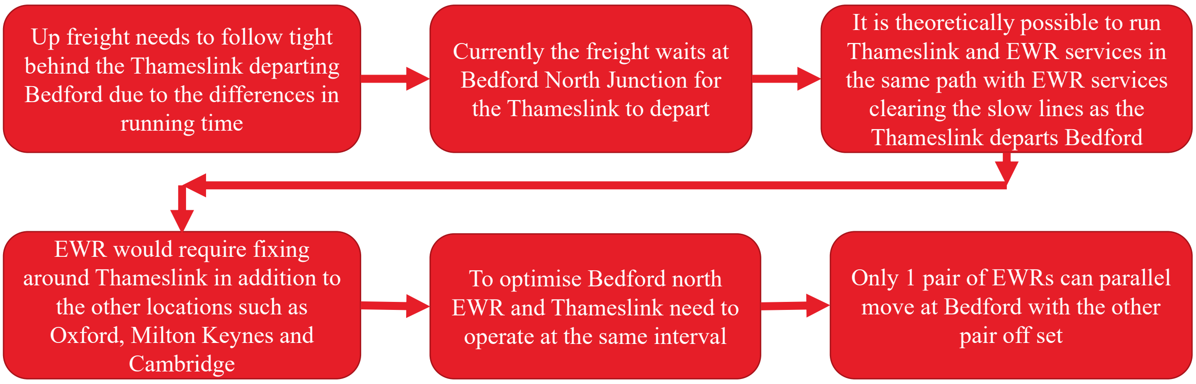

Figure 12 Constraints acting on Bedford Slow Line Capacity

Figure 13Figure 13 below shows an idealised operation of EWR at Bedford with synchronised operation of Thameslink and EWR services in a simultaneous pair of parallel moves. These moves are then followed by a pair of freight trains maximising the use of capacity. This sequence of moves is detailed in the accompanying animated slides of the presentation.

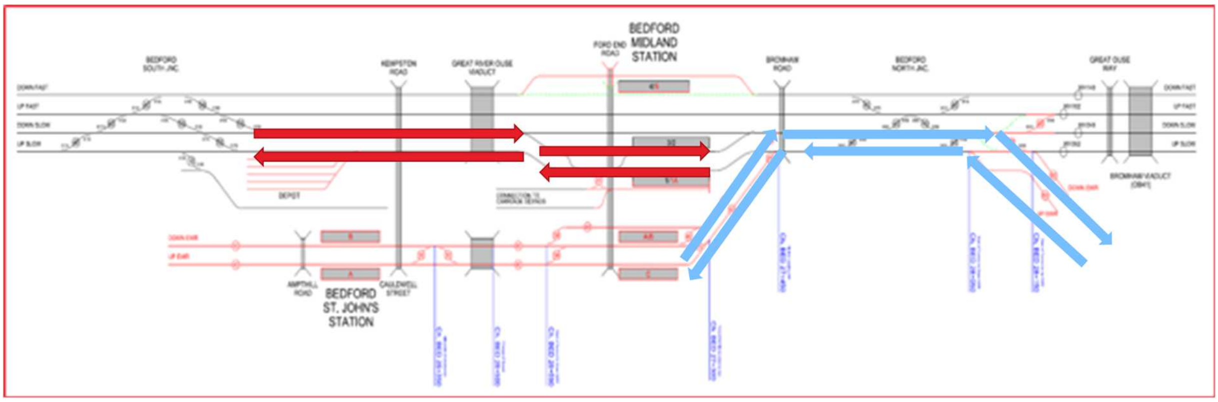

Figure 13 Idealised operation of Bedford

If this sequence of moves cannot be synchronised it becomes a sequence of conflicting moves which does not make the best use of the available capacity. The most constrained section is the up slow line as the down EWR services need to cross to the down slow and back again. The EWR development timetable has one pair of services synchronised with the Thameslink but the other pair are offset due to wider route constraints on the timetable. This leads to the following sequence of moves:

1. Down EWR
2. Pair of Thameslinks
3. Pair of freight trains
4. Up EWR

This sequence of moves requires four moves to take place around Bedford in around 10 minutes. Given that this is over a junction stretching 800m and includes freight traffic this scenario represents both a risk to capacity and performance.

The following outlines the key outputs from the timetable capacity assessment:

1. If Jowett stabling site is impacted by EWR and relocated adjacent Cauldwell (as the assumed preferred location) then Platform 1a will require lengthening to support existing GTR services at Bedford. Upgrading Platform 1a additionally improves capacity on the Slow Lines at Bedford by offering an additional Platform to terminate GTR services in. Platform 1a in turn reduces the need for bi-directional routing between Bedford and Bedford South Junction.
2. The indicative high-level concept design for 4-track means there is a potential impact to journey times for GTR services accessing Platforms 1-3 due to the potential use of restrictive signalling (Reduced Overlaps) approaching Bedford, this could increase Down direction journey times by 1 minute, subject to the development of an overall scheme and further assessments.
3. With the base service assumptions, operating EWR on the slow lines north of Bedford at 4tph is constrained, requiring the EWR timetable to be developed around the MML timetable to support north-south freight paths. Noting EWR is constrained at other key locations where it interacts with other services, this would add a further constraint.
4. When considering the strategic position of 3ftph on the MML there was a considerable capacity challenge to accommodate this with the EWR services on the slow lines north of Bedford.
5. The ability to also support 1ftph on EWR is also significantly constrained with limited availability of paths competing with MML freight capacity.
6. Provision of an Up Fast Platform at Bedford minimises the impact to EMR Up services which currently need to stop at Bedford on the Slow Lines, but does not resolve the interlinking between EWR, GTR and freight on the MML Slow Lines.
7. In essence EWR and freight paths on the MML are competing for capacity and performance on the MML, and in addition tied to the overall MML timetable south of Bedford, limiting the availability of paths.
8. The current timetable proposals for Wixams result in an increased use of the existing platforms at Bedford increasing the need for Platform 1a and an Up Fast solution to support EWR on the Slow Lines north of Bedford.

5. Performance Assessment Findings

5.1 Overview

The analysis has looked at all services which run through Bedford. This section will focus on the EWR services as they are most impacted by a four-track layout. The full modelling results are included in the appendix and show a considerable benefit to the semi-fast Corby services from having an up fast platform provided at Bedford.

5.2 Key Performance Modelling Limitations

The following should be considered when reviewing the outcomes of the performance modelling assessment completed:

- The performance assessment is an early indication of the relative performance differences and is high-level, noting there is currently not a detailed scheme design for either option tested.
- The modelling undertaken for this exercise is a comparative and shows the relative differences between infrastructure and timetable options. This modelling is therefore not able to produce absolute values for lateness or punctuality.
- Modelling is based on a "typical day", in the sense of high-frequency, low-impact delays and not covering low-frequency, high-impact delays which may typically require service intervention measures in the sense that operational decisions such as of full/part cancellations are not captured with the modelling.
- Modelling works on an algorithmic regulation logic. Bedford will require complex regulation and the decisions taken by the signaller could lead to different outcomes than in the model.

Given these limitations the modelling undertaken at this stage cannot produce a PPM figure for example. Further design work is required to validate the designs and in turn validate the operational feasibility of the design including performance implications.

5.3 Implications of Relocation of Jowett Sidings and Platform 1A

The benefits from enhanced platform 1A are expected to exceed the potential performance risks from running additional empty stock moves on the slow lines between Bedford and the relocated stabling facility. The additional platform capacity provided will increase the resilience in the shoulder-peaks when services are entering and exiting the stabling facility, which should lead to improved peak performance.

Platform 1A provides an opportunity to replatform the Thameslink services at Bedford to increase the robustness of through freight paths.

5.4 4-Track Timetable Implications

The four-track design modelled has the junction where EWR join the MML clear of Bromham Road bridge. This does not provide enough distance for full overlap therefore Thameslink services for platforms 1-3 will be approaching Bedford at a slow speed on a reduced overlap. This will lead to an increased journey time or a reduction in performance.

The performance impact of EWR sharing the slow lines north of Bedford is linked to the freight growth assumptions and covered in the following scenarios.

5.4.1 Base Timetable

The base timetable has been taken from the Wixams study with a low level of freight. This scenario does not contain the up fast platform in either option. Enhanced platform 1A is included in both models to mitigate the impact of Jowett sidings being removed. There is a worsening in performance on the existing Thameslink and semi-fast services on the four-track layout. The worsening on Thameslink services is due to the trains now coming in slower on the reduced overlaps and the worsening on the semi-fast services is due to increased train movements from EWR services on the slow lines between Bedford and Bedford North Junction.

The graph below shows the EWR Westbound services. A large delay distribution has been applied at Bedford which increases the lateness of EWR services passing through in all options. The location of Bedford North is different in the infrastructure options which gives a slightly different level of lateness and the sectional running time should be rebalanced to compensate for this. The 4-track alignment shows a minor worsening in performance coming into Bedford which carries through to the rest of the route this is due to the slightly longer running time as the base model has a low level of freight.

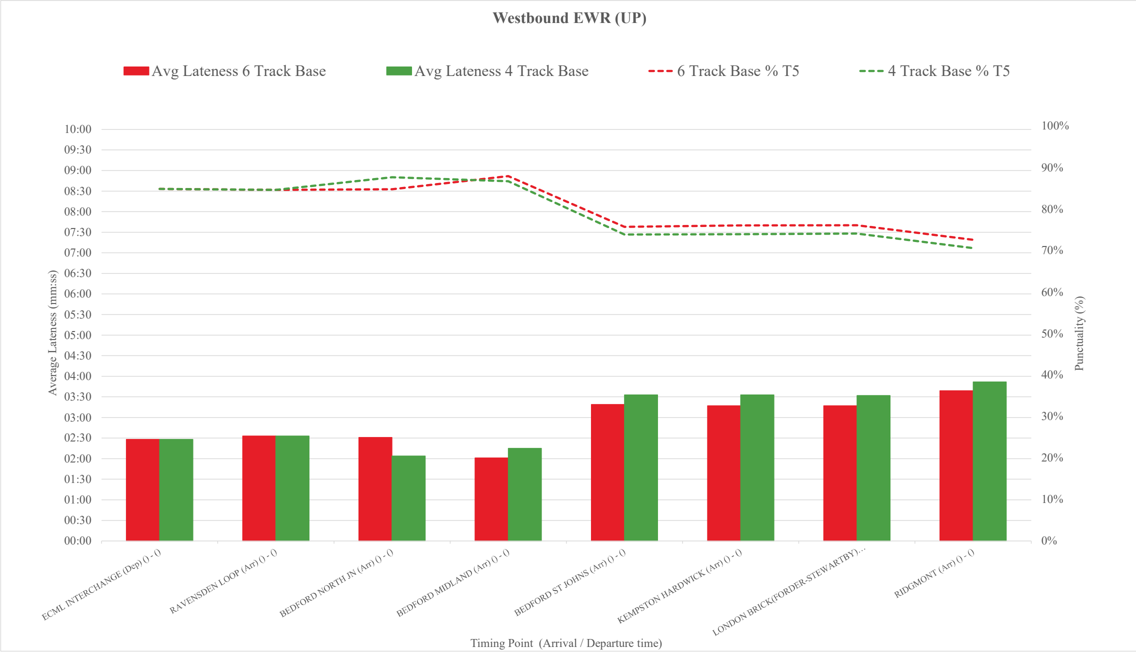

Figure 14 EWR Westbound Services - Base

The graph below shows the EWR Eastbound services. The 6-track alignment gives a faster approach for EWR services as the line speed is higher and they can arrive on a proceed aspect with full overlaps as there are no conflicting moves at the end of the platform. There is a significant decline in performance after Bedford where the service interacts with the semi-fast Corby service on the Midland Main Line.

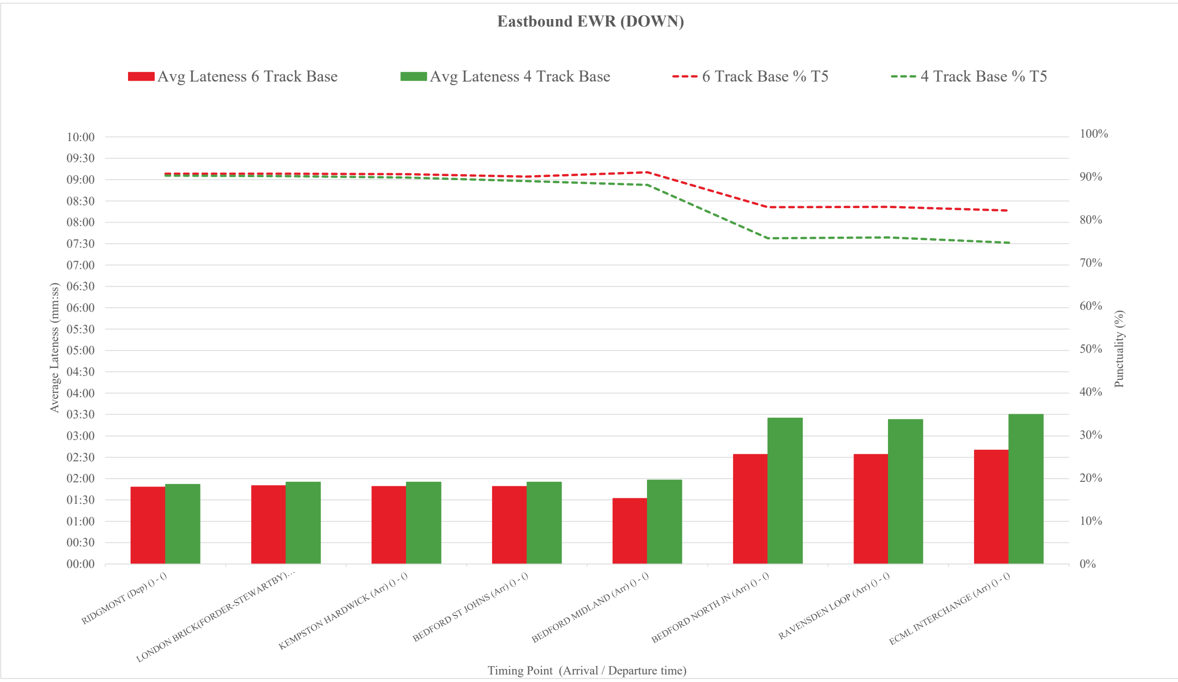

Figure 15 EWR Eastbound Services - Base

5.4.2 MML EWR Freight Assumption (3ftph)

This scenario has an increased level of freight on all options and a further enhanced four-track option; this option includes up fast platform. All options have maximised the use of the bay platform 1A for Thameslink terminating services freeing up capacity for freight. The up fast option moves the semi-fast services away from the slow lines and allows further optimisation of the Thameslink platforming.

Increasing MML freight to three paths per hour presents a significant performance risk and has not been regularly achieved in the study. Without Platform 1A there is limited capacity to accommodate the freight trains on the slow lines through Bedford. Under this scenario most of the freight would need to cross to the fast lines to get through Bedford then cross again, increasing the potential for reactionary delay to pass between different service groups.

The up-direction freight path runs through Bedford behind a departing Thameslink service. The freight is significantly slower than the Thameslink service on the climb up the Chilterns towards Luton and is caught by the following Thameslink service with any late running on the freight train passing to the Thameslink.

The Thameslink service crosses to the fast line at Harpenden Junction which causes reactionary delay to spread to the down slow and up fast lines. This move happens in front of a down freight service which has the potential to bring the reactionary delay back towards Bedford increasing the performance risk.

The EWR services interact with the freight services heading North-South on the four-track section. The EWR service is followed from Bedford by the MVL stopping service which needs to be held for a late running EWR service. This service gets looped for the following EWR service to pass it at Ridgemont which can pass delay between services.

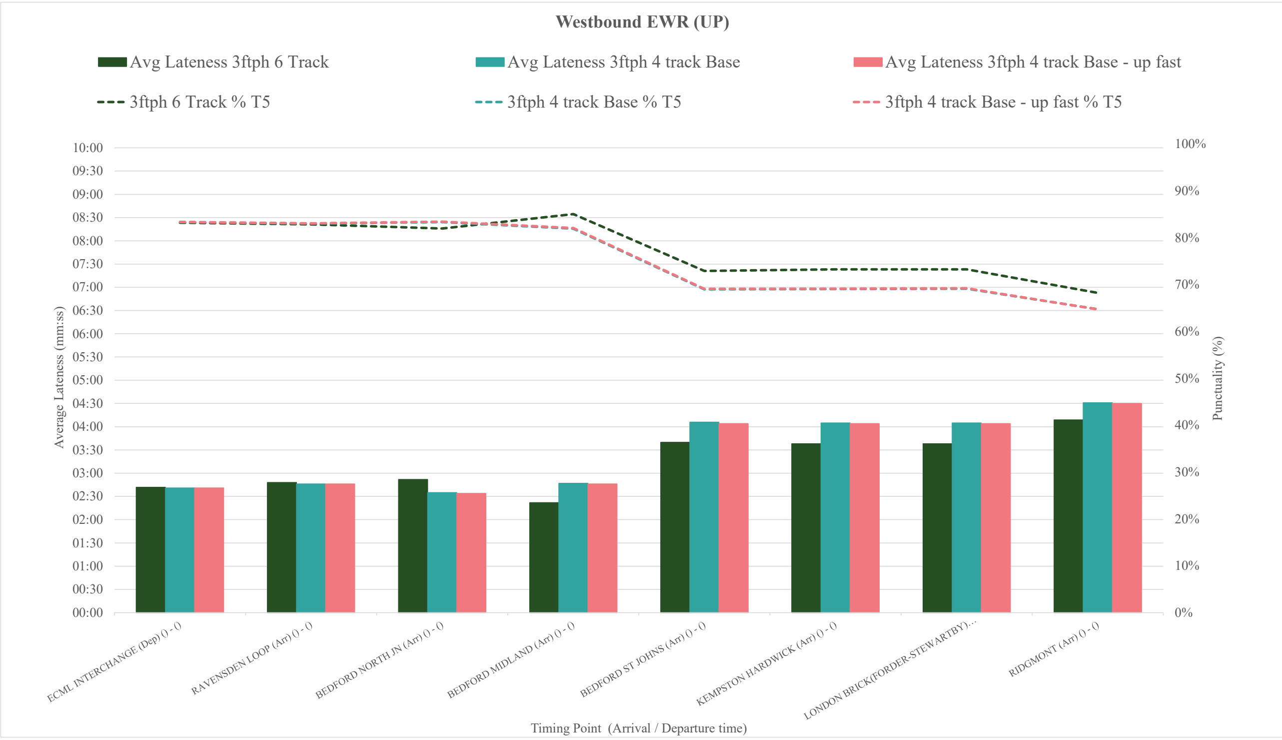

Figure 16 EWR Westbound – 3ftph

The graph below shows the EWR Eastbound services. These services have the greatest interaction with MML services as they cross the up slow to run on the down slow before crossing back again. In the four-track base option the EWR services need to find a path through the freight trains in both directions with the conflicting moves and the semi-fast Corby service which crosses to the slow lines to call at a platform. The 4-track with the Up Fast Platform removes the Corby service slightly easing the constraint against the 4-track base option, but the fully segregated 6-track option provides the greatest level of robustness.

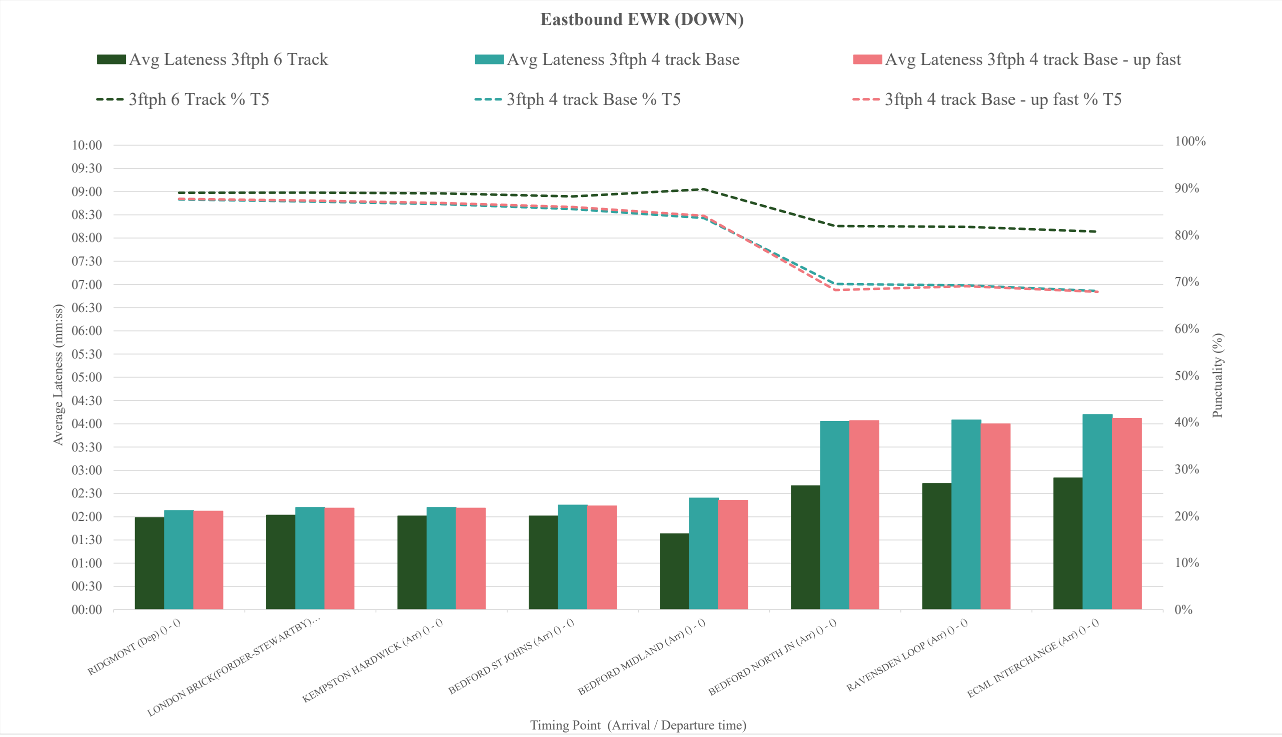

Figure 17 EWR Eastbound – 3ftph

5.4.3 Best Case 4-track Scenario

This scenario reduces the level of freight from an aspirational 3ftph and caps the freight at an average of 1.5ftph. Along with the base, option, and enhanced base the proposed Wixams scheme is included in this scenario.

The changes introduced by this additional station stop drive changes to the stock working and increase the off-peak turnround time of Thameslink services, which restricts the ability of the freight trains through Bedford. Under perturbation this reduces the chance of the through platform being available when a late running freight train presents at Bedford.

The additional station call slows the Thameslinks down reducing the difference in running time between passenger and freight trains; this makes the freight paths south of Bedford more resilient.

The graph below shows the EWR Westbound services. This graph shows the 6-track option performing better than all the 4-track options for this service group.

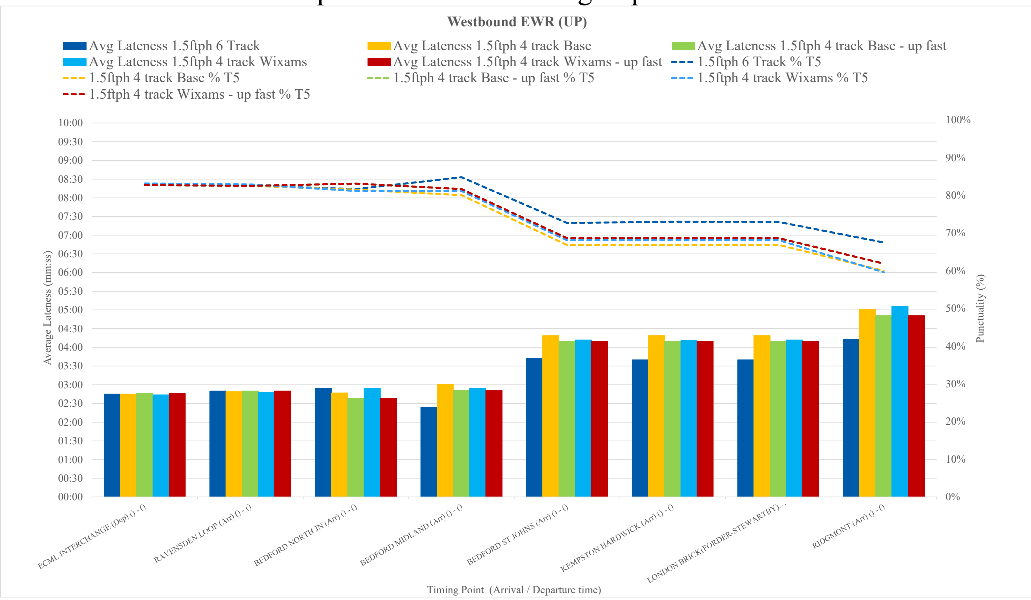

Figure 18 EWR Westbound 1.5ftph

The graph below shows the EWR Eastbound services. The additional up fast platform reduces the number of interactions north of Bedford and provides a benefit above that of the 4-track base infrastructure but the 6-track option performing significantly better than all the 4-track options for this service group.

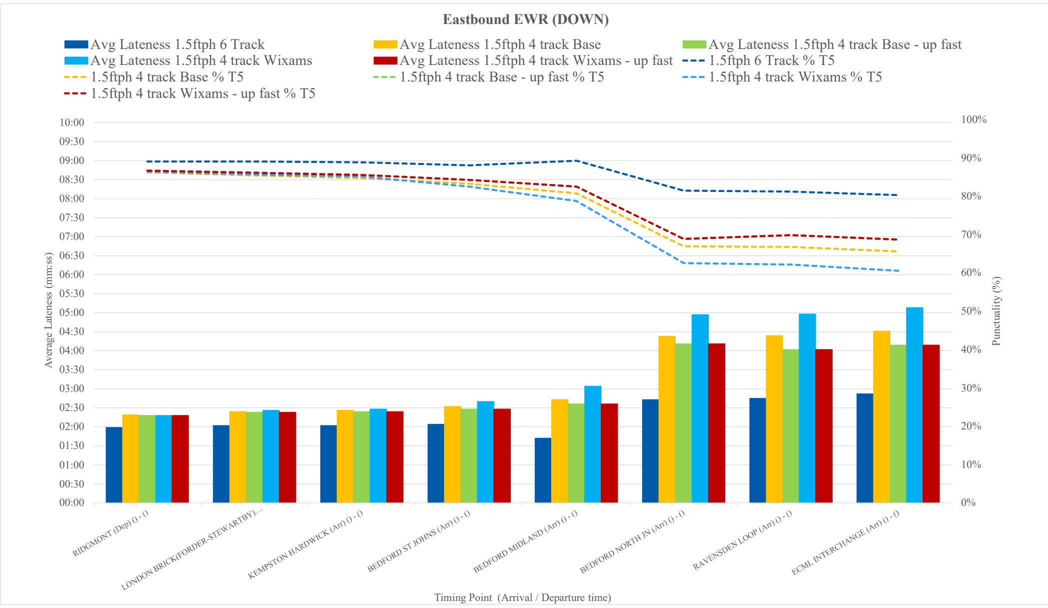

Figure 19 EWR Eastbound 1.5ftph

5.5 Performance Assessment Summary

1. The proposed enhancements for platform 1A can deliver significant capacity and performance benefits allowing Bedford to be replatformed to enable freight growth.

2. There is a negative performance impact on existing services when EWR and freight are integrated on the four-track base infrastructure with EWR services most impacted with further enhancements likely required at Bedford to improve the level of performance impact on existing services.

3. The enhanced four-track infrastructure with the up fast platform gives significant benefits to the semi-fast Corby and less reactionary delay passing from it to other services. However, the performance risk to EWR services remains with the potential to impact on the wider route at Cambridge, Bletchley and Oxford.

4. The six-track alignment is the most resilient for EWR services and reduces the potential for reactionary delay to spread over a wider area.

5. The modelling has looked at Bedford in isolation; the impact of worsening EWR performance at Bedford is likely to lead to increased reactionary delay at neighbouring constrained locations.

6. Given the frequency and number of interactions of Thameslink services with the existing network it is anticipated that they will be prioritised to minimise overall network disruption; this will also require the freight to be prioritised. Under this scenario EWR is likely to be impacted greater than suggested in the modelling under times of disruption.

7. The modelling shows the six-track alignment provides the most resilient solution for EWR services. The level of performance that these services need to achieve to avoid impacting on the wider network cannot be determined at this stage as the interactions along the wider route are not fully understood.

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6. Conclusions

The initial modelling study concluded that the 3ftph freight level could not be robustly accommodated with EWR and the Thameslink service pattern, without enhancements to the infrastructure.

This study has investigated the impact of enhancing the infrastructure with an additional up fast platform and extended 1A to provide an additional platform for Thameslink services. In addition, a reduced level of freight growth on the MML is assumed. The Thameslink services at Bedford have been replatformed to make best use of the enhanced infrastructure. The following conclusions can be drawn from this study:

- The proposed infrastructure enhancements including Platform 1A and the new up fast platform allow the Thameslink services to be re-platformed at Bedford. This moves the Thameslink turnrounds out of the way of through freight services and reduces the performance risk.
- The Thameslink paths are fixed and dictate the available freight paths. Pathing freight through Bedford is difficult and any performance issues are amplified by the gradients coming out of Bedford in all directions.
- Including EWR requires Thameslink and EWR paths to be aligned in order to maintain and provide a viable freight path through Bedford both for existing and additional freight. This in turn creates a further constraint on the EWR timetable in addition to Cambridge, Oxford and the West Coast Main Line; a four-track layout will need to find a timetable solution which works at all of these constrained locations which would potentially jeopardise aspirational journey times and restrict the ability to accommodate future timetable changes.
- A theoretical timetable with a reduced level of freight (see Appendix C – Freight Paths) than previously required is possible on the four-track layout but this leaves very little room to flex services in the future. This will build a further constraint into the route.
- The greatest performance risk relating to the four-track layout is on the EWR paths; of these the Westbound is most significant as it needs a path on the up and down slow together. This is likely to increase the performance risk from EWR at neighbouring constrained locations.
- A detailed design including the signalling and maintenance requirements has not been established. In addition to the operational limitation a 4-track design has on the delivery of EWR, further constraints may exist, including maintenance, signaller workload, and construction impacts.
- This study indicates that the 3ftph MML and 1ftph EWR freight level could not be robustly accommodated with EWR and the Thameslink service pattern, with the potential enhancements to the infrastructure reviewed in this report.
- The analysis has been based on an assumed level of freight, including both the trains per hour and the tonnage, and the results are sensitive to this assumption. If less than 3-4ftph is required then a 4-track solution could be acceptable from a performance perspective of existing services as long as proposed infrastructure enhancements is delivered. The level of constraint and performance risk on would then remain with EWR services to be weighed up against the design impacts of 6-track – this may include reviewing the level of service (tph) EWR provides throughout the day e.g., 2tph during off-peak.
- If 3ftph or more are required, a 6-track solution is needed otherwise there will be an unacceptable deterioration in performance of Thameslink and MML services and new EWR services. As this decision has long term consequences a freight strategy for the MML and EWR is needed to understand the actual level of freight that will run on the routes and number of paths required to support it.

7. Appendix A – Sponsor's Requirements

The PWOS requirements below applied to the previous studies on Bedford but have been relaxed for this study into the viability of the four-track approach.

1. Services for CS3 between Oxford, Bletchley and Cambridge shall be a regular clock face pattern that compliments CS1 services to provide regular clock face departures at Oxford and Cambridge and provide a regular departure pattern and frequency along the route (PWOS cl 7.5.5)
2. Deliver a maximum journey time of up to 95 minutes between Oxford and Cambridge (PWOS cl 7.5.1)
3. The risk of poor performance being imported from or exported to the wider railway network shall be reduced through provision of latent redundancy and resilience within the design. (PWOS cl 7.28.3) and additionally:
    a. Sponsor's requirement 5.1. "The Railway infrastructure shall maximise the new route's capability of operating with high levels of train service performance, reliability and resilience".
    b. Sponsor's requirement 5.2. "Performance targets for the Railway will be agreed with DfT, but as a minimum shall be in line with those of similar well performing services on the wider network. There shall be an ambition to improve on existing performance levels of similar services."
    c. Sponsor's requirement 5.3. "The Railway shall, insofar as practical, be resilient to any periods of poor performance on the wider network."
    d. Sponsor's requirement 5.4. "The Railway shall isolate the wider network from any periods of poor performance on the Railway."
    e. Sponsor's requirement 5.6. "The project shall be designed and constructed to minimise any operational impact or risk in such interaction."
4. Minimise any detrimental effect on the performance of the routes where EWR interfaces and/or introduces new services through working collaboratively with industry partners (PWOS cl 7.28.4) and additionally:
    a. Sponsor requirement 13.3 "In designing and developing The Railway, the capacity and journey time improvements that are planned at interfaces with other parts of the network, must be considered. The Railway should have no detrimental impact on the performance of these routes, including, where practical, not precluding future enhancements in these areas."

8. Appendix B – MML Performance Analysis

The Figure 12 shows the Down Thameslink services which have a worsening in performance when approaching Bedford in the 4-track option, as they are arriving at a lower speed on reduced overlaps. While the technical running time can just be accommodated within the planned sectional running time this might drive an increase in the sectional running time.

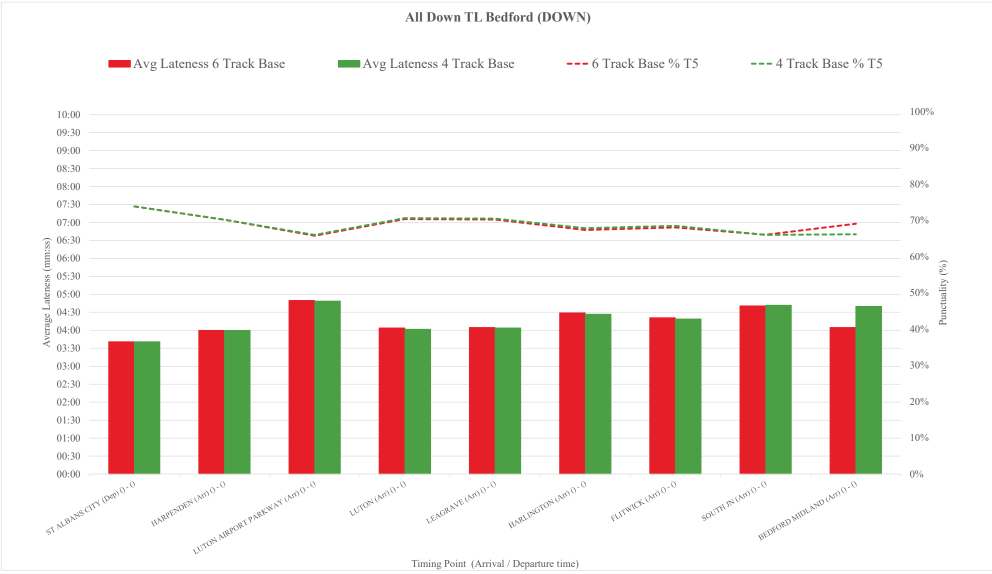

Figure 20 Down Thameslink Services - Base

The graph below shows the Up Thameslink services. These services perform worse on departure from Bedford. This is due to the arriving services performing worse in the 4-track option. This increases the amount of lateness to be recovered in the turnround and passes reactionary delay between up and down services with tight junction margins in the throat of Bedford and at Bedford South Junction.

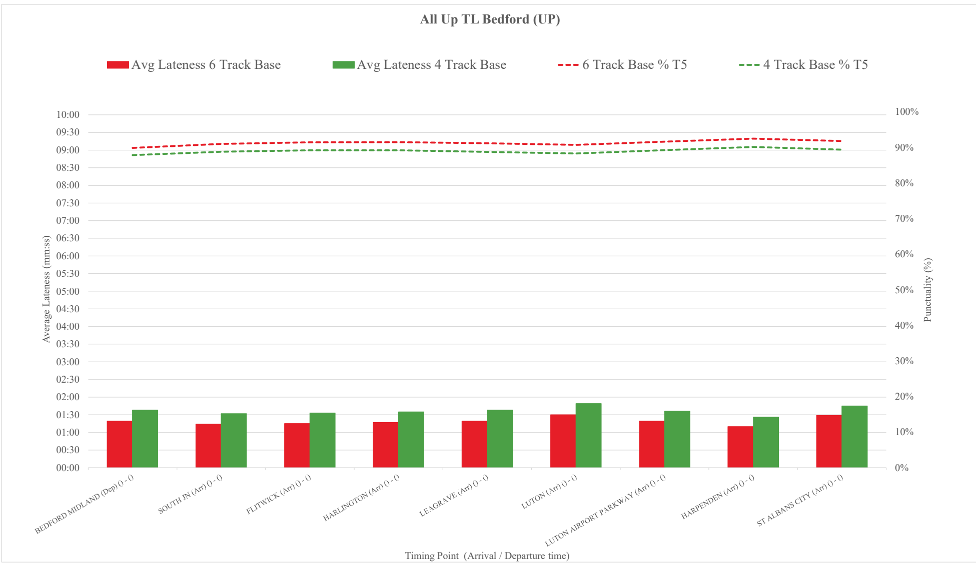

Figure 21 Up Thameslink Services - Base

The graph below shows the Up Corby semi fast services. In both options there is a significant increase in lateness approaching Bedford due to the interaction with Thameslink services as they need to cross to the slow lines for a platform at Bedford. The 4-track alignment performs worse than the 6-track alignment with the additional interactions between the semi-fast and EWR services.

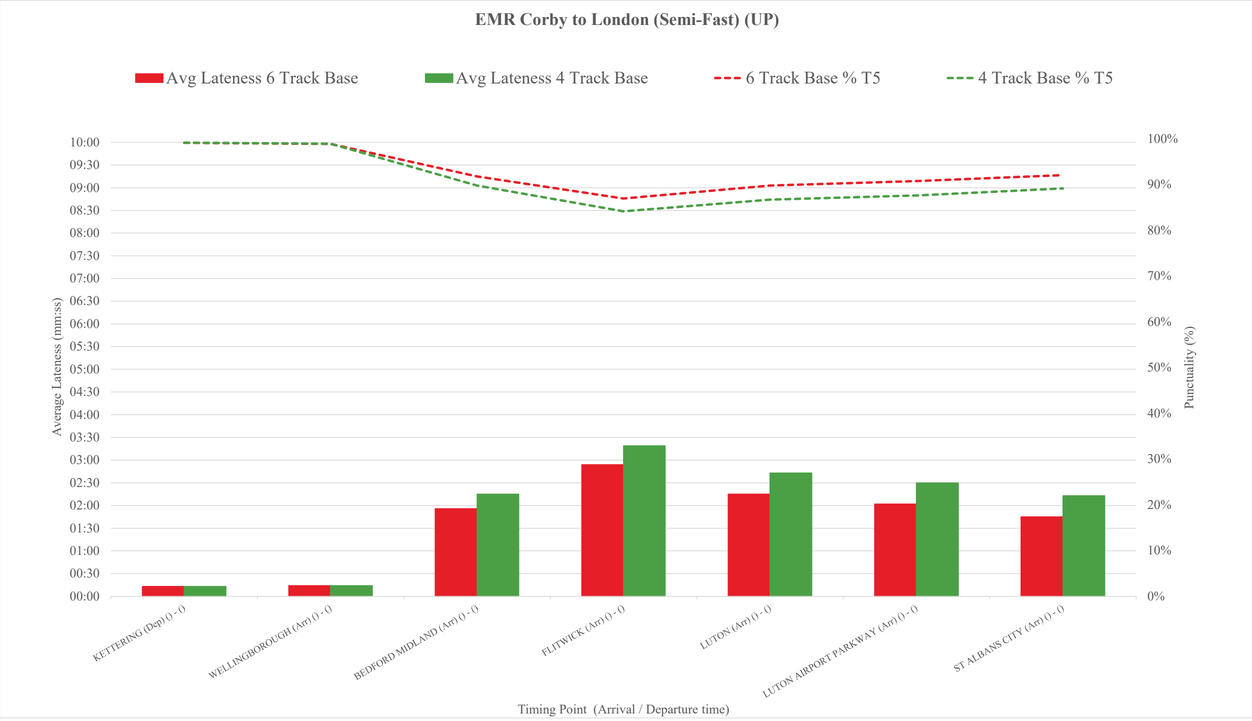

Figure 22 Up Corby Services - Base

The graph below shows the intercity services from Nottingham. These services are 7 minutes behind the semi-fast so there is a minimal impact from the semi-fast Corby service, with some reactionary delay transferring between them.

Figure 23 Up Nottingham Services - Base

The graph below shows the Down Thameslink services. There is a minimal difference between these services with the base 4 and 6 track infrastructure options. The 4-track option with the additional up fast platform shows an improvement in performance with a reduction in interactions between the semi-fast and Thameslink services.

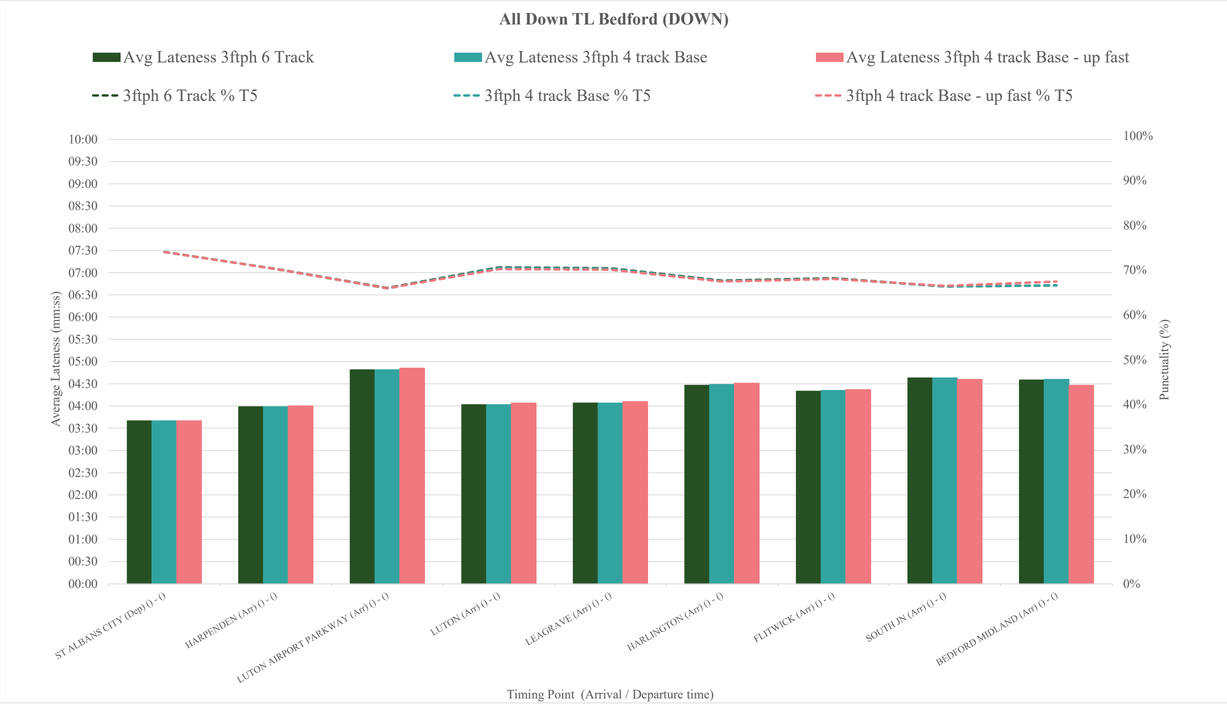

Figure 24 Down Thameslink Services – 3ftph

The graph below shows the Up Thameslink services. Lateness increases for all options, as the Thameslink services pick up lateness due to following freight trains on the climb up towards Luton. This increase is greatest on the 4-track option without the up fast platform, as the freight trains have a tighter path through Bedford. The up fast platform removes some interactions and allows Bedford to be replatformed to a greater degree, and the 6-track alignment removes the interactions with EWR.

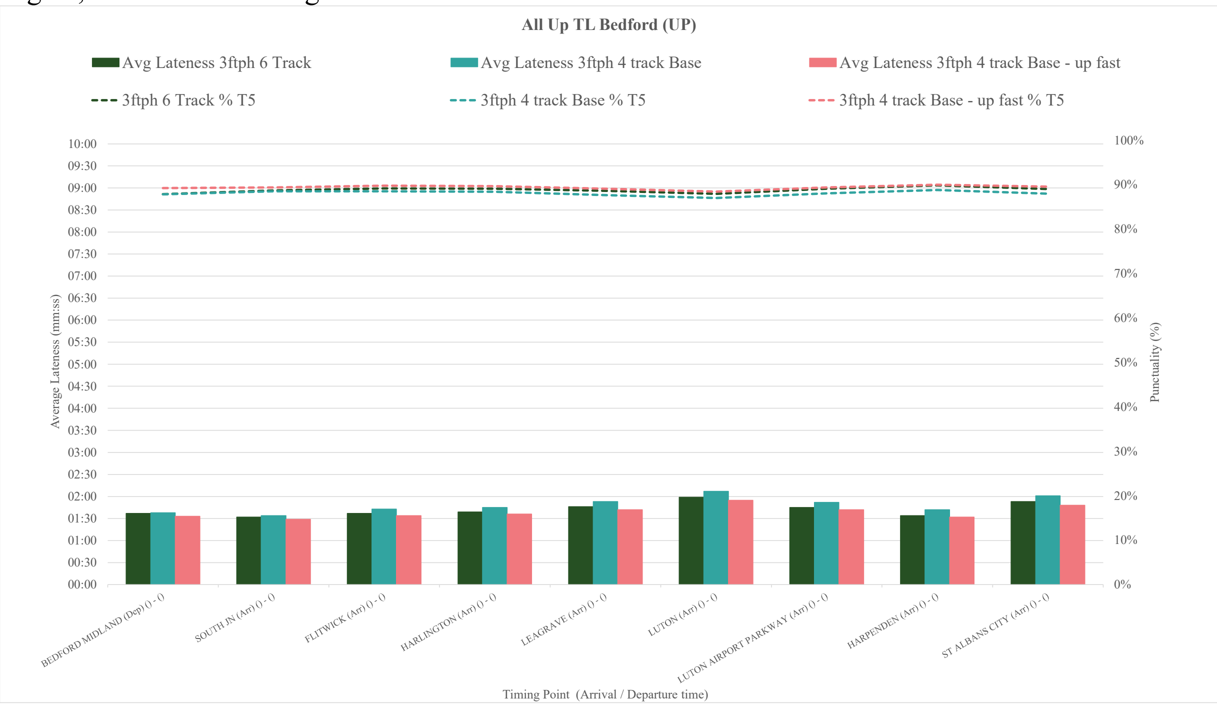

Figure 25 Up Thameslink Services – 3ftph

The graph below shows the Up Corby semi fast services. The 4-track with the up fast platform has a significant improvement on this service group, as all interactions between this group and slow line services are removed.

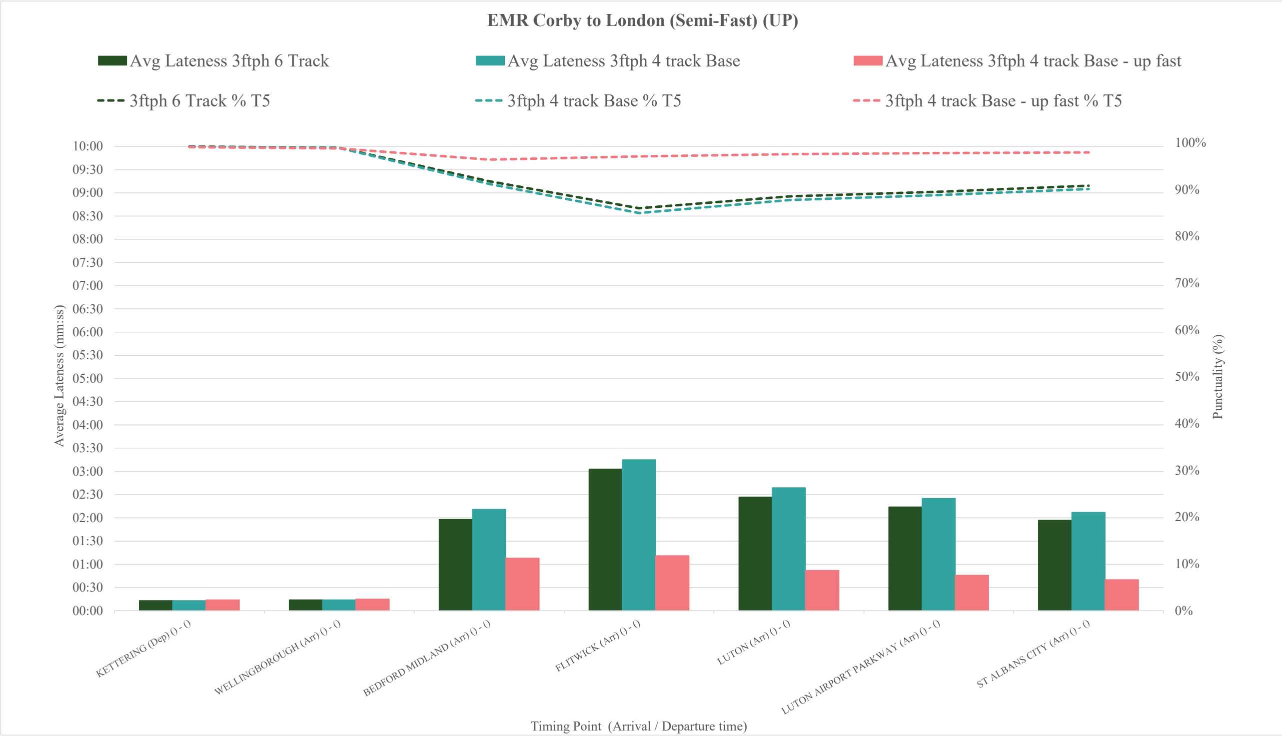

Figure 26 Up Corby Services – 3ftph

The graph below shows the intercity services from Nottingham. This service follows the semi-fast service, so any improvement to the semi-fast service results in less reactionary delay to the following services.

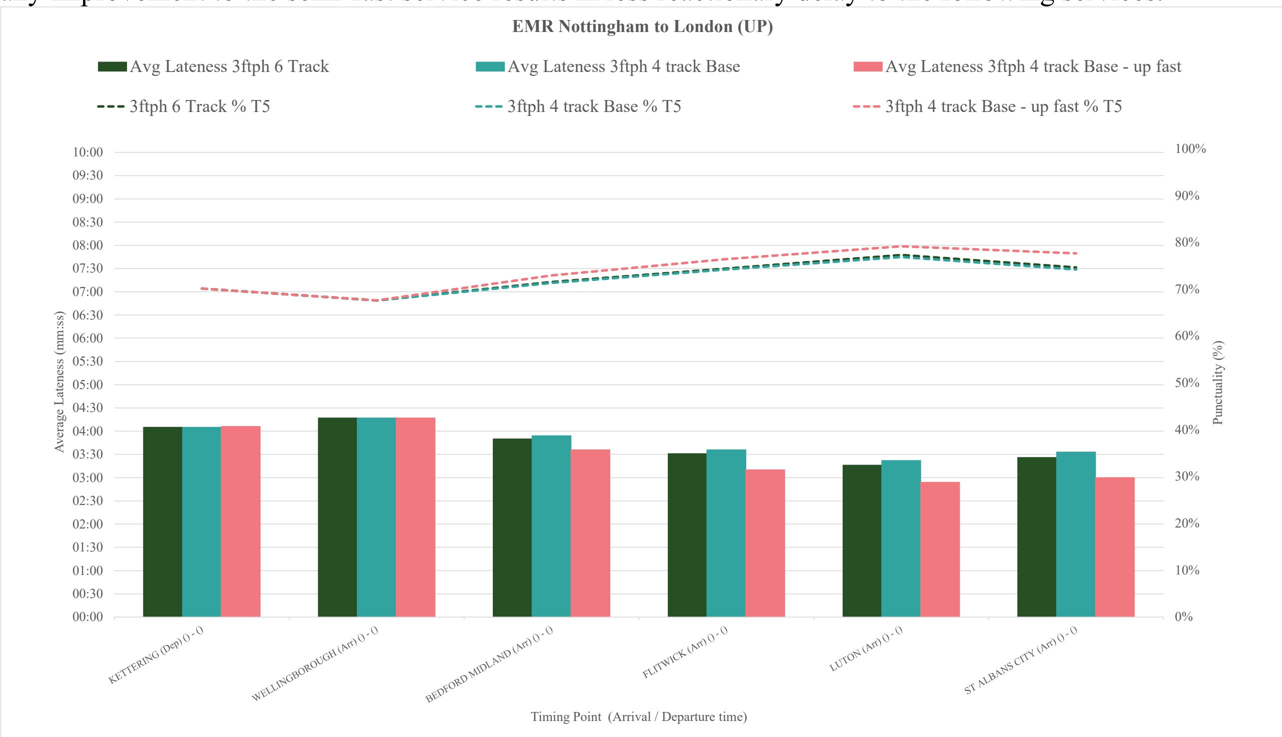

Figure 27 Up Nottingham Services – 3ftph

The graph below shows the Down Thameslink services. There is an increase in average lateness for the 4-track Wixams infrastructure option, with minor differences between other options.

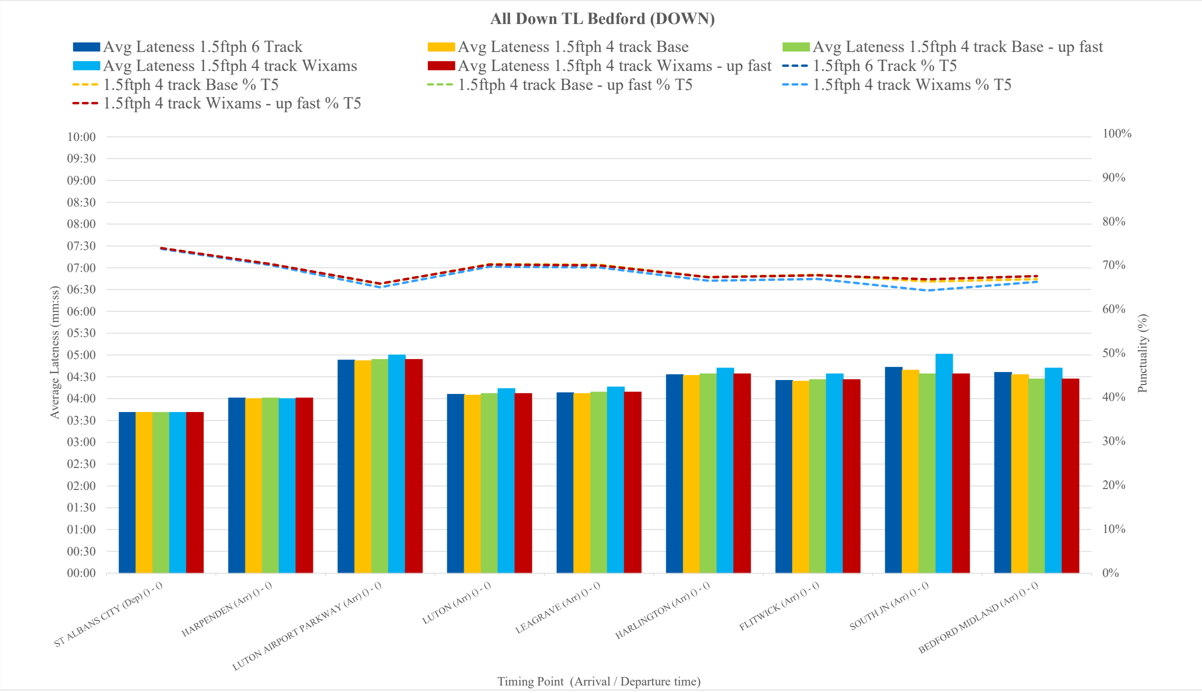

Figure 28 Down Thameslink 1.5ftph

The graph below shows the Up Thameslink services. Due to the tight interactions in the throat of Bedford and at Bedford South Junction, late running down services delay departing up services.

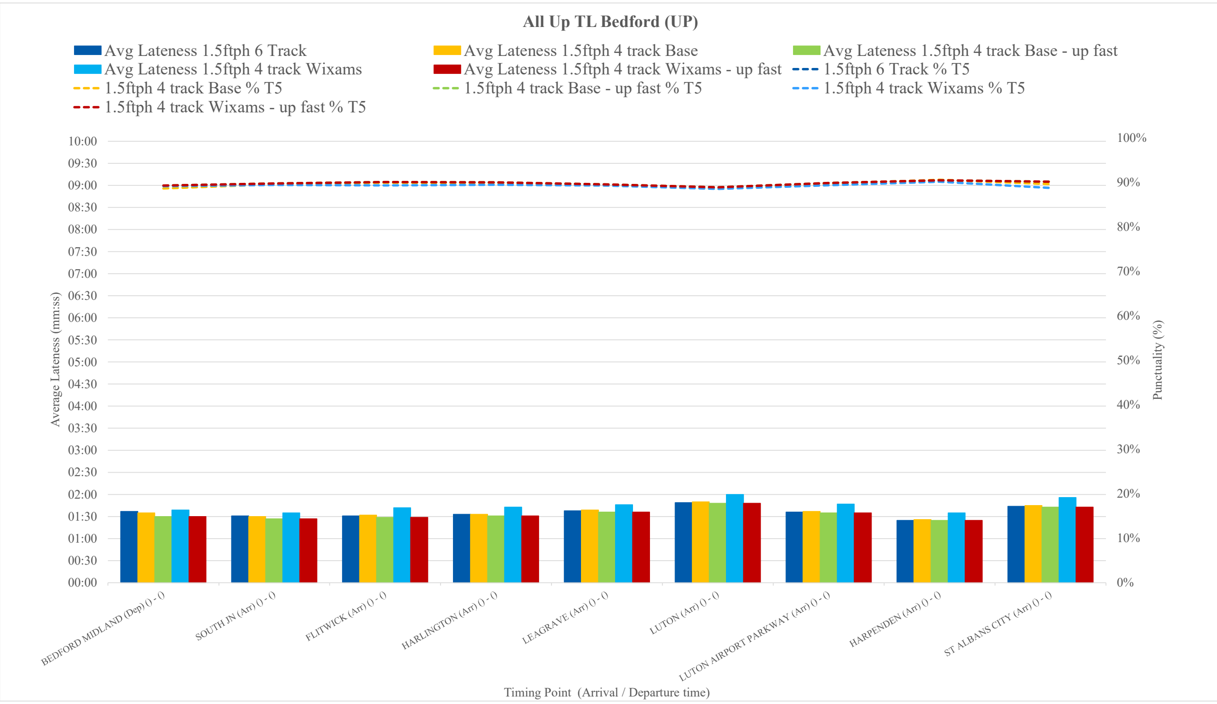

Figure 29 Up Thameslink 1.5ftph

The graph below shows the Up Corby semi fast services. These services have a significant improvement in performance, with an up fast platform provided to remove interactions with the slow line services. These services are also impacted by the increased platform utilisation of the slow line platforms driven by the Wixams scheme.

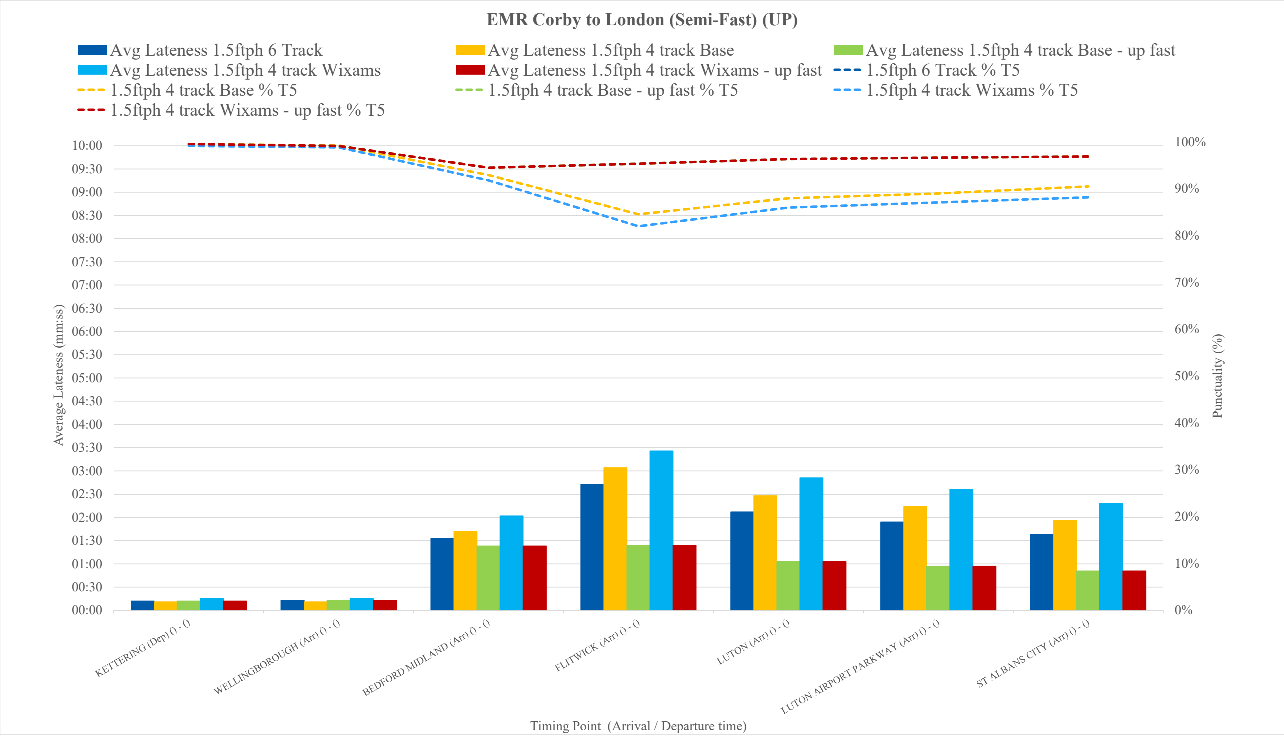

Figure 30 Up Corby – 1.5ftph

The graph below shows the intercity services from Nottingham. These services follow the semi-fast Corby services and can pick up reactionary delay from them.

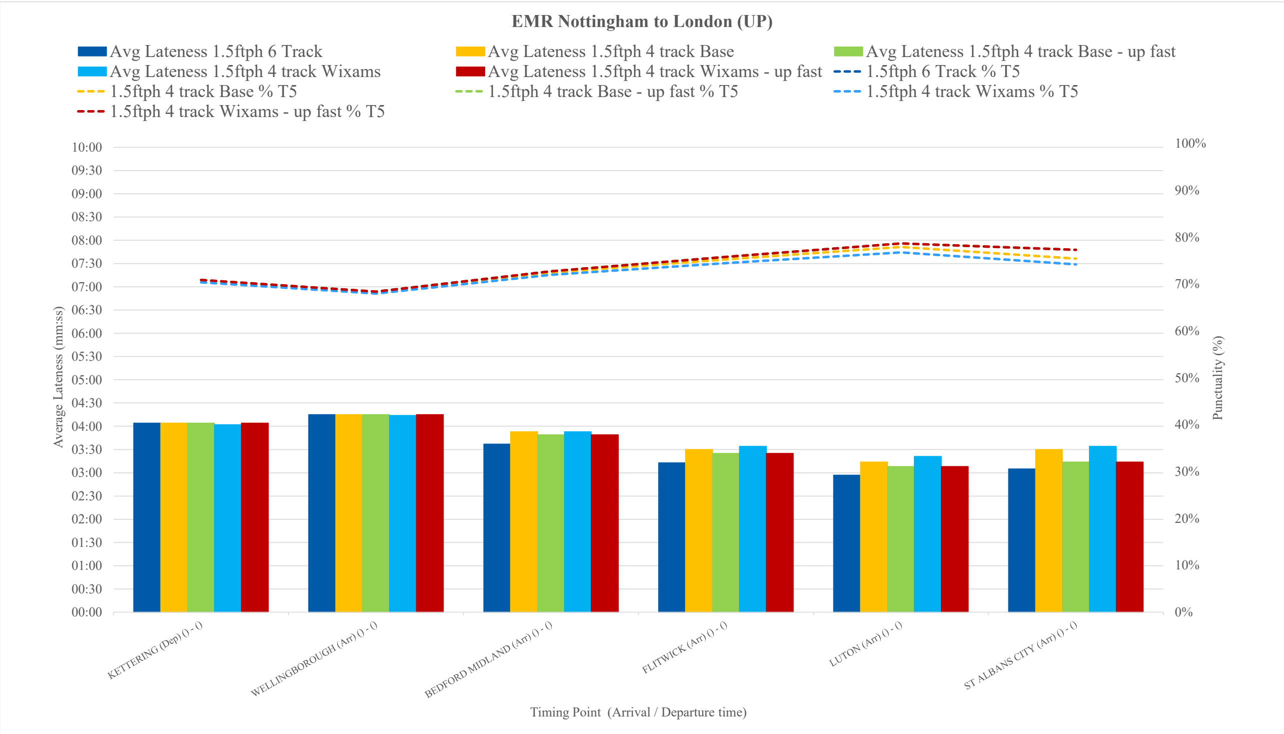

Figure 31 Up Nottingham – 1.5ftph

9. Appendix C – Freight Paths

		Base		1.5ftph		3ftph	
From	To	Up	Down	Up	Down	Up	Down
00:00	01:00	0	0	2	2	0	0
01:00	02:00	0	0	0	0	0	0
02:00	03:00	2	0	2	0	2	0
03:00	04:00	0	1	0	0	1	0
04:00	05:00	1	0	0	0	1	0
05:00	06:00	1	0	1	1	1	1
06:00	07:00	0	0	0	0	0	1
07:00	08:00	0	0	0	0	0	0
08:00	09:00	0	0	0	0	0	0
09:00	10:00	1	1	0	0	1	1
10:00	11:00	1	0	0	0	1	0
11:00	12:00	0	0	1	0	3	3
12:00	13:00	0	1	2	1	2	3
13:00	14:00	0	1	1	1	2	3
14:00	15:00	0	0	2	1	1	2
15:00	16:00	0	0	0	0	0	2
16:00	17:00	0	1	0	0	0	1
17:00	18:00	0	0	0	0	0	0
18:00	19:00	0	0	0	0	0	0
19:00	20:00	1	0	0	0	1	0
20:00	21:00	0	0	1	1	2	0
21:00	22:00	0	0	2	1	2	2
22:00	23:00	0	0	1	1	1	1
23:00	00:00	0	0	2	2	0	0

10. Appendix D – Quality Assurance Statement

10.1 Introduction

This note outlines the analytical assurance completed for the North of Bedford 4-track Operational Assessment (EWR_PGM-ARU-OP-XX-RP-Z-000003). At the commencement of this assessment collaboration between Arup, EWR and Network Rail outlined this assessment as a candidate to support a new assurance process being developed by Network Rail.

The purpose of the assessment has been to provide early quantitative analysis regarding the implications of 6-track compared to 4-track to the north of Bedford station. It is noted that throughout the assessment an on-going programme reviewing the train service and route options for EWR has being undertaken.

A 6-track model has been assessed as part of the work in comparison to 4-track. Noting there is no impact to existing capacity on MML from a 6-track design as its almost operationally separated from existing services in Bedford. There remains a potential link where existing freight operates between the MML and MVL, with a crossover route relocated to the north of Bedford. The impact from relocating the MML-MVL freight crossover is likely to be minimal due to the limited existing freight, it may also offers a slight improvement as it avoids freight running through Bedford.

10.2 Source of Information

The scope of the assessment is outlined in EWR_PGM-ARU-OP-XX-BF-Z-000001_P04. As part of the assurance process the scope was reviewed by Network Rail including the Capacity Analysis Team. Changes to the scope and assumptions are outlined in the output report.

A pre-established RailSys performance model was sourced from Network Rail and developed by Ed Jeffery Ltd for the Wixams station project. As this model was already established and the scope of this assessment included options with Wixams station, it was adopted for this assessment to reduce the timescales. and converted from RailSys version 10 into version 11.

A light review of the infrastructure model was performed by the modelling analyst and reviewed by the modelling lead. At the time, Network Rail were proposing changes to the RailSys Standards, included brake rates. Whilst not consistent with the latest standards the "simplified brake rate" setting was disabled in the new model as outlined in the remit. The impact of this change along with conversion to RailSys V11 was checked and to have found minimal differences in the reported outputs.

10.3 Option Infrastructure Data

The MML route was sourced from the Wixams performance model and updated to include changes for each EWR option case.

The 6-track EWR option case was adopted from the previous EWR Full Route Concept Timetable model. This was based on a Pway infrastructure design, with the sources referenced in the scope documentation. Pway infrastructure design includes details on the track such as length, line speeds, gradients and S&C. Excluded is signalling designs and related inputs, as these had not been developed.

The 4-track option case models' infrastructure was also based on Pway track designs referenced in the scope documentation. In addition, EWR's signalling lead provided a signalling concept for the design, which was adopted into the model, the main operational implication being the requirement for reduced overlaps. The designs for the Up Fast Platform have not been provided, therefore the model assumes a notional stopping location at the existing Signal located on the Up Fast. Recent work completed by NRDD implied there are no line speed impacts in the provision of an Up Fast Platform.

10.4 Scope and Reliability

Given the nature of the analysis, the performance outputs need to be considered as trend differences between options and as a comparative assessment. Detailed analysis and comparison of scale of differences e.g., in AML should not be considered directly. Instead, the analysis is purely focused on outlining the comparative performance merits of each option considered, i.e., "major/minor worsening, neutral or major/minor improvement". Further design work is required to support more detailed performance assessments of options which would improve confidence in the level of analysis that can be performed from the outputs.

The delay distributions were adopted from the source Wixams model. These and the EWR distributions were based on a generic distribution basis because the baseline was a future timetable and due to issues obtaining performance data at the time. As set out in the standards the generic distributions on EWR were increased above the level in the remit to drive a greater level of interaction between services in the model.

10.5 Level of Risk and Robustness

The level of risk in terms of the accuracy of the outcomes of the analysis on the current assumptions is considered medium to low as it is a comparative assessment rather than a prediction. As noted in the introduction, the analysis was completed to provide further assurance on previous non-quantitative assessment regarding the performance implications of 4-track compared to 6-track. The outputs are, however, highly dependent on the service assumptions and project requirements set out in the scope. This includes for example the number of freight paths operated within the performance model. Changes to these assumptions could have a significant impact on the outputs and presents a high risk. Noting the on-going programme to review the requirements, train service options and routes for EWR.

There are several exclusions that could alter the detailed outcomes of analysis, namely that a signalling design and related features has not being developed for the modelling.

Development of a signalling design may impact the following:

1. The signalling design is likely to have a significant implication to the Sectional Running Times in the Bedford area and in turn journey times. The analysis has not completed IRT/SRT analysis due to this and assumed SRTs are applied.
2. The signalling design will support the determination of the Timetable Planning Rules, these may differ to that assumed in the analysis.
3. The signalling design may not be compatible with the Pway and other elements of railway design requiring iteration of the design across multi-disciplines. This may impact on the concept of the design and its ability to support the requirements of the train service specification.
4. The detailed performance outcomes assuming points 1-3 do not have a detrimental impact on the timetable feasibility, may also be impacted. The signalling design can influence both the recovery time and impact time from delays in the timetable.

The modelling study has used standard industry tools and techniques for the analysis. However, there is a significant risk that greater weighting is given to the outputs than they can provide given the uncertainty on the inputs of the assessment. Therefore, the overall level of risk associated with the study is high.

13 Appendix 13 – Cambridge Area Assessment Summary Report

See separate document “Appendix 13 – Cambridge Area Assessment Summary Report”.

East West Rail Ltd

East West Rail Engineering Partner

Cambridge Area Assessment Summary Report

Reference: EWR_PGM-ARU-OP-XX-RP-Z-000004

P01 | 29 March 2023

Job number 29294600

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Drawings

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Pictures

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1. Executive Summary

This report provides a summary of the findings for the early-stage capacity feasibility assessments completed for several options approaching Cambridge. Technical notes for two options have previously been produced and are summarised in this report in addition to a high-level comparison of these options. There are currently four potential options for both approach to Cambridge as listed below:

1. Southern Approach to Cambridge (SATC)
    a. South Option A (Design Freeze 2)
    b. South Option B
2. Northern Approach to Cambridge
    a. North Option A (ACP recommendation)
    b. North Option B

Two options have been assessed under this scope: South Option A and North Option B, with the findings of each summarised in this report. The other two options, South Option B was deemed not likely to support the full requirements of EWR. North Option A, however, remains a potentially viable.

- North Option B Technical Note: EWR_PGM-ARU-OP-XX-TN-Z-000006_P03
- South Option A Technical Note: EWR_PGM-ARU-OP-XX-TN-Z-000007_P02

The following Table 1 outlines the key conclusions as a comparison of the two options considered:

Table 1 Key Conclusions and Comparisons of South Option A and North Option B.

Capability	South Option A	North Option B
Support for 4tph EWR to Cambridge	Capable of supporting a 4tph even interval service (subject to wider EWR route constraints)	Capable of supporting a 4tph EWR service, even-intervals more challenging to achieve, at worst case this could 10/20 minutes intervals.
Support for 2tph EWR extension to Cambridge North	Requires further enhancements at Cambridge North station or alterations to existing services to remove them from terminating at Cambridge North bay platform.	N/A
Significant impacts to existing services (curtailment/journey times)	No significant impacts to base timetable.	Does not require curtailment of GA services due to improved design at Cambridge North. Has potential significant journey time implications to GN services between Ely and Cambridge.
Support for Low Freight Growth	Additional freight paths can be accommodated within the scope of this assessment and subject to wider network constraints. Significant challenges remain with gradients/freight load assumptions on core section. – May require alterations to EWR services when operating if not providing additional enhancements such as passing loops.	Additional freight paths could be supported subject to wider network constraints not covered in this assessment.

Capability	South Option A	North Option B
Support for High Freight Growth	South Option A is more constrained in comparison to North Option B in its ability to support additional freight paths. In addition, as noted above gradients on the core section also present a potential feasibility challenge. This is however dependant on wider network feasibility.	North Option B has the potential to support significant growth in freight onto EWR, namely as it avoids conflicts in running through Cambridge. This is however dependant on wider network feasibility.
Support for an additional Ipswich Service	South Option A does not significant alter the WAML route north of Cambridge and is likely to support a second Ipswich service with minimal further enhancements at Cambridge. Enhancements to the Newmarket line would likely to be required. Noting the wider network feasibility as not been assessed.	North Option B actively provides provision to support a second Ipswich service through a 4th dedicated bi-di route between Cambridge and Coldham Lane Jn. Upgrades on the wider network such as the Newmarket Line would likely be required although not covered in this scope.
Support for 2tph additional services to Norwich/Peterborough	South Option A does not significant alter the WAML route north of Cambridge and assuming EWR terminates at Cambridge would not consume additional capacity. These services may require additional Platform capacity at Cambridge (not reviewed under this scope). If EWR has 2tph extended to Cambridge North, further interventions such as that provided in North Option B may be required to support these additional services (in addition to additional Platform capacity). An alternative would be to consider extension of GA services from Cambridge North.	North Option B provides additional capacity between Cambridge and Coldham Lane Jn but also uses more capacity for EWR. Provision of 1 additional tph may be feasible but noting the line north of Coldham Lane would be at times operated near full capacity and likely creates a significant performance risk. Further enhancements may therefore be required to support both services.
Performance Implications (comparison to current)	Depending on scenarios South Option A design is likely to have a worsening to performance compared to current operations, namely due to the complex nature of the approaches to Cambridge station. This is not however quantified and may change through design and timetable optimisation should this option be progressed. Further performance modelling would be required to assess the relative performance impacts.	Depending on scenarios North Option B design is likely to have a worsening to performance compared to current operations again due to the complex nature of the approaches to Cambridge station. This is not however quantified and may change through design and timetable optimisation should this option be progressed. Further performance modelling would be required to assess the relative performance impacts.

Recommended Next Steps

- All options will require further operational assessments given the high-level review nature of this assessment completed. A key area of focus that will require further work to understand:
  - The feasibility of the scheme design to support the assumptions made as part of this report.
  - Consider the potential trade-offs presented between options such as possible impacts to existing journey times compared to facilitating the aspirational additional services.
  - Revisions based on learning from this exercise and the recommendations made.
  - TPR validation of the final station design and impacts resulting final signalling design

- The performance impacts are assessed at a suitable level of maturity.
- Consider the additional cost/benefits and sponsor requirements that North Option B provides in comparison to North Option A – noting the wider network implications of additional NR aspirational services are not known at this stage.

2. Introduction & Background

This report provides a summary of the findings for the early-stage capacity feasibility assessments completed for several options approaching Cambridge. Technical notes for two options have previously been produced and are summarised in this report in addition to a high-level comparison of these options. The tech notes are:

- North Option B Technical Note: EWR_PGM-ARU-OP-XX-TN-Z-000006_P03
- South Option A Technical Note: EWR_PGM-ARU-OP-XX-TN-Z-000007_P02

East West Rail (EWR) have recently completed an affordability review of project under the Affordable Connections Programme (ACP), which followed the completion of Design Freeze 2 (DF2) in January 2022. The outputs included recommended a heavy rail scheme approaching Cambridge from the North with a concept design that could support a 2 or 4 train per hour between Bedford and Cambridge. This contrasts to DF2 which was developed against achieving the requirements set out in EWR's Programme Wide Output Specification (PWOS), and approaches Cambridge from the south.

In addition, EWR has subsequently developed two further options, a second southern approach option and a second northern approach option. The second southern approach option sought to reduce the impact on land-take requirements identified in DF2, whilst the second northern approach option was developed in collaboration with Network Rail (NR) to identify unconstrained opportunities to improve current network constraints and potential for supporting wider service growth. In summary, four options exist for the approaches into Cambridge two southern and two northern approach options, these are:

3. Southern Approach to Cambridge (SATC)
   a. South Option A (Design Freeze 2)
   b. South Option B
4. Northern Approach to Cambridge
   a. North Option A (ACP recommendation)
   b. North Option B

The details of each option are outlined in the scope (EWR_PGM-ARU-OP-XX-BF-Z-000002_P01). Only two options have been progressed: South Option A and North Option B. The other two options, South Option B was deemed not likely to support the full requirements of EWR as it removes enhancements specifically required in South Option A to deliver the EWR requirements North Option A, however, remains a potentially viable, lower-cost, lower construction impact option, and may be considered as a phased option before implementation of the concept of North Option B should this be required for future growth outlined by NR.

The capacity assessments have been completed with the following key objectives:

- To provide further insight and clarity on the options for approaching Cambridge in terms of operational feasibility.
- To update base timetable assumptions in the Cambridge area
- To test the implications of the proposals on future service aspirations that NR have indicated (although not assumed as part of EWR)
- Provide operational feedback on the concept designs include a comparative and qualitative assessment on performance based on major/minor/neutral impact.

The following Figure 1 outlines both the Northern and Southern approach routes in context of the existing West Anglia Main Line (WAML) and EWR route.

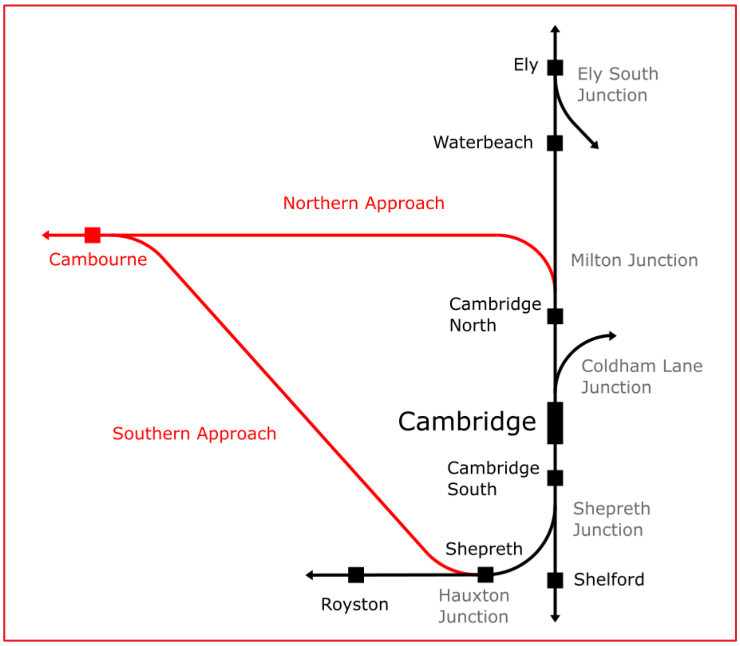

Figure 1 Outline geographic scope of assessments showing both northern and southern approach routes.

2.1 Approach

The capacity assessments completed are high-level first pass assessments, aimed at checking for significant capacity or designs constraints for the options assessed. The assessment has been completed using RailSys version 11, purely to indicate potential Sectional Running Times (SRTs) e.g., for enhanced line speeds or new rolling stock. The assessment is otherwise a concept timetable assessment using assumed Timetable Planning Rules (TPR) values and is not a modelling assessment. Detailed information regarding the assumption made are outlined in the technical notes and assessment remit.

2.2 Train Service Specifications

2.2.1 Base Timetable

A new base timetable has been established for the Cambridge area to conduct this assessment. This base timetable has been adapted from a recently developed May 2023 Working Timetable (WTT) provided by NR. Because there are known near-future changes coming in the May 2024 WTT, the base timetable was revised on the advice of NR. The base timetable comprises of the following:

- The May 2023 timetable for Greater Anglia (GA) services, Great Northern (GN), Thameslink (TL) and Cross Country (XC) services in the Cambridge area.
- The proposed May 2024 GA service amendments and uplifts (see scope document for details).
- The proposed May 2024 XC service amendments (see scope document for details).
- Alterations to services south of Cambridge to include stops at Cambridge South station. This has been completed based on including stops where feasible within the base timetable and has been achieved through altering arrival and departure times at Cambridge. It is noted the base timetable is not optimised to include Cambridge South station, and therefore the full project objectives may not be fully represented in this assessment.

The full Train Service Specification (TSS) can be found within the scope document. Empty Coaching Stock (ECS) moves, and other services included in the base timetable have also been included with the modelling.

2.2.2 EWR TSS

The EWR train service specification for this assessment assumes a 4tph service to and from Cambridge. The assessment will be based on achieving as close as possible even-interval frequencies for EWR services, even if this requires alterations to other services. This is to highlight potential implications of even-interval services, as required in the PWOS, but is not fixed on clock-face timings as also required in the PWOS. Other solutions may be feasible but without even-interval EWR services. Also noted that this is not a route-wide assessment of EWR and other constraints on the EWR network may limit the ability to achieve even interval services to/from Cambridge.

For the SATC options, the assessment includes a further option to test the feasibility in extension of EWR services to Cambridge North station, which was not previously required as part of the PWOS.

For all options an enhanced level of freight is assumed for EWR, based on identifying a maximum of an hourly freight path in the immediate scope area and timeframes. This incorporates any paths already provided in the base timetable, to make up an hourly path. An hourly path is assumed as the likely wider capability in terms of quantum of paths per hour before more significant enhancements would be required. The EWR core section design is also based on an assumed capability for an hour path within a 4tph EWR service.

2.2.3 Future Aspired Services

NR have indicated that the assessments should consider the potential for future aspirational services that are in addition to existing and EWR services. These have also been considered, although the requirements to support these services has not been reviewed and any significant level, nor has the wider network feasibility been assessed. It is assumed these services do not form part of the requirements for EWR, noting the enhancements under North Option B potentialyl exceed the requirements for delivery of EWR alone. North Option A, which has not considered these services explicitly, is however, capable of supporting EWR, although not considered under this assessment.

The following outlines these services:

- An additional hourly Cambridge – Ipswich service (to make up 2tph)
- An additional hourly Cambridge - Norwich service (to make up 2tph with the current Norwich – Cambridge/Stanstead Airport service) *additional service assumed to terminate at Cambridge).*
- A new hourly service Cambridge – Peterborough.

2.3 Service Scenarios

It was decided to split the various service options being assessed for both EWR and existing operators into 4 scenarios to compare the area designs. The following outlines the service scenarios considered in both assessments:

Table 2 Scenario Service summary table

Scenario	Service Specification
Scenario 1	• Base timetable • 1tph freight Y-Path (incorporating existing paths) • 4tph EWR to Cambridge
Scenario 2a*	• Base timetable • 1tph freight Y-Path (incorporating existing paths) • **2tph EWR to Cambridge** • **2tph EWR to Cambridge North**
Scenario 2b	• As Scenario 2a but +1tph Ipswich – Cambridge service
Scenario 2c	• As Scenario 2b but +2tph *Peterborough/Norwich via Ely* – Cambridge service

**Scenario 2a is only appliable to SATC options.*

3. Infrastructure Options

3.1 South Option A (Design Freeze 2)

The following Figure 2 outlines schematically the track and station layout for the South Option A design for approaching Cambridge from the south. This design was originally conceptualised to fulfil EWRs PWOS statements and is designed to accommodate EWR services on a 15-minute interval with full replication of existing facilities at the station. This design has the following key features:

- A grade separated ‘Hauxton Junction’ where the EWR merges with the existing Royston Branch south of Cambridge.
- A new pair of running lines between Shepreth Branch Junction, through Cambridge South station and into the Cambridge Station southern throat (to either side of the existing 2 track alignment). The extra pair of lines allows for two pairs of tracks with one for the WAML and one for the Royston Branch, however some services do cross from the Royston branch onto the WAML at Shepreth Jnc
- A new 250m island platform with 2 new faces (Platform 9 and 10).
- A twin lead into platforms 2 and 3.
- A twin lead through to the new and existing eastern platforms (7,8,9 and 10) to the north and south.
- Platforms 5/6 bays- Maintained with approach alignment modified to accommodate slight move north of platforms 1 and 4. This does remove access to these platforms from the depot.
- Replication of existing reception roads for freight on the Eastern side of the station.
- Under requirements to extended 2tph EWR services north modification to Cambridge North station to provide further operational flexibility and capacity are required. Options for this are identified in section 3.5.2

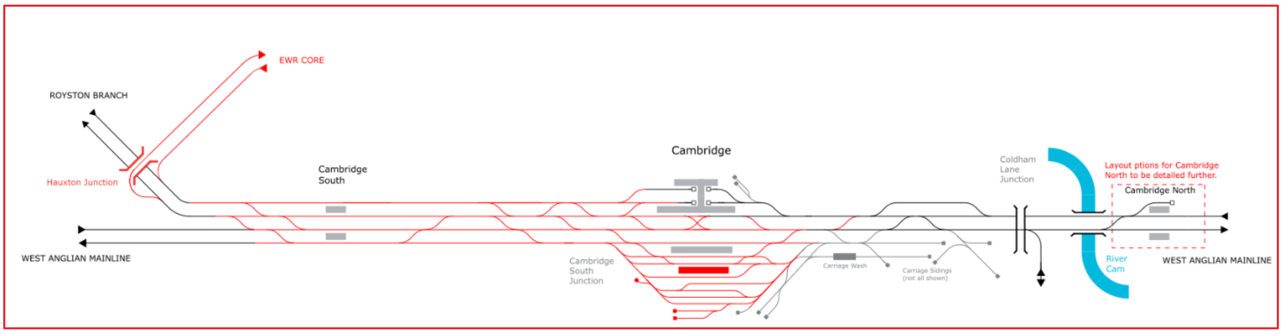

Figure 2 Schematic Layout for Cambridge South Option A.

3.2 North Option B (NATC) Design

The following Figure 3 outlines schematically the track and station layout for the North Option B design for approaching Cambridge from the north. This option is designed to bring a greater level of resilience and capacity for all operators in the area following discussions with NR and EWR. The design has been focused on improving broader factors and benefits. This design has the following key features:

- A south facing grade separated ‘Milton Junction’ where the EWR merges with the existing Fen line/WAML. This includes the potential for a north-west freight chord.
- An upgrade at Cambridge North station to provide further operational flexibility, reconfiguring the station to provide a central turnback platform, removing conflicting moves and low speed turnouts.
- A new pair of running lines between Cambridge and Coldham Lane Jn (to either side of the existing 2 track alignment). A 3rd line to the west to separate EWR services on approach to the existing platforms 5 and 6 and a 4th line to the east of the current tracks segregates the Newmarket line but as

it uses the alignment of an existing depot road it impacts on the existing depot operations. The impact on the internal working of the depot is not covered in this analysis.

- A new 250m south facing bay platform ‘Platform 9’.
- A new 90m north facing bay platform ‘Platform 10’.
- A new side platform with a length of up to 368m ‘Platform 11’.
- Platform 7/8 island- these are moved north compared to today, but lengths are maintained.
- Platforms 5/6 bays- Maintained with approach alignment modified to accommodate future 34m extension to 160m

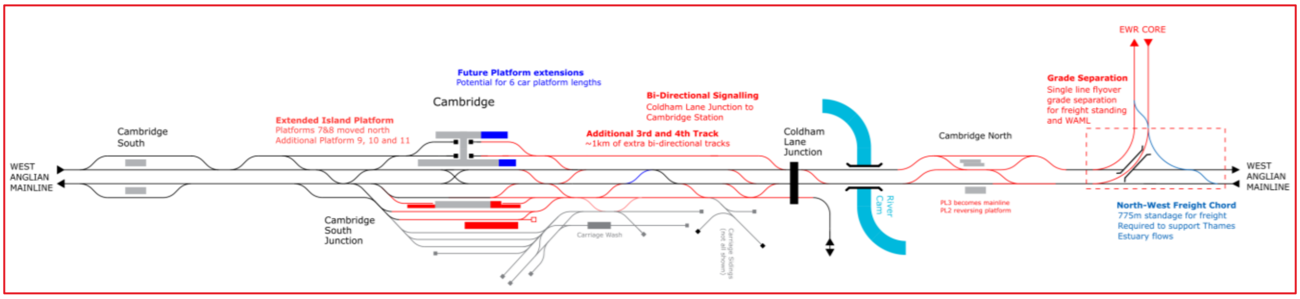

Figure 3 Cambridge North Approach Option B Track Schematic. Track design source: EWR_PGM-ARU-RA-ZZ-SK-C-771601_P01 and EWR_PGM-ARU-RA-ZZ-SK-C-771801_P01

4. South Option A Summary

The following provides an outline summary of the key findings for the assessment completed on the South Option A design. Full details are outlined in the technical note (EWR_PGM-ARU-OP-XX-TN-Z-000006)

4.1 EWR Train Service Feasibility

4.1.1 Existing Services

- The South Option A design requires the re-routing and platforming of existing services into Cambridge in tandem with accommodation EWR.
- In order to support services calling at Cambridge South station, services from the Royston Branch need to cross at Shepreth Junction to the eastern pair of lines due to the flighting structure of these services.
- Calls indicatively provided at Cambridge South through modification of the base timetable by reducing turnround times and run time allowances to accommodate the 3 minutes additional time assumed required to support the stop.
- At Cambridge station the general platforming arrangements have focused on routing GA services to the higher numbered platforms to the east, particularly for Up direction services. Down direction services also make use of Platform 4, accessed via the through line. Platforms 1, 2 and 3 are used to terminate GN/TL services alongside EWR services. Additionally, Platform 7 supports termination of services.
- As noted in the previous FRTT, the routes and access to/from Cambridge station in the southern throat are complex and requires several parallel moves enabled by the design. The assessment is however, based on assumed TPRs which require validation, subsequentially it is recommended performance modelling is carried out to seek solutions which can optimise the timetable and potentially the design further.

4.1.2 EWR Services

- As found with the last FRTT, the design is conceptually viable for providing 4tph EWR service terminating at Cambridge throughout the day.
- An even frequency timetable for EWR has been possible on a 14 – 16-minute service interval though it should be noted that this assessment has not considered route wide constraints on the rest of EWR that may impact this (as found in the last FRTT).
- EWR services have been planned to use Platforms 1, 2 and 3 sharing with Thameslink services.
- EWR services have a turnround times greater than 10-minute throughout the day.

4.1.3 Freight Services

- The South Option A design was developed up top Design Freeze 2 with the project assumption to maintain and re-provide any existing infrastructure capability impacted by the enhancements. In relation to freight this includes re-providing the existing freight reception siding located to the east of the existing station.
- The re-mapping of the timetable on to the South Option A design was possible for existing freight, including moves in the timetable that indicatively use the current reception sidings for run-around moves (the loco movements are not present in the timetable).
- Additional standard paths were sought as part of the assessment objectives to get to an hourly freight path through the Cambridge area. Note that these paths have only been indicated in the immediate scope area and not over a broader geographic scope, for the purposes of testing high-level feasibility.

- The current timetable provided has 5 Up direction freight paths though Cambridge and 8 Down direction freight paths over the day, including paths that reverse in the reception siding at Cambridge. Over the 18-hour scope of this assessment, an additional 14 Up and 11 Down paths have been found.

- At the start and end of the evening peak freight paths could not be accommodated due to conflicts with ECS moves in the Cambridge station throat and the availability of matching paths north and south of Cambridge station. **Additional paths have however been provided outside the evening peak, with some hours including 2 freight paths**. On average an ~hourly freight path is provided in the timetable including existing freight.

- Further challenges remain with the Design Freeze 2 core route section between Hauxton and Cambourne West loop. Under the first FRTT, it was discovered that the assumed freight formation may require operating below the Continuous Rated Tractive Effort, meaning, there is a **likelihood of traction failure, or if an unplanned stop occurs, it would not be possible to proceed.** This is driven by the significant length of gradients at 1in80 and the assumed tonnages for freight, as outlined in the first FRTT.

- Ignoring the potential risk to traction failure, the impact on journey times to freight from the gradient in the Up direction, results in a speed differential between EWR and EWR freight **that requires a passing loop** to enable EWR to pass the freight between Cambridge and Cambourne West Loop. Indicatively this would be provided at Hauxton Jn in order to also serve a secondary purpose of enabling regulation of EWR freight paths in both directions, however noting this is at the base of the significant 1in80 gradient.

- Whilst additional freight paths have been sought within the timetable scope area, the paths assume a clear run between Ely/Soham and Cambourne West Loop on the EWR core, noting Ely/Soham is not within the study scope. It is recommended that in the interest of timetable flexibility and performance that additional freight loops are provided through this section to regulate paths, such as that suggested at Hauxton Jn. Note that the re-provided reception sidings at Cambridge station would not facilitate the assumed 775m freight on EWR. Solutions for any potential new loops needs to be considered in tandem with potential mitigations or solutions to the gradients profile between Hauxton and Cambourne.

4.2 Enhanced Service Scenario Findings

4.2.1 Scenario 2a – 2tph EWR Cambridge & 2tph EWR Cambridge North

- Extension of 2 of the 4tph EWR service to Cambridge north is only possible with further enhancements provided at Cambridge North Station. This is due to GA services occupying the current bay platform capacity at Cambridge North during the off peak.

- Paths have been found between Cambridge and Cambridge North for extending EWR services although requires an extended dwells of 4-5 minutes (above TPR minimum) at Cambridge station due to the timings in the base timetable.

- Enhancements may include additional platform capacity or provision of turnback sidings at Cambridge North, potential solutions are indicated in **Error! Reference source not found.**

- It is noted that, an alternative solution could be sought in place of enhancements at Cambridge North through extension of the off-peak GA services that currently terminate in the bay platform. Whilst this has been not assessed in this study, such extension could also facilitate the aspirational services uplifts indicated by NR, and at the same time free the bay platform for EWR to extend 2tph to Cambridge North.

4.2.2 Scenario 2b - +1tph Ipswich – Cambridge

- Building on the EWR timetable with extension of 2tph to Cambridge North station and a freight uplift of an hourly path in each direction a second path has been found between Cambridge and Coldham Lane Junction for a potential second Ipswich service.

- An even 30-minute service interval has not been possible with the existing service between Ipswich and Cambridge due to the limited available paths remaining for crossing at Coldham Lane Junction. This presents a potential for increased risk to timetable performance in combination with the assumed increase in north-south paths (freight and EWR to Cambridge North).

- The scope of the assessment has not included the Newmarket route or beyond, but its clear enhancements such as double tracking this route is likely required to give flexibility in the timings of services to and from Cambridge and over the at-grade Coldham Lane Junction.
- Further feasibility assessments would be required to validate the feasibility of this aspired service including assessing the potential performance risks to the overall timetable.

4.2.3 Scenario 2c - +2tph Peterborough/Norwich – Cambridge

- In addition to the above scenarios, further paths were sought between Cambridge and Ely (excluded). With the exception on evening peaks, a further 1tph could be sought in the timetable, at which capacity is effectively full. During the evening peaks the additional paths could not be facilitated due to the high number of ECS moves in the northern throat of Cambridge.
- It is likely that support this scenario, in addition to the other scenarios considered further enhancements would be require north of Cambridge, these may potentially be similar to that indicated for North Option B such as 3 or 4-tracking between Cambridge and Coldham Lane Jn.

5. North Option B Summary

5.1 EWR Train Service Feasibility

5.1.1 Existing Services

- As with the South Option A design, the base timetable has required re-mapping onto the North Option B design. This has included the following general changes:
  - Re-Platform Ipswich and Norwich (peak) services from Platforms 5 & 6 into the new platforms provided on the eastern side of Cambridge station including the dedicated bay platform. This includes routing Ipswich services on the additional 4th (eastern most) line between Cambridge and Coldham Lane Junction in both directions.
  - Re-Platform ECS paths currently using Platforms 5 & 6 into alternative new platforms on the eastern side of the station.
  - Path EWR services into Platforms 5 & 6 to act as dedicated EWR platforms.
  - North-South through services at Cambridge also re-platformed to the new eastern platforms to reduce the number of potential conflicts between services – making use of the layout provided.
- As with South Option A, alterations to services have been required to allow for stops at Cambridge South Station but the design is not likely to preclude Cambridge South station.

5.1.2 EWR Services

- A 4tph EWR service into Cambridge on the North Option B design has been possible and without requiring curtailment of existing passenger services.
- The service interval for the EWR services ranges between 10 and 20 minutes, although there may be opportunities to improve this with further timetable development.
- With EWR using Platforms 5 & 6, turnround times of over 20 minutes can be achieved. The 3rd western track in the design supports improved flexibility of arrivals and departs for EWR services into the bay platforms separated from the existing pair of lines in the centre.
- Accommodating near even interval EWR services has however, required potential significant alterations to the timings of GN between Ely and Cambridge. The timings have been altered so that Ely services depart 10 minutes earlier and regain their original paths south of Cambridge with an extended 8-minute dwell. This was done to alter the order of services on the route between Ely and Cambridge to provide more even interval paths for EWR services. There is potential to avoid this through a more holistic timetable assessment, however, it has not been possible under the scope and timeframes of this assessment.
- Platform 9 included in the North Option B design, has not been required under this option as the curtailment of Greater Anglia services to Cambridge North is not required. There may operational performance benefits to the curtailment of off-peak GA services as these are effectively replaced by EWR, this may then require Platform 9 subject to further assessment.

5.1.3 Freight Services

- North Option B design has a greater impact to existing freight than the South Option A due to the necessary removal of the freight reception sidings adjacent to Cambridge station.
- As part of the remapping of the existing timetable onto the design it has been assumed possible to hold the same paths in the Through Line at Cambridge, this is partly made possible via the additional through Platforms to the east of the station avoiding the situation where a freight held on Through Line effectivity blocks access to Platform 4 from the south. Note that some paths in the timetable appear to **require a run-around movement, this may not be feasible under this design solution.**

- Additional freight paths have been overlaid between Ely Chord and Cambourne West Loop via Milton Junction. 17 Up paths and 18 Down paths have additionally been accommodated in the timetable. These services cross on the flat at Milton Jn in the Up direction and Ely South Chord Jn in the Down direction. Noting the assessment has not validated conflicts in the Ely area due to the unknown design of a South chord.
- Consideration should be given so the Up-direction freight paths can be held prior to Milton Junction to regulate paths before the flat crossing move. Down direction paths can already do this on Milton Chord which has been designed to do so in either direction. This could potentially be replicated for Ely South Chord or located on the Soham Line as part of wider network upgrades required on this route.
- Whilst additional freight paths have been sought within the timetable scope area, the assessment has not covered the wider network constraints that may limit capacity, such as through Ely, or the Soham route and west on the EWR route.

5.2 Enhanced Service Scenario Findings

5.2.1 Scenario 2b - +1tph Ipswich – Cambridge

- Building on the EWR timetable with a freight uplift of an hourly path in each direction a second path has been found between Cambridge and Coldham Lane Junction for a potential second Ipswich service.
- An even 30-minute service interval could be achieved in the timetable.
- Both Ipswich services have been routed to exclusively use the 4th (eastern most) running line bi-directionally between Cambridge station (Platform 10) and Coldham Lane Junction.
- The service is self-contained using Platform 10 exclusively and only crosses other services and ECS moves to access the higher numbered platforms at Cambridge.
- The scope of the assessment has not included the Newmarket route or beyond, but its clear enhancements such as double tracking this route is likely required to give flexibility in the timings of services using the bi-directional 4th line into Cambridge station.
- Further feasibility assessments would be required to validate the feasibility of this aspired service including assessing the potential performance risks to the overall timetable.

5.2.2 Scenario 2c - +2tph Peterborough/Norwich – Cambridge

- In addition to the above scenario, further paths were sought between Cambridge and Ely (excluded), to understand the remaining potential capacity for additional services to Peterborough and Norwich.
- On the plain line route through Cambridge North, there are approximately 3-4 remaining paths in each direction in the off peak after inclusion of EWR. In the Peaks the in the counter peak direction this drops to 2-3 paths. This theoretically could be used to accommodate additional Peterborough and Norwich services but likely at significant risk to performance as the give the route utilisation would be above 80% in some hours.
- Platform capacity for terminating these additional services at Cambridge is also constrained and it is likely that support this scenario, further enhancements would also be require at Ely and to the north of Ely.

6. Service Comparisons

The following provide a high-level comparison between the South Option A design and North Option B in terms of the initial capacity assessment completed.

6.1 EWR feasibility

Both the South Option A and North Option B designs assessed can support a 4tph EWR service to and from Cambridge. South Option A supports a slightly more even service interval than North Option B with most services being on a 14 – 16-minute interval for both arrivals and departures. North Option B on the other hand is limited to most services being on a more offset 10-20 service interval driven by several constraints on the route, the primary one being the single lead junction into platforms 5&6, as well as structure of the timetable between Cambridge and Milton Jn.

EWR turnround times exceed the project assumed minimum of 10-minutes for both options providing potential performance robustness in the turnround time. North Option B facilitates dedicated EWR platforms at Cambridge using the current bay Platforms 5 & 6, whilst South Option A requires shared platform use with existing Thameslink services using Platforms 1 to 3.

North Option B timetable assessment has resulted in potential significant alterations to GN services between Ely and Cambridge increasing journey times between these two locations by 10 minutes. However, at this stage of development this is not a conclusive outcome and may be resolvable through a broader scope and more holistic view of the overall timetable. The implications in resolving this may however impact on EWR service frequencies for example as outlined in the ACP work when testing the concept of North Option A given a 10-20minute service interval. The trade-off of this longer journey time compared to the benefits of North Option B and accmondaitng the additional services should be considered as a next step.

Whilst the design for South Option A does not currently support extension of 2 of the 4tph EWR services to Cambridge North station this is potentially viable provided enhancements are made at Cambridge North station to increase platform capacity, or the current terminating GA services altered to avoid terminating at Cambridge North. This may for example as part of a phased delivery include potential extensions to Ely, Peterborough, or Norwich subject to any wider network capacity constraints being resolved.

Overall, both options assessments present a viable solution to supporting a 4tph service to Cambridge. In terms of performance, with the limited information available at present, both options are likely to be comparable, excluding potential impacts of the additional aspirational services. The feasibility of either option requires further design development to support validation and modelling of potential Indicative Running Times and Indicative TPRs assumed in this assessment.

6.2 Freight

South Option A supported capacity to maintain existing freight paths in the base timetable including potential run-around movements for freight operating to Barrington Quarry, this is possible due to the retention of the freight reception sidings at Cambridge. North Option B, however, results in the loss of these sidings and in terms of existing freight is more constrained. The concept timetable has managed to re-plan these services through holding of freight paths on the through line. However, the Barrington Quarry freight that requires a run-around may not be supported with this solution and as such alternative solutions may be required.

In terms of enhanced EWR freights of up to an hourly path through the Cambridge area, both timetables have supported an uplift. Whilst the assessment is not validation of freight capability given the limited scope, both options have the potential to support hourly freight paths. However, the assessment for South Option A did find constraints with routing freight through Cambridge during the evening peaks due to conflicts with ECS moves. This may be possible to resolve with further timetable development, but in general compared to North Option A where freight is routed onto EWR at Milton Jn, South Option A is likely to be more constrained that North Option A. South Option A is also likely to require new freight loops capable of supporting the assumed 775m freight trains, between Cambridge and Cambourne West Loops. In addition, as previously noted in the FRTT's the core section has significant gradients that may potentially result in traction failure in the Up direction with the assumed freight load. Ignoring the potential issue of traction failure, the gradient results in a journey time differential that requires a passing loop between Cambridge and Cambourne West in the Up Direction. Locating such loop at Hauxton from a time perspective would be ideal, however, this is at the start of the significant 1in80 gradient any may not be feasible. A review of gradients, freight assumptions and loop's locations are required to optimise the potential overall solution in supporting freight in South Option A.

6.2.1 Low Freight Growth

Subject to the infrastructure constraints outlined above, both options could support a low freight growth (1-2) freight paths per day within the scope of this assessment. Assuming limited further enhancements with the scope area, this may require minor alterations to some EWR paths e.g., increasing the interval between services in the Up direction to provide a longer window for freight to reach Cambourne West loop.

6.2.2 High Freight Growth

Whilst the scope of the assessment focused on achieving an hourly freight path in each direction as a likely reasonable balance capacity and wider network constraints, EWR's latest assumption for a high freight growth assumes an unconstrained potential for 12-15 paths per weekday. The assessment findings indicate that the South Option A design, may not fully support this level of growth depending on assumed network wide growth. North Option B design, however, has potential to support more freight paths namely due to avoiding constraints running through Cambridge station. Note that the feasibility of paths on South Option A route have additional risks due to potential gradient issues on the core section and the assumed freight tonnages.

6.3 Enhanced Scenario findings

6.3.1 Scenario 2b - +1tph Ipswich – Cambridge

Both design options potentially can support a second Cambridge – Ipswich service to provide 2tph in total. North Option B actively provides provision to do so between Coldham Lane Jn and Cambridge, whilst South Option A doesn't. However South Option A has little impact to capacity of the route north of Cambridge and increases overall platform capacity at Cambridge and could support the additional service without the need for further enhancements on the WAML. Both design options are likely to at least require enhancements to Coldham Lane Jn and the route to Newmarket such as a double junction and double tracking of the route. The wider feasibility to support the additional service has not been assessed under this scope but indicates potential capacity within the Cambridge area for both options considered.

6.3.2 Scenario 2c - +2tph Peterborough/Norwich – Cambridge

Additional paths between Cambridge and towards Ely (to Peterborough/Norwich) are constrained in both options; South Option A, due to no active provision for enhancements north of Cambridge and North Option B, due to the increased use of capacity even with enhancements provided. Further still both options whilst providing additional platform capacity at Cambridge may require further platform capacity to support these additional services depending on overall service assumptions. Both options could potentially support an additional hourly service, subject to performance impacts, or as an alternative consideration should be made as to extension of existing services such as the GA services currently terminating at Ely/Cambridge North. This may require a trade of between the performance implications of each option.

As with the Ipswich services this assessment as not considered the wider network feasibility to support these paths including through Ely station and would require a broader scope to understand the potential implications should these be required to be supported alongside EWR.

7. Conclusions

The following table presents the high-level findings in comparison on South Option A and North Option B.

Capability	South Option A	North Option B
Support for 4tph EWR to Cambridge	Capable of supporting a 4tph even interval service (subject to wider EWR route constraints)	Capable of supporting a 4tph EWR service, even-intervals more challenging to achieve, at worst case this could 10/20 minutes intervals.
Support for 2tph EWR extension to Cambridge North	Requires further enhancements at Cambridge North station or alterations to existing services to remove them from terminating at Cambridge North bay platform.	N/A
Significant impacts to existing services (curtailment/journey times)	No significant impacts to base timetable.	Does not require curtailment of GA services due to improved design at Cambridge North. Has potential significant journey time implications to GN services between Ely and Cambridge.
Support for Low Freight Growth	Additional freight paths can be accommodated within the scope of this assessment and subject to wider network constraints. Significant challenges remain with gradients/freight load assumptions on core section. – May require alterations to EWR services when operating if not providing additional enhancements such as passing loops.	Additional freight paths could be supported subject to wider network constraints not covered in this assessment.
Support for High Freight Growth	South Option A is more constrained in comparison to North Option B in its ability to support additional freight paths. In addition, as noted above gradients on the core section also present a potential feasibility challenge.	North Option B has the potential to support significant growth in freight onto EWR, namely as it avoids conflicts in running through Cambridge. This is however dependant on wider network feasibility.
Support for an additional Ipswich Service	South Option A does not significant alter the WAML route north of Cambridge and is likely to support a second Ipswich service with minimal further enhancements at Cambridge. Enhancements to the Newmarket line would likely to be required. Noting the wider network feasibility as not been assessed.	North Option B actively provides provision to support a second Ipswich service through a 4th dedicated bi-di route between Cambridge and Coldham Lane Jn. Upgrades on the wider network such as the Newmarket Line would likely be required although not covered in this scope.

Capability	South Option A	North Option B
Support for 2tph additional services to Norwich/Peterborough	South Option A does not significant alter the WAML route north of Cambridge and assuming EWR terminates at Cambridge would not consume additional capacity. These services may require additional Platform capacity at Cambridge (not reviewed under this scope). If EWR has 2tph extended to Cambridge North, further interventions such as that provided in North Option B may be required to support these additional services (in addition to additional Platform capacity). An alternative would be to consider extension of GA services from Cambridge North.	North Option B provides additional capacity between Cambridge and Coldham Lane Jn but also uses more capacity for EWR. Provision of 1 additional tph may be feasible but noting the line north of Coldham Lane would be at times operated near full capacity and likely creates a significant performance risk. Further enhancements may therefore be required to support both services.
Performance Implications (comparison to current)	Depending on scenarios South Option A design is likely to have a worsening to performance compared to current operations, namely due to the complex nature of the approaches to Cambridge station. This is not however quantified and may change through design and timetable optimisation should this option be progressed. Further performance modelling would be required to assess the relative performance impacts.	Depending on scenarios North Option B design is likely to have a worsening to performance compared to current operations again due to the complex nature of the approaches to Cambridge station. This is not however quantified and may change through design and timetable optimisation should this option be progressed. Further performance modelling would be required to assess the relative performance impacts.

8. Recommended Next Steps

- All options require further operational assessments given the high-level review nature of this assessment completed. A key area of focus that will require further work to understand:
  - The feasibility of the scheme design to support the assumptions made as part of this report.
  - Consider the potential trade-offs presented between options such as possible impacts to existing journey times compared to facilitating the aspirational additional services.
  - Revisions based on learning from this exercise and the recommendations made.
  - TPR validation of the final station design and impacts resulting final signalling design
  - The performance impacts are assessed at a suitable level of maturity.
  - Consider the additional cost/benefits and sponsor requirements that North Option B provides in comparison to North Option B – noting the wider network implications of additional NR aspirational services are not known at this stage.