Rail Alternatives to HS2 Phase 2a

Department for Transport

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Notice

This document has 37 pages including the cover.

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1. Introduction

In May 2015, the Department for Transport (DfT) commissioned Atkins to design and assess potential alternatives to building the section of High Speed 2 (HS2) between the northern end of Phase One[1] and Crewe known as HS2 Phase 2a. This section of the HS2 network is planned to open in 2027, a year after the opening of Phase One, and six years earlier than the remainder of Phase Two that would complete the "Full Y" network[2] in 2033. Delivering this section to Crewe earlier than the rest of the Phase Two will bring additional journey time, capacity and performance benefits to the North West above those already provided by HS2 Phase One.

This report describes the work undertaken by Atkins to develop and assess three rail based alternative options to HS2 Phase 2a, and is structured as follows:

- Chapter 1 describes the background and remit of the work provided to Atkins by the Department for Transport;
- Chapter 2 describes the design of the three shortlisted alternative options to Phase 2a. It begins with an overview of the main constraints on the West Coast Main Line (WCML) between where the end of Phase One joins the WCML at Handsacre Junction and Crewe, and then describes how three alternative options to Phase 2a have been developed as a means of overcoming these constraints;
- Chapter 3 then provides an assessment of these options against the following criteria:
    - the capital and operating costs;
    - impact on journey times;
    - forecasts of demand, revenue and benefits in order to undertake an economic appraisal consistent with the Government's standard WebTAG guidance and the appraisal of HS2;
    - the impact of each option on route capacity;
    - the impact of each option on operating performance;
    - any disruption caused by the construction of the options; and,
    - a high level assessment of the environmental impacts.
- Chapter 4 summarises the main conclusions from this assessment.

1.1. Study Remit

The Department for Transport commissioned Atkins in 2013 to design and assess strategic alternative options to the entire HS2 Phase Two network[3]. In light of the broad remit of the previous work, the Department for Transport limited the scope of this study to the examination of alternative options to building HS2 Phase 2a only. These alternative options seek to improve journey times and capacity specifically between the northern end of HS2 Phase One and Crewe as an alternative to Phase 2a. The remit excluded the development and analysis of options that provided:

- alternative high speed alignments for Phase 2a, as this was examined by HS2 Ltd as part of their own consulted option development work;
- improvements to routes north of Crewe or to any routes not serving Crewe, as this would not provide an alternative to Phase 2a;
- opening Phase 2a at a different date, as DfT do not consider this to be sufficiently alternative from the core Phase 2a proposal; and,
- doing nothing, as this option has been separately analysed by HS2 Ltd.

[1] HS2 Phase One is due to open in 2026 and provide a high speed route between London Euston, Birmingham and the West Coast Main Line at Handsacre Junction in Staffordshire.
[2] The HS2 Full Y network is planned to be fully open in 2033 and complete the remainder of the high speed rail route to Manchester, the East Midlands, Sheffield and Leeds.
[3] http://www.gov.uk/government/publications/rail-alternatives-to-hs2

Rail Alternatives to HS2 Phase 2a

The Department specified that any rail alternative to Phase 2a had to be capable of delivering the HS2 programme wide objectives as set out in the 2013 HS2 Strategic Case[4]. These are:

- to provide sufficient capacity to meet long term demand, and to improve resilience and reliability across the network; and,
- to improve connectivity by delivering better journey times and making travel easier.

To be consistent with the HS2 Strategic Case, any solutions should:

- minimise disruption to the existing network;
- use proven technology that can deliver the desired results;
- be affordable and represent good value to the tax payer; and,
- minimise impacts on local communities and the environment.

Further to this, DfT specified that any rail based alternative to HS2 Phase 2a also needed to meet the following Phase 2a specific objectives:

- improve connectivity and journey times for cities north of Birmingham;
- deliver benefits to northern cities earlier than originally planned under HS2 Phase Two; and,
- enable the efficient delivery of the remainder of HS2 Phase Two.

To meet both these network wide and Phase 2a specific objectives, the Department specified that any Phase 2a rail alternatives must be capable of delivering:

- the Phase 2a train service specification;
- a similar level of capacity to Phase 2a; and,
- an environmental impact that is no worse than Phase 2a.

The Department asked Atkins to develop three alternative options for assessing against HS2 Phase 2a. Within the scope of the remit above, the three shortlisted options were required to represent as wide a range of costs and solutions as possible. The Department remitted that each option should be analysed against an agreed set of criteria in order that the alternative options could then be compared to HS2 Phase 2a. These were as follows:

- Economic objective: Assessing the benefit to cost ratio for each option using an appraisal approach consistent with the appraisal of HS2 Phase 2a;
- Capacity objective: Assessing the potential route capacity each option can deliver both for high speed services, and residual classic line services, including freight; and,
- Supplementary objectives: Assessing the level of disruption to rail services during construction, assessing the operational performance, and undertaking a high level assessment of the environmental impact of each option.

Each alternative option was required to be assessed against these objectives under two different network scenarios. Both of these scenarios are consistent with the way HS2 Ltd have assessed Phase 2a:

- Full Y Scenario: the alternative option forms a permanent part of the long term Full Y network. In this scenario the alternative option opens in 2027, from Handsacre to Crewe. From 2027 to 2033 high speed services run on the WCML north of Crewe, but from 2033 with the opening of the rest of Phase 2 from Crewe to Manchester, the alternative option operates as an integral part of the Full Y network.
- Crewe Standalone Scenario: the alternative option is assessed on the basis that the Full Y high speed network north of Crewe is not constructed. In this scenario, the alternative opens in 2027, with high speed services using the WCML north of Crewe thereafter. This allows an appraisal of the alternative option to be undertaken as a pure increment to Phase One, with only the costs and benefits of the alternative itself captured.

[4] www.gov.uk/government/publications/hs2-strategic-case (page 18)

2. Option Design

2.1. The West Coast Main Line (WCML)

The main design objective for all the alternative options is to avoid the capacity and journey time constraints on the section of West Coast Main Line (WCML) between Handsacre Junction[5] at the northern end of HS2 Phase One and Crewe.

Figure 2-1 below shows the current train planning headways for different sections of the WCML as provided by Network Rail's July 2015 Timetable Planning Rules[6]. It also shows key constraints imposed by conflicting moves[7] at junctions.

The Timetable Planning Rules' train planning headways represent the minimum time trains can be timetabled to follow one another, and this therefore provides the absolute maximum theoretical capacity or a particular route section. For instance a 3 minute headway would imply a maximum theoretical capacity of 20 trains per hour (tph). In practice the actual number of services that can operate a resilient timetable will always be less than that provided for by the timetable headways, in order to account for junction conflicts, the mix of different services (inter-city, commuter and freight) with their different operating characteristics and speeds, and the need to provide a contingency margin to maintain operational resilience.

For these reasons, in most circumstances, the Timetable Planning Rules do not provide a maximum capacity in terms of trains per hour for any particular route section. However, for the route section between Stafford and Crewe, the Timetable Planning Rules do suggest a maximum limit of 13 trains per hour. This is interpreted by Atkins to be the fast lines, for reasons likely to be associated with the restrictions at Stafford and Norton Bridge Junction.

Network Rail is currently delivering a major project known as the Staffordshire Area Improvement Program to improve capacity between Stafford and Crewe. This is due for completion in 2017, and according to Network Rail[8] will provide the following improvements to the WCML between Stafford and Crewe:

- Stafford resignalling which replaces existing signalling through Stafford station with bi-directional signalling and provides a freight loop;
- increasing maximum speeds on the slow lines from 75mph to 100mph between Norton Bridge and Crewe, allowing fast services to operate without any reduction in capacity; and
- grade separation of the junction at Norton Bridge, allowing services to run to and from Manchester via Stone without constraining capacity for services running to and from Crewe.

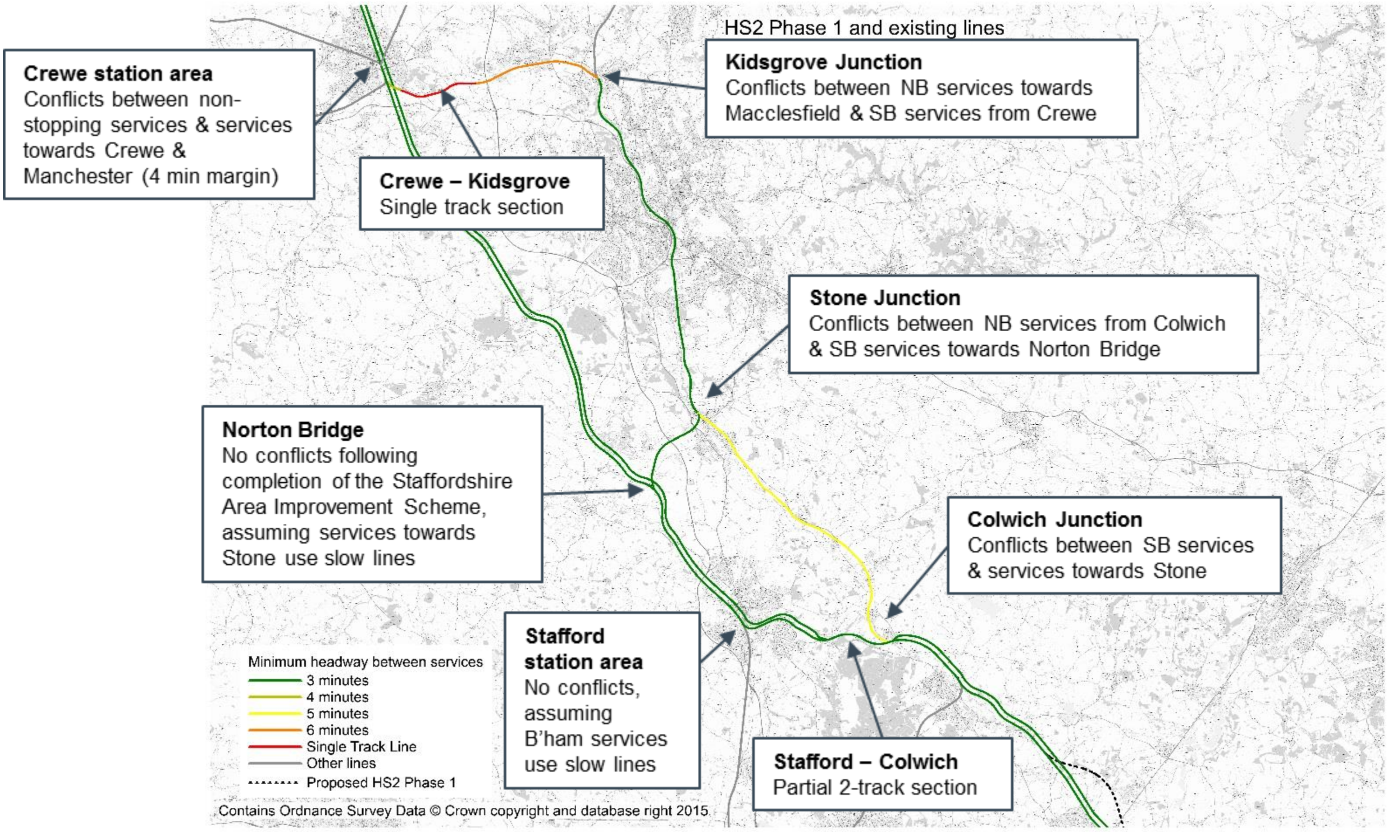
As a result, the key capacity constraints impacting Phase One services running on the WCML in 2026 between Handsacre and Crewe are expected to be:

- the two-track section through Shugborough Tunnel, which is located between Colwich Junction and Stafford; and,
- Colwich Junction where northbound services running via Stoke conflict with southbound services coming from the Stafford direction towards London.

There is further discussion of the capacity of this part of the WCML and the implications of the proposed HS2 timetables in Section 3.4.1.

[5] Handsacre Junction is where HS2 Phase One is proposed to join the WCML in Staffordshire.
[6] http://www.networkrail.co.uk/browse%20documents/Rules%20Of%20The%20Route/Viewable%20copy/TPRyearYY/lnwYYp.pdf
[7] A conflicting move occurs when a train movement blocks more than one line at once due to the track layout. For instance, a train cannot use a crossover to transfer from line A across line B to line C whilst there is another train signalled to pass straight through on line B (or vice versa).
[8] http://www.networkrail.co.uk/improvements/stafford-crewe/

Figure 2-1 WCML current capacity[9]



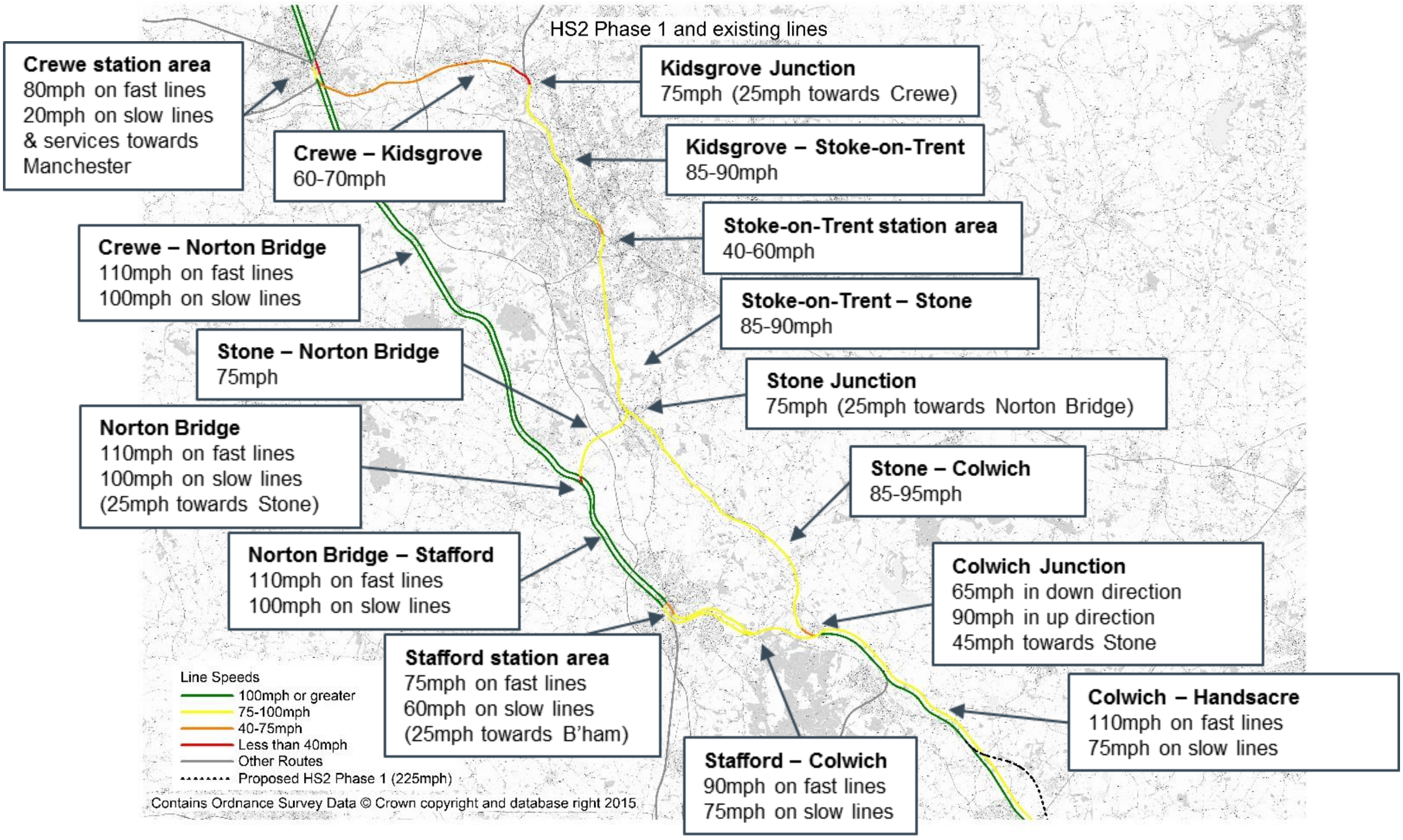
The WCML infrastructure allows for two different maximum line speeds for passenger services, depending on the technology fitted to the trains operating over it. Permissible speed (PS) is the normal maximum speed available to any rolling stock capable of attaining that speed. Enhanced permissible speed (EPS) allows the trains equipped with tilt technology (such as the current Class 390 Pendolinos) to travel at higher speeds, specifically round curves but also on sections of straight track.

The permissible speeds on the WCML for non-tilt rolling stock are shown Figure 2-2 below. These speeds have been taken from Network Rail's Sectional Appendix[10], and include the committed line speed improvements of the Staffordshire Area Improvement Program described above.

Much of the WCML fast lines between Handsacre and Crewe operates at the maximum permissible speed of 110 mph for non-tilt services. However, the line speeds are lower on the slow lines as well as some sections of the fast lines, most notably at Colwich Junction, through the two-track section between Colwich and Stafford, and in the Stafford area itself. These all impose limitations on journey times.

[9] Source Network Rail Timetable Planning Rules and Atkins analysis
[10] http://www.networkrail.co.uk/browse%20documents/sectional%20appendix/london%20north%20western%20north%20sectional%20appendix.pdf

Figure 2-2 WCML current non-tilting line speeds



2.2. Option Sifting

To design alternative options to Phase 2a, Atkins began by developing a long list of options that all tried to various degrees to overcome the capacity and journey time limitations of the WCML described in section 2.1 above. All of these long list options required constructing some sections of new alignment away from existing rail corridors, in order to bypass the most constrained sections of the WCML through Colwich Junction and Stafford. Many of the routes for these sections of new alignment were either developed from proposals originally considered as part of the West Coast Route Modernisation Programme delivered in 2009[11], or by using elements of the proposed HS2 Phase 2a alignment. Extensively upgrading the existing route entirely within the existing rail boundaries was not considered a feasible option, as the nature of the existing alignment would likely make it very difficult and costly to develop suitable alternatives that could deliver the necessary improvements to capacity and journey times, as well as avoiding disrupting existing services during construction[12].

Some high level analysis of the long list's journey times, costs and capacity was undertaken to help discard options with either low benefits and high costs, or which could not be expected to provide enough capacity to robustly support the indicative HS2 service pattern proposed to run under the Full Y. Through workshops with Department for Transport, Network Rail and High Speed Two Limited, the long list of high level options was sifted to a shortlist of three options for further development and analysis.

The shortlisted options were deliberately chosen to provide a wide range of costs. As such they represent a range of approaches to meeting the criteria set out in the remit, and offer different cost solutions involving new high speed track, new conventional track or a combination of both.

[11] https://www.networkrail.co.uk/browse20documentsStrategicBusinessPlanRoutePlans2009Route201820 20West20Coast20Main20Line.pdf

[12] The previous strategic alternative study also considered upgrading elements of the existing network albeit as part of a wider set of alternatives to the Full Y scheme https://www.gov.uk/government/uploads/system/ uploads/attachment_data/file/253456/hs2-strategic-alternatives.pdf

For reasons of time and resource none of the shortlisted options have been fully optimised within the analysis undertaken. It is worth noting that a more refined design and service pattern is likely to impact both costs and benefits.

2.3. High Cost Alternative Option: 44km of new high speed alignment

The high cost alternative option[13] involves constructing roughly two-thirds (43km) of the Phase 2a high speed alignment as proposed by HS2 Ltd, from Streethay Junction[14] to a point near the village of Baldwin's Gate. At this point the Phase 2a alignment comes within less than 1km of the WCML which provides a four track railway all the way to Crewe. An additional length of high speed alignment would link the Phase 2a route to the West Coast Main Line (WCML) fast lines (which run to the east of the slow lines at this point) via a flat junction.

Under the proposed HS2 indicative service pattern, there will only be a few residual classic line trains per hour operating on the southbound fast line from Crewe towards Norton Bridge that would conflict with northbound HS2 services crossing the southbound line via a flat junction. As such, Atkins' assessment of the indicative timetable at this location is that there are not enough conflicting moves to justify the costs of a grade separated junction. The option has therefore been designed, costed and assessed on the basis of a flat junction which Atkins believe could robustly operate the proposed HS2 and residual timetables[15].

To avoid all conflicts entirely, Atkins' recommended solution when operating under normal circumstances, would be to operate all the residual classic line services on the slow lines between Baldwin's Gate and Crewe, and all the HS2 services on the fast lines[16]. This would result in the HS2 services operating without any conflicts or interactions with other non-HS2 services. Not only would this negate entirely the need for a grade separated junction, but the segregation of services could also provide additional capacity, performance and journey time benefits. As described in section 3.4 and 3.5, such an arrangement would more evenly balance services across the fast and slow line and avoid performance contamination between HS2 and residual services. A flat junction would be maintained to provide operating and flexibility and resilience during maintenance or disruption and to provide timetabling flexibility.

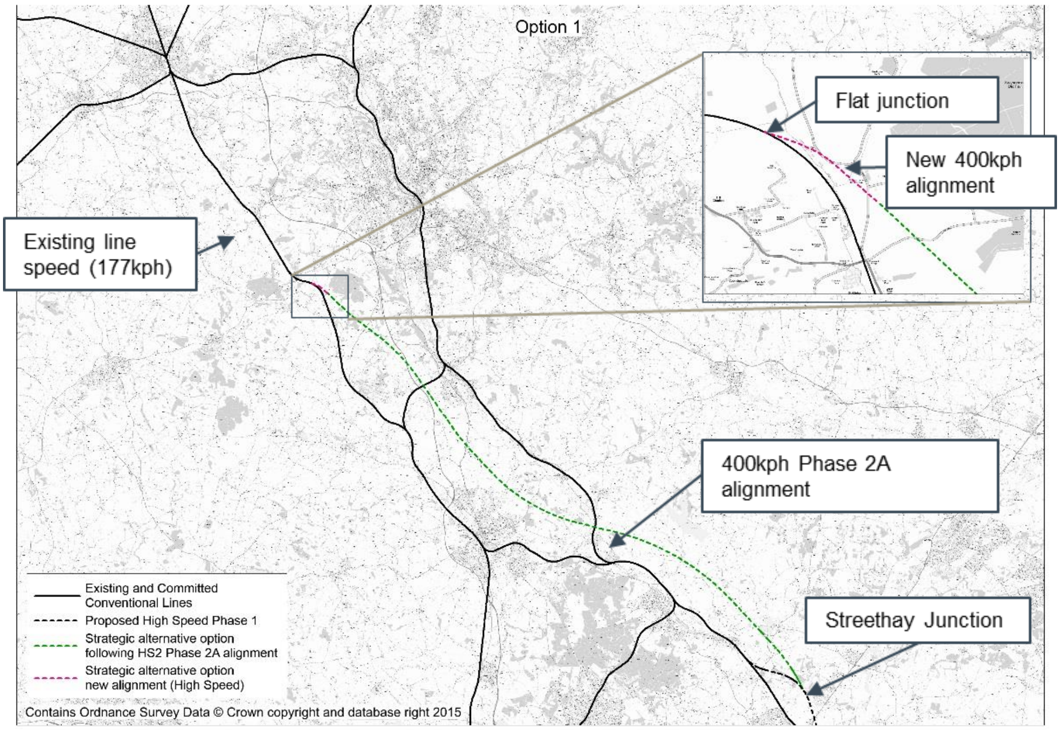
Atkins note that the HS2 Ltd design requirements specify that any interface between the classic and high speed routes should be via grade separated junctions. Should this be necessary, Atkins estimate the additional unit cost of building a typical grade separated junction over a flat junction to be around £130m (2011 prices including optimism bias) as set out in see section 3.1.1.

The key elements of this option can be summarised as follows:

- 42.5km of HS2 Phase 2a alignment (from Streethay Junction to near Baldwin's Gate).
- 1.4km of new HS alignment to WCML, including one small bridge crossing a minor brook.
- new flat junction onto WCML fast lines near Baldwin's Gate which would also need to facilitate parallel movements from the fast to the slow lines on the WCML;
- 18.3km running on existing WCML from Baldwin's Gate to Crewe. This section has the potential to allow 125mph running and, under normal operation, to allocate HS2 services exclusively to the fast lines.

[13] This option was referred to as Option 1 during the Atkins option selection process.
[14] Streethay Junction is the name nominally given to the HS2 junction between Phase 2a and Phase One near Fradley.
[15] The use of a flat junction has not been agreed by Network Rail or HS2 Ltd because it runs contrary to the HS2 Ltd design standards.
[16] This recommendation is made purely in relation to the operating practice of a 4 track railway in terms of which services are allocated to which tracks. Atkins are not making any recommendations on ownership or maintenance responsibilities for that route section.

Figure 2-3 High Cost Alternative Option: 44km of new high speed alignment



The core option taken forward for the analysis described in Chapter 3, assumes that the operating speed for HS2 services on the WCML between Baldwin's Gate and Crewe is limited to the current permissible speed for non-tilt trains of 110mph. As described in Section 3.2, should the HS2 trains be able to operate at the enhanced permissible speed of 125mph, which is the same speed as Pendolinos run currently on this section, then this has the potential to save between 30 seconds and one minute of additional journey time. Atkins' initial assessment of this route section suggests that apart from a curve just north of Baldwin's Gate Junction the alignment is straight enough to support such speeds for non-tilt services, and that this could be enabled for little additional cost.

In addition to this, further journey time savings might be obtainable by upgrading this section to allow 140mph running. Atkins' assessment suggests that the alignment would appear straight enough to allow this, although it is likely there would need to be additional investment to the power supply and signalling. An indicative unit cost for upgrading the route to 140mph is provided in section 3.1.1.

2.4. Low Cost Alternative Option: 18km of new conventional speed alignment

The low cost option was originally developed by the West Coast Route Modernisation Team up to around GRIP level[17] 2/3 for inclusion in the West Coast Route Modernisation programme delivered between 2000 and 2009. This option deliberately limited the design of the new alignment to 140mph in order to provide a relatively low cost option that operates at conventional line speeds.

This low cost alternative option[18] is designed to bypass the capacity constraints of Colwich Junction, the two track section through Shugborough Tunnel, and the flat junctions immediately to the north of Shugborough Tunnel and at Stafford, as well as the speed restrictions known as the "Stafford wheel" curve.

Colwich Junction is bypassed with a new section of conventional speed (140mph) alignment. This would leave the current WCML via a new grade separated junction on the 6km straight line north-west of Rugeley to form the start of a new 140mph alignment to the Stone line towards Stoke which it would join by way of a new flat junction at Hixon. Atkins do not consider a grade separated junction to be required at this point as

[17] http://www.networkrail.co.uk/aspx/4171.aspx
[18] This option was referred to as Option 7 during the Atkins option selection process.

the Stone line is only used by 2 trains per hour with the result that there would be only a few conflicting moves. Furthermore, these services could be diverted via Norton Bridge if required. The construction of a new flying junction and chord to the Stone line, means that the low cost alternative option could render the existing flat junction at Colwich redundant.

The Stone line alignment between Hixon and Sandon is relatively straight and lightly used, and an initial assessment has found no significant impediment to upgrading this section of the WCML to 140mph. Using the high level unit rate based approach described in section 3.1.1, Atkins estimate that the cost of upgrading this 6.5km section would be around £141m (2011 prices).

11km of new 140mph conventional speed alignment would be constructed, so as to bypass Stafford and link the Stone line to the WCML Crewe route via flat junctions at Sandon and Norton Bridge. As with the junction at Hixon, Atkins do not consider that the costs of grade separated junctions at Sandon or Norton Bridge would be justified due to the low volume of non-HS2 traffic and resulting low number of conflicting moves. At Norton Bridge, the layout of the lines and number of conflicting moves at the junction with the existing WCML to Crewe is the same as at Baldwin’s Gate under the high cost option, and the arguments for having a flat junction at these locations are therefore the same.

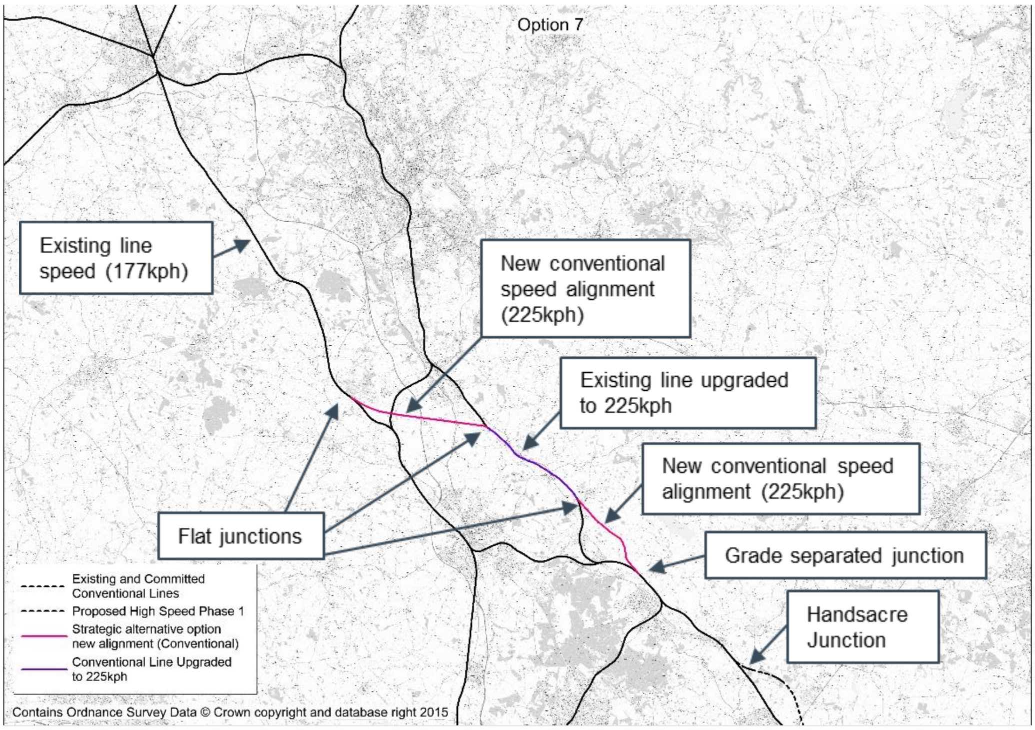
The design of this option would therefore provide a continuous section of 140mph running from near Colwich to just north of Norton Bridge. A few non HS2 services would operate over the section between Colwich and Sandon, but the rest of the route from Sandon to Norton Bridge could be assigned for the exclusive use of high speed services. Under normal operating circumstances, the length of route operated exclusively by HS2 services could be further extended, by diverting 1 or 2 residual services per hour operating between Rugeley and Sandon via Stafford, Norton Bridge and Stone instead. As proposed in the high cost option, between Norton Bridge and Crewe, residual services could be timetabled to normally operate on the slow lines and HS2 services on the fast lines. Such an arrangement would then provide a segregated route for HS2 services all the way from Rugeley to Crewe, albeit with some residual services diverted via Norton Bridge.

Should the HS2 design requirements mandate the construction of flying junctions (even on sections of the conventional network) then, based on the unit rates described in Section 3.1, the incremental cost of converting the three flat junctions to flying junctions could be an additional £390m (2011 prices).

The key elements of this low cost option can be summarised as follows:

- 6.8km of new 140mph alignment from Rugeley to Hixon.
- upgrade of 6.5km of existing WCML line between Hixon and Sandon to 140mph.
- 10.8km of new 140mph alignment from Sandon to WCML near Norton Bridge. Key features would include:
  - Crossing of Trent and Mersey Canal and Trent River;
  - Three major bridges crossing the A34 dual carriageway, M6 motorway and the existing railway line between Norton Bridge and Stone; and
  - Four small bridges crossing minor roads.
- a total of three new flat junctions at Hixon, Sandon and Norton Bridge, and one new grade separated junction at Colwich.
- 26.1km running on existing WCML from Norton Bridge to Crewe. This section has the potential to allow 125mph running and, under normal operation, to allocate HS2 services exclusively to the fast lines.

Figure 2-4 Low Cost Alternative Option: 18km of new conventional speed alignment



Although not forming part of the core option taken forward for the analysis described in Chapter 3, as with the high cost option, there is also the potential to allow faster running on the WCML fast lines between Norton Bridge and Crewe to further reduce journey times. If non tilt HS2 services were permitted to run at the current enhanced permissible speed of 125mph for the majority of this 26km section, then a further journey time saving of around one minute could be achieved. To increase the line speeds to 140mph is likely to require much greater level of investment (with additional costs) but would also offer even greater time savings and benefits.

2.5. Medium Cost Alternative Option: 15km of new high speed and 11km of new conventional speed alignment

This medium cost alternative option[19] is similar to the low cost option, but rather than using new conventional speed alignment to bypass Colwich, it uses roughly one third of the HS2 Phase 2a high speed alignment from Streethay Junction to a point near Moreton Farm. From this point an additional 5km of high speed alignment is built to join the WCML Stone line via a flat junction near the site of the former level crossing at Hixon, approximately 15km from Streethay Junction.

From this point north the design is the same as low cost option. The Stone Line would be upgraded to 140mph, and a new conventional 140mph line built to link the Stone line to the WCML Crewe route just north of Norton Bridge.

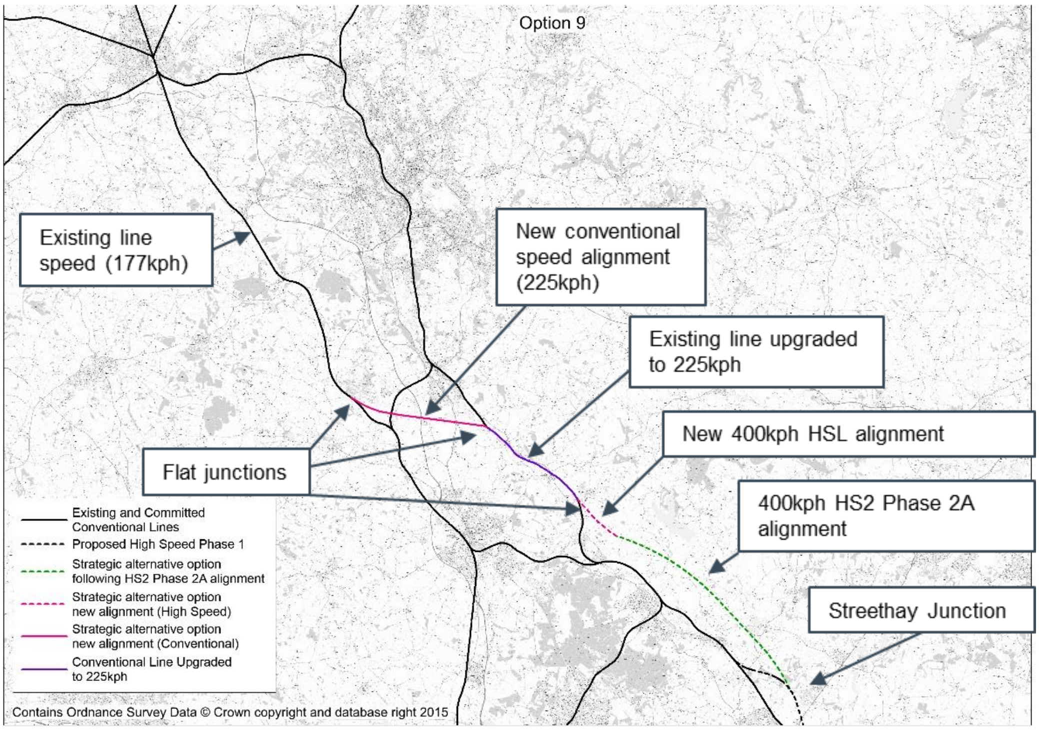
This option would require the construction of three junctions at Hixon, Sandon and Norton Bridge. As with the high and low cost options, Atkins' assessment is that with only a few non-HS2 services operating on either the Stone lines or fast lines north of Norton Bridge that are likely to cause train conflicts, a robust timetable could be operated with flat junctions at all these locations. Should however the design requirements of HS2 necessitate grade separated junctions then, based on the unit rates described in Section 3.1, converting the three flat junctions to flying junctions could cost an additional £390m (2011 prices).

[19] This option was referred to as Option 9 during the Atkins option selection process.

The key elements of this option can be summarised as follows:

- 15.2km of Phase 2a alignment from Streethay Junction to Great Haywood.
- 4.8km of high speed alignment from Great Haywood to existing Stone line at Hixon, including three small bridges crossing minor roads and tracks.
- upgrade of 6.5km section of Stone line between Hixon & Sandon to 140mph.
- 10.8km of new 140mph alignment to WCML near Norton Bridge, including;
  - Major crossing of Trent and Mersey Canal and Trent River;
  - Three major bridges crossing the A34 dual carriageway, M6 motorway and the existing railway line between Norton Bridge and Stone; and,
  - Four small bridges crossing minor roads.
- 26.1km running on existing WCML from Norton Bridge to Crewe. This section has the potential to allow 125mph running and, under normal operation, to allocate HS2 services exclusively to the fast lines.
- requires 3 flat junctions

Figure 2-5 Medium Cost Alternative Option: 15km of new high speed and 11km of new conventional speed alignment



As with the high and low cost options, there is also the potential opportunity to improve journey times by allowing HS2 trains to operate at the current enhanced permissible speed of 125mph between Norton Bridge and Crewe, or by upgrading the route to 140mph line speeds.

3. Assessment of Options

This chapter assesses the three shortlisted options against the strategic criteria of costs, journey time, economic appraisal, capacity, performance, disruption and environmental impact as set out in Chapter 1.

Each option is assessed against two network scenarios that are analogous to how HS2 Ltd have assessed Phase 2a:

- the Full Y network incorporating the alternative option. In this scenario, the alternative option opens in 2027 between the end of Phase One and Crewe, with the rest of the Y network north of Crewe then opening in 2033. Under this scenario the alternative option forms part of the long term Y network and the costs and benefits of the full network are assessed.
- the alternative option as a standalone increment to Phase One. This scenario, which is examined only for appraisal purposes, assesses the costs and benefits of the alternative option only, and therefore excludes any benefits from Phase One or the rest of Phase 2 which for the purpose of the appraisal is assumed not to be built.

Throughout this work, the analytical approach, assumptions and methodology for assessing the alternative options has been kept as consistent as possible with that used by HS2 Ltd for their assessment of Phase 2a.

3.1. Costs

3.1.1. Construction Costs

As much as possible the derivation of both the capital and operating costs were estimated using the same assumptions and approach as used by HS2 Ltd for the assessment of HS2 Phase 2a.

The construction costs of the alternative options were calculated on a unit rate basis, with the unit rates determined in reference to the costs of HS2 Phase 2a. The unit rates for different types of infrastructure are shown in the table below and were calculated as follows:

- for HS2 Phase 2a high speed alignment, the unit costs were determined from HS2 Ltd's assessment of HS2 Phase 2a costs. The per kilometre unit rates are calculated from the capital costs and distances of the southern section of HS2 Phase 2a known as HSM3. HSM3 covers the entirety of any section of Phase 2a used by the alternative options and therefore is the most suitable section of HS2 for basing the unit rates upon. As per the assessment of HS2 Phase 2a by HS2 Ltd an optimism bias uplift of 40% has been applied to the base unit cost.
- the same HS2 Phase 2a unit rate has also been used for new high speed alignment which is not part of the Phase 2a route planned by HS2 Ltd, although in these circumstances optimism bias has been applied at 66%. The higher level of optimism bias reflects the fact that this alignment has not reached the same level of design maturity as the Phase 2a alignment as advised by HMT guidance[20].
- for new alignment designed for classic line speeds (140mph), a unit rate 10% lower than the Phase 2a unit rate has been used, with an optimism bias of 66% applied. The 10% lower cost reflects the lower design standards that a 140mph alignment would need compared to a 250mph alignment and is an assumption previously used by HS2 Ltd in their assessment of a classic line alternative to HS2 Phase One[21]. It is worth noting that with the higher optimism bias the assumed cost of building new 140mph alignment is higher than the cost of building HS2 Phase 2a's 250mph alignment.
- Atkins have determined the unit rate for upgrading the existing WCML to allow running at 140mph and for the construction of both grade separated and flat junctions. The basis and assumptions used to calculate these rates are consistent with the unit rates used by previous strategic alternative analysis and have been reviewed by Network Rail. The unit rates for both the junctions and upgraded route include an allowance of 4% for possessions and 4% for TOC compensation. An optimism bias of 66% is applied to all of these costs to account for the early stage of the scheme's

[20] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191507/Optimism_bias.pdf
[21] http://webarchive.nationalarchives.gov.uk/20121107103953/http://www.dft.gov.uk/pgr/rail/pi/highspeedrail/hs2ltd/demandandappraisal/pdf/report.pdf

development. Note that the junction costs are for the costs of the junctions only, as the cost of alignment needed to reach the junctions is included within the alignment unit costs above.

- the costs of Phase 2a include the cost of a large depot at Crewe for supporting the track maintenance of both Phase 2a and from 2033, and the rest of Phase 2 north of Crewe. Given that a significant proportion of the depot is to support the rest of Phase 2, the full depot costs have therefore also been included in the assessment of all the alternative options, even if the alternatives have much less new infrastructure to maintain. Atkins have not undertaken a detailed review of how the infrastructure maintenance depot requirements might change for the alternative options, which amongst other things would need to consider:
  - Whether an infrastructure maintenance depot of the same cost and size would be required to support the rest of Phase 2 and the alternative options. The medium, and in particular, low cost options have significantly less new infrastructure to maintain than Phase 2a which could reduce the size and cost of the required maintenance depot.
  - Whether the costs of linking the depot to the WCML fast lines and the rest of Phase 2 would be more or less than the costs of linking the depot to Phase 2a and the rest of Phase 2 as contained in the HS2 Ltd assessment of costs.
  - Whether the type of maintenance vehicles required for the maintenance of the infrastructure would have to be built to UK loading gauge which could increase their costs.

  For these reasons, DfT have instructed Atkins to apply a higher level of optimism bias to the costs of the infrastructure maintenance depot when it is considered as part of the alternative options than when it considered as part of Phase 2a. The optimism bias for the depot is therefore 66% rather than 40%.
- the costs of Phase 2a include the costs of building a tunnel portal for the start of a tunnel under Crewe that is then completed under the rest of Phase 2. The costs of these enabling works for the rest of Phase 2 are also included in the costs of all the alternative options, with the same level of optimism bias as has been applied in Phase 2a.
- £17m of sunk costs have been excluded from the appraisal of HS2 Phase 2a on the basis that these are costs already spent. No such exclusion has been made for the alternative options, although it may be that some or all of those sunk costs could also support elements of the alternative options. Were this to be the case this would slightly reduce the costs of the alternative options within the appraisal.
- as with the HS2 Phase 2a reference case, no allowance has been made for network enhancements north of Crewe needed to support the indicative HS2 train service specification.

Table 3-1 Construction Cost Unit Rates (2011, Q2 prices)

Cost Type	Source	Unit rate per double track km (£2011, Q2)	Optimism Bias	Unit rate with optimism bias per double track km (£2011, Q2)
HS2 Phase 2a alignment	HS2 Phase 2a	£28m	40%	£39m
New 250mph alignment	Same as Phase 2a	£28m	66%	£47m
New 140mph alignment	Phase 2a reduced by 10%	£25m	66%	£42m
Upgraded WCML alignment to 140mph	Atkins	£13m	66%	£22m
Grade separated junction (junction cost only)	Atkins	£89m	66%	£148m
Flat Junction (junction cost only)	Atkins	£11m	66%	£18m

Cost Type	Source	Unit rate per double track km (£2011, Q2)	Optimism Bias	Unit rate with optimism bias per double track km (£2011, Q2)
Crewe infrastructure maintenance depot	HS2 Ltd	£119m	66%	£197m
Crewe Tunnel Portal	HS2 Ltd	£48m	40%	£67m

The capital costs of each option were calculated from the unit rates in the table above and the specification of each option, with the shown in the table below. All costs are presented in Q2 2011 prices as per HS2 Ltd's assessment of HS2 Phase 2a costs.

Table 3-2 Construction costs of alternative options

Capital Cost (2011 Q2 Prices)	Phase 2a	High Cost Option	Medium Cost Option	Low Cost Option
Increment over Phase One	£3,163m	£2,018m	£1,732m	£1,346m
Full Y	£45,170m	£39,033m	£38,747m	£38,361m

It can be seen from this that the high cost option is £1.1bn cheaper than Phase 2a, the medium cost option is £1.4bn cheaper and the low cost option is £1.8bn cheaper. All of the options avoid building the highest cost section of Phase 2a which north of Baldwin's Gate involves some relatively expensive sections involving tunnelling and a complex junction with the WCML at Crewe.

At this early stage of the alternative options design, the cost estimates are necessarily unit rate based and high level. Although, where possible many of the unit rates and assumptions have been derived from those used by HS2 Ltd and previous strategic alternative studies, the application of those unit rates may not be entirely applicable to the particular design requirements and local geography of each option. As a unit rate approach is therefore subject to a degree of inherent uncertainty, a higher level of optimism bias has been applied to the alternative options' cost estimates than that which has been applied by HS2 Ltd to Phase 2a.

For these reasons, Atkins have also tried to make many of the cost assumptions deliberately conservative. However, with more detailed option design and costing, it is possible that the costs of the alternative options could change for the following reasons:

- the kind of infrastructure maintenance depot needed to support HS2 Phase 2a may not be the same as needed to support the alternative options, particularly the medium and low cost options which involve maintaining a much smaller length of high speed network. Further work to understand the implications of redesigning the depot to connect to the WCML fast lines would also allow the level of optimism bias applied to the maintenance depot to be reduced to the same level as applied to the HS2 Phase 2a depot. It seems unlikely that the cost of the maintenance depot needed to support the alternatives will be more expensive than the depot needed to support Phase 2a as currently assumed.
- the costs of building new 140mph alignment has been assumed to be 10% cheaper than building new HS2 alignment. This is a very high level and relatively crude assumption that has been used in the past by HS2 Ltd. For this reason, a higher level of optimism bias has been applied to the conventional speed alignment than for HS2 alignment, although the result of this is that the cost of new conventional speed alignment is assumed to be higher than the cost of new high speed alignment. With a more refined design and similar levels of optimism bias, it would be expected that the costs of building new alignment for 140mph with its lower engineering tolerances and design requirements would be less than the cost of building the Phase 2a alignment at 250mph.

- the costs of upgrading the existing WCML line speed to support 140mph running has been derived from a high level unit cost basis. It does not take account of the specific signalling, power supply or civil works that might be required in any specific locations. The unit rate for upgrading an existing line to 140mph, is about half that for building an entirely new line to 140mph. More detailed design and development work would allow a better understanding of the likely upgrade costs, and for the level of optimism bias to be reduced. There may be opportunities for some cost savings if some of the upgrade work could be phased with other signalling and infrastructure renewals expenditure.
- the costs of a grade separated junction can vary greatly depending on location, the complexity of the junction and the number of tracks to be crossed. However, benchmarking the unit cost of a grade separated junction from other recently completed schemes[22] does suggest that the unit cost of £148m used in this assessment is relatively conservative. It should be noted that the £148m cost is just for the grade separated junction itself; the costs of building new alignment to the new junction is covered in those unit rates.
- the costs of providing adequate power supply connections from the National Grid, such as the provision of new or upgraded substations or electricity distribution networks, are included within the unit rates for the construction of new or upgraded alignment. It may be that for some of the alternative options additional costs are required beyond this unit rate, as power distribution infrastructure can incur high fixed costs.
- the assumptions used by Atkins and HS2 Ltd for the costs of HS2 alignment and upgraded WCML alignment may not be entirely consistent or applicable in all situations. These include assumptions around land take, Transport and Works Act (TWA) compensation, environmental mitigation, on-costs, possession and TOC compensation.

Of all the alternative options, the high cost option has perhaps the lowest uncertainty around costs as it contains the highest proportion of HS2 Phase 2a route and costs. The low and medium cost options have a much higher degree of uncertainty, which is reflected in the level of optimism bias, due to their use of unit rates for new or upgraded conventional speed alignment or junctions that have a much lower level of design maturity.

3.1.2. Infrastructure, Operations, Maintenance and Renewal Costs

The infrastructure operating, maintenance and renewal (OMR) costs for new high speed alignment has been calculated on a per kilometre unit rate basis using the same assumptions as that used for the OMR costs of Phase 2a.

The infrastructure OMR costs for the existing WCML or for new conventional speed (140mph) alignment have been determined within the calculation of rolling stock operating costs. As described in section 3.1.3, the rolling stock operating costs include operating cost charges per kilometre (such as Variable Track Access Charges, VTAC) that are applied to any service using the conventional infrastructure. These charges implicitly include infrastructure OMR and costs. The overall approach and assumptions for assessing the OMR of the conventional WCML running is entirely consistent with that used for the assessment of Phase 2a.

Overall the approach means that the full infrastructure operations, maintenance and renewal costs for all sections of each alternative option, whether operating on existing lines, or new high speed or conventional lines, have been included in the assessment of costs.

3.1.3. Rolling Stock Costs

The capital cost of rolling stock needed to operate the Full Y with an alternative option in place of Phase 2a, has been assessed using the same rolling cost unit cost and optimism bias assumptions as used by HS2 Ltd.

The proposed HS2 service pattern between 2027 and 2033 with either Phase 2a or the alternative options, is the same as proposed in 2026 with Phase One, albeit with faster journey times. This means that the train

[22] By way of reference, the Hitchin flyover which opened in 2013 cost is stated publically to cost around £47m, the Reading West flyover which opened in 2015 cost around £45m, the Stockley Flyover which opens in 2017 cost around £50m, and the Acton dive under which opens in 2017 cost around £30m. Note however that these costs may be in different price years and contain different scopes of work, making any direct comparisons difficult.

fleet needed to operate Phase One is also capable of operating the Phase 2a or alternative options between 2027 and 2033, and that no additional rolling stock need be purchased above that already purchased to operate Phase One.

From 2033 when the Full Y is built north of Crewe, a different rolling stock fleet will be required depending on whether the section between Phase One and Crewe is built as Phase 2a or an alternative option. If the Full Y incorporates Phase 2a, then services to Manchester can be operated by a captive[23] fleet of HS2 trains as the whole route to Manchester will be dedicated high speed line built to European loading gauge. However, were the Full Y to incorporate the alternative options instead of Phase 2a, then, services to Manchester would have to be operated by a fleet of classic compatible[24] rolling stock as all the alternative options involve some element of classic line running with UK loading gauge. By itself this would not change the overall fleet size, only the fleet mix, although, as HS2 Ltd assume that classic compatible rolling stock is slightly more expensive then captive rolling stock, this would increase the overall rolling stock purchase costs.

Beyond the change in fleet mix required to accommodate differences in loading gauge, from 2033 additional units of rolling stock may also be required to compensate for the increased journey time of the alternative options, which would otherwise reduce the turnaround times at the end of each journey. Atkins have not reviewed HS2 Ltd's train diagramming assumptions to ascertain whether any additional units might be required for the alternative options, and more work is required to reach a definitive view of the rolling stock requirements. At this stage Atkins have therefore assumed that to compensate for this increased journey time, all of the alternative options would require an average of two additional 200m train sets. As an average it may be that the high cost option requires fewer additional units as it has the highest journey time increment over Phase 2a, and that the low cost option requires more units. In proportion to the overall scheme costs, the impact of slightly more or less additional units of rolling stock is relatively small, and should a small increase or decrease in the number of unit be required, this is unlikely to make a significant difference to the assessment of the options.

The table below summarises Atkins assessment of the rolling stock requirements for the alternative options taking into account both the requirements of loading gauge and longer journey times.

Table 3-3 Rolling Stock Requirements

	Base cost of 200m train set (2011 prices)	Train sets required for Phase One, Phase 2a and alternative options	Train sets required for Full Y with Phase 2a	Train sets required for Full Y with alternative options
Captive Fleet	£20.75m	16	70	42
Classic Compatible Fleet	£21.25m	45	95	125

3.1.4. Operating Costs

Operating costs for the alternative options have been calculated using the operating cost model and assumptions developed by HS2 Ltd to assess Phase 2a operating costs and have been calculated on the following basis:

- the rolling stock maintenance costs for HS2 trains are calculated on a kilometre basis. As the distance operated by HS2 rolling stock stays broadly the same under all the alternative options, the HS2 rolling stock maintenance costs for all the alternative options are assumed to be the same as Phase 2a.
- electricity costs for HS2 services have been adjusted from those used to assess Phase 2a according to the different distances under each option that HS2 services travel at 225mph, 140mph, or 110mph.

[23] Captive rolling stock can only operate on HS2 infrastructure as it is built to European loading gauge.
[24] Classic compatible rolling stock can operate both on the high speed HS2 line at up to 250mph and the existing classic lines at conventional line speed. In order to fit on the classic network it is built to the UK loading gauge.

- office and station staff costs are assumed to be the same as HS2 Phase 2a.
- the costs of operating HS2 services on either the existing WCML or new conventional alignment, are adjusted to account for the different lengths of classic line route that the HS2 services operate over within the alternative options. These costs include Network Rail's variable track access charges (VTAC), capacity charges, station access charges and rolling stock insurance.
- testing and commissioning costs for all the alternative options are the same as assumed for Phase 2a.
- cost savings from running the classic line residual non-HS2 timetable are the same for all the alternative options as assumed for Phase 2a.

The net impact on the operating costs for each alternative option is shown in the table below. It should be noted that compared to the capital costs, the differences in operating costs between Phase 2a and the alternative options are relatively small, and that therefore any uncertainty attached to the derivation of operating costs is unlikely to have an impact on the appraisal of options.

Table 3-4 Operating Costs

Cost (2011 Present Value, 2011 prices)	Phase 2a	High Cost Option	Medium Cost Option	Low Cost Option
Increment over Phase One	£121m	£85m	£48m	£11m
Full Y	£22,864m	£22,828m	£22,791m	£22,754m

3.2. Journey Time Impact

The journey time impact of each option was assessed using a bespoke journey time model based on the different line speed profiles and distances of each route. The model has been calibrated to replicate the journey times for HS2 Phase 2a, and as a result the calculation of journey times for the alternative options and Phase 2a are broadly consistent.

The journey times of the alternative options have all been assessed on the basis that HS2 trains will travel on non-upgraded sections of the WCML at the non-tilt permissible speed of 110mph. It is on this basis that the economic appraisal conducted in section 3.3 has been undertaken.

Currently tilting trains (eg. Pendolinos) are permitted to operate at 125ph. If it is possible to operate HS2 trains at 125mph on the straighter sections of classic line – which HS2 Ltd believe will be the case - then this could further reduce journey times of the alternative options by up to a minute (see table 3.5). As described in chapter 2, further journey time savings might also be achievable if the line speed on appropriate sections of the existing WCML could be increased to 140mph, although this would also involve additional capital expenditure.

The results of the journey time modelling are shown in Table 3.5 below. For the purpose of the economic appraisal the journey times have been rounded to the nearest half minute.

Table 3-5 Journey time of alternative options compared to Phase 2a

Assumed running speed on classic line sections	Additional journey time over Phase 2a		
	High Cost Option	Medium Cost Option	Low Cost Option
110mph	2min 28sec	5min 23sec	8min 7sec
125mph	1min 44sec	4min 23sec	7min 7sec

Assumed running speed on classic line sections	Additional journey time over Phase 2a		
	High Cost Option	Medium Cost Option	Low Cost Option
140mph	1min 11sec	3min 37sec	6min 21sec

In addition to improving the journey time of the HS2 services, the medium and low cost alternative options might also be able to offer journey time improvements to some residual services operating on the WCML. If residual services continue to operate on the Stone line then these could benefit from the line speed improvements planned between Hixon and Sandon. The low cost option could also run residual services over the new infrastructure from Rugeley to Sandon thus avoiding Colwich Junction, which could offer journey time improvements to those services. The medium cost option offers the possibility of running HS2 services to Stoke with bigger time savings than would be available from Phase 2a, although this would require re-casting the HS2 timetable which could result in longer journey times to other destinations such as Manchester. Given these uncertainties, within the economic appraisal presented in section 3.3 below, no journey time improvements have been assumed for residual services, and the impact of running new HS2 services has not been tested.

3.3. Economic Appraisal

Using the journey time and cost assumptions described above, the demands and benefits of each alternative option have been assessed using the same version of the PLANET Framework Model (PFMv5.2)[25] as has been used to assess HS2 Phase 2a. The use of the same PFM forecasting model ensures that all the key assumptions used in the appraisal of the alternative options are consistent with the appraisal of HS2 Phase 2a. This includes areas such as the level at which demand is capped, the values of time, the do minimum scenario, the approach to calculating benefits and the calibration of the model.

The assumed train service specification for each option is exactly the same as is assumed to run under the HS2 appraisal of Phase 2a and the Full Y. The only differences are adjusting the journey times of HS2 trains using the alternative option infrastructure as per table 5.3 above (noting that journey times are rounded to the nearest half minute). The released capacity timetable for residual services is also consistent with the HS2 scenarios.

The appraisal of Phase 2a includes £140m of benefits that are attributable to the improved operational performance offered by HS2 services using Phase 2a rather than the WCML between Handsacre and Crewe. Using a similar approach to HS2 Ltd, the reliability benefits of the alternative options have been determined using the proportion of each alternative option's route that is operating over existing or new alignment. As all the alternative options operate over less new infrastructure than Phase 2a, this means all the options provide less performance benefit than Phase 2a. More detailed analysis of the likely operating performance of the options is provided in section 3.5.

In order to allow comparison with the benefits, all costs are converted to a 2011 present value. This is also undertaken in the same way as the main HS2 appraisal, with the same assumptions made as Phase 2a for the profile of construction, renewal rates and discount rates.

3.3.1. Appraisal of the Full Y with Alternative Options

Table 3-6 shows the economic appraisal of the Full Y network with the alternative options. This assumes Phase One opens in 2026, the alternative option in 2027 and the rest of Phase Two in 2033. For the purpose of comparison, the HS2 Ltd assessment of the Full Y with Phase 2a is also shown.

[25] See separately published PLANET Framework Model (PFM V5.2) - Model Description Report

Table 3-6 Economic Appraisal of the Full Y Incorporating Phase 2a and the Alternative Options

£2011, 2011 PV	Full Y incorporating Phase 2a	Full Y incorporating the high cost option	Full Y incorporating the medium cost option	Full Y incorporating the low cost option
Transport User Benefits (Business)	£43.2bn	£42.3bn	£41.7bn	£41.0bn
Transport User Benefits (Other)	£18.2bn	£17.9bn	£17.8bn	£17.6bn
Other quantifiable benefits	£0.2bn	£0.2bn	£0.2bn	£0.2bn
Loss to Government of Indirect Taxes	-£3.0bn	-£3.0bn	-£2.9bn	-£2.9bn
Net Transport Benefits (PVB)	£58.6bn	£57.3bn	£56.7bn	£55.9bn
Wider Economic Impacts	£14.2bn	£14.0bn	£13.8bn	£13.7bn
Net Benefits including WEIs	£72.8bn	£71.3bn	£70.5bn	£69.5bn
Capital Costs	£39.0bn	£38.1bn	£37.8bn	£37.5bn
Operating Costs	£22.9bn	£22.8bn	£22.8bn	£22.8bn
Total Costs	£61.9bn	£60.9bn	£60.6bn	£60.2bn
Revenues	£33.1bn	£32.3bn	£31.8bn	£31.3bn
Net Costs to Government (PVC)	£28.8bn	£28.6bn	£28.8bn	£28.9bn
BCR without WEIs (ratio)	**2.0**	**2.0**	**2.0**	**1.9**
BCR with WEIs (ratio)	**2.5**	**2.5**	**2.4**	**2.4**
NPV without WEIs	**£29.7bn**	**£28.7bn**	**£27.9bn**	**£26.9bn**
NPV with WEIs	**£44.0bn**	**£42.7bn**	**£41.7bn**	**£40.6bn**

As expected given the journey times, when considered as part of the Full Y all of the alternative options provide lower benefits than Phase 2a. Of the alternative options, the high cost option provides the highest benefit, although they are around £1.5bn less than Phase 2a (including wider economic impacts), while the low cost option provides the lowest benefits which are around £3.3bn lower than Phase 2a (including wider economic impacts). The medium cost option provides benefits £2.3bn lower than Phase 2a (including wider economic impacts).

The alternatives also all provide lower revenues than Phase 2a, but in all cases this is more or less offset by lower costs. The result is that the net costs to Government are about the same as Phase 2a for all of the options.

The net impact is that the benefit cost ratios (BCRs) of the Full Y for all the options are broadly similar. The differential between these options is considered to be within the error margins of standard modelling and appraisal techniques. The BCR of the high cost option is the highest at 2.5, with the BCR of the medium and low cost options at 2.4 (including wider economic impacts).

With lower overall benefits, and similar net costs to Government, the Net Present Value (NPV)[26] of the Full Y network with any of the alternative options is lower than the Full Y network with HS2 Phase 2a. Of the alternative options, the high cost option, with the highest benefits, has the highest NPV, and the low cost option, with the lowest benefits, has the lowest NPV.

[26] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/427086/TAG_Unit_A1.1_-_Cost_Benefit_Analysis_November2014.pdf

3.3.2. Appraisal of the Alternative Options as a Standalone Scheme

An economic assessment has also been undertaken for the scenario in which the alternative options forms a permanent increment to Phase One.

Table 3-7 Economic Appraisal of the Alternative Options as an Increment to Phase One

£2011, 2011 PV	Incremental Phase 2a	Incremental high cost option	Incremental medium cost option	Incremental low cost option
Transport User Benefits (Business)	£1.5bn	£1.2bn	£0.9bn	£0.6bn
Transport User Benefits (Other)	£0.4bn	£0.3bn	£0.3bn	£0.2bn
Other quantifiable benefits	£0.0bn	£0.0bn	£0.0bn	£0.0bn
Loss to Government of Indirect Taxes	-£0.1bn	-£0.1bn	-£0.1bn	£0.0bn
Net Transport Benefits (PVB)	£1.9bn	£1.5bn	£1.1bn	£0.7bn
Wider Economic Impacts (WEIs)	£0.4bn	£0.3bn	£0.2bn	£0.1bn
Net Benefits including WEIs	£2.2bn	£1.7bn	£1.3bn	£0.9bn
Capital Costs	£2.7bn	£1.7bn	£1.4bn	£1.1bn
Operating Costs	£0.1bn	£0.1bn	£0.0bn	£0.0bn
Total Costs	£2.8bn	£1.8bn	£1.5bn	£1.1bn
Revenues	£1.4bn	£1.1bn	£0.9bn	£0.6bn
Net Costs to Government (PVC)	£1.4bn	£0.7bn	£0.6bn	£0.5bn
BCR without WEIs (ratio)	**1.3**	**2.2**	**1.8**	**1.5**
BCR with WEIs (ratio)	**1.6**	**2.6**	**2.2**	**1.8**
NPV without WEIs	**£0.4bn**	**£0.8bn**	**£0.5bn**	**£0.2bn**
NPV with WEIs	**£0.8bn**	**£1.1bn**	**£0.7bn**	**£0.4bn**

As expected the alternative options again have lower benefits of compared to Phase 2a, although the difference is much less than under the appraisal of the Full Y. The high cost option has £0.5bn less benefits than Phase 2a, the low cost option £1.4bn less, and the medium cost option £0.9bn less (including wider economic impacts). The decrease in benefits is lower under the incremental appraisal than when assessed as part of the Full Y for the following reasons:

- in the assumed train service specification, five high speed trains per hour operate under the incremental standalone scenario while ten operate under the Full Y. The number of services thus impacted by longer journey times in the alternative scenarios is much lower under the incremental assessment than under the Full Y assessment.
- the number of passengers travelling on the incremental network is much less than under the Full Y. This is a result of the lower service level and longer journey times to destinations such as Manchester and Scotland in the standalone scenario. The impact of having longer journey times on the alternative options therefore impacts fewer people in the incremental scenario.

Similarly, the reduction in revenue from Phase 2a is much smaller under the incremental scenario than under the Full Y scenario. With the same cost differential as between the alternatives and Phase 2a as under the Full Y, this means that under the incremental scenario the net costs to Government of the alternatives are all less than half of Phase 2a.

The result of a much smaller reduction of benefits and revenue is that when assessed as an increment to Phase One, the BCR of all the alternative options is higher than the BCR of Phase 2a. The high cost option provides a BCR of 2.6, followed by medium cost option with a BCR of 2.2 and the low cost option with a BCR of 1.8 (including wider economic impacts).

As a result of the much lower net costs to Government, when assessed incrementally as a standalone scheme, the Net Present Value (NPV) of the high cost option is higher than Phase 2a. Despite the lower net cost to Government, the NPV of the medium and low cost options are lower than Phase 2a due to their lower level of overall benefits.

It is worth noting that the incremental BCRs may not represent the full scale of benefits for Phase 2a or the alternative options, because the train service specification assumptions are based on the Phase One service pattern and have not been optimised for Phase 2a or the alternative options. In the hypothetical scenario where the remainder of Phase Two were not to be constructed, alternative train service specifications could provide greater benefits. The sensitivity of the BCRs to alternative service patterns has not been tested.

3.3.3. Sensitivity Testing

The impact on the BCR of applying different journey times or costs has been tested to understand the sensitivity of the BCR to key assumptions.

If it is possible to operate HS2 services on straight sections of the classic network at 125mph (as discussed in section 3.2), then the impact on journey times for all options would be to save around 45 seconds to 1 minute of journey time. The impact of this on the appraisal of the alternative options has been tested by dividing the change in benefits and revenue of each option from Phase 2a, with the change in journey time from Phase 2a, to provide an approximate impact of a minute's journey time saving[27] on both the Full Y and incremental scenarios. Using this approach, the impact on the Full Y is to increase benefits by between approximately £400m and £600m, and revenues by between £200m and £300m (including wider economic impacts). This would increase the BCR by 0.05 for the high cost option, and 0.03 for the low and medium cost options (including wider economic impacts). The NPV would increase by between £600 and £900m to £43.6bn for the high cost option, £41.2bn for the medium cost option, and £42.4bn for the low cost option (including wider economic impacts). This would not change the conclusions in section 3.3.1 above.

The impact of an additional minute's journey time saving on the incremental appraisal would be greater; benefits increase by between £170m and £190m (including wider economic impacts), and revenue by £90m to £100m. As under the incremental appraisal these represent a much greater proportion of the overall benefits and revenues, the BCR increases by 0.8 for the high cost option, 0.7 for the medium cost option and 0.9 for the low cost option (including wider economic impacts). The NPV would increase by £300m to £1.4bn for the high cost option, £1.0bn for the medium cost option, and £0.6bn for the low cost option (including wider economic impacts).

If capital costs were to decrease by £100m, such as might be possible with less conservative unit rates or optimism bias, then this would improve the appraisal of all the alternative options with the Full Y by 0.01. Again, however, the impact on the incremental appraisal is much larger, as £100m is a much greater proportion of the net costs. The BCR of the high and medium cost options would increase by 0.4 and the low cost option by 0.5 (including wider economic impacts). In both cases the NPV increases by £100m. Conversely if costs were to rise by £100m, for example to accommodate a grade separated junction, this would impact the appraisal of the alternative option by reducing the BCR.

3.4. Route Capacity

The impact of each option on the overall route capacity has been undertaken by a high level assessment of how many trains per hour operate on key sections of the WCML for each option under the proposed HS2 service pattern. By comparing this against the capacity of those route sections, it can be determined whether the alternative option is likely to be able to accommodate the currently proposed HS2 trains service specification (TSS), as well as how much remaining capacity might be available for running additional HS2, classic or freight services beyond the currently proposed TSS in the future.

All of the alternative options are capable of operating the currently proposed Full Y HS2 service pattern using 400m trainsets. The sections of the WCML used by the alternative options already operate freight trains longer than 400m, and are therefore capable of supporting 400m hybrid HS2 train without any additional

[27] Were this sensitivity to be run through the PLANET model, the results of this sensitivity might be different due to non-linear responses within the demand model to journey time changes.

investment. As hybrid and captive train services are expected to have the same seating capacities, the number of seats available under the alternative options is therefore the same as is available under Phase 2a. As a result, an assessment of seated capacity has not been undertaken.

Instead, each option is described in terms of the number of passenger or freight train paths that are required to support the currently proposed Full Y service pattern for running both HS2 and residual classic line services, alongside a discussion of the route capacity.

3.4.1. Current Route Capacity of the WCML between Crewe and Handsacre

As described in Chapter 2, the current capacity of the WCML has been determined from the current train planning headways in Network Rail's Timetable Planning Rules. These show that both the fast and slow lines have 3 minute planning headways which would imply a maximum theoretical capacity of 20 trains per hour (tph). In practice the actual number of services that can operate a robust timetable will be less than that provided for by the timetable headways, in order to account for junction conflicts and margins, signal placing and margins, the mix of different types of services (inter-city, commuter and freight) and their different operating characteristics and speeds, the need to provide a contingency margin to maintain operational resilience, the design of the timetable, and the desire to operate regular service patterns.

Within the minimum headways, the maximum number of trains that can robustly operate over a particular route section therefore varies according to the type of route and kinds of trains operating over it. For these reasons, in the most part, the Train Planning Rules do not provide any advice on a maximum level of capacity a route section can support other than providing minimum headways.

There are currently sections of the WCML south of Rugby with 3 minute headways that are operating 15 fast passenger trains per hour during the peaks, which is one of the highest train frequencies operating on a mixed use intercity route in Europe. 15 trains per hour can therefore be considered a practical maximum level of capacity for a mixed use intercity railway, such as between Handsacre and Crewe, signalled with conventional technology for 3 minute headways.

For the route section between Stafford and Crewe, despite having 3 minute headways, the Train Planning Rules specifically limits capacity to 13 trains per hour. It is unclear whether this applies to the fast or slow lines, or both the fast and slow lines, although historically it has been assumed to apply to the fast line. It is also unclear why the Train Planning Rules unusually have this particular restriction between Stafford and Crewe, as the sections both north and south have no such restriction. Atkins' view is that this restriction reflects the concern to ensure that trains of different types can still operate with sufficient punctuality and reliability through Stafford and Norton Bridge Junction.

3.4.2. 2027 and 2033 Proposed Train Service Specification

3.4.2.1. High Speed 2 Services

The proposed train service specification (TSS) for HS2 services as currently designed by HS2 Ltd[28] proposes running 7 HS2 services per hour on the WCML between Handsacre Junction and Crewe in 2026. When Phase 2a opens in 2027, 5 of these services would transfer onto the Phase 2a infrastructure, one would remain on the WCML via Stafford and Crewe and one would remain on the WCML via Stoke. In 2033, with the opening of the Full Y network north of Crewe the number of HS2 trains operating on Phase 2a infrastructure would increase to 10 trains per hour.

3.4.2.2. Residual and HS2 Passenger Services operating on the WCML

Table 3-8 shows the indicative train service specification for HS2 and residual passenger services operating on the WCML between Crewe and Norton Bridge, as used by HS2 Ltd for the purposes of economic modelling in both 2027 under Phase 2a and 2033 under the Full Y. Although the indicative TSS is slightly different in 2027 and 2033, under both scenarios there is one HS2 service per hour that joins the WCML at Handsacre and reaches Liverpool by way of Stafford and Crewe. There are also 5 residual classic passenger services per hour off-peak and 7 per hour in the peak. As there are no intermediate stations between Stafford and Crewe, these would mainly be expected to operate on the fast lines, leaving the slow lines available for freight.

Table 3-8 Proposed 2027 and 2033 TSS operating between Norton Bridge and Crewe

[28] See separately published Assumptions report: PLANET Framework Model Version 5.2

Off Peak	Notes
Euston – Liverpool	HS2 service using the HS2 Phase One alignment between Euston and Handsacre and the existing WCML via Crewe north of Handsacre
Euston – Chester	Residual service operating on the WCML via Stafford and Crewe
Birmingham – Liverpool	Residual service operating on the WCML via Stafford and Crewe
Birmingham – Liverpool	Residual service operating on the WCML via Stafford and Crewe
Birmingham – Scotland (2026 to 2033 only)	Residual service operating on the WCML via Crewe
Birmingham – Preston (from 2033 only)	Residual service operating on the WCML via Stafford and Crewe
Bournemouth – Manchester	Additional cross-country service via East West Rail and the Trent Valley
Additional Peak	
Euston – Crewe	Residual service operating on the WCML via Crewe
Birmingham – Crewe	Residual service operating on the WCML via Stafford and Crewe

Table 3-9 shows the residual service pattern currently proposed by HS2 Ltd for the operation of classic line services on the WCML infrastructure between Colwich and Handsacre junctions. The indicative TSS is slightly different in 2027 and 2033, in 2027 6 passenger services per hour would operate off-peak and 8 per hour during the peak. In 2033 this would go down to 5 per hour off peak and 7 per hour in the peak. These residual classic services would operate on both the fast and slow lines, to serve the intermediate station at Rugeley, with the slow lines also supporting freight services.

Table 3-9 Proposed 2027 and 2033 TSS operating between Handsacre and Colwich Junctions

Off Peak	Notes
Euston – Manchester (2027 – 2033 only)	HS2 service using the HS2 Phase One alignment between Euston and Handsacre and the existing WCML via Stoke north of Handsacre
Euston – Liverpool	HS2 service using the HS2 Phase One alignment between Euston and Handsacre and the existing WCML via Crewe north of Handsacre
Euston – Chester	Residual service operating on the WCML via Crewe
Euston – Crewe	Residual service operating on the WCML via Stafford and Stoke
Euston – Scotland	Additional service operating on the WCML via Stoke and Manchester
Bournemouth – Manchester	Additional cross-country service via East West Rail and the Trent Valley
Additional Peak	
Euston – Crewe	Residual service operating on the WCML via Crewe
Euston – Manchester	Residual service operating on the WCML via Stoke

Table 3-10 shows the residual service pattern currently proposed by HS2 Ltd for the operation of classic line services operating on the WCML branch between Colwich and Stone junctions. Under the Full Y this section of railway would operate with 1 service per hour off peak and 2 per hour in the peaks. This section of the WCML is a two track railway.

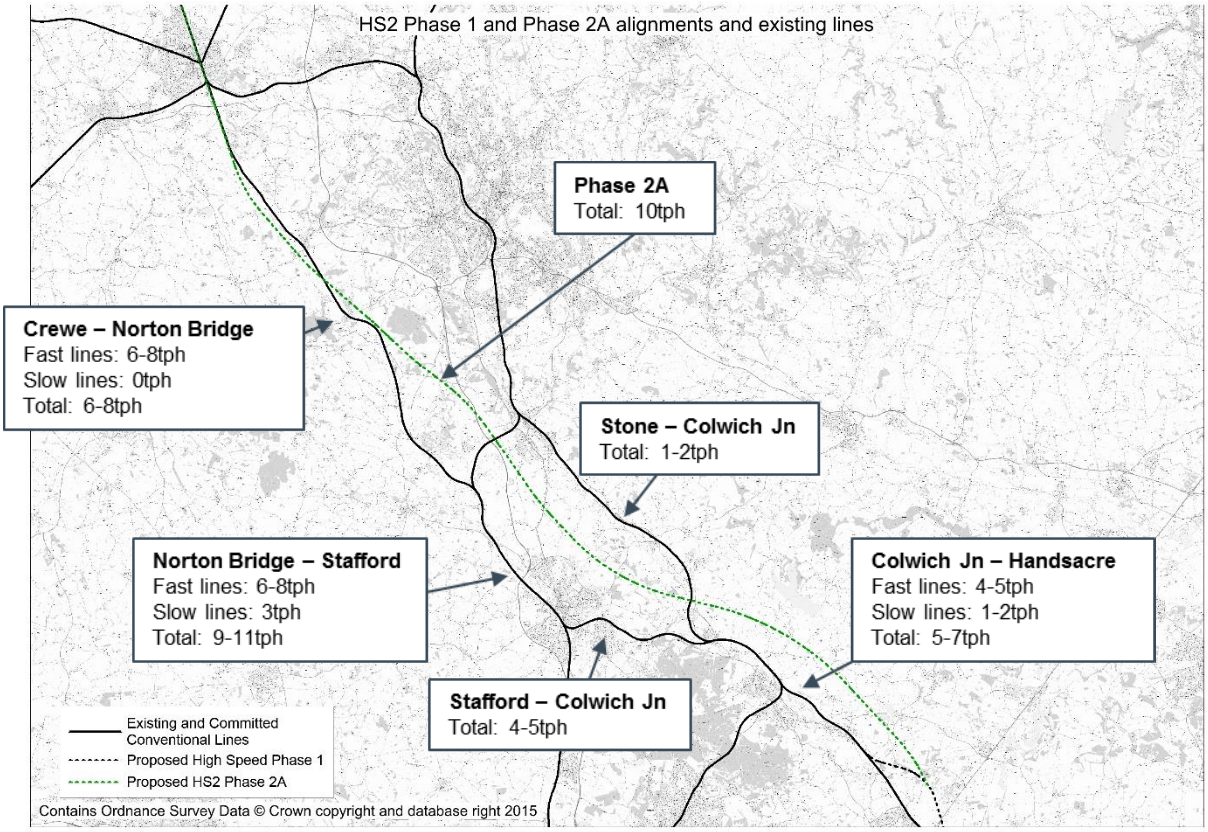
Table 3-10 Proposed 2027 and 2033 TSS operating between Colwich and Stone Junctions

Off Peak	Notes
Euston – Manchester (2027 – 2033 only)	HS2 service using HS2 Phase One alignment between Euston and Handsacre and the existing WCML via Stoke north of Handsacre (2027 – 2033 only)
Euston – Scotland	Additional service operating on the WCML via Stoke and Manchester
Additional Peak	

Off Peak	Notes
Euston – Manchester	Residual service operating on the WCML via Stoke

Figure 3-1 summarises the number of passenger services operating on each section of the WCML between Crewe and Handsacre under the proposed HS2 Phase Two TSS.

Figure 3-1 Proposed HS2 and Residual TSS (2033): passenger services per hour



3.4.2.3. WCML Freight Services

In addition to accommodating the indicative passenger TSS described above, the WCML will also need to accommodate future freight services. The number of paths reserved for freight on the WCML currently varies across the day. Analysis of the current working timetable (WTT) shows that a maximum of 4 timetabled freight paths per hour are timetabled between Crewe and Stafford, and up to 2 freight paths between Stafford and Handsacre. Between Colwich and Stone there are typically no freight trains, with almost all freight services running via Stafford and Norton Bridge. The number of freight paths timetabled is not constant across the day and typically halves during the peaks.

Of the available paths reserved for freight services, only a proportion are typically used on any one day. This flexibility is required by the freight operators to be able to respond to different market conditions and the requirements of their customers across different times of the day, week or year.

For the purpose of this analysis, it is assumed that 4 freight train per hour will operate across the whole day between Stafford and Crewe. It is expected that, as today, freight would not normally be routed via the Colwich to Stone line.

This assumption offers an increase in freight capacity over that available today because it assumes a higher number of overall paths. Some further growth could also be accommodated by increasing the utilisation of the paths which are provided in the timetable.

3.4.2.4. Overall Route Capacity with Phase 2a for HS2, Residual and Freight Services

On the basis of the assumptions described above, the proposed utilisation of the WCML in 2033 for residual passenger, freight and HS2 services is shown in the table below.

Table 3-11 Route Capacity in 2033 with Phase 2a

Route Section	Fast Line Passenger Trains	Slow Line Passenger Trains	Freight Trains	Total number of trains	Potentially available paths[29]
Phase 2a (2 track)	10 (10 peak)	N/A	0	10	6-8
WCML Crewe-Norton Bridge (4 track)	6 (8 peak)	0	4	10 (12 peak)	14-20
WCML Norton Bridge-Stafford (4 track)	6 (8 peak)	3 (3 peak)	4	13 (15 peak)	11-17
WCML Stafford-Colwich (sections of 2 and 4 track)	4 (5 peak)	N/A	4	8 (9 peak)	4-7
WCML Rugeley-Handsacre (4 track)	4 (5 peak)	1 (2 peak)	4	9 (11 peak)	15-21
WCML Stone-Colwich (2 track)	1 (2 peak)	N/A	0	1 (2 peak)	11-14

Theoretically the Phase 2a alignment could support 16 to 18 trains per hour, although in practice the actual number of services that can run on Phase 2a infrastructure will be limited to the south by the capacity of HS2 Phase One and the platform capacity of Birmingham Stations, and to the north by the platform capacity of Manchester Station and northern parts of the classic network.

With Phase 2a, most sections of the WCML between Handsacre and Crewe are operating at about half of their theoretical maximum capacity, and could therefore support approximately twice the number of residual or freight services as proposed in the indicative TSS described above. The 2-track section of the WCML between Colwich and Stafford has less spare capacity, although in theory the number of services can still be increased by 50%. In practice capacity constraints elsewhere on the network will limit the ability to run this quantum of additional services, but as noted in Section 3.5 the operational performance of the railway is likely to be better when running at fewer services than the maximum available capacity.

3.4.3. Route Capacity with the High Cost Option

If the high cost alternative option were to be built, the WCML between Baldwin's Gate and Crewe would have to accommodate 5 HS2 trains per hour from 2027 that would otherwise have used the Phase 2a infrastructure. This is the same number of services that this section of the WCML will be accommodating in 2026 prior to the opening of Phase 2a or the alternative option in 2027.

In 2033, following the opening of the Full Y incorporating the high cost option as an alternative to Phase 2a, a further 5 HS2 trains per hour will also operate. This section of WCML track would therefore need to accommodate a total of 10 HS2 services per hour that would otherwise have travelled on Phase 2a.

As outlined in the section above, there will also be another high speed service operating on the WCML between Norton Bridge and Crewe that joins the WCML north of Handsacre to serve Stafford, as well as 5 off-peak and 7 peak classic line residual services. It will also have to support freight services, anticipated to be 4 trains per hour across the day. In total this means there are 11 HS2 services, 5 off-peak and 7 peak classic line residual passenger services and up to 4 freight trains per hour.

As outlined in Chapter 2, Atkins' recommendation for the design of this option would be to run HS2 services on the fast lines, and the remaining residual and freight services on the slow lines. Such an arrangement

[29] This is calculated on the basis that there are 13-15 paths per hour available on all route sections. The actual ability to use these paths will depend on the type of services and their performance characteristics, the timetable and stopping patterns.

would mean that in 2033 a total of 11 high speed services per hour would be operating exclusively on the fast lines between Baldwin's Gate and Crewe. This would mean that under the 13 train per hour capacity limit imposed by the current Timetable Planning Rules, an additional 2 trains per hour would be able to operate. However, Atkins would expect this section to be able to operate robustly with 15 trains per hour given the relatively short distance involved, the lack of stations, junctions or conflicting moves, and the fact that trains will all have the same speed and acceleration profiles. This would mean that in total up to 4 additional high speed services per hour could operate on the fast lines above the level indicated in the proposed 2033 TSS.

The slow lines would be required to operate the remaining residual passenger service of 5 off-peak and 7 peak trains per hour as well as freight services assumed to be 4 trains per hour across the day. Assuming a maximum capacity of 13 trains per hour from the Timetable Planning Rules this would allow a further 4 residual passenger or freight trains per hour to run during the off-peak and 2 trains per hour in the peak, although this would be dependent amongst other things on the differential speed profiles of any additional passenger or freight services operating. If the slow lines could support 15 trains per hour, then two further trains per hour above this level could operate although it should be noted that operating such an intense timetable across the whole day would be expected to impact operational performance.

It might also be possible to create additional capacity on the slow lines between Baldwin's Gate and Crewe by diverting some passenger or freight services via other routes, such as Stafford to Stoke via Norton Bridge, or Colwich Junction to Stoke.

In summary, the high cost option can support the Full Y TSS proposed in 2033, as well as 4 freight trains per hour. Above this there is the potential to allow the operation of between 4 and 10 additional services per hour depending on the time of day and whether the fast and slow lines route section could operate 13 or 15 trains per hour. It is also dependent on the different operating characteristics of any additional services and the timetable that is being operated. As noted in section 3.5, operating a timetable for long periods at such high levels of utilisation are likely to have implications on the operational performance of the railway.

Table 3-12 Route Capacity in 2033 with High Cost Option

Route Section	Fast Line Passenger Trains	Slow Line Passenger Trains	Freight Trains	Total number of trains	Potentially available paths[30]
WCML Crewe-Norton Bridge (4 track)	11 (11 peak)	5 (7 peak)	4	20 (22 peak)	4-10
WCML Norton Bridge-Stafford (4 track)	6 (8 peak)	3 (3 peak)	4	13 (15 peak)	11-17
WCML Stafford-Colwich (sections of 2 and 4 track)	4 (5 peak)	N/A	4	8 (9 peak)	4-7
WCML Rugeley-Handsacre (4 track)	4 (5 peak)	1 (2 peak)	4	9 (11 peak)	15-21
WCML Stone-Colwich (2 track)	1 (2 peak)	N/A	0	1 (2 peak)	11-14

3.4.4. Route Capacity with the Medium Cost Option

The medium cost option utilises two sections of the WCML: from Norton Bridge to Crewe and from Sandon to Hixon on the Colwich to Stone line. The number of services and available capacity on the fast and slow lines between Norton Bridge and Crewe would be exactly the same as that between Baldwin's Gate and Crewe, as presented under the high cost option.

The medium cost option is also required to operate on part of the 2-track section of the WCML between Colwich and Stone. This option proposes upgrading this part of the route to 140mph. At the same time, the

[30] This is calculated on the basis that there are 13-15 paths per hour available on all route sections. The actual ability to use these paths will depend on the type of services and their performance characteristics, the timetable and stopping patterns.

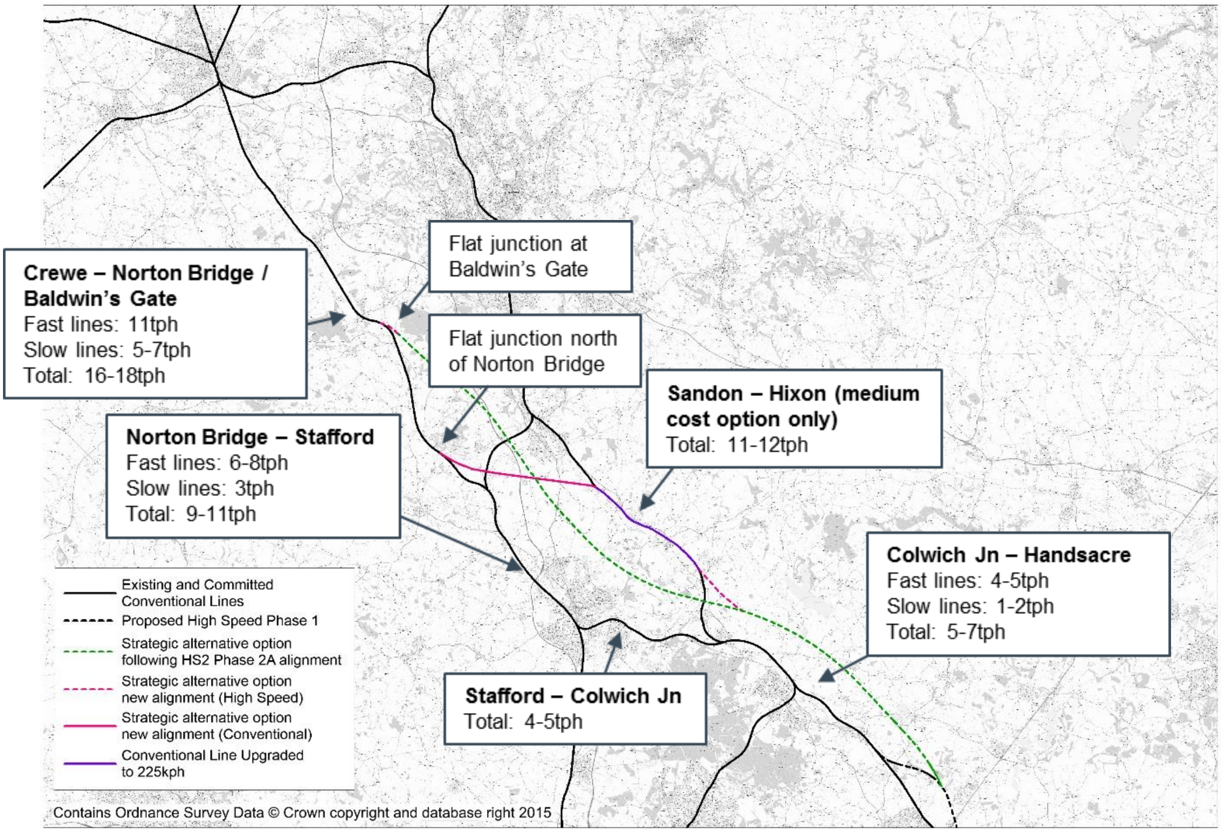
option proposes upgrading the signalling to allow 3 minute headways. This section would need to accommodate 11 services per hour off-peak and 12 in the peaks. This would allow up to 4 additional fast residual services or high speed services to operate, assuming a maximum capacity of 15 trains per hour. There are currently no freight trains typically timetabled between Colwich and Stone as they generally run via Stafford and Norton Bridge instead.

Table 3-13 Route Capacity in 2033 with Medium Cost Option

Route Section	Fast Line Passenger Trains	Slow Line Passenger Trains	Freight Trains	Total number of trains	Potentially available paths[30]
WCML Crewe-Norton Bridge (4 track)	11 (11 peak)	5 (7 peak)	4	20 (22 peak)	4-10
WCML Norton Bridge-Stafford (4 track)	6 (8 peak)	3 (3 peak)	4	13 (15 peak)	11-17
WCML Stafford-Colwich (sections of 2 and 4 track)	4 (5 peak)	N/A	4	8 (9 peak)	4-7
WCML Rugeley-Handsacre (4 track)	4 (5 peak)	1 (2 peak)	4	9 (11 peak)	15-21
WCML Stone-Colwich (2 track)	11 (12 peak)	N/A	0	11 (12 peak)	1-4

A summary of the number of passenger trains operating under the Full Y with the high and medium cost alternative option is shown in Figure 3-2 below.

Figure 3-2 High and medium cost alternative options (HS2 Phase Two TSS): services per hour



3.4.5. Route Capacity with the Low Cost Option

In addition to operating on the same sections of the WCML as the medium cost option, the low cost option would also operate on the WCML between Handsacre Junction and a new junction at Rugeley. This route section would therefore have to accommodate 10 HS2 services in addition to the residual passenger and freight services.

This would require the fast lines to operate with 14 trains per hour off peak and 15 trains per hour peak, while the slow lines would operate one residual train service to Euston calling at Rugeley per hour off-peak, and two residual trains per hour in the peak. It might be possible to switch non-stopping services to the slow lines without an adverse impact on journey times but due to the presence of stopping services calling at Rugeley, this would be subject to precise pathing.

As a result, while there would be spare capacity on the slow lines to operate additional residual passenger or freight services, the fast lines would be operating at close to capacity. Not only does this mean that there is limited opportunity to run additional HS2 or non-stop residual services, there would also be likely to be an impact on operational performance.

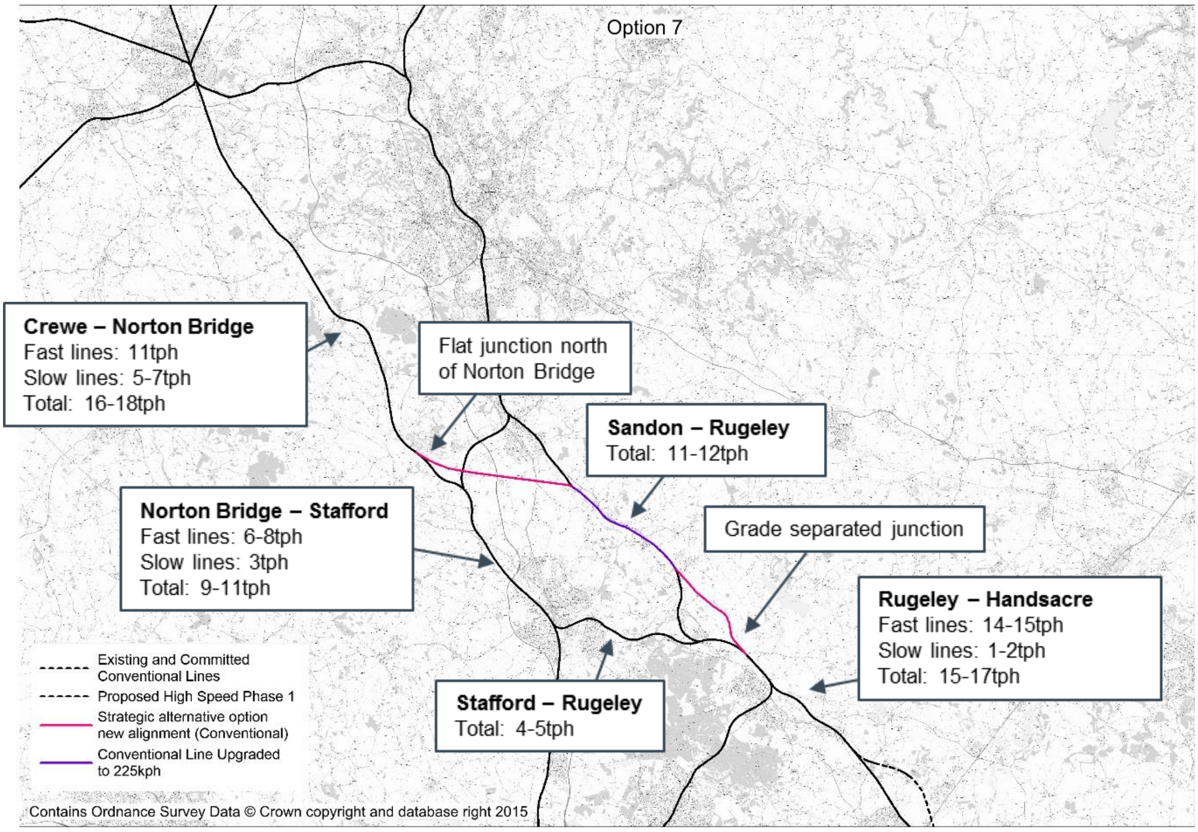
Table 3-14 and Figure 3-3 below summarise the number of trains operating on the WCML in the low cost option.

Table 3-14 Route Capacity in 2033 with Low Cost Option

Route Section	Fast Line Passenger Trains	Slow Line Passenger Trains	Freight Trains	Total number of trains	Potentially available paths[31]
WCML Crewe-Norton Bridge (4 track)	11 (11 peak)	5 (7 peak)	4	20 (22 peak)	4-10
WCML Norton Bridge-Stafford (4 track)	6 (8 peak)	3 (3 peak)	4	13 (15 peak)	11-17
WCML Stafford-Colwich (sections of 2 and 4 track)	4 (5 peak)	N/A	4	8 (9 peak)	4-7
WCML Rugeley-Handsacre (4 track)	14 (15 peak)	1 (2 peak)	4	19 (21 peak)	5-11
WCML Stone-Colwich (2 track)	11 (12 peak)	N/A	0	11 (12 peak)	1-4

[31] This is calculated on the basis that there are 13-15 paths per hour available on all route sections. The actual ability to use these paths will depend on the type of services and their performance characteristics, the timetable and stopping patterns.

Figure 3-3 Low cost alternative option (HS2 Phase Two TSS): services per hour



3.5. Operational Performance

The operational performance or reliability implications of the alternative options has been assessed against Phase 2a. Due to the early stage of the scheme design and the lack of a detailed high speed timetable, it has not been possible to undertake detailed performance modelling using specialist models. Instead a high level qualitative assessment of the performance options has been undertaken, with particular reference to the utilisation and capacity of key sections of line or junctions as described in the previous sections.

As described in section 3.3, the economic appraisal of the alternative options has included an assessment of the performance benefits for all the options. This high level estimate did not take into account the specific features of each route that might impact performance, and was instead obtained by adjusting the HS2 Phase 2a performance benefits according to the length of new alignment in each option.

3.5.1. High Cost Option

Atkins' recommended design for the high cost option involves running HS2 services on the WCML fast lines between Baldwin's Gate and Crewe, and running all remaining services on the slow lines. Such an arrangement would provide a two track railway used exclusively by HS2 services all the way from Streethay Junction to Crewe, which would be operating at well below its maximum capacity.

As with Phase 2a, such a configuration would mean that under normal operation high speed services are entirely segregated from the classic line services, and there would therefore be no opportunity for delays on the classic network to impact HS2 services or vice versa.

The high cost option requires running on 18km of the existing WCML infrastructure. The historic nature of this infrastructure means the track, power supply and signalling could be less reliable than new infrastructure built to modern standards. However, the long term reliability of this section of infrastructure compared to new infrastructure over a 60 year appraisal period is difficult to assess and would be highly dependent on the long term renewals and maintenance polices, which themselves are related to issues around ownership and accountability outside of the remit of this work.

With appropriate maintenance, Atkins do not consider the impact of running for 18km on the WCML to provide significant performance disbenefits to Phase 2a. Nevertheless the appraisal of the high cost option presented in section 3.3 adjusts the performance benefits of Phase 2a in proportion to the distance travelled on the existing network.

Between 2027 and 2033, the high cost option could offer some performance benefits to Phase 2a in respect to the way it connects the high speed alignment directly into the fast lines of the WCML well south of Crewe, whereas Phase 2a connects to the slow lines at Crewe. Having a connection to the WCML fast lines could avoid the need for high speed trains towards Manchester to cross the whole of the WCML at Crewe. From 2033 with the opening of the Full Y, Crewe is removed as an operational constraint on high speed services, and the performance benefits of joining the fast lines south of Crewe no longer apply.

Although Atkins consider that under normal operation the performance of high speed services under the high cost option is likely to be very similar to Phase 2a, the performance for the remaining classic line residual services operating on the slow lines is likely to be worse than under Phase 2a. With a mix of different passenger and freight services, the slow lines would be operating at close to the route capacity. This is likely to result in the residual services suffering a lower operational performance than will be the case under Phase 2a, where the same number of services would be able to operate over both the fast and slow lines.

Compared to Phase 2a, the option also offers less overall network resilience during periods of major disruption or maintenance, as a result of there being fewer alternative routes to divert services onto.

3.5.2. Medium Cost Option

The medium cost option would make use of the existing WCML infrastructure between Norton Bridge and Crewe and between Hixon and Sandon. It would also use new 140mph conventional infrastructure rather than new high speed line.

The impact on performance of using the WCML between Norton Bridge and Crewe is expected to be similar to the high cost option as described above. However, between Hixon and Sandon on the WCML, HS2 services would have to interact with one or two residual services per hour over 6km of two track of railway. There would also be a small number of conflicts as high speed services join and leave the WCML at the flat junctions near Hixon and Sandon. Both of these factors are likely to adversely impact on performance, and as a result the medium cost option is likely to require careful timetabling of services to ensure robust operation.

In total the medium cost option operates for 33km on existing WCML infrastructure. As described in section 3.5.1 the long term reliability of this infrastructure comparted to Phase 2a is difficult to assess, and highly dependent on the maintenance and renewals regime, although by itself this would not be expected to have a significant impact on performance. The long term reliability of new 140mph infrastructure is also expected to be similar to that offered by new high speed alignment.

In summary, as a result of having to operate HS2 and residual services on a two track section of the existing railway between Hixon and Sandon, the medium cost option is unlikely to offer the same level of performance as the high cost option or Phase 2a, either for HS2 trains or residual classic line trains. In particular, unlike the high cost option and Phase 2a, delays on some classic services could impact HS2 services and vice versa. It also offers less network resilience in times of major disruptions by reducing the number of alternative routes.

3.5.3. Low Cost Option

In addition to the reliability impact resulting from the interfaces described in the medium cost option, the low cost option would also be required to interface with the existing WCML between Handsacre and Rugeley, as well as operate for longer distances on the existing WCML infrastructure. Between Handsacre and Rugeley the fast lines would be operating both HS2 and residual services, and operating at close to their maximum capacity of the line. This would make maintaining performance on this line section more challenging, and for this reason, the low cost option is therefore likely to offer lower operational performance than both the high and medium cost options

3.6. Impact of Construction

Proportional to the early stage of development of these alternative options, Atkins have undertaken a high level assessment of the impact that constructing the options might have on existing WCML operators. At this early stage of design, it is very difficult to know what the level of disruption will be, with any certainty, although it will be closely linked to the number and type of interfaces each option has with the existing WCML network.

3.6.1. High Cost Option

The high cost option's only interface with an existing railway would be a single flat junction onto the WCML fast lines near Baldwin's Gate. The construction of the flat junction onto the fast lines (which are to the east of the formation) at this location is likely to cause less disruption to existing services than the construction of a Phase 2a's grade separated junction over the fast lines onto the slow lines at Crewe.

3.6.2. Medium Cost Option

The construction of the medium cost option requires some upgrading of a live railway between Hixon and Sandon, and the construction of three flat junctions.

Upgrading the Stone line to 140mph running may cause some disruption, although as shown in Table 3-10 (which equally applies to operations in 2026), the number of services operating on this route is expected to be 2tph. Atkins' assessment is that these could potentially be diverted onto other routes, and on this basis, the construction of flat junctions at Hixon and Sandon would therefore not expected to cause significant disruption. Atkins also expects the disruption caused by the construction of a flat junction at Norton Bridge to be limited, although Network Rail have noted that further work is needed to substantiate this assessment. As with the junction at Baldwin's Gate under the high cost option, the construction of a flat junction would not be expected to cause as much disruption as a grade separated junction, and it is likely that services could be diverted to the slow lines during its construction.

3.6.3. Low Cost Option

The construction of the low cost option is likely to have similar impact to the medium cost option for upgrading the railway between Hixon and Sandon and constructing three flat junctions. However, the low cost option would also require construction of a grade separated junction at Rugeley. The construction of such a junction could cause significant disruption with major new construction to be undertaken close to a live railway, and limited opportunity to divert services to alternative routes.

3.7. Environmental Assessment

A high level environmental assessment has been undertaken for each of the alternative options. The assessment has only considered the environmental impact of new alignment that is not part of the Phase 2a route, as the environmental impact of Phase 2a alignment has been separately assessed by HS2 Ltd. The methodology used to assess the potential environmental impact of the alternative options is high level, and is not the same as the approach taken by HS2 Ltd in its assessment of Phase 2a.

If these alternative options were to progress then further analysis would need to be done to understand the impact of environmental impact, and whether any environmental mitigations would be needed.

3.7.1. High Cost Option

The high cost option would use the Phase 2a infrastructure as far as Baldwin's Gate, where a new 1.4km spur is constructed to re-join the WCML. The high level environmental assessment of the spur has identified the following potential environmental issue:

- loss of woodland and ecology in Meece valley, and visual and noise impact due to proximity to hamlet of Shelton-under-Harley.

3.7.2. Medium Cost Option

The medium cost option would utilise a section of the Phase 2a infrastructure, part of the existing WCML branch from Hixon to Sandon, and the north section of the Stafford bypass scheme, with a short section of additional alignment near Hixon. For the route sections away from the Phase 2a alignment, the high level environmental assessment revealed the following potential environmental impacts:

- visual and noise impacts in the Hixon area with some property demolition likely;
- visual impact of new bridge over Trent and Mersey canal and river near Sandon, and proximity to listed buildings;

- crosses golf course driving range; and
- junction with WCML near to Meece Brook.
- the proposed alignment would run approximately 1km to the north of the Pasturefields Salt Marsh Special Area of Conservation (SAC) and Site of Special Scientific Interest (SSSI). Although this was considered some time ago as part of the West Coast Route Modernisation, more recent work by HS2 Ltd with the Environment Agency and Natural England showed that effects on the SAC could not be ruled out due to complex hydrological issues. This has led HS2 Ltd to reject potential routes in this area in advice to Government because of the high risk associated with ensuring compliance with the Habitats Directive. If this alternative option was to be considered further, more analysis would be needed to understand the detailed impacts of the proposed alternative alignment, whether those were acceptable or what mitigations would be needed. Any solution would need to be consistent with the Habitats Directive and European Regulations.

3.7.3. Low Cost Option

The low cost option would replicate the Stafford bypass scheme alignment which was developed and assessed as part of the WCML upgrade. The high level environmental assessment of the new sections of alignment near Colwich and north of Stafford has revealed the following environmental impacts:

- visual and noise impact of the grade separated junction near Rugeley and Colton, proximity to Cannock Chase, and possible requirement to realign overhead electricity wires north of Colwich;
- visual and noise impacts in the Hixon area with some property demolition likely;
- visual impact of new bridge over Trent and Mersey canal and river near Sandon, and proximity to listed buildings;
- crosses golf course driving range; and
- junction with WCML near to Meece Brook.
- the proposed alignment runs approximately 1km to the north of the Pasturefields Salt Marsh Special Area of Conservation (SAC) and Site of Special Scientific Interest (SSSI). Although this was considered some time ago as part of the West Coast Route Modernisation, more recent work by HS2 Ltd with the Environment Agency and Natural England showed that effects on the SAC could not be ruled out due to complex hydrological issues. This has led HS2 Ltd to reject potential routes in this area in advice to Government because of the high risk associated with ensuring compliance with the Habitats Directive. If this alternative option was to be considered further, more analysis would be needed to understand the detailed impacts of the proposed alternative alignment, whether those were acceptable or what mitigations would be needed. Any solution would need to be consistent with the Habitats Directive and European Regulations.

4. Conclusions

All three of the shortlisted alternative options provide an operable alternative to Phase 2a, either as a standalone scheme or as part of the Full Y network.

The alternative options save between £1.1bn and £1.8bn (2011 prices) in their capital costs of construction compared to Phase 2a, but they do not provide the same level of journey time improvements. This means their economic benefits and revenues are lower than Phase 2a.

When assessed as part of the Full Y, the alternative options have broadly similar BCR's to Phase 2a. The alternative options deliver between £1.5bn and £3.3bn (2011, PV) less benefits than Phase 2a, while the net costs to Government range from a being £200m lower to £100m (2011, PV) higher. The result is that all the options have marginally lower BCRs compared to Phase 2a. The Net Present Value (NPV) for the Full Y with any of the options is lower than the NPV for the Full Y with Phase 2a.

When assessed as a standalone incremental scheme, the difference in benefits and revenues between the alternative options and Phase 2a is much lower. The result is that all the options have a higher BCR than Phase 2a, although only the high cost option has a higher NPV.

All the alternative options provide sufficient capacity to allow the full operation of the indicative train service specification proposed for the Full Y scenarios. Beyond this indicative train service specification, all of the options provide some spare capacity to run additional HS2, residual or freight services, although this varies between options. None of the options provide the same overall capacity as Phase 2a, which together with the WCML effectively provides a six track railway between the end of Phase One and Crewe. This inevitably provides more capacity than the alternative options which to different degrees all have sections with four tracks. As well as allowing more easily for future growth, this much greater amount of potential additional capacity available with Phase 2a, is also likely to provide performance and resilience benefits compared to the alternative options.

Construction of the high cost option is not expected to cause more disruption than the construction of Phase 2a. Construction of the medium and low cost options will cause greater disruption, although given the lightly used nature of the lines being upgraded this is not expected to impact a large number of services. A high level assessment of the environmental impact suggests that the high cost option is likely to have a lower environmental impact that than Phase 2a. The low and medium cost options have some environmental risks in respect of the Pasturefields Special Area of Conservation as discussed in section 3.7 above.

Of the three alternative options developed in this study, the high cost option offers the closest capacity and journey times to Phase 2a. Despite being the most expensive of the alternative options, it offers the greatest benefits and returns the highest BCR of the options, both when it is assessed as part of the Full Y and when it is assessed as a standalone scheme. Its construction cost is £1.1bn less than Phase 2a, while its journey time is 2.5 minutes slower than Phase 2a.

If HS2 services are able to operate on straight sections of the WCML between Baldwin's Gate and Crewe at enhanced permissible speed of 125mph, then there is the potential for this journey time differential to Phase 2a be reduced to around 2 minutes. This would increase the benefits and revenues of this option, and given that trains are already currently operating at that speed on those sections would not be expected to require significant investment. To increase the line speeds to 140mph is likely to require much greater level of investment (with additional costs) but would also offer even greater time savings and benefits.

The key capacity constraint for all the alternative options are the sections that involve running on the existing WCML. For the high cost option, this is requires using around 18km of the existing WCML route between Baldwin's Gate and Crewe. This section of route needs to operate the proposed 11 HS2 services, 5-7 residual classic line services and what is assumed to be 4 freight trains per hour. Operating on a 4 track railway, the high cost option has the spare capacity to run around 5 additional HS2 services on the fast lines above the level currently proposed in the Full Y HS2 train service specification. The slow lines, however, will be operating at close to maximum capacity during the peaks, and the ability to operate additional residual or freight trains is more limited.

The operational performance of high speed services using the high cost option is likely to be similar to Phase 2a, as allowing the fast lines to be used exclusively by HS2 services would remove any conflicts or interface with residual WCML services. The reliability of residual passenger and freight services operating on the slow lines is likely to be lower than under Phase 2a due to the higher utilisation of these lines. It may be that the reliability of the historic WCML infrastructure used by the alternative options is less reliable than the Phase 2a infrastructure although this is dependent to a large extent on the renewal and maintenance policies.

The medium and low cost options provide a greater cost saving but also provide fewer benefits and a lower BCR than the high cost option. They also both have greater capacity constraints which reduces both the number of additional services that could be run and also introduces a greater risk of unreliability or poor operational performance.