HS2 Cost and Risk Model Report

A report to Government by HS2 Ltd

March 2012

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Preface to March 2012 reports

This report was submitted to Government by HS2 Ltd at the end of March 2012 and is part of a suite of documents produced to provide preliminary advice to Government on potential options for phase two of the high speed rail network.

For details of the initial preferred scheme selected by Government, please see the Command Paper[1]. The initial preferred scheme will form the basis of further engagement. A preferred scheme will be published in 2013 that will form the basis of full public consultation.

Anyone reading the March 2012 reports should be aware of the following:

- The reports describe the development of options. The base proposition referred to is not a recommended or preferred scheme.

- The reports describe route and station options serving Heathrow T5. The options do not reflect an initial preferred scheme. The Government has announced its intention to suspend work on high speed rail options to Heathrow until the Airports Commission has reported.

- Where the Ordnance Survey Licence Number is shown on maps it should read 100049190.

[1] *High Speed Rail: Investing in Britain's Future*
Phase Two: The route to Leeds, Manchester and beyond

Contents

Appendices

List of acronyms

DfT	Department for Transport
DL	Davis Langdon, an AECOM company
DMU	Diesel Multiple Unit
ECML	East Coast Main Line
EMU	Electrical Multiple Unit
HST	Intercity 125 High Speed Train
IEP	Intercity Express Programme
IMD	Infrastructure Maintenance Depot
OB	Optimism Bias
OHLE	Overhead Line Equipment
QRA	Quantified Risk Assessment
RSD	Rolling Stock Maintenance Depot
TOC	Train Operating Company
UIC	International Union of Railways

Executive summary

1. This is HS2 Ltd's advice to Government on the cost of the Y network, based on the post-consultation route for phase one London to West Midlands and the routes contained in the base proposition within *Options for phase two of the high speed rail network* which this document supports.

2. During 2011, we have further developed our thinking on the build-up of HS2 costs and risk. Changes have occurred to our estimates as a result of a number of initiatives:

    - further development of our base construction database and update of our rates to 2011 price levels;
    - amendment of the scope of the HS2 London to West Midlands route as a result of public consultation undertaken during 2011;
    - improved understanding of possible routes and stations for the West Midlands to Manchester and Leeds;
    - increased rolling stock numbers as a result of enhanced service specification assumptions for the full Y network;
    - consideration of the outcomes of the cost challenge process undertaken by the Department for Transport (DfT) on HS2 costs; and
    - review of operating cost assumptions covering both HS2 and the strategic alternatives analysis carried out by Atkins.[2]

3. This paper describes how these effects have been incorporated into our current HS2 cost estimates, prepared in support of our advice to Government in March 2012.

4. The components of the estimated cost of HS2 are:

    - capital construction cost – the cost of land purchases, design, materials, and construction (including labour and power), plus allowance for risk and optimism bias in line with HM Treasury guidance;
    - rolling stock capital costs – the purchase costs of rolling stock (trains) plus an allowance for optimism bias; and
    - operating costs – the operation and maintenance of the railway infrastructure and its trains, including train crew and station staff, plus an allowance for optimism bias.

5. Capital cost summaries are shown for both phase one London to West Midlands and also the full Y network post implementation of phase two West Midlands to Manchester and Leeds with a spur to Heathrow. Phase one costs are based on the London to West

[2]Network Rail, 2011, *Review of Strategic Alternatives to High Speed Two,* http://www.dft.gov.uk/publications/hs2-review-of-strategic-alternatives

Midlands route as amended post-consultation. For the legs to Manchester and Leeds and the spur to Heathrow, we have used the routes contained in the base proposition within the options for phase two report.

6. The capital construction cost of the phase one London to West Midlands infrastructure is estimated at between £15.4 billion and £17.3 billion, with a mean value of £16.3 billion. This includes construction risk and an additional £4.2 billion to cover additional risks in line with the HM Treasury guidance on adjusting for optimism bias.[3] The phase two capital construction cost is £17.1 billion within a cost range of £15.7 billion to £18.7 billion. As above, this includes construction risk and an additional £4.2 billion to cover additional risks in line with the HM Treasury guidance. Our current estimate for the full Y network is, therefore, estimated at between £30.9 billion and £36.0 billion, with a mean value of £33.4 billion.

7. To calculate HS2 rolling stock capital costs and operating costs, assumptions are made regarding the train service specification used for phase one and then full Y network operations. The estimated HS2 rolling stock costs, including optimism bias, for the service levels currently assumed are £3 billion for phase one and £7.5 billion for the full Y network (which includes the cost of phase one stock).

8. The HS2 operating cost assumptions are described within this document. See the updated HS2 Economic Case[4] for further detail on the HS2 and classic line operating costs included within the HS2 business case.

[3] Optimism bias is the tendency of project planners to be optimistic about the costs. HM Treasury guidance states that when planning Government funded projects, an allowance to compensate for this tendency must be included. This is referred to as an "allowance for optimism bias".

[4] HS2 Ltd 2012, *Economic Case for HS2: Updated appraisal of transport user benefits and wider economic benefits,* http://www.dft.gov.uk/publications/hs2-economic-case-appraisal-update

1 Introduction

1.1.1 The original HS2 Cost and Risk Model[5] was developed in 2009. This was submitted in December 2009 as a supporting document to the HS2 report to Government *High Speed Rail – London to the West Midlands and Beyond*[6] and subsequently published in March 2010. The approach described within that document was used to refresh the London to West Midlands cost estimate used for the 2011 consultation document *Economic Case for HS2: The Y Network and London West Midlands*.[7]

1.1.2 Since then, we have undertaken work on the wider Y network. In doing so, we engaged an external cost consultant, Davis Langdon (DL), to provide independent cost estimation support to HS2 Ltd. To date, this work has focused on infrastructure capital costs. Davis Langdon has updated and extended the HS2 set of infrastructure base rates drawing on their extensive cost database. This database is used by DL annually to produce the industry standard *Spon's Civil Engineering and Highway Works Price Book*. The enhanced rate set which is expressed at Quarter 2, 2011 price levels is being used to estimate the costs of emerging options for phase two of the high speed network. We have also applied the rates to the London to the West Midlands post-consultation route, so that there is consistency in our costs for reporting to Government in March 2012.

1.1.3 We have sought to develop a more refined approach to the assessment of project on-costs (contractor administration and preliminaries, design and HS2 project management costs) by looking at the composition of the work to be undertaken, its complexity and efficiency potential.

[5] HS2 Ltd, 2009*, High Speed Rail London to the West Midlands and Beyond Cost and Risk Model,* http://www.railwaysarchive.co.uk/documents/HS2_HS2CostAndRiskModel2010.pdf

[6] HS2 Ltd, 2009, *High Speed Rail London to the West Midlands and Beyond,* a report to Government by HS2 Ltd, http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/rail/pi/highspeedrail/hs2ltd/hs2report/

[7] HS2 Ltd, 2011, *Economic Case for HS2: The Y Network and London West Midlands,* http://webarchive.nationalarchives.gov.uk/20110720163056/http://highspeedrail.dft.gov.uk/library/documents/economic-case

2 Infrastructure capital costs

2.1 Base construction rates for asset types

2.1.1 HS2's cost and risk consultant, DL, has updated and extended the HS2 set of base rates. The update draws on the extensive DL cost database which is used by DL to produce the industry standard price book *Spon's Civil Engineering and Highway Works Price Book* on an annual basis. It is not possible to directly compare all the unit rates now used with those applied previously, however, in overall terms the application of new rate set to the route used for consultation would result in the cost of that route increasing by around 5 to 6%.

2.1.2 The DL cost database incorporates out-turn cost effects, such as contingency, into the as-built rates. Conversely, within the HS2 cost model, out-turn cost effects are calculated after base construction costs[8] have been developed. To address this issue, DL considered the rates from their database further and applied a 10% reduction. In some specific cases, additional reductions of between 7.5% and 12% have been made to compensate for the fact that a significant amount of urban benchmarking information was used to establish the original rates. In the case of HS2, large parts of the route, where practicable, avoid major conurbations and therefore will be green field construction.

2.1.3 For tunnels, the best available data for benchmarking costs continues to be the data provided by the British Tunnelling Society through the Infrastructure UK cost study work. This data enables tunnel length and construction approach to be reflected, particularly for tunnel boring methodology. Rates for each tunnel proposed are considered on an individual basis using the available data.

2.1.4 The DL unit rates derived as above are shown in Appendix A. The original Arup rates are also included. It is not always possible to make direct comparisons between the two, as in some cases DL have derived a number of rates (e.g. for earthworks dependent upon height / depth) whereas the Arup rate made no differentiation on height/depth. There are three areas where significant variance in rate is apparent:

- permanent way[9] – DL rates are typically 66% higher. Investigation indicates that the Arup rates for ballast and sleepers were below current market rates. Concrete cable ducting was originally assumed. However, secure cable troughing is more appropriate for a high speed line and has been used in the DL rate. The DL rate is therefore appropriate. The permanent way costs make up a low percentage of construction costs (previously 5%);

- bridges – divergence in rates arises from assumptions regarding the extent of major piling suitable for high-speed structures and vertical formwork. There is better knowledge within the project now to confirm the scale of the requirements for these elements, which are reflected in the DL rates; and

[8] Base construction costs in the HS2 model are the costs of constructing something before items such as project management, design and environmental mitigation are added on.
[9] The components of permanent way are explained in 2.2.3

- cuttings and embankments – the variance seen here is due to the underlying assumptions made regarding ground conditions and preparation, the removal or re-use of spoil.

Price Index

2.1.5 For our report to Government in December 2009 and since then, we used costs as at Quarter 3, 2009. We updated our price levels in our January 2012 report to closer to current day using the Tender Price Index (TPI) for Quarter 2, 2011. At this date, tender prices are circa 3% lower than in Quarter 3, 2009. We recognise that the TPI can go up as well as down. Future index variance is addressed through the Quantified Risk Assessment (QRA) process as a risk / opportunity.

2.2 Construction base cost

2.2.1 To derive the base costs, the updated rate set is applied to the scope defined by the engineering teams. As part of the ongoing development of our cost models, the scope templates now used provide a greater level of granularity – previously 45 scope elements could be selected, 250 elements are now available. This enables us to more accurately reflect our understanding of the scope as it emerges. In some cases, this level of detail has meant that we have been able to reflect on the balance of costs between potential options for a route section. A particular example is the balance of costs between complex surface works versus the costs of tunnelling and the associated environmental benefits.

2.2.2 In the case of the London to West Midlands cost estimation, the scope used is for the Route 3 consultation route as amended post-consultation. We estimate that the post-consultation scope changes have reduced the phase one base construction estimate by around 2.5%. For the legs to Manchester and Leeds, we have used the routes contained in the base proposition within the options for phase two report.

2.2.3 The scope upon which the base construction cost has been calculated covers the following:

- permanent way – rail, sleepers, ballast, cess walkway, track drainage and high security fencing;
- switches and crossings – based on number of crossings and associated linespeed;
- Overhead Line Equipment (OHLE) – overhead line equipment, support structures and power supply;
- train control systems – based on route length and number of point ends, includes all signalling and communication requirements and control centre;
- stations – station buildings, station facilities, and utility diversions. Also any station specific requirements, i.e. connectivity with other stations or transport systems, car parking, construction difficulties etc;

- earthworks – site clearance, earthworks, soiling, seeding and small structures for the permanent way only; all other earthworks (for stations, roads, tunnels and structures) are included in those line item costs;

- retaining walls – associated earthworks, concrete, formwork, reinforcement, back of wall drainage and finishing works;

- structures – associated earthworks, concrete, formwork, reinforcement, pre-cast units, structural steelwork and finishing works;

- tunnels – excavation, tunnel lining, cross passages (for twin-bore tunnels), shafts, plant and associated control systems. The rates include for establishment (reception pits, segment fabrication yard, mobilisation and demobilisation) and portals;

- highways – include site clearance, fencing, vehicular barriers, drainage, earthworks, pavement, kerbs, footways, signs, lighting and small structures/accommodation bridges;

- utilities – priced as a percentage allowance (typically 3%) of the base construction cost; and

- additional items – includes further rebuild works, multi-storey car parks and people mover.

2.2.4 The recent HS2 cost challenge undertaken by the DfT considered emerging costs of recent work relating to London Underground infrastructure. As a result, a concern was raised that there was insufficient provision for London Underground related works at Euston. We have made an additional provision of £100 million within the base construction costs to address this.

2.3 Approach to contractor, design and client costs

2.3.1 Previously, we have adopted an approach of using percentage add-ons for costs relating to contractor preliminaries and supervision, design and client costs as shown in Table 1.

Table 1: Percentage add-ons applied previously

Item	Percentage applied
Contractor preliminaries	10% base construction cost
Contractor site supervision	5% base construction cost
Design costs	8% total construction cost
Client costs	8% total construction cost

Source: HS2 Ltd

2.3.2 This was an appropriate approach recognising the levels typically seen on other projects and the constrained time and resource available to undertake further assessment. Work has been undertaken by DL to consider the application of contractor and design costs at the asset type level, recognising that different assets require different levels of effort.

2.3.3 An early assessment has also been made to consider a bottom-up approach to costing design and client costs by considering the level of resource required to design and deliver the project as a whole. This approach should provide a more appropriate cost for the HS2 project recognising the scale of work required but also some of the efficiencies that are achievable in terms of overheads, etc.

2.3.4 We have therefore reduced the percentages applied for these elements in line with the conclusions from our assessment. The percentages applied for this cost estimate are equivalent to those outlined in Table 2.

Table 2: Equivalent percentage add-ons now applied

Item	Percentage applied
Contractor preliminaries	8% base construction cost
Contractor site supervision	4% base construction cost
Design costs	7% total construction cost
Client costs	5% total construction cost

Source: HS2 Ltd

2.3.5 The DfT cost challenge process highlighted concerns with the reduced coverage levels for these elements. In overall terms, their view was that up to an additional £500m should be included within the phase one cost estimate. This has not been included within our figure of £16.3 billion for phase one costs, reflecting our view of the scope for achieving cost efficiency in these areas, but does fall within our phase one cost range (£15.4 billion – £17.3 billion). Within the HS2 business case, sensitivity analysis has been undertaken to demonstrate the effect on the business case of the cost range. An additional £500m on infrastructure capital costs has a marginal effect on the business case (reducing the cost benefit ratio by around 0.05).

2.3.6 Percentages applied to the rail and control systems costs for contractor training (5%), spares (1%) and testing and commissioning (1%) remain unchanged.

2.4 Land costs

Phase one London to West Midlands

2.4.1 HS2's land and property consultants, CBRE, refreshed their London to West Midlands land cost estimate in September 2011. Their estimate includes property, disturbance and resale values. Since 2009, the estimated value of land has risen by a little over 3% to £966 million reflecting the relevant market forces.

Phase two beyond West Midlands

2.4.2 CBRE are undertaking a land valuation exercise similar to that of the London to West Midlands, where they have estimated the overall property costs for the base

proposition routes. As with phase one, this assessment includes property, disturbance and resale values within the planned railway corridor.

2.5 Approach to other cost elements

2.5.1 In line with our previous estimates, we have applied the following allowances for phase one and the full Y network:

- environmental mitigation in urban areas or areas of known environmental significance - 5% of base construction cost excluding utilities, in other areas 3% and in tunnelled areas 0%;
- surveys (ground and topography) - allowance of £150,000 per route kilometre.
- rail possession / isolation / safety management - 2% of base construction cost for route sections affecting existing railway; and
- train operating company compensation - 8% of base construction cost for route sections affecting existing railway.

2.5.2 We have reflected on feedback from the recent DfT cost review regarding the adequacy of the train operating cost compensation for phase one. As a result, we have strengthened coverage for this item by making an additional provision of £130 million within our programme-level risk register.

2.6 Depot and stabling facilities

Phase one London to West Midlands

2.6.1 We have previously made a provision of £200 million for the main rolling stock maintenance facility (RSD) at Washwood Heath and allowed £50 million for London area stabling. The recent DfT cost review enabled further benchmarking of current depot construction costs. Reflecting the extensive range of facilities required for a heavy maintenance facility at Washwood Heath and overall stabling requirements, we have increased the London to West Midlands provision by an additional £100 million. Within our cost model, we have also made provisions totalling a further £100m to reflect the complexities of interfaces with other schemes within the Old Oak Common area.

Phase two beyond West Midlands

2.6.2 For phase two we have derived the base cost of the RSDs and infrastructure maintenance depots (IMD) by applying the rate set to the scope defined by Appendix 5 of the HS2 technical appendix. This has generated an allowance of £670 million for the additional RSD and IMD required for the Y network.

2.6.3 Within our cost model, we have also made provisions totalling a further £250m for stabling at the northern end of the Y network.

Statutory charges

2.6.4 We have previously allowed £200 million for costs relating to the statutory process of achieving the London to West Midlands hybrid bill such as legal and consultation-related costs. The recent DfT cost review recommended that this provision was reconsidered.

2.6.5 Through calibration with the Crossrail experience, we reduced this allowance to £70 million. We have currently conservatively assumed a provision of £140 million for a subsequent phase two hybrid bill, reflecting that this is twice the geographical scale of phase one.

Allowance for emerging issues

2.6.6 Through the Concept of Operations work undertaken as part of our full Y network workstream during 2011, we have identified potential additional scope which may be required to support the envisaged service levels for the full Y network including the range of inter-regional services.

2.6.7 Pending further clarification on the requirement for these items, we have made a provision of £225 million to cover possible enhanced facilities in the Birmingham Curzon Street and Washwood Heath area.

2.6.8 The cost for the base proposition includes five platforms at the Leeds station to allow for the envisaged service levels for the full Y network including the range of inter-regional services.

2.6.9 There is also an allowance of £95 million included for potential additional scope around the beginning of the Leeds route to support the envisaged service levels for the full Y network.

2.7 Efficiencies

2.7.1 As described above and by taking more of a bottom-up approach to estimating these elements, we have incorporated reductions for contractor overheads, design and client-related costs. The net effect of these reductions is equivalent to efficiencies of around 5% of the total project cost.

2.7.2 Consideration was given as to whether additional efficiencies should be claimed for potential long-term orders and procurement packaging due to the scale of the works proposed. These efficiencies have not been taken at this stage, as HS2 procurement strategies and the approach to packaging of construction works have not yet been developed.

2.7.3 Having benefited previously from better access to tunnelling cost data via the Infrastructure UK cost study in 2011, we are continuing to work with Infrastructure UK to develop further plans to drive down the cost of UK civil engineering construction projects such as HS2.

2.8 Approach to risk and optimism bias

2.8.1 All of the infrastructure costs referred to above exclude any risk or provisions for optimism bias factors. Reflecting the different stages of development, our approach to risk and optimism bias is currently different for the two scheme phases.

Phase one London to West Midlands

2.8.2 For London to West Midlands, we have continued with our approach of using values from our location-specific and programme-wide QRA coupled with an appropriate additional provision for optimism bias.

2.8.3 Post consultation, we have reviewed the QRA risks and updated these to reflect mitigations and revisions incorporated within the scheme, including provision for items in the Old Oak Common area that have emerged through our Concept of Operations work covering the full Y network. See Appendix B for the top ten location-specific risks identified and Appendix D for the programme-level risks.

2.8.4 The phase one location-specific risks total £980 million and the programme-level risks are valued at £1.23 billion. The total construction risk estimate is therefore £2.21 billion, which is equivalent to 22.5% of the estimated phase one cost excluding provision for optimism bias factors.

2.8.5 The optimism bias factors that contribute to calculation of the HS2 additional risk provision for this phase are shown in Appendix F. This results in additional provision of 34.3% of the total estimated scheme cost.

2.8.6 There is a total risk provision of £6.38 billion within the phase one cost estimate, equivalent to an additional 64% of scheme costs.

Phase two beyond West Midlands

2.8.7 For the base proposition routes outlined in the phase two options report, we have continued with the approach from phase one of using values from our location-specific and programme-wide QRA coupled with an appropriate additional provision for optimism bias.

2.8.8 The phase two location-specific risks total £960 million and the programme-level risks are valued at £1.24 billion. The total construction risk estimate is therefore £2.20 billion, which is equivalent to 21% of the estimated phase two cost excluding provision for optimism bias factors.

2.8.9 We have reviewed the optimism bias factors that contribute to calculation of the HS2 additional risk provision for phase two. The scored weightings recognise that this is phase two of the scheme and therefore there is a different weighting of factors than in phase one.

2.8.10 The factors that have been reviewed are as follows:

- Project Specific – design complexity has been reduced from 8 to 7 on the grounds that the design of the Y contains nothing as intrinsically complex as phase one; and

- External Influences – legislation/regulation has been reduced from 6 to 5 on the grounds that this is a greater risk for phase one.

2.8.11 The detailed commentary that supports the optimism bias factor weightings for phase two is in Appendix G. This results in additional provision of 33.0% of the total estimated scheme cost for phase two.

2.8.12 There is a total risk provision of £6.43 billion within the phase two cost estimate, equivalent to an additional 61% of scheme costs.

2.9 Route package cost summaries

2.9.1 The phase one total cost estimate is £16.3 billion within a cost range of £15.4 billion to £17.3 billion. The cost summary is shown in Table 3.

2.9.2 The phase two total cost estimate is £17.1 billion within a cost range of £15.7 billion to £18.7 billion. The cost summary is shown in Table 4.

2.9.3 The full Y network cost estimate is £33.4 billion within a cost range of £30.9 billion to £36.0 billion. The Y network cost summary is shown in Table 5.

Table 3: Phase one cost estimate

Item	Cost £ million	Includes
Rail systems	510	Track, ballast, fencing, drainage, junctions
Control systems	145	Signalling control and telecommunications
Traction power systems	185	Overhead line equipment and power supply
Stations	1,675	Euston, Old Oak Common, Birmingham Interchange and Curzon Street
Civil works	585	Earthworks, retaining walls and roads
Structures	790	Bridges and viaducts
Tunnels	1,410	Twin and single bore tunnels
Utilities	120	Relocation of utilities e.g. water, power
Additional items	470	People mover and rail reconstruction work
Contractor administration costs	775	Preparatory work, site supervision, testing, training, spare equipment
Total Construction Cost	**6,665**	**Excluding risk**
Environmental mitigation	250	Additional environmental mitigation
Land costs / compensation	965	Land acquisition / compensation plus scheme administration (as assessed at Sept 2011)
Depot facilities	500	Main rolling stock depot, London stabling, depot relocations (HEX and IEP)and infrastructure maintenance depot
Provisional sum	225	Allowance for emerging requirements from concept of operations work
Project overheads	435	Client and project management costs
Design	600	All design costs and topographical / ground investigation surveys
Existing rail interface costs	190	Possession management, compensation for operational disruption
Statutory charges	70	Consultation and planning consent related costs
Construction risk	2,215	Route section and route-wide construction risks from the Quantified Risk Analysis
Additional scheme risk provision	4,165	Provision for external risks in line with HM Treasury Supplementary Green Book Guidance
Total	**16,280**	**At Q2 2011 prices**

Source: HS2 Ltd

Table 4: Phase two cost estimate

Item	Cost £ million	Includes
Rail systems	920	Track, ballast, fencing, drainage, junctions
Control systems	300	Signalling control and telecommunications
Traction power systems	300	Overhead line equipment and power supply
Stations[10]	600	Toton, Meadowhall, Leeds New Lane, Manchester Piccadilly and Heathrow T5
Civil works	1,740	Earthworks, retaining walls and roads
Structures	1,510	Bridges and viaducts
Tunnels	980	Twin and single bore tunnels
Utilities	180	Relocation of utilities e.g. water, power
Additional items		None
Contractor administration costs	890	Preparatory work, site supervision, testing, training, spare equipment
Total Construction Cost	**7,420**	**Excluding risk**
Environmental mitigation	200	Additional environmental mitigation
Land costs / compensation	870	Land acquisition / compensation plus scheme administration (as assessed at Sept 2011)
Depot facilities	765	Two light maintenance rolling stock depots, two infrastructure maintenance depots and a provision for stabling
Provisional sum	95	Allowance for emerging requirements from concept of operations work
Project overheads	460	Client and project management costs
Design	700	All design costs and topographical / ground investigation surveys
Existing rail interface costs	20	Possession management, compensation for operational disruption
Statutory charges	140	Consultation and planning consent related costs
Construction risk	2,200	Route section and route-wide construction risks from the Quantified Risk Analysis
Additional scheme risk provision	4,250	Provision for external risks in line with HM Treasury Supplementary Green Book Guidance
Total	**17,120**	**At Q2 2011 prices**

Source: HS2 Ltd

[10] The stations cost includes the station buildings, station facilities, and utility diversions as well as any station specific requirements, i.e. connectivity with other stations or transport systems, car parking, construction difficulties etc.

Table 5: Full Y network cost estimate

Item	Full Y	Includes
Rail systems	1,430	Track, ballast, fencing, drainage, junctions
Control systems	445	Signalling control and telecommunications
Traction power systems	485	Overhead line equipment and power supply
Stations	2,275	LWM stations, plus Toton, Meadowhall, Leeds New Lane, Manchester Piccadilly and Heathrow T5
Civil works	2,325	Earthworks, retaining walls and roads
Structures	2,300	Bridges and viaducts
Tunnels	2,390	Twin and single bore tunnels
Utilities	300	Relocation of utilities e.g. water, power
Additional items	470	People mover and rail reconstruction work (LWM)
Contractor administration costs	1,665	Preparatory work, site supervision, testing, training, spare equipment.
Total Construction Cost	**14,085**	**Excluding risk**
Environmental mitigation	450	Additional environmental mitigation
Land costs / compensation	1,835	Land acquisition / compensation plus scheme administration (as assessed at Sept 2011)
Depot facilities	1,265	As LWM, plus 2 light maintenance rolling stock depots and two infrastructure maintenance depots
Provisional sum	320	Allowance for emerging requirements from concept of operations work
Project overheads	895	Client and project management costs
Design	1,300	All design costs and topographical / ground investigation surveys
Existing rail interface costs	210	Possession management, compensation for operational disruption
Statutory charges	210	Consultation and planning consent related costs
Construction risk	4,415	Route section and route-wide construction risks from the Quantified Risk Analysis
Additional scheme risk provision	8,415	Provision for external risks in line with HM Treasury Supplementary Green Book Guidance
Total	**33,400**	**At Q2 2011 prices**

Source: HS2 Ltd

3 Rolling stock capital costs

3.1 Cost and risk derivation for HS2 rolling stock

3.1.1 Although our assumptions regarding rolling stock capital costs have remained stable, the full Y work raises the potential for operation of 260m long sets in addition to 200m sets, so rates have been derived for this longer train.

3.1.2 Two types of stock will be used to operate HS2 services. Captive sets operating on HS2 can be procured as an "off-the-shelf" item, as they are analogous to existing European high speed trains. Classic compatible sets that operate along HS2 and then on to the classic network must be of a smaller gauge, requiring adaptation of a European high speed train design and a customised assembly. We have included a significant cost premium as a result for these sets.

3.1.3 During 2009, a number of sources were used to confirm the costs of a standard European high speed train including the International Union of Railways (UIC) and the DfT. The premium incurred for customisation of an interoperable high speed train (similar to the Eurostar experience) was agreed with the DfT after consultation with Eurostar, a range of rolling stock suppliers and train operators.

High speed captive rolling stock

3.1.4 The captive high speed train was estimated at £25 million per trainset for a 360kph capable, 200m long European standard train. Within our models, we have uplifted this figure in line with inflation, resulting in a provision of £26.5m at 2011 price levels. This cost represents the one-off costs of the purchase of each set. Allowances for the maintenance and renewal of rolling stock are made separately within the HS2 model.

3.1.5 A risk provision of 18%, analogous to a level 4 optimism bias provision, has been made for these sets reflecting the relatively low risk associated with standard, off-the-shelf European designs.

High speed classic-compatible rolling stock

3.1.6 A 50% premium reflecting technical redesign has been applied to derive the cost for a 360 kph capable, 200m long classic compatible set, resulting in an estimated cost of £37.5 million per set at 2009 or £39.8 million at 2011 levels.

3.1.7 Within the HS2 cost model, a risk provision of 40% analogous to a level 3 optimism bias provision has been made for these sets reflecting the potential issues including design and approval risks and the commercial attractiveness of the classic compatible one-off fleet.

3.1.8 The full Y network service specification now also includes utilisation of 260 metre long classic compatible sets. At this stage we have conservatively assumed that the

capital cost of a 260m long train will be 1.3 times the cost of a 200m set. A risk provision of 40% has also been applied.

Future considerations

3.1.9 We intend to undertake further work regarding assumptions on rolling stock costs during 2012. Consideration of the scale of the total fleet for the Y, the associated procurement and phasing strategies should enable more cost effective solutions than the values estimated currently.

3.2 Rolling stock capital cost summaries for phase one and the full Y network

Phase one London to West Midlands rolling stock capital cost estimate

3.2.1 The number of sets needed to operate the service is a product of the assumed train service specification. For phase one, the number of sets required is as outlined at consultation. We have applied the 2011 prices to produce the cost estimate in Table 6, items are rounded to the nearest £5 million.

Table 6: London to West Midlands rolling stock capital cost estimate

Item	**£ million**
Captive fleet (16 x 200m sets) base cost	425
Classic-compatible fleet (45 x 200m sets) base cost	1,790
Total base cost at 2011	**2,215**
Captive fleet (16 x 200m sets) risk at 18%	75
Classic-compatible fleet (45 x 200m sets) risk at 40%	715
Total risk provision at 2011	**790**
Total	**3,005**

Source: HS2 Ltd

Full Y network rolling stock capital cost estimate

3.2.2 The Y network train service specification has been developed since consultation. The new specification is shown as an appendix to the updated economic case document[11]. The total rolling stock estimate reflects this updated specification and the application of 2011 price levels.

Table 7: Y network rolling stock capital cost estimate

Item	£ million
Captive (92 x 200m sets) base cost	2,440
Classic-compatible (64 x 200m sets) base cost	2,550
Classic-compatible (15 x 260m sets) base cost	775
Total base cost at 2011	**5,765**
Captive (92 x 200m sets) @ 18% risk	440
Classic-compatible (64 x 200m sets) @ 40% risk	1,020
Classic-compatible (15 x 260m sets) @ 40% risk	310
Total risk provision at 2011	**1,770**
Total at 2011 prices	**7,535**

Source: HS2 Ltd

11 HS2 Ltd 2012, *Economic Case for HS2: Updated appraisal of transport user benefits and wider economic benefits*, http://www.dft.gov.uk/publications/hs2-economic-case-appraisal-update

4 Renewals

4.1.1 Recognising that the HS2 business case is evaluated over a 60 year period, the assumptions outlined in Table 8 have been applied to derive renewal costs for relevant infrastructure assets and trains.

Table 8: Renewal costs for relevant infrastructure assets and trains

Asset type	Assumption made
Infrastructure	
Permanent way	Full replacement by end of 30 and 60 years, each taking four years 25% spend each year
Switches and crossings	Full replacement by end of 30 and 60 years, each taking four years 25% spend each year
OHLE	Renew 50% each by year 15, 30, 45 and 60, each taking two years
Power supply	Renew 50% each by year 15, 30, 45 and 60, each taking two years
Signalling	Renew 50% each by year 15, 30, 45 and 60, each taking two years
Communications	Renew 50% each by year 15, 30, 45 and 60, each taking two years
Stations	40% renewal by year 40 taking four years
Earthworks	No renewal in evaluation period
Retaining Walls	No renewal in evaluation period
Structures	No renewal in evaluation period
Tunnel	No renewal in evaluation period
Depot / stabling	50% renewal by year 30 and 60 taking three years
Rolling Stock	
Captive and classic compatible train sets	Renewal by year 35 spread in line with initial expenditure phasing

Source: HS2 Ltd

5 Operating costs

5.1.1 Since consultation, we have also updated our operating cost unit rates in line with inflation to bring them to 2011 prices. The review of operating costs that took place following consultation looked across both HS2 and the strategic alternatives considered by Atkins for DfT.[12] Our underpinning assumptions are set out below. These rates have been applied for phase one and the full Y network operation. The changes that have been made to the costs of the strategic alternatives are described in Atkins' report.

5.2 Infrastructure operations and maintenance.

5.2.1 The costs we have used are a direct reflection of the HS1 costs. This is the most representative cost comparator, although we recognise that it includes a relatively large overhead due to the shorter length of HS1. At 2011 prices, we have used an annual figure of £191,000 per route kilometre.

5.3 Rolling stock

Captive set maintenance

5.3.1 Based on advice from rolling stock operators in Britain and elsewhere in Europe we have estimated a maintenance cost of £2.97 per kilometre travelled for a 200m captive train.

Classic compatible set maintenance

5.3.2 The more complex classic-compatible trains would be more expensive to maintain than the standard captive fleet. We have included an additional 25% premium to reflect this resulting in £3.71 per kilometre travelled for a 200m set. We have factored this value up by 1.3 for a 260m set i.e. £4.82 per kilometre travelled.

[12] Atkins, 2011, *High speed rail strategic alternatives study: Update following consultation,* http://www.dft.gov.uk/publications/hs2-strategic-alternatives-study-update/

Traction power

5.3.3 Our earlier traction power modelling calculated that a 200m long set would consume 28 kilowatt hours per kilometre whilst running on HS2. In the case of classic compatible services running on the classic network, we have assumed the same energy consumption as a Pendolino – 14 kilowatt hours per kilometre.

5.3.4 Using Department for Energy and Climate Change projections, we have derived the following traction power costs:

Table 9: Traction power costs

Costs (£/km travelled)	Captive (200m)	Classic compatible (200m)	Classic compatible (260m)
On HS2	3.90	3.90	5.00
On classic network	n/a	2.00	2.60

Source: HS2 Ltd

Classic line running

5.3.5 We now include a variable cost element for those HS2 services which operate on the classic network. We had previously assumed that the costs of maintaining the classic lines were fixed costs which would be paid regardless of changes as a result of HS2. We now assume that a 200m classic compatible set running on the classic network pays the same variable track access charge and electrification asset usage charge as a classic train, and the same network capacity charge as trains are currently charged. On average these charges total £1.39 per kilometre for day 1 services and £1.26 per kilometre for services operating the full Y network.

5.4 Train crew

Driver and conductor costs

5.4.1 During 2009, we calculated train crew costs by estimating the number of drivers and conductors required to operate the assumed phase one and full Y train service specifications using current UK longer distance operators' typical working hours, practices and costs. We assumed that a 200m set would be operated by one driver and one conductor and considered that any other staff on-board services would be present only if revenue generation opportunities justified it.

5.4.2 A 2x200m set would be operated by one driver and two conductors, as there will be no through walkway between sets. At 2009 prices, driver costs were calculated applying a rate of £0.78 per kilometre and conductor costs at £0.56 per kilometre. Driver costs were grown by a factor of RPI + 1.5% until 2043, to reflect wage inflation.

5.4.3 Through the DfT cost review process, we identified that the £ per kilometre values used for driver and conductor were over-estimated. We have re-calibrated assumed annual salaries against the current salaries of representative train crew as at the end of 2011. We have also included a provision of 17% within the rate to cover staff management overheads. The rates applied within the HS2 model for driving HS2 trains on the HS2 network are now £0.60/km for a driver and £0.39/km for a

conductor. When driving HS2 trains off the HS2 network on the classic network, driver and conductor costs are assumed to be the same as a Pendolino, with rates of £0.77/km for a driver and £0.46/km for a conductor. Driver costs are grown by RPI+1.5% until 2037 (the same year as the demand cap).

Additional on-board crew

5.4.4 We have also included additional HS2 on-board crew costs. We had previously assumed that catering and any other service staff would be a commercial decision for an operator; therefore, additional revenues would offset such staff costs. However, we now make the more conservative assumption that it is possible that some of this revenue generated is actually implicit in the fare yields used in the modelling.

5.4.5 Whilst no decision has yet been made regarding the scale of any catering offer aboard HS2 services, we have also now included additional allowances to reflect the possible costs of increased staffing. Trains with an end to end journey time of more than an hour are assumed to have on average five catering staff and one cleaner per train, trains under an hour have on average two and half catering staff per train. We assume that half of the costs of the catering staff are off set by any revenue they might earn.

5.4.6 On average this means for the phase one services there are additional staff costs of £0.55 per kilometre for HS2 captive and £1.01 per unit kilometre for 200m classic compatible trains. For the Y services this increases to £0.83 and £1.02 per unit kilometre for HS2 captive and 200m classic compatible trains respectively.

5.5 Additional overheads

5.5.1 We also now assume that there are some additional variable overhead, administration and headquarters costs relating to the operation of train services. These are assumed to be 15% of all staff costs. We also assume an insurance cost of £0.02 per train kilometre.

5.6 Station costs

5.6.1 Bottom-up operational staffing estimates for each of the different station types identified through our work were derived. Example station utility and maintenance costs have also been included. This does not include any non-operational commercial and retail activities. Typical values at 2011 prices are shown in Table 10.

Table 10: Station costs

	£k per annum
Station staffing 10 platform terminus	5,626
Station staffing 6 platform through	2,215
Station staffing 4 platform through	1,748
Station staffing 6 platform terminus	3,108
Station maintenance and utilities (4 platforms)	503

Source: HS2 Ltd

5.7 Released capacity on the existing classic network e.g. West Coast Main Line

5.7.1 We have also reviewed our estimates of the change in operating costs on the classic network that arises as a result of the introduction of HS2. This is a net impact, as services are both removed from, and added to, the classic network after the introduction of HS2. Assumptions on the costs of running classic services are shown in Table 11.

Table 11: Costs of running classic services

Rolling Stock Type	£k per km
Pendolino 9 car	£14.49
Pendolino 11 car	£17.03
DMU 3 car	£6.51
DMU 4 car	£7.85
DMU 5 car	£9.24
DMU 7 car	£13.40
EMU 4 car	£7.88
EMU 8 car	£13.25
EMU 12 car	£18.61
ECML Average Intercity Train	£13.60
HST	£10.16

Source: HS2 Ltd

5.8 Application of optimism bias

5.8.1 In line with HM Treasury guidance, a cautious allowance of 41% is applied to all operating costs with the exception of classic line lease costs to which 18% is applied.

5.9 Derivation of operating costs

5.9.1 The unit rate assumptions above for rolling stock and train crew are combined with our service specification assumptions (e.g. number of trains operated) in our business case model to produce total operating costs for these items.

6 References

HM Treasury, *Green Book*, http://www.hmtreasury.gov.uk/data_greenbook_index.htm

HS2 Ltd 2012, *Economic case for HS2: Updated appraisal of transport user benefits and wider economic benefits*, http://www.dft.gov.uk/publications/hs2-economic-case-appraisal-update

HS2 Ltd, 2009, *High Speed Rail London to the West Midlands and Beyond: HS2 Cost and Risk Model*, http://www.railwaysarchive.co.uk/documents/HS2_HS2CostAndRiskModel2010.pdf

HS2 Ltd, 2009, *High Speed Rail London to the West Midlands and Beyond*: A Report to Government by HS2 Ltd, http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/rail/pi/highspeedrail/hs2ltd/hs2report/

HS2 Ltd, 2011, *Economic Case for HS2: The Y Network and London West Midlands,* http://webarchive.nationalarchives.gov.uk/20110720163056/http://highspeedrail.dft.gov.uk/library/documents/economic-case

Network Rail, 2011, *Review of Strategic Alternatives to High Speed Two,* http://www.dft.gov.uk/publications/hs2-review-of-strategic-alternatives

Systra, 2012, *Operational Concept Study, Report for HS2 Ltd*

Appendix A: Infrastructure rate comparison

Base cost only excludes contractor costs, design, testing and commissioning, client costs, risk and Optimism Bias

Item	Unit	Rate (£) Previous	Rate (£) Current	Notes
Permanent Way				
Single track	£ / route m	£860	£1,431	Average rate
2 track	£ / route m	£1,370	£2,273	Average rate
4 track	£ / route m	£2,440	£3,686	Average rate
Overhead Line Equipment				
Single track	£ / route m	£390	£377	Typical rate
2 track	£ / route m	£780	£544	Typical rate
4 track	£ / route m	£1,530	£1,084	Typical rate
Signalling and comms				
Train control - route	£ / route km	£320,000	£320,000	Rate as previously
Train control - point end	£ / point end	£510,000	£510,000	Rate as previously
Earthworks				
Embankment	£ / cubic metre	£21.50	£11.02	Averaged across 4 different heights
Cutting	£ / cubic metre	£17.85	£27.91	Averaged across 4 different depths
Structures				
Single span bridge (12.6m wide)	£ / square metre	£1,900	£2,346	Rail over Road Bridge 2 track 0 - 10 metres high
2 span bridge (12.6m wide)	£ / square metre	£1,400		
3 span bridge (12.6m wide)	£ / square metre	£1,300		
Elevated section (12.6m wide)	£ / square metre	£900	£1,072	Viaduct 2 track 0 - 10 metres high
Retaining Wall	£ / square metre	£370	£637	Average rate across 3 height bands
Tunnels				
Single bore 9.8m internal diameter	£ / tunnel route metre	£45,050	£66,300	Single Bore 12m internal diameter
Twin bore 7.25m internal diameter	£ / tunnel route metre	£61,625	£32,400 to £61,600	Range dependent on length
Road				
Rural	£ / square metre	£120	£138	Averaged across different road widths
Urban	£ / square metre	£200	£230	Averaged across different road widths
Major	£ / square metre	£210	£207	Averaged across different road widths

Appendix B: Top ten site specific risks for phase one London to West Midlands

Risk	Route Section	Value (£k)
Tunnels - ground conditions / obstructions affect methodology / alignment	Tunnelled Sections	245,783
Additional interface requirements	Euston	69,583
Uncertainty associated with elevated section length	Coleshill to Belfry Golf Course	62,500
Vertical clearances at Heartlands spine road	Water Orton Corridor	50,667
Possible additional requirements to enable capacity approaching Old Oak Common	Old Oak Common area	50,000
Proximity to Central Line at Hanger Lane - additional bridge/highway works, impacts on Central Line	Hanger Lane area	50,000
Additional interface requirements	Delta Junction area	48,000
Construction more complicated - e.g. increased box size	Old Oak Common	44,584
Uncertain highway infrastructure requirements (HS2 works only)	NEC to Coleshill	39,000
Uncertainty associated with length of elevated section	Spur Lines (Delta Junction)	36,667

Appendix C: Top ten site specific risks for phase two

Risk Identification – Heathrow Spur		
Risk Description **There is a risk / issue that…**	**Consequence** **This will result in…**	**Value (£k)**
Stakeholder expectations higher than envisaged. Satisfying these, including Planning Approval, Heritage etc, necessitates enhanced design.	Redesign, Cost & delay	33,000
BAA gain permission for Third Runway	Need to redesign route into Heathrow Potential tunnel	18,000
Flood risk, cannot re-route culvert river	Unique design solution required	18,000
Spoil disposal costs greater than expected	Additional costs	16,000
BAA impose onerous restrictions on construction	Increased costs	15,000
Not enough platforms & circulation space (inaccuracy of assumptions made, without definitive demand data)	1. Wider station/ more land/ demolition/ build (if identified in time) or 2. Only evident as future operational constraint	14,000
Proximity to existing roads / rail (especially at tunnel portals) necessitate unplanned reinforcement of those roads /rail structures	Additional works and costs, disruptions to local residents	13,000
HA object to proposed Road Junctions	Need to redesign junctions	12,000
Station cannot join T5 at Mezzanine level as planned	Major re-design required; additional cost and time	11,000
Risk of obstructions to tunnel route (e.g. unknown piling foundations)	Delays and added costs	10,000

Risk Identification – Manchester Leg		
Risk Description **There is a risk / issue that…**	**Consequence** **This will result in…**	**Value (£k)**
Insufficient materials to build embankment (cannot achieve cutting/embankment balance)	Additional cost to import materials and design changes	46,000
Poor condition of existing infrastructure	Additional strengthening works to vaulted areas	46,000
Power connection to National Grid may be more difficult/costly than planned	Additional cost	35,000
Stakeholder expectations are higher than envisaged. Satisfying these, including Planning Approval, Heritage etc, necessitates enhanced design.	Redesign, Cost & delay Note that parts of Piccadilly Station are Listed and design must satisfy this	33,000
Rail Company objections lead to changes on interfaces (e.g.. Junctions / Parallel Running)	Changes, delay and added cost	30,000
Objections by public at landfill disturbance	Added costs and delays to programme	24,000
Highways Agency object to proposed Road Junctions	Need to redesign junctions	18,000
Ardwick Viaduct may be in poor condition and structurally unstable.	Impacts on Network Rail resulting in significant penalties. Increased costs	18,000
There is a lack of knowledge of existing structures and services (no investigations carried out at this stage)	Redesign, expensive service diversions, NB this is complicated further by presence of listed structures	17,000
Spoil disposal costs greater than expected	Additional cost	16,000

Risk Identification – Leeds Leg		
Risk Description **There is a risk / issue that…**	**Consequence** **This will result in…**	**Value (£k)**
Interface with Classic rail not accepted as current design proposals for East Midland modifications	Scope of modifications increase and increase construction costs. May also increase programme for approvals and works	45,000
Risk of no consent to build over River Mease	Diversion around River Mease	39,000
Highways Agency object to proposed M1 junction changes and all access to South Yorks Station	Need to modify junction this will include additional Sustainability work	33,000
Route passes through proposed developments	Compensation for developer for loss of land value	33,000
River Erewash & Erewash Canal - Adjacent vertical constraints prevent full clearances over waterways being achieved	Cost of additional highway diversion of Derby Road and A52 (raising of A52) as well as modifications to station, NR infrastructure and adjacent properties.	27,000
Vents and Access Shafts required under East Midlands airport	Increase tunnelling design & associated construction cost (or revert to alignment that avoids airport). 2 Tunnels/X-passages/Fire Doors - or extra Service Tunnel	22,000
Uncertain location of natural gypsum cavities (in the area of E. Midlands Airport)	More expensive construction solution required.	18,000
Connection into ECML may cause excessive disruption to operations/signals/power including added works on ECML	Increased operational and construction costs (base costs)	16,000
Crossing back-filled open cast sites	Significant additional costs for remedial works and construction costs (such as complex piling arrangements)	16,000
Stabling locations every 50 kms not designed, provision to be made (3 Locations)	Additional cost	15,000

Appendix D: Phase one programme level risks

Risk Category	Cause	Consequence	Likelihood	Probability %			Minimum (£)	Most Likely (£)	Maximum (£)	Estimated Value (Pert)
Procurement	Inappropriate procurement structure selected / tender rates not achieved	Contractors include significant price premium in commercial tenders. Liabilities for consequential losses lie with client	2	Medium	35%	65%	£150,000,000	£300,000,000	£600,000,000	£162,500,000
Market Context	Construction industry resources (e.g. tunnelling contractors, concurrency of major projects (Crossrail, other railway projects)	Increased tender prices. Delay whilst await for available resource	2	Low	5%	35%	£350,000,000	£700,000,000	£1,400,000,000	£151,666,667
Statutory Consultees (Technical)	Rail company disruption greater than planned	Increased Cost to project	2	Medium	35%	65%	£100,000,000	£250,000,000	£500,000,000	£135,000,000
Statutory Consultees (Technical)	Rail company objection to scheme details (e.g. parallel running, junction configuration)	Programme delay whilst rework. Cost of redesign and associated works	3	Medium	35%	65%	£100,000,000	£200,000,000	£400,000,000	£108,333,333
Utilities	Unknown buried services	Increased cost of protection or diversion	3	Medium	35%	65%	£100,000,000	£200,000,000	£300,000,000	£100,000,000
Geotechnical	Uncertain ground conditions	Cost of ground improvements higher than expected. Cost of alternative design	3	Medium	35%	65%	£100,000,000	£200,000,000	£300,000,000	£100,000,000
Statutory Consultees (Technical)	Statutory technical approval bodies require additional assurances	Approvals take longer than expected Cost of mitigations (e.g. additional station)	3	Medium	35%	65%	£50,000,000	£100,000,000	£200,000,000	£54,166,667
Environmental	Extent and activity of contaminated land different from expected	Cost of treatment and disposal	3	Medium	35%	65%	£75,000,000	£100,000,000	£150,000,000	£52,083,333
Constructability	Contractor questions constructability of design	Associated costs higher than expected. Programme delay associated with alternative methods	2	Low	5%	35%	£120,000,000	£240,000,000	£360,000,000	£48,000,000
Non-Statutory Stakeholders	3rd party objections to construction methodology	Delay owing to restricted working hours. Cost of more expensive methods	2	Low	5%	35%	£120,000,000	£240,000,000	£360,000,000	£48,000,000
Environmental	Unexpected discovery of archaeological artefacts	Cost of expert investigation. Programme delay whist investigate	2	Low	5%	35%	£120,000,000	£240,000,000	£360,000,000	£48,000,000
Project Scope	Interfaces with proposed developments (e.g. BAA , LUL, Crossrail, HS1, other railways). Terminal points unclear	Cost of scope changes to integrate with interfacing schemes	2	Low	5%	35%	£100,000,000	£200,000,000	£400,000,000	£43,333,333
Railway Technology	Emerging technical equipment unavailable in time (e.g. ERTMS)	Cost of modifying scheme to match available technology Programme delay whilst rework design	2	Low	5%	35%	£100,000,000	£200,000,000	£300,000,000	£40,000,000
Railway Technology	Obsolescence of technical equipment (e.g. GSM switched off)	Cost of providing replacement/alternative equipment. Applies to pre-construction phase	2	Low	5%	35%	£100,000,000	£200,000,000	£300,000,000	£40,000,000
Optioneering	Unreliable optioneering process (e.g. options mistakenly parked) owing to for example insufficient EIA (significant environmental issue overlooked)	Cost of rework and associated delays Adverse effect on HS2 reputation	2	Medium	35%	65%	£5,000,000	£75,000,000	£150,000,000	£37,916,667
Input data	Incorrect input data leads to incorrect scope definition	Cost of redesign and associated works	3	Medium	35%	65%	-£50,000,000	£75,000,000	£200,000,000	£37,500,000
Land	Additional commercial property at risk due to proximity to rail corridor	Acquisition of additional properties (and subsequent resale potential?)	2	Medium	35%	65%	(£40,000,000)	£50,000,000	£156,000,000	£26,333,333
Land	Uncertain land acquisition costs	Land costs higher than expected. Legal process delays land take	3	Medium	35%	65%	(£30,000,000)	£50,000,000	£120,000,000	£24,166,667
Traction Power	Additional cost incurred connecting to National Grid / additional cabling required	Additional power supply scope / cost / redesign	2	Medium	35%	65%	20000000	£40,000,000	£100,000,000	£23,333,333
Waste	Waste regulation changes	Related costs of treatment/disposal higher than expected	2	Low	5%	35%	£50,000,000	£100,000,000	£150,000,000	£20,000,000
Design Standards	Changes in standards (e.g. TSIs) during design lifecycle	Cost of designing to alternative standards	2	Low	5%	35%	£30,000,000	£50,000,000	£75,000,000	£10,166,667
HS&E Standards	H&S standards change	Cost of mitigation (e.g. clearances, safety fencing) increases	2	Low	5%	35%	£30,000,000	£50,000,000	£75,000,000	£10,166,667
Environmental	Adverse effect of noise and vibration	Floating slab track required in tunnels and restricted choice of viaduct solutions	3	Medium	35%	65%	£10,000,000	£20,000,000	£30,000,000	£10,000,000
Project Scope	Enabling works delayed or cancelled (e.g. LUL)	Cost of enabling works borne by HS2	2	Low	5%	35%	£20,000,000	£40,000,000	£60,000,000	£8,000,000
Design Standards	Major incident on HSL	Alteration of standards introducing rework at increased cost Higher cost of risk financing (e.g. insurance cover)	4	Minimal	0%	5%	£50,000,000	£150,000,000	£250,000,000	£3,750,000
Constructability	Efficiencies in construction of elevated structures	Elevated scope cost reduced	2	Medium	35%	65%	(£150,000,000)	(£75,000,000)	£0	(£37,500,000)
Procurement	Continental construction rates achieved	Tender prices reduced	2	Low	5%	35%	(£1,500,000,000)	(£100,000,000)	(£50,000,000)	(£65,000,000)

Total	£1,239,916,667

Appendix E: Phase two programme level risks

Risk Identification		Analysis					
Risk Description **There is a risk / issue that…**	**Consequence** **This will result in…**	**Prob %**	Design delay	Build delay	**Min Cost**	**Most Likely**	**Max Cost**
Interfaces with other developments unclear until later	Scope & design changes to integrate with other schemes, compensation and/or change to tunnel	68%	y	-	50	250	500
Value of pound and any imported costs fluctuate	Increase scheme costs	25%	y	y	350	525	700
Cost escalation for general material price fluctuations	Added cost	25%	-	-	350	525	700
Consultations / approvals necessitate more tunnel	Added costs for Green Tunnels AND FOR more bored tunnels	68%	y	-	20	100	300
During design development as more detail of mining (coal, limestone, salt etc) becomes known (present and past) - designs must change adding cost	Additional works and costs	68%	y	-	10	80	200
Inaccurate input data (whether strategic or site-specific) leads to scope change (e.g. tunnels, shafts etc), or incorrect option chosen	Increased Cost, Design Change & delay (see also mining/landfill discoveries)	38%	y	-	20	100	400
Statutory Technical Approval bodies require changes inc. H&S & Design Standards	Change, delay and added cost	68%	y	-	5	60	120
By not declaring route, developments occur making the route infeasible or excessively costly	Delays and added cost	68%	y	-	10	50	100
Accommodation works e.g. routes which split land may necessitate unplanned link/bridge etc.	Additional design and cost	68%	-	-	20	50	100
Changes in Cities (inc station) disrupt road traffic and necessitate additional highways works	Delays, additional work and costs	38%	y	-	10	80	200
More costly land acquisition, more temporary or permanent rehousing required to gain access, and more noise insulation than planned is required	Added cost	30%	y	-	10	75	200
Design of Interfaces worse than planned (systems integration) e.g. neutral sections, crossovers and engineering siding. May require route revision	Redesign, delays and added costs	30%	y	-	20	60	250
Inappropriate procurement strategy used. Tender rates exceed plan or contractor insolvency	Increased cost &/or financial risk	10%	-	y	50	200	500
Unexpected contamination found	Delay and added cost	30%	-	y	20	75	125
Currently no clear international standards for 400 kph Railway. Risk that assumptions may prove insufficient requiring wider structures/extra land	Design change and costs	15%	y	-	10	80	500
Extreme or unexpected weather conditions	Delay and added cost	38%	-	y	0	50	100

Risk Identification		Analysis					
Risk Description **There is a risk / issue that…**	**Consequence** **This will result in…**	**Prob %**	Design delay	Build delay	**Min Cost**	**Most Likely**	**Max Cost**
Contractor or 3rd party objections to construction methodology	Delay & cost for restricted working etc	25%	y	y	15	75	150
Utilities unknown and allowance proves insufficient (especially those hidden below ground)	Additional cost and delays versus current cost assumptions	38%	y	y	25	50	75
Insufficient strength of formation for higher speeds necessitates firmer more costly formation (track foundation) (Separate from 707D above)	Delays, additional work and costs	20%	y	-	20	80	200
Public and neighbourhood pressure lead to more retained cutting rather than earthworks	Added costs	38%	-	-	20	40	100
Scope creep	Increase scheme costs	10%	y	-	50	100	500
Change in status (e.g. Listing or Site of Special Interest)	Additional costs, may necessitate route relocation	50%	y	-	10	20	100
Ground collapse during tunnel construction	Delay, additional work and costs	15%	-	y	10	80	250
Legislation change (e.g. climate change) put extra constraints and costs on works	Added costs, delays	38%	y	-	10	40	60
Steel & rebar price fluctuation (steel for structures, rails etc) and also therefore supply risk too.	Added cost	15%	-	y	45	90	180
Moving power line - provision to be made	Additional costs (10% of route = 20km)	50%	y	-	10	25	50
Tunnelling process may cause groundwater contamination or blockage of flows	Major environmental remedial work	15%	-	y	10	80	150
Ground condition not as expected, necessitating revised designs and ground works	Delay and added cost	25%	-	y	10	40	100
Proximity to existing roads / rail (especially at tunnel portals) necessitate unplanned reinforcement of those roads /rail structures	Additional works and costs, disruptions to local residents	15%	-	-	10	80	100
Costs/rates not as assumed	Added cost	10%	-	-	10	50	400
Adverse Noise & Vibration necessitates use of higher cost track bed than planned	Increased Cost	25%	y	-	10	40	75
Encountering mine water in cuttings	Leads to separate drainage solution being required (e.g. reed beds) which may also require additional land take	38%	-	y	5	25	50
Provision for ongoing maintenance of landfill gases and contaminants etc - may need to buy extra land	Additional costs	50%	-	-	10	20	30
Trying to build too much at once, stretches resources (manpower, materials, kit, TBMs etc) and reduces competition	Delay and added cost	15%	-	y	5	20	250
Footprints change (e.g. need to re-align highways etc) and may necessitate additional building purchase/ demolition, sustainability assessments and possible impact on neighbouring sites	Delays, additional work and costs	38%	y	-	5	20	50

Risk Identification		Analysis					
Risk Description **There is a risk / issue that…**	**Consequence** **This will result in…**	**Prob %**	Design delay	Build delay	**Min Cost**	**Most Likely**	**Max Cost**
Increased barrier size/strength required between motorway and HS2 when side by side	Additional work and costs	38%	-	-	10	20	50
Labour price fluctuations; new minimum wage etc	Added cost	15%	-	-	25	50	100
Protests, industrial strikes	Delay and added cost	15%	-	y	0	50	100
Unexpected archaeological discovery	Delay and added cost	25%	-	y	5	25	75
Water source protection zone requires added control and drainage	Additional cost	25%	-	y	5	25	75
Obsolescence of technical equipment so that replacement/alternative equipment must be provided. (e.g.. GSM switched off)	Change in costs	15%	y	-	5	50	75
Lack of Construction Specialists (e.g. Tunnellers) and Plant owing to excess demand	Increased tender prices - and delay for available resource	10%	-	y	25	60	150
Unknown landfill locations	Cost for remedial works - and increased cost for structures	25%	-	-	10	25	50
Viaducts/underbridges require to be widened for increased walkway	Design change and costs	15%	-	-	20	20	150
Current maintenance allowance not adequate (400Kph tolerates less settlement). Increased spec planned to reduce the future operating risk	Higher spec build to minimise the future operating risk of increased maintenance costs/disruption	15%	-	-	18	36	72
Unexploded ordnance found	Delays and added costs	15%	-	y	5	40	50
Programme tight, adds cost to cut lead times	Delays and added cost	15%	-	y	5	20	100
Enabling Works by (or with) other parties (eg NR, Utilities, Highways) delayed or cancelled	Added cost and delay	15%	y	y	5	20	75
Routes under A-Roads necessitate temporary diversions etc, beyopnd what's budgeted	Disruptions and cost	15%	-	-	10	20	50
Excessive infiltration of groundwater due to delay of getting tunnel water tight	Delay, additional work and costs	15%	-	y	10	20	50
Unexpected breaking out of rock	Delay and added cost	38%	-	y	-25	0	50
Unanticipated objections from local lobby groups, Wildlife Trusts, Natural England, National Trust etc.	Changes required during design period	25%	y	-	1	10	20
Unanticipated objections from local lobby groups, Wildlife Trusts, Natural England, National Trust etc.	Delays caused and changes required during construction	25%	-	y	1	10	20
Excess difficulty/cost to relocate displaced and disadvantaged business and private properties, including Listed Buildings	Delays and added cost	15%	y	y	5	10	20
Tunnelling equipment is broken or damaged	Delays while another machine is sourced. Note that there are not many available in the world	3%	-	y	10	25	100
Environmental risk of contamination in flood plains from construction materials	Remedial works, delays and costs	3%	-	y	10	20	100
Waste regulations change	Increased cost for waste treatment and/or disposal	15%	-	-	1	5	15

Risk Identification		Analysis					
Risk Description **There is a risk / issue that…**	**Consequence** **This will result in…**	**Prob %**	Design delay	Build delay	**Min Cost**	**Most Likely**	**Max Cost**
Existing rolling stock may need modification as a result of HS2 rolling stock running on classic network (immunisation)	Additional costs to modify WCML stock & other stock	3%	-	-	2	7	100
Proximity of construction / operation causes disruption to 3rd parties necessitating excessive compensation	Added costs	3%	-	-	0	20	25
Climate differences require more wind & frost protection further North	Additional work and costs	3%	-	-	2	7	10
Approval objections cause delays (Planners, Utilities, Special Interest Groups etc.)	Delays	68%	y	-	0	0	0
Continental Construction Rates achieved	Cost Saving Opportunity	15%	-	-	-500	-200	-50

Appendix F: Optimism bias factors for additional risk provision in phase one

Contributory Factors to upper bound OB (%)			Capital Expenditure 66%	Proposed weighting	Reasoning
Procurement	Complexity of contract structure Late contractor involvement in design Poor contractor capabilities Government guidelines Dispute and claims occurred Information management	N/A at this stage	- - - - - -	- - - - - -	Unchanged. Standard public sector procurement anticipated.
	Other (specify)		2	-	No additional issues identified at this stage.
Project Specific	Design Complexity	E.g. design being built in difficult conditions	8	8	12% route in tunnels;significant viaducts; complex stations at Euston and Old Oak; complex infrastructure West Midlands area. Open line of route zero complexity but retain full weighting.
	Degree of Innovation	New generation design, unusual site conditions requiring innovation	9	-	Technology planned for Day 1 is all available and interoperable, including ERTMS (working in Spain, Italy and Switzerland), relevant train braking technology, power supply. So not an innovation issue - more design complexity which is reflected above and also in link specific construction risks. We have considered our initial approach to construction - no aspects of scope were identified requiring novel construction methodologies. Ground condition risks are addressed in the QRA.
	Environmental Impact	Contamination, noise pollution, impact on wildlife	5	2	Alignment was initially optimised to reduce impacts and has been further amended due to extensive consultation activites undertaken; environmental allowance (up to 5%) is already included in base price; routewide ground condition and contamination risks are included in the QRA figure. Weighting reduced to reflect work already undertaken, but some element of risk remains hence reduced weighting.
Client Specific	Inadequacy of the Business Case	Output specifications not clearly defined, number of services were not anticipated, oversight in facilities required, full range of stakeholder needs not identified and included	35	10	The infrastructure specified already has a high degree of futureproofing in-built such as the number of platforms specified at each of the four stations in relation to the proposed levels of service for Day One, the size of the rolling stock depot and the technical capability of the route (specified to support up to 18 tph each way, Day One current service assumptions are for 11 tph and we have undertaken extensive work to validate the technical feasibility of sustaining 18tph; maximum design speed of 250mph specified, Day One services expected to run at a maximum of 225mph and evaluation work undertaken to confirm that there is no case for running at even higher speeds). The proposed route and specification has been subject to wide review and formal consultation during the last two years, resulting in a large numbers of route amendments which have been incorporated within the proposed alignment to address stakeholder concerns; the risk of subsequent changes to the specification and parts of the route has been mitigated to a significant extent (although not eliminated). We have also made provision within our cost estimate for environmental mitigation work. The number of sets required to operate the defined Day 1 services already include strengthening assumptions where permitted by the infrastructure available. Actions have significantly mitigated this major factor, however a degree of risk remains.
	Large number of stakeholders	Different public sector parties have different interests in project, approvals takes longer due to number of parties involved	-	2	Active stakeholder management strategy already being implemented, risk reduced but still exists.
	Funding availability	Difficulties in obtaining financial backing, additional funding available later causing scope change	5	5	Weighting unchanged.
	Project Management team	Inexperienced project delivery team; inadequate drawing review before construction	2	2	Experienced Development Partner to be engaged at earliest stage possible to work with HS2 in specifying and then managing design contracts. Engineering design framework contracts being activated immediately following Development Partner arrival to provide sufficient scale and quality of engineering design resource including appropriate design checks. Weighting not amended recognising that these capabilities are to be implemented once HS2 governance arrangements confirmed should scheme proceed.
	Poor Project Intelligence	Insufficient ground investigation, detailed design based on insufficient site information, insufficient surveying of existing conditions	9	9	Provision made for surveying / ground investigation commencing start of 2012, not appropriate to have undertaken prior to confirmation of preferred alignment. Note routewide QRA includes allowances for ground conditions and buried services. Weighting retained.
Environment	Public Relations	Local community opposition, environmental protests	-		
	Site Characteristics	Protected wildlife within site, underground streams to protect, archaeological findings	5	3	AoS strategic level appraisal has been undertaken and used to inform alignment development, work continues throughout subsequent stages mitigating the impact of this risk. Routewide risks already include some provision for archaeological finds and rework associated with environmental impact assessment. Weighting reduced to reflect mitigation and provision in QRA.
	Permits / Consents / Approvals	Parliamentary Bill required, difficulties in obtaining planning permision, appeals to SoS	-	-	Active stakeholder engagement across all parties and potential consitituencies ongoing however this will remain a major risk for time being
	Other (specify)		-	-	We have considered the risks of schedule delay arising from difficulties in obtaining approvals or progressing works on site due to issues arising with consultees or other stakeholder objections and made provision in our QRA.
External Influences	Political	Opposition by major political party, impact on sensitive constituencies, lacks support from key political stakeholders	-	-	Active stakeholder engagement across all parties and potential consitituencies ongoing however this will continue to remain a major risk for time being
	Economic	Change in market demand causing changing funding priorities, stock market crash	3	3	Weighting retained (but no PFI assumed)
	Legislation / Regulations	Change in required standards	8	6	Ongoing risk due to long-term nature of project, however slow rate of change of TSIs and active participation in TSI forum (UIC) already ongoing, so risk partially mitigated.
	Technology	Unanticipated technological advancements, computer virus, limits in technology	8	2	Day 1 technology assumptions for our core sub-systems such as train technology are conservative, technology advancements should present opportunity rather than impact in this context.Our business critial computer-based systems will be specified and subsequently operated with high degrees of firewall protection and security. We have made provision in our QRA for technology related risks such as obsolescence.
	Other (specify)		1	-	No additional issues identified at this stage.
			100	52	
				34.3	% additional risk

Appendix G: Optimism bias factors for additional risk provision in phase two

Contributory Factors to upper bound OB (%)			Capital Expenditure 66%	Proposed weighting	Reasoning
Procurement	Complexity of contract structure Late contractor involvement in design Poor contractor capabilities Government guidelines Dispute and claims occurred Information management Other (specify)	N/A at this stage	- - - - - - 2	- - - - - - -	Unchanged. Standard public sector procurement anticipated. No additional issues identified at this stage.
Project Specific	Design Complexity	E.g. design being built in difficult conditions	8	7	10% route in tunnels; significant viaducts; Open line of route zero complexity, phase two is less complex than phase one. There are no stations such as Euston or Old Oak Common that added to the complexity of phase one.
	Degree of Innovation	New generation design, unusual site conditions requiring innovation	9	-	None of the technologies identified are unproven and the core systems underpinning our specification are available now. Phase two is also an extension of the application of the technologies used for phase one. The issues are therefore not innovation issues f
	Environmental Impact	Contamination, noise pollution, impact on wildlife	5	2	Alignment has been optimised to reduce impacts; environmental allowance (up to 5%) is already included in base price; route wide ground condition and contamination risks are included in the QRA figure. Weighting reduced to reflect work already undertaken,
Client Specific	Inadequacy of the Business Case	Output specifications not clearly defined, number of services were not anticipated, oversight in facilities required, full range of stakeholder needs not identified and included	35	10	Phase two of the project will benefit from the work carried out to deliver phase one. The infrastructure will benefit from the operations concept work which has highlighted areas where additional work is required to ensure the infrastructure reflects the prop
	Large number of stakeholders	Different public sector parties have different interests in project, approvals takes longer due to number of parties involved	-	2	Active stakeholder management strategy already being implemented, risk reduced but still exists.
	Funding availability	Difficulties in obtaining financial backing, additional funding available later causing scope change	5	5	Weighting unchanged.
	Project Management team	Inexperienced project delivery team; inadequate drawing review before construction	2	2	In line with phase one experience, it is assumed that an experienced Development Partner will be engaged on phase two at earliest stage possible to work with HS2 in specifying and then managing design contracts. Engineering design framework contracts would be
	Poor Project Intelligence	Insufficient ground investigation, detailed design based on insufficient site information, insufficient surveying of existing conditions	9	9	Provision made for surveying / ground investigation commencing during 2015, not appropriate to have undertaken prior to confirmation of preferred alignment. Note routewide QRA includes allowances for ground conditions and buried services. Weighting retain
Environment	Public Relations	Local community opposition, environmental protests	-		
	Site Characteristics	Protected wildlife within site, underground streams to protect, archaeological findings	5	3	Strategic level appraisal has been undertaken and used to inform alignment development, work continues throughout subsequent stages mitigating the impact of this risk. Routewide risks already include some provision for archaeological finds and rework asso
	Permits / Consents / Approvals	Parliamentary Bill required, difficulties in obtaining planning permision, appeals to SoS	-	-	Active stakeholder engagement across all parties and potential constituencies ongoing however this will remain a major risk for time being
	Other (specify)		-	-	We have considered the risks of schedule delay arising from difficulties in obtaining approvals or progressing works on site due to issues arising with consultees or other stakeholder objections and made provision in our QRA.
External Influences	Political	Opposition by major political party, impact on sensitive constituencies, lacks support from key political stakeholders	-	-	Active stakeholder engagement across all parties and potential constituencies ongoing however this will continue to remain a major risk for time being
	Economic	Change in market demand causing changing funding priorities, stock market crash	3	3	Weighting retained (but no PFI assumed)
	Legislation / Regulations	Change in required standards	8	5	Ongoing risk due to long-term nature of project, however slow rate of change of TSIs and active participation in TSI forum (UIC) already ongoing, so risk partially mitigated. - As a risk this is greater for LWM as this will be setting the parameters and standards by which the whole project will be built. Any change in standards post commencement of works on phase one would therefore be harder to apply to phase two as it could, potentially, create a system in-balance. In addition our active participation within the UIC will further help mitigate the impact of any changes to standards
	Technology	Unanticipated technological advancements, computer virus, limits in technology	8	2	Day 1 technology assumptions for our core sub-systems such as train technology are conservative, technology advancements should present opportunity rather than impact in this context. Our business critical computer-based systems will be specified and subseq
	Other (specify)		1	-	No additional issues identified at this stage.
			100	50	
				33.0	% additional risk