High speed rail international benchmarking study

HS2 Phase Two

November 2016

pwc

Contents

Foreword

The UK has a reputation for great engineering and we are once again investing heavily in different forms of infrastructure to support economic growth and social cohesion. HS2 is one of the major programmes that aim to transform our transport infrastructure, with HS2 Ltd established as a new organisation to plan, construct and operate the railway. A number of studies[1] have shown that in some circumstance the UK delivers infrastructure projects at a higher capital cost when compared to other countries. As a result of the programme phasing and longevity of the delivery organisation, HS2 affords the UK rail sector, and wider UK infrastructure industry, a significant opportunity to focus on how major capital projects are planned, developed, constructed and operated; with a view to delivering these major schemes for an appropriate capital cost.

This comprehensive study was commissioned by the Chancellor of the Exchequer and Secretary of State in December 2014 to examine ways for the UK high speed rail community to learn from international experience and deliver HS2 Phase Two within budget. The study looked at 32 comparator high speed rail schemes, with interviews and site visits across Europe. An expert panel was formed, chaired by Sir John Armitt, to direct the analysis and oversee the study findings.

The study found that the early estimate of £81m per route km for the capital cost of HS2 Phase Two[2] is at the high end of the range of costs of international high speed rail schemes. This finding must be taken in context of significant differences in the strategic objectives, UK conditions and sponsor requirements of HS2 Phase Two when compared to the majority of European high speed rail schemes; and with the expectation that this early stage capital cost estimate will mature as the scheme moves through the standard design and cost maturity process.

The scale and scope of the HS2 scheme and the creation of a new HS2 Ltd infrastructure delivery and railway operation company make the programme materially different to other high speed rail schemes. The declared objectives of 'Rebalancing Britain' and being an 'Engine for Growth' drive costs that cannot be avoided without reductions in strategic outcomes. There are further differences including: the high level of forecast passenger demand; the high levels of existing infrastructure density in the UK; the availability of existing rail corridors to enter city centres; and the challenging topography; all of which combine to limit opportunities for cost reduction.

There are other differences that do offer potential opportunities to optimise the cost and programme efficiency and reduce the capital cost of HS2 Phase Two – the study estimated that based on the early estimates of HS2 Phase Two these opportunities could be up to 27%. If fully realised these opportunities could reduce the capital cost to £59m per route km or £19.9bn[3].

The majority of the potential savings come from the ability to reduce supply chain inefficiencies and through adopting comparators' ways of designing and building high speed rail assets in a more integrated way. A smaller proportion of the savings are derived from localised route and scope refinements, while protecting the delivery of the strategic objectives.

Since the completion of the initial benchmarking work 18 months ago, HS2 Ltd and DfT have incorporated many of the lessons from comparator projects and made a number of material changes to the early stage design and route. It is good to see that benchmarking has been incorporated into the control and management of the HS2 programme, supporting a greater focus on design to cost throughout the programme lifecycle.

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[1] Previous IUK studies found UK project capital costs are typically 10-30% greater than European projects.

[2] Expressed in 2011 prices including contingency allowance.

[3] Expressed in 2011 prices including contingency allowance, based on the M18/Eastern route option.

We are grateful for the contribution of over 30 global transport organisations from the public and private sectors, including personal input from over 20 industry senior executives. HS2 Ltd also gave the study unconstrained access to available data and information and a significant amount of access to the Phase Two delivery teams and Technical Directorate, for which we are also very grateful.

Sir John Armitt

Chairman IBS Panel

Jamie Houghton

Partner PwC LLP

Executive summary

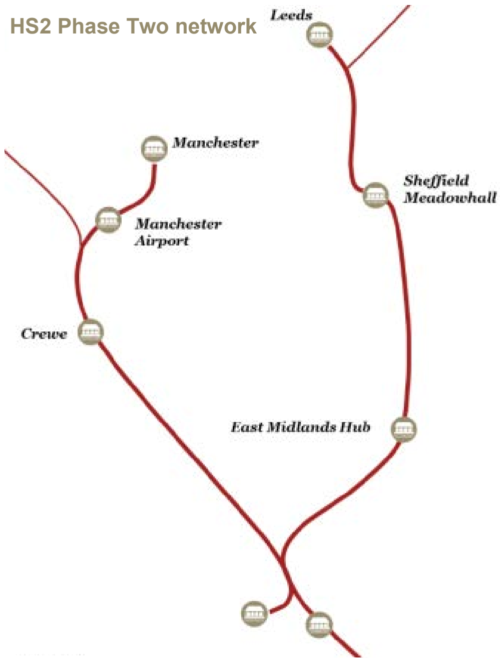
The International Benchmarking Study

The International Benchmarking Study (IBS) was undertaken in 2015, when the capital cost and schedule estimates for Phase Two reflected the early stage of design. It was anticipated that the level of definition and certainty in these early estimates would increase as the design developed and as lessons are learnt from Phase One.

The study identified five key drivers of capital cost when delivering a high speed railway in the UK:

1. The **strategic objectives** of the proposed railway;
2. The **UK infrastructure context** and programme **sponsor's requirements**;
3. The programme **delivery model and the UK industry**;
4. The **design requirements and the assets** to be built; and
5. The **process for developing the scope** of the programme and the cost and schedule estimate for it.

Looking at each of these drivers, the study identified a number of significant differences between HS2 Phase Two and other international high speed railway projects. Some of these differences are **explained differences in capital cost,** which offer no, or limited opportunity to reduce capital costs or benefit the delivery schedule. Other differences do present **opportunities to make capital cost and schedule savings** while continuing to deliver the benefits of HS2 Phase Two.



Explained differences in capital cost

Strategic objectives: Some of the differences in capital cost are driven by HS2's strategic objective of improving connectivity to enable regional growth, and a more balanced economy. This requires three new stations[4] to be provided at intermediate points. This is different from many comparators, which tend to have fewer on line intermediate stations. These objectives drive costs that cannot be avoided without reductions in strategic outcomes and benefits.

UK infrastructure context & **sponsor's requirements:** The high level of forecast passenger demand that underpins the business case for HS2 Phase Two, and the capacity constraints on the existing conventional railway, drive a need for dedicated high speed lines into city centre terminal stations at Manchester and Leeds. These requirements drive higher costs when compared with overseas comparators that often use existing conventional railways to enter city centres. The location and complexity of intermediate stations in urban or semi-urban locations, and the number of platforms required to serve the passenger demand, also increases capital costs against comparators that tend to locate intermediate stations in more rural areas. These cost differences do not present an opportunity to reduce cost or schedule without fundamentally changing the business case for HS2 Phase Two.

[4] The Sheffield Meadowhall station and route were part of the baseline used for the study

There are further differences which combine to limit opportunities for cost reduction including: the higher density of existing infrastructure; population density and distribution; the challenging topography of the UK; and the proximity and crossing of existing transport corridors.

Opportunities to optimise cost and schedule efficiency

Other differences identified by the study, offer opportunities to optimise the cost and programme efficiency and reduce the capital cost. The study estimated that these combined opportunities could reduce the early estimated capital cost of HS2 Phase Two by up to 27%. Considering the fact that the early estimate was at £27bn or £81m per route km[5] (including contingency expressed as optimism bias, proportionate to the early stage of design), this reduction to a cost optimised scheme offers an opportunity to reduce the capital cost to £59m per route km.

Delivery model and the UK industry: The construction industry in the UK is more fragmented than in other countries, which increases layering of costs in the supply chain (where administration costs, profits and risk premiums are added at each tier), reduces investment and creates inefficiencies in design and construction. This presents opportunities for cost and schedule reduction through the application of delivery, contracting and procurement models that reduce layering, create a closer affinity between design and construction, and encourage investment in staff development, innovative designs and construction equipment. There is an opportunity for HS2 Phase Two to benefit from supply chain related improvements that are realised through Phase One; although further medium and long term interventions may also be required.

In the longer term, Government commitment to infrastructure and high speed rail should further encourage the industry to invest, create longer term partnering relationships or industry consolidation, and therefore generate greater efficiencies. Encouraging continuous improvement within individual major projects and between different major projects should result in greater continuity of client teams, suppliers and supply chain teams, and allow the industry to move away from an inefficient stop-start approach to discrete projects.

Design requirements and assets: The study found that key assets were being developed to higher specifications on HS2 Phase Two than some comparator schemes. There are opportunities to reduce costs through: revisiting the maintenance strategy to reduce the requirements for depots; delivering stations through adopting practices from international projects; optimising the technical requirements, standards and specifications for HS2; and maximising the application of efficient construction methodologies.

The study identified smaller opportunities to reduce the cost of HS2 Phase Two through localised refinements to the route and alterations to the scope of some stations and major structures, while protecting the delivery of the strategic objectives. There are also opportunities to reduce costs further through delivering some key assets in phases. However, any options to do so should be carefully assessed so that deferment of parts of the scheme does not result in a failure to attract passengers, or increase the total capital cost.

Scope and estimate development processes: The requirements, designs, and cost estimates available at the time of the study were under continuous development, as would be expected at such an early stage in the project lifecycle. There is limited experience of delivering high speed rail schemes in the UK, which has resulted in limited access to historical capital and whole-life cost data. Whilst this does not lead to an opportunity to directly reduce cost or accelerate the schedule, further improvements in confidence in forecasts will enable improved decision-making to optimise the specification and scope of the scheme.

Comparator projects are seen to have affordability constraints established at an early stage and to have a more detailed consideration of cost in all alignment, design and scope decisions. The study concluded that HS2 Phase Two would benefit significantly from an affordability target that is established through a rigorous understanding of the assets to be delivered. At the end of this report we have set out further recommendations that aim to support the creation of an environment that will allow HS2 Phase Two to optimise cost and schedule efficiency. HS2 Ltd, the Department for Transport, Her Majesty's Treasury, UK Government and the UK industry all have a role to play in meeting the challenge of delivering HS2 Phase Two, and other future UK major infrastructure projects, to optimal cost and schedule.

[5] Expressed in 2011 prices

A note on estimates

The IBS used a Phase Two capital cost estimate from April 2015, originally in Q2 2011 prices, for the purposes of comparison with international high speed rail projects. This estimate represented an early stage of design and estimating maturity and was being refined and developed throughout the study and up to the 2015 Spending Review in November 2015. Some adjustments to the Phase Two estimate were made to allow for comparison to international projects.

Throughout this publication three definitions are used:

- Estimate: The internal cost forecast that reflects the current scope and design assumptions with allowances made for planned efficiencies and risk contingencies.
- Budget: The budget envelope set by the client organisations (DfT and HMT) that the project must be delivered within, inclusive of contingency.
- Target: An additional figure used to challenge the delivery organisation to beat the budget.

Introduction

Structure of this report

This document is structured as follows:

Introduction sets out the objectives for the study and the breadth and depth of the methodology.

The costs of international high speed rail provides analysis of international comparator project capital costs presented in £m per route km at an overall level, and also looks at how those costs break down in a number of ways, by asset type.

The HS2 Phase Two scheme introduces the 2015 status of HS2 Phase Two and the maturity of the cost and schedule estimate at that time.

How HS2 Phase Two compares with international high speed rail provides a breakdown of the differences that drive capital costs and the opportunities available to HS2 Phase Two. These differences and opportunities are discussed against a number of key cost drivers.

Findings and recommendations provides a summary of the main findings and recommendations.

All prices in this section of the report are quoted in 2011 values.

Objectives

At the request of the then Chancellor of the Exchequer and the Secretary of State for Transport, our commission was for a comprehensive report that benchmarks HS2 Phase Two capital costs against other international high speed rail projects. We were asked by HS2 Ltd[6] to undertake an independent, wide ranging and comprehensive study to allow the identification of ambitious cost and schedule savings for HS2 Phase Two via comparison with international high speed rail projects[7].

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[6] Under tendered contract reference HS2/797 dated 30/01/2015

[7] With a focus on European projects

The study reviewed over £230bn of high speed rail projects across 8,261km of railway in 12 countries

£230bn
12 countries
8,261km

The study included the review of technical data from 32 international high speed rail comparator schemes

Approach

To achieve the remit, the study undertook a comprehensive review of high speed rail projects from around the world. To support the credibility and independence of the study, a senior advisory panel of industry experts and senior civil servants was formed. The panel, which convened periodically to provide guidance and challenge to the PwC study team, was chaired by Sir John Armitt and included the Government's chief construction adviser Peter Hansford, the Italian high speed rail expert Claudio Capriati and PwC's senior economic adviser Andrew Sentance. Steve Hudson, HS2 Ltd.'s Phase One Commercial Director, and Alan Couzens, of Infrastructure UK (IUK[8]), attended the panel sessions as observers.

The study sought to identify differences between the challenges faced by HS2 Phase Two and those faced by other international high speed railways, and differences in the approaches taken to delivering high speed rail schemes by overseas comparators. These differences and the resulting opportunities for realising greater efficiencies became the focus of the study.

The study team undertook in-depth qualitative and quantitative technical reviews to inform the study. This included the review of technical data from 32 international high speed rail comparator schemes, 11 international workshops and site visits, and 110 interviews with subject matter experts from 12 countries. Insight has been further augmented by desktop reviews of over 50 economic research and transport benchmark papers.

As with all benchmarking studies it has been impossible to find any two identical major infrastructure projects in the same phase of design and build, within a comparable economic environment. To minimise the inherent challenges this presents, the study has normalised data and been selective on the routes and specific characteristics that have been selected for comparisons. We are confident that, while no two comparisons can be perfect, the comparative data presented in the report is robust and has enabled sound comparisons to be made.

The study does not cover the potential impacts of cost saving opportunities on the benefits of HS2 Phase Two or whole life cost considerations.

[8] IUK has now merged with the Major Projects Authority to create the Infrastructure and Projects Authority (IPA)

Key Comparators Summary

World map with key comparators highlighted

Key:

- Cost comparators
- Key similar characteristic comparators

Total Comparator Projects	Cost Comparators	Key Similar Characteristic Comparators
32	20	12

8,261 HS Route Length of Comparators (km)

1,629 Number of comparator bridges and viaducts

135 Number of comparator tunnels

69 Number of comparator stations

The costs of international high speed rail

£32m per route km

Average cost of high speed rail comparators

The costs of international high speed rail projects range from £11m per route km to £79m per route km[10]

The study drew on costs from high speed rail projects that were completed at different times and in different currencies. Therefore international benchmarking cost data has been normalised into GBP in 2011 prices, this being the base year in which the original funding envelope of £21.2bn for HS2 Phase Two was set.

The benchmark data indicates that high speed rail lines can be delivered under certain circumstances at an average cost of £32m per km[9], based on data from 20 European comparator projects and over 3,400 route kilometres. These comparisons are based on costs of infrastructure, including stations, railway systems, and depots, which differ in number between schemes. A significant variance exists in the cost per kilometre of comparator high speed rail projects, with schemes ranging from £11m per km to £79m per km.

Typically rural routes that require little interface with existing infrastructure along the line of route, can be delivered for between £11m per km and £20m per km. In comparison, more urban routes, or those that have a high density of existing infrastructure, are typically delivered for between £43m per km and £61m per km.

High speed rail schemes that require a high proportion of the route to be in tunnel have proven to be the most expensive lines to construct, typically costing up to £79m per km. The study has found that subsections of schemes that mainly consist of tunnels and viaducts can commonly cost between £72m per km and £93m per km.

The following pages present the range of costs of international high speed rail schemes investigated by this study, breaking down costs in several different ways as follows:

- Cost per route kilometre, both as an average across the entire schemes and separated for those sections of the line with different topographical characteristics;
- Types of ancillary cost, including indirect costs, land and property costs and contingency; and
- Civil asset costs, including tunnels, viaducts and earthworks.

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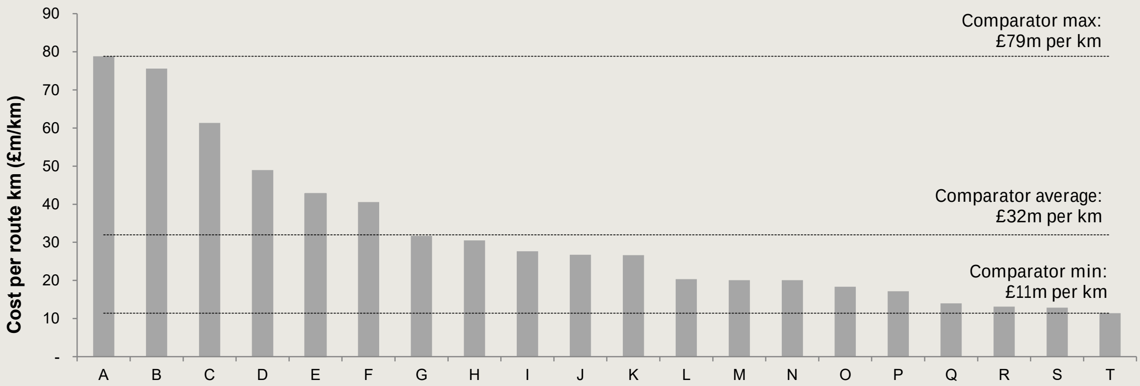
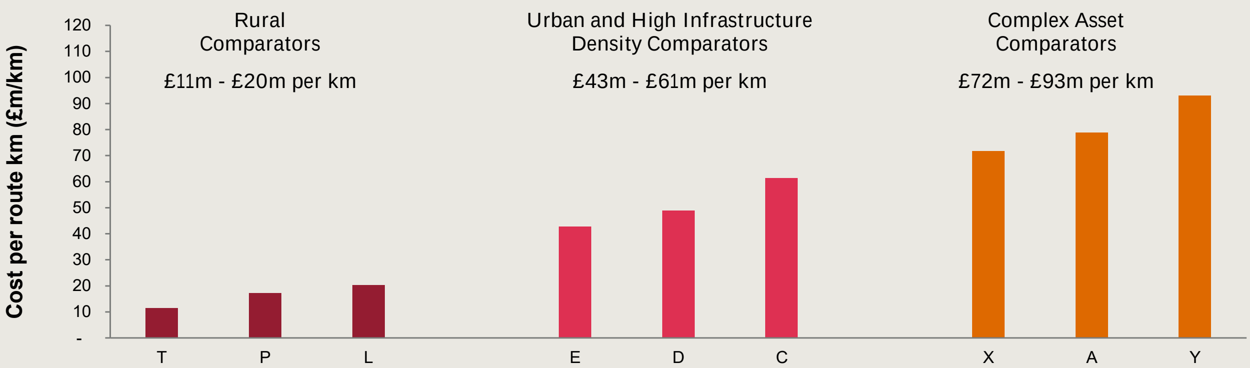
[9] Throughout this report £/km refers to route kilometres.
[10] Prices are quoted in 2011 values.

Comparator costs per kilometre



Urban, rural and complex asset sections of international high speed rail schemes



Notes on analysis

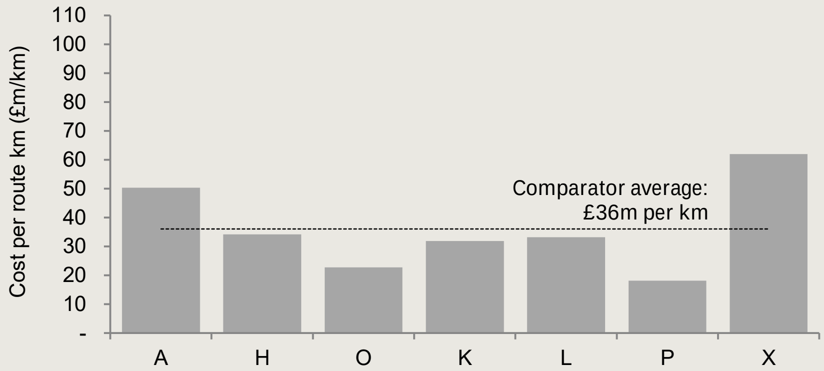
- Comparator costs were converted into 2011 prices using GDP deflators and into GBP using Purchasing Power Parity (PPP) exchange rates. It would have been possible to use construction price indices instead of GDP deflators but we chose the latter in order to be consistent with approaches used in other studies. It would have been possible to use Market Exchange Rates (MER) instead of PPP exchange rates but we chose the latter because most construction costs involved in high speed rail are likely to be domestically sourced. We think the approach we have used is appropriate given the task in hand, which was to obtain a reasonable (rather than precise) estimates of comparative costs. Source: GDP deflator and GDP at PPP data is sourced from International Monetary Fund World Economic Outlook 2014.
- Urban/rural classification is calculated by evaluating the percentage of the section/block of the route within 1km of urban conurbation: Less than 25% is classified as rural and greater that 45% is classified as urban and of high infrastructure density. The complex asset classification has been defined as comparator routes which require a high proportion of tunnelling or elevated structures.
- The majority of comparator values are based on outturn costs, with a small number based on forecasts. Comparator data has been anonymised due to the commercial sensitivity of some privately financed and constructed schemes. Note that the letters used to identify comparators are not consistent between different charts, to protect anonymity.

Civil asset costs

The major categories of civils assets on a high speed rail scheme are tunnels, structures and earthworks.

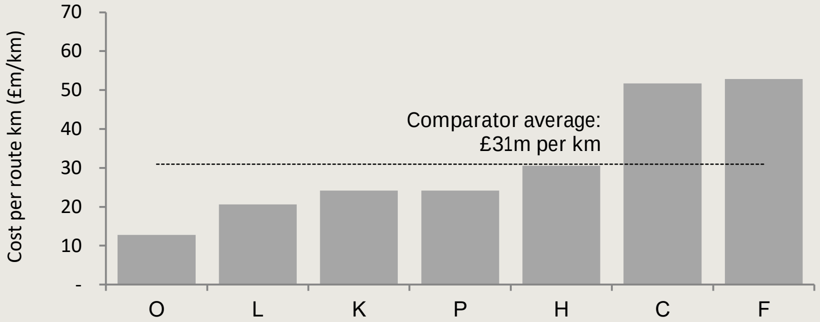
Tunnels

The costs of tunnels range from £18m per km to £62m per km, with an average of £36m per km across the comparators.



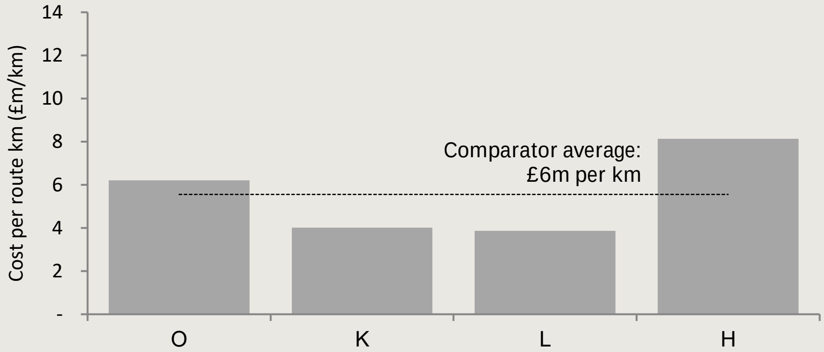
Viaducts

The costs of viaducts range from £13m per km to £53m per km, with an average of £31m per km across the comparators.



Earthworks

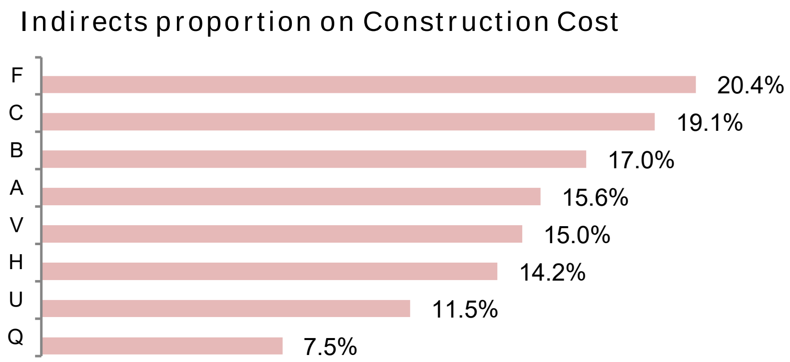
The costs of earthworks range from £4m per km to £8m per km, with an average of £6m per km across the comparators.



Ancillary costs

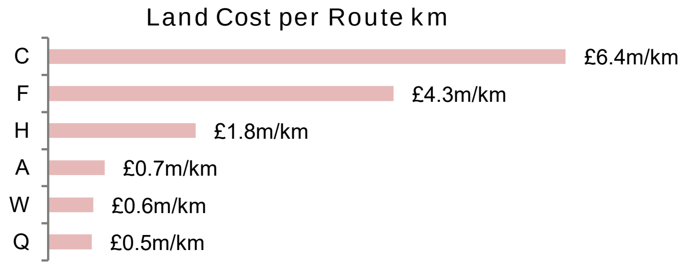
Indirect costs

Indirect costs include cost components like project management, design and project insurance. Reported indirect costs for the international comparators vary from 7.5% to 20.4% of construction costs.



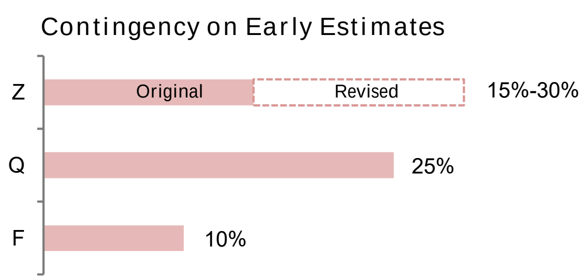
Land and property costs

The costs of purchasing the land and property required to enable the railways to be constructed vary from £0.5m per km to £6.4m per km on the comparator high speed rail projects.

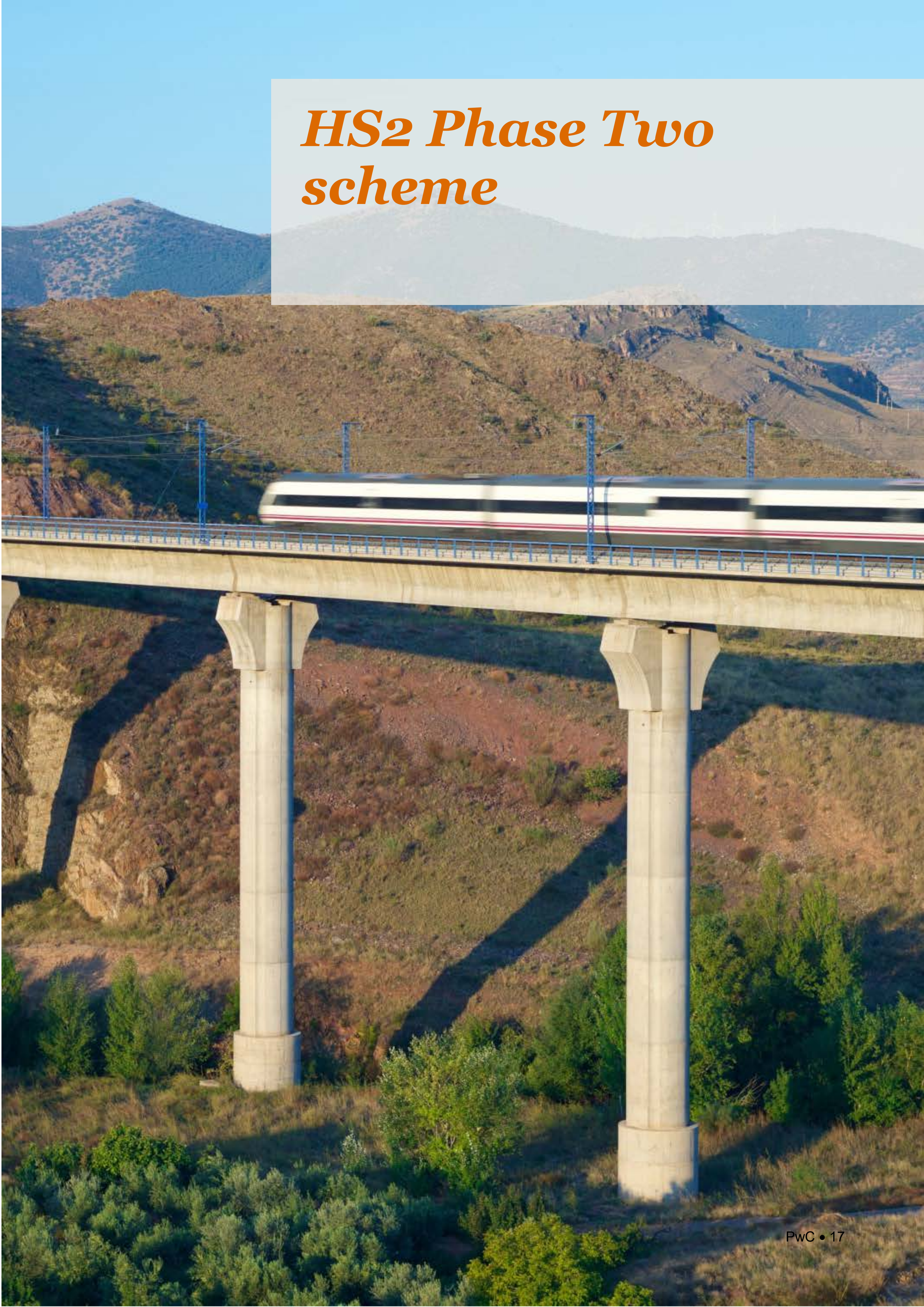


Contingency

Contingency allowances are set to provide cover against uncertainties in the scope of works or costs. Across the high speed rail comparators, the contingency allowances range from 10% to 30% for projects at a similar stage of estimate maturity.



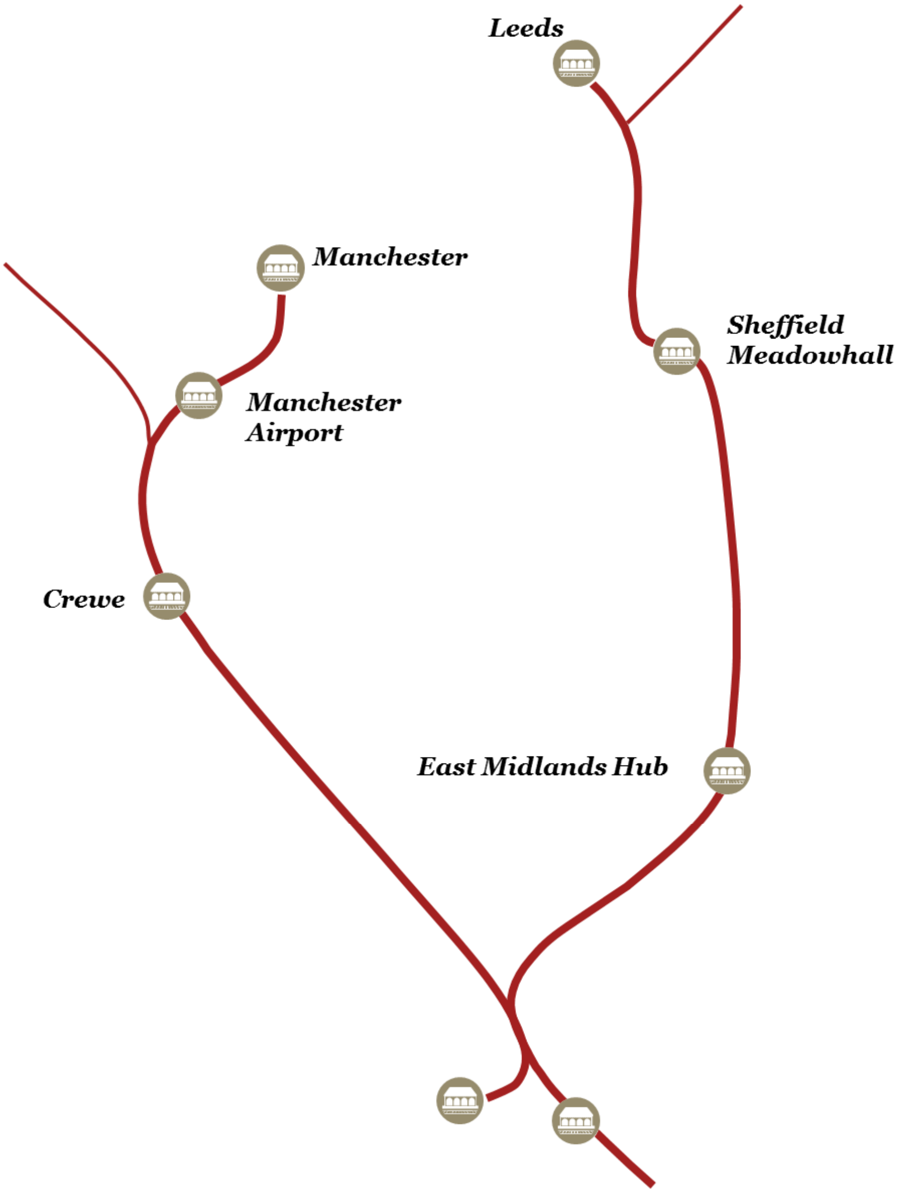
HS2 Phase Two scheme



The HS2 programme in 2015

HS2 Ltd was created to assess the options for constructing and ultimately delivering high-speed rail lines from London to Birmingham ('Phase One') and Birmingham to Manchester and Leeds ('Phase Two'). Since 2010 HS2 Ltd has developed the scheme for the 'Y' network, which included public consultation in 2013, following which the current alignment was developed for the Phase Two route.[11] The process to develop the Parliamentary Bill for HS2 Phase Two is ongoing and it is anticipated that Royal Assent will be achieved in December 2019.

HS2 Phase Two Y network



Source: HS2 Ltd

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[11] Since the completion of this study, HS2 Ltd has proposed an alternative route for the eastern leg, known as the "M18/Eastern route".

A budget of £21.2bn for HS2 Phase Two was set in the 2013 Spending Review based on the Phase Two design that was subject to public consultation. This figure excludes rolling stock but includes rolling stock depots.

Cost and schedule estimate maturity

In 2015, HS2 Ltd had developed a cost and schedule estimate for Phase Two which both reflect the early stage of design, the experience of high speed rail in the UK and the resulting lack of precedent data.

As would be expected at such an early stage in the project lifecycle:

- Scope is only defined at a high-level, in terms of a proposed route alignment and proposed asset types (e.g. tunnels, viaducts, etc.);
- Design is continually evolving, meaning parameters critical to cost remain fluid (e.g. the width of a structure);
- The construction methods and technologies that will be used to deliver the project are not fully defined;
- The schedule is not fully defined and cannot yet account for site-specific access issues; and
- Risks and opportunities can only be analysed at a limited level of detail with the majority of risk allowance being expressed as optimism bias.

The level of definition and certainty of each of these aspects will naturally increase as the design progresses, with the cost and schedule estimates being revisited accordingly. Significant lessons in terms of design requirements, construction methodology, innovation and costs will also be learnt from Phase One

That said, there is sufficient information about the proposed scheme to be able to draw useful comparisons with international high speed rail schemes to identify key differences, and to determine which of those differences present opportunities to optimise the cost and schedule efficiency with which the objectives of HS2 Phase Two can be delivered. These are discussed in the next section.

How HS2 Phase Two compares with international high speed rail

Cost drivers

HS2 Phase Two faces some different challenges to those faced by other international high speed railways, which drive greater costs that are difficult to avoid without changing some of the fundamental objectives of the scheme. However, there are some differences in the approaches taken to delivering high speed rail schemes by overseas comparators that do present opportunities to reduce capital cost and/or the delivery schedule.

Through initial research and drawing on the experience of leading industry figures and global experts, the study identified five key drivers of the cost of high speed rail schemes, as shown in the diagram below.

High speed rail cost drivers

Source: PwC

The study identified five key drivers of cost and schedule differences

Summary of differences and opportunities

For each of the drivers set out in the figure above, the study has identified a number of differences between HS2 Phase Two and the comparator projects. These are termed **cost differences** and can be split into the following groups:

1. **Explainable differences**, where the driver of the cost differences can be explained, but which offer no or limited opportunity to reduce capital costs or benefit the schedule for delivery.

2. Differences where there is an **opportunity** to reduce HS2 Phase Two capital costs and/or benefit the schedule for delivery.

3. The study has also identified a number of areas where there may be a perception that there should be a difference, and hence opportunity, but where this has been found to not be the case.

Summary of cost differences between HS2 Phase Two and Comparator F, and the opportunities they present for capital cost reduction

Differences			Opportunities	
7%	Costs differences attributable to strategic objectives driving the need for intermediate stations	Strategic objectives	This difference does not present an opportunity to reduce cost or schedule without fundamentally changing the strategic objectives of HS2 Phase Two	0%
15%	Cost differences attributable to: • Intermediate station locations and route costs - including topography and high density population and infrastructure • City centre dedicated high speed lines into terminal stations • Land & property costs	UK Infrastructure Context and Sponsor requirements	Opportunities to save cost through localised route and scope refinements	Up to 5%
12%	Cost differences attributable to layered overheads, risk and profit as a result of the structure of the UK supply chain	Delivery model and the UK industry	Opportunities in supply chain through the application of delivery, contracting and procurement models that reduce layering, create a closer affinity between design and construction, and encourage investment in staff development, innovative designs and construction equipment	Up to 12%
5%	Cost differences attributable to: • Depots • Asset costs – civils, structures, railway systems	Design requirements and assets	Opportunities to reduce asset costs through reducing requirements and specifications and employing efficient construction methods	Up to 4%
			Opportunities to reduce requirements for rolling stock and infrastructure maintenance depots	Up to 3%
			Opportunity to apply learning from comparators to deliver stations at significantly lower costs	Up to 3%
10%+	Resulting cost difference attributable to the estimating process and other unexplored drivers	Scope and estimate development process	Improved processes for developing the scope of work and cost and schedule estimates may result in further opportunities being identified	

Summary of cost differences

To provide a meaningful comparison, and to enable quantification of the cost differences, one European high speed line was selected as a single comparator project to illustrate the differences with HS2 Phase Two. This comparator project, referred to as Comparator F, has many similar characteristics, most notably:

- Alignment speed is 400kph and planned maximum operating speed is 360kph;
- Extensive environmental mitigations;
- Tunnelled sections into city centres;
- Dedicated intermediate station; and
- Extensive use of elevated sections

The cost differences between Comparator F and HS2 Phase Two, and the opportunities they might present for cost and schedule reduction, are presented in the figure above and summarised below:

Comparators tend to have fewer intermediate stations and use existing conventional railways to enter city centres

1. Strategic objectives: HS2's strategic objective of improving connectivity to enable regional growth, and a more balanced economy, requires three new stations to be provided at intermediate points. This is different to many comparators, which tend to have fewer intermediate stations, and drives a cost difference of 7% when compared to Comparator F.

   This difference does not present an opportunity to reduce cost or schedule without fundamentally changing the strategic objectives of HS2 Phase Two.

2. UK Infrastructure Context and Sponsor requirements: The business case for HS2 Phase Two and the limited capacity of the existing conventional railway require dedicated high speed lines into city centre terminal stations at Manchester and Leeds. The business case also requires intermediate stations to be provided at East Midlands (Toton), Sheffield and Manchester Airport. These intermediate station locations are also favoured by many local stakeholders and increase public support for HS2.

   These requirements drive costs higher when compared with overseas comparators that use existing conventional railways to enter city centres. The locations of intermediate stations constrain the route alignment, which means less flexibility to avoid challenging topography and areas of high-value land and property. They also have a higher level of complexity and a greater number of platforms when compared to comparators. Overall they drive a cost difference of 15% when compared to Comparator F.

   However, there may be some opportunities to reduce the cost of HS2 Phase Two by up to 5% through localised refinements to the route and alterations to the scope of works for some stations and major structures. There might also be opportunities to reduce costs further through delivering the scheme in phases or making passive provision. Of course, any options to do so should be carefully assessed so that the deferment of parts of the scheme does not result in a failure to attract passengers.

The construction industry in the UK is more fragmented than in other countries

3. **Delivery model and the UK industry**: The construction industry in the UK is more fragmented than in other countries, which increases layering of costs in the supply chain (where administration costs, profits and risk are added at each tier), reduces investment and creates inefficiencies in design and construction. This is estimated to drive a cost difference of 12% when compared to Comparator F.

   This is not a new finding[12], but the scale of HS2 presents opportunities for cost and schedule reduction through the application of delivery, contracting and procurement models that reduce layering, create a closer affinity between design and construction, and encourage investment in staff development, innovative designs and construction equipment. There is also an opportunity for Phase Two to benefit from the improvements in these areas that are realised through Phase One.

   In other countries, the benefits of a multi-year programme of HSR schemes were seen in terms of: the continuity of client professionals; industry investment; innovation; affinity between design and construction functions; use of historical data for structures and risk allowances; and collaboration between client and supply chain. Although these issues are industry wide and broader than HS2 alone, this study concludes that improving supply chain efficiencies, through implementing effective delivery, contracting and procurement strategies, presents cost saving opportunities of up to 12% for HS2 Phase Two. In the longer term, Government commitment to infrastructure and high speed rail plans should further encourage the industry to invest and generate greater efficiencies.

4. **Design requirements and assets**: The specifications of key assets on HS2 Phase Two, such as viaducts, tunnels, stations and depots, are more onerous than on some comparator schemes. Such differences drive a cost difference of 5% when compared with Comparator F.

   There may be opportunities to reduce costs by up to 3% through revisiting the maintenance strategy to reduce the requirements of rolling stock and infrastructure maintenance depots, and by up to another 3% by delivering stations through adopting practices from international projects. Optimising the technical requirements, standards and specifications for HS2, and maximising the application of efficient construction methodologies could unlock further opportunities to reduce costs by up to 4% and reduce the delivery schedule.

5. **Scope and estimate development processes**: As would be expected at such an early stage in the project lifecycle, requirements, designs, and cost estimates represent the current level of development. This is compounded by the limited experience of delivering high speed rail schemes in the UK, which means limited access to historical whole-life cost data. Together these factors drive uncertainty that results in a cost difference of around 10% when compared with Comparator F. Whilst this uncertainty does not directly present an opportunity to reduce cost or schedule, improving confidence in cost estimates will enable effective analysis and decision-making to optimise the scope of the scheme.

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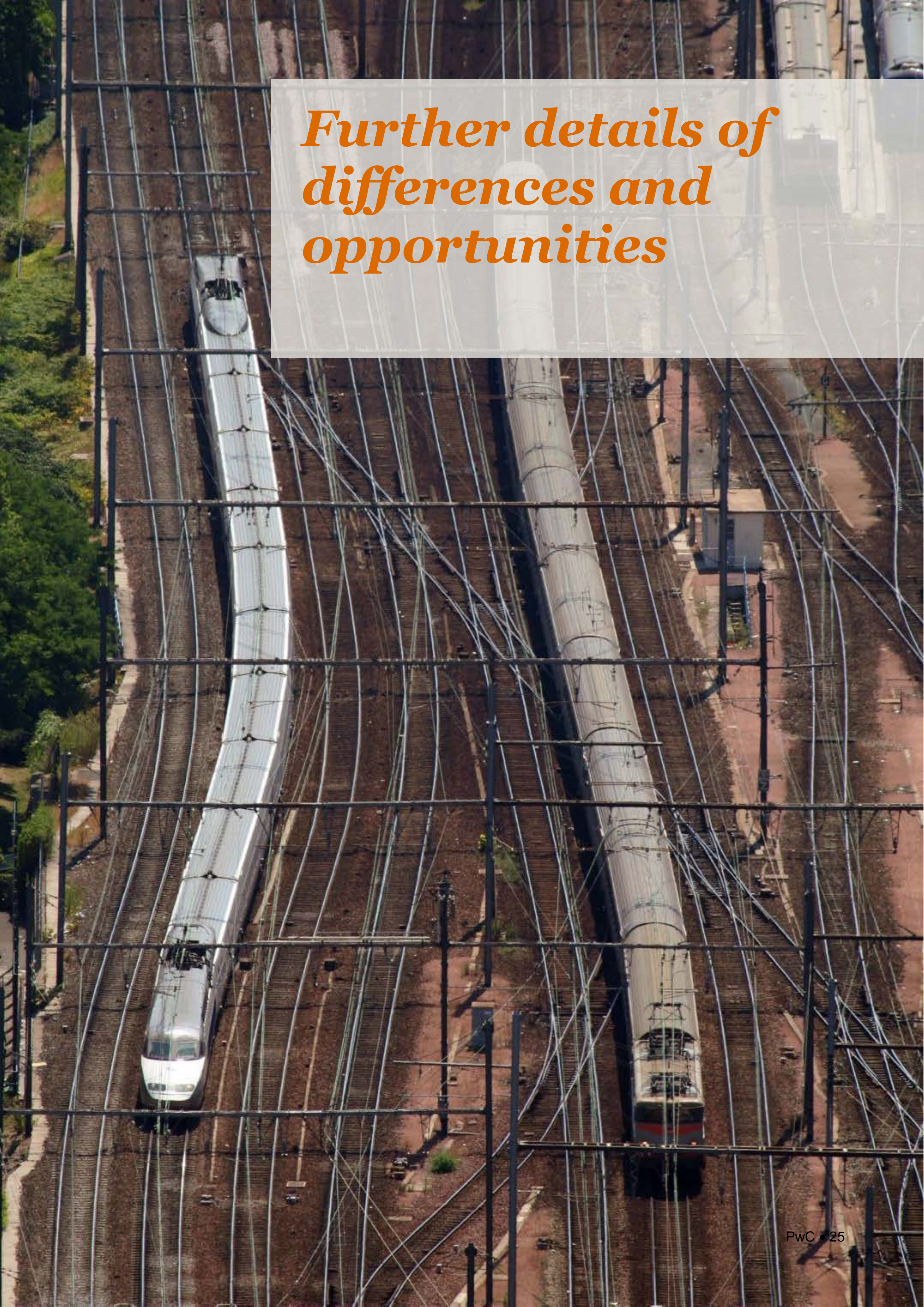
[12] Previous IUK studies found UK project capital costs are typically 10-30% greater than European projects.

Further details of differences and opportunities



Further details of differences and opportunities

The following sections discuss the differences in more detail, against a full range of comparator projects, and identify how they present opportunities for cost and schedule reduction for HS2 Phase Two.

Driver 1: Strategic objectives

The strategic objectives for HS2 Phase Two differ from those of many international comparators

The strategic objectives for HS2 Phase Two differ from those of many international comparators.

In his 2014 publications *"HS2 Plus: A report by David Higgins"* and "*Rebalancing Britain: from HS2 to a national transport strategy*", HS2 Ltd.'s Chairman Sir David Higgins described the need for HS2 Phase Two to "rebalance and grow" the national economy, increasing connectivity between cities in the Midlands and the North. He stressed its role in capacity relief as well as the importance of delivering radical reductions in journey times, both in the East and the West, not to the benefit of one region at the expense of another. It is also widely accepted that there has been historic underinvestment in rail infrastructure in the UK and much of the existing rail network was designed to serve Victorian needs.

Capacity

HS2 Phase Two will be required to handle 11 trains per hour on the Manchester leg (five of which proceed to Manchester, with others leaving the high speed network to join the West Coast Main Line), and 9 trains per hour on the Leeds leg (five of which proceed to Leeds, with others leaving the high speed network to join the East Coast Main Line)[13]. These capacity requirements, although not unique, are typically higher than the current service frequencies operated on most international high speed lines. They are not necessarily higher than the quoted design frequencies of many routes, but because many countries, including Italy, expand infrastructure as demand arises over time, the costs of meeting quoted design frequencies are not necessarily built in to the capital costs incurred at opening.

The capacity requirements for HS2 Phase Two drive costs due to, for example, the sizing of stations, the sizing and locations of depots, the requirements for passing loops and the traction power supplies needed to meet the capacity requirements.

Annual passenger forecast

Route	Annual passenger forecast informing design (million)
Paris – Lyon	39
California HSR	38.5
HS2 Phase Two Manchester branch	36.8
HS2 Phase Two Leeds branch	36.2
HSL Zuid	24
Valence – Marseille (LGV Med)	20
Lyon – Valence (LGV Rhone-Alpes)	19
Frankfurt – Koln	12
Paris – Nord de la France	6
Madrid – Seville	3

Source: Further Development of the European High Speed Rail Network: System Economic Evaluation of Development Options, Civity, 2013

[13] Development Agreement between the Secretary of State for Transport and High Speed Two (HS2) Limited, 8 December 2014, Annex 4: Functional Response, pg.117

Two key reasons for the high capacity requirements emerge from the strategic objectives of HS2 Phase Two:

1. An objective of high speed lines such as HS2 Phase Two is to relieve strained capacity on the existing railway network, over relatively short distances. Although not unique, and comparable with HSL Zuid in the Netherlands, it is more common for the objectives of international high speed lines to be to reduce long distance journey times (as with the LGV SEA and Rome/Naples lines) and to fulfil the broader requirements of the EU's TEN-T network.

2. To provide a strong business case for a new HS2 Phase Two network, the success of the line depends on being able to attract passengers to transfer from existing railways. To achieve that transfer, the new line needs to provide attractive journey times, particularly considering Network Rail's plans for improvements in speed across the network. HS2 Ltd forecasts that within 4 years of opening, 65% of passengers using HS2 Phase Two will have transferred from existing rail.[14]

Connectivity

As well as providing connectivity to Manchester and Leeds, the objectives for HS2 Phase Two include intermediate connectivity to the East Midlands, South Yorkshire and Manchester Airport, and connections to the East and West Coast Main Lines.

Many comparator projects across Europe have been driven by the requirement to provide long distance point-to-point connectivity, with less emphasis on intermediate stops, often directed at fulfilling the broader requirements of the EU's Trans European Transport Network (TEN-T).

TEN-T network

Source: PwC

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[14] Economic Case for HS2: Updated appraisal of transport user benefits and wider economic benefits, Department for Transport, 2012, pg.23

Although the high capacity requirements and the requirement to provide intermediate stations drive costs higher, they can only be regarded as presenting an opportunity to reduce cost if there were a willingness to make changes to the strategic objectives of HS2 Phase Two.

Driver 2: UK Infrastructure Context and Sponsor requirements

In all countries that this study has looked at, governments consistently set the requirements for high-speed rail projects. Similarly, the Department for Transport (DfT) has set the requirements for HS2 Phase Two and is responsible with HS2 Ltd for ensuring that the right balance is achieved between cost, railway performance and wider benefits.

The requirements for HS2 Phase Two, set by DfT in the Development Agreement, state the locations of the stations, the journey times that must be achieved and the delivery schedule for the project. The cost of delivering these requirements is impacted by the UK's property costs and planning compensation scheme, the density of the UK's population and existing infrastructure (i.e. rail and roads), as well as the position taken in determining the optimum balance of costs and benefits in the business case.

Comparators do not tend to lock in requirements at such an early stage of a project, allowing greater flexibility to optimise the scheme

DfT and HS2 Ltd have worked collaboratively to develop the Sponsor requirements, a practice that has similarities to that adopted in the development of other European lines, including those in France and Italy, in which the ministries typically rely on an appointed body to shape the schemes. However, comparators do not tend to lock in requirements at such an early stage of a project, allowing greater flexibility to optimise the scheme, as the design develops, to meet affordability criteria.

The study has identified a number of Sponsor requirements and decisions that drive differences between the scope of HS2 Phase Two and the comparators. These include the specific route alignment and station locations, the decision to have dedicated high speed lines serving city centres and the ambitious journey times.

DfT's requirements that are drivers of project scope

- Locations of the stations and connections to the existing network which are a key cost driver as they set the high-level corridor for the route.
- Capacity requirements in the form of the number of passengers per day between stations, which influences the number of trains per hour and the sizing of stations, number of platform faces and sizing of rolling stock.
- Journey times between stations which drive the speed of the railway.
- Service reliability which influences the specification of the assets and reduces the opportunity to integrate the high speed and existing networks.
- The schedule for delivering HS2 (both Phases One and Two) with a fixed completion date of 2032.

Source: HS2 Ltd

HS2 Phase Two passes through areas of more challenging topography and higher population densities, and crosses more roads and railways than many comparator projects

Station locations and route costs

The regions that HS2 Phase Two passes through have more challenging topography, higher population density and more roads and railways to cross than many comparator projects, including those in France and Spain.

The topography of the route drives significant costs, with undulating terrain and multiple river and floodplains requiring greater volumes of earthworks and expensive viaduct and tunnel sections.

The UK has a population density marginally above Italy and Germany, and significantly above that of France and Spain (see figure). The UK, like the Netherlands and Germany, has lower populations residing in cities and a higher population density outside of cities, which increases the challenges associated with routing a new railway. An estimated 42% of the HS2 Phase Two route passes within 1km of a conurbation.

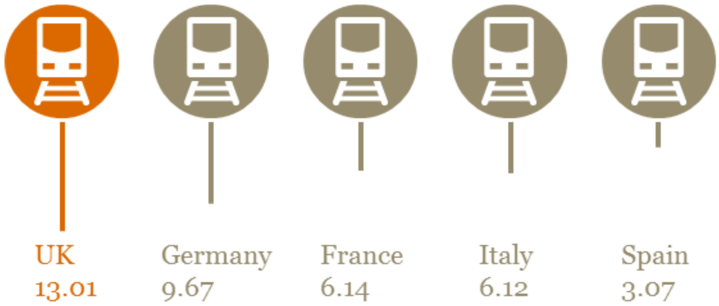
Population density

Source: Worldbank, UN, ONS

Rail density in the UK is higher than in France and Germany, although road density is broadly similar (see figures). New high speed lines that cut through areas of high infrastructure density face costly challenges. These challenges require the vertical alignment of the new line to cross above or below existing infrastructure, and existing roads and railways to be diverted.

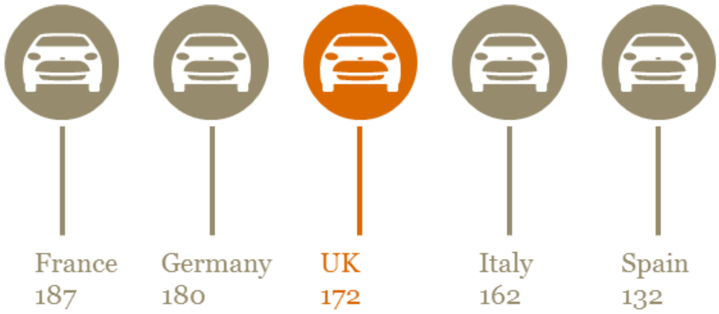
These characteristics are prevalent on HS2 Phase Two. It currently anticipates building a greater length of new road for such diversions than the length of the new high speed railway, exacerbated by sections of the route that run close to existing road or motorway corridors to minimise environmental impacts. This study has not identified comparator projects with similar levels of infrastructure crossings that also have similarly challenging topography. This combination makes HS2 Phase Two unique against these comparators.

Rail density – km of Rail per 100 km² of territory



Source: http://www.indexmundi.com/facts/topics/infrastructure

Road density – km of road per 100 km² of territory



Source: http://www.indexmundi.com/facts/topics/infrastructure

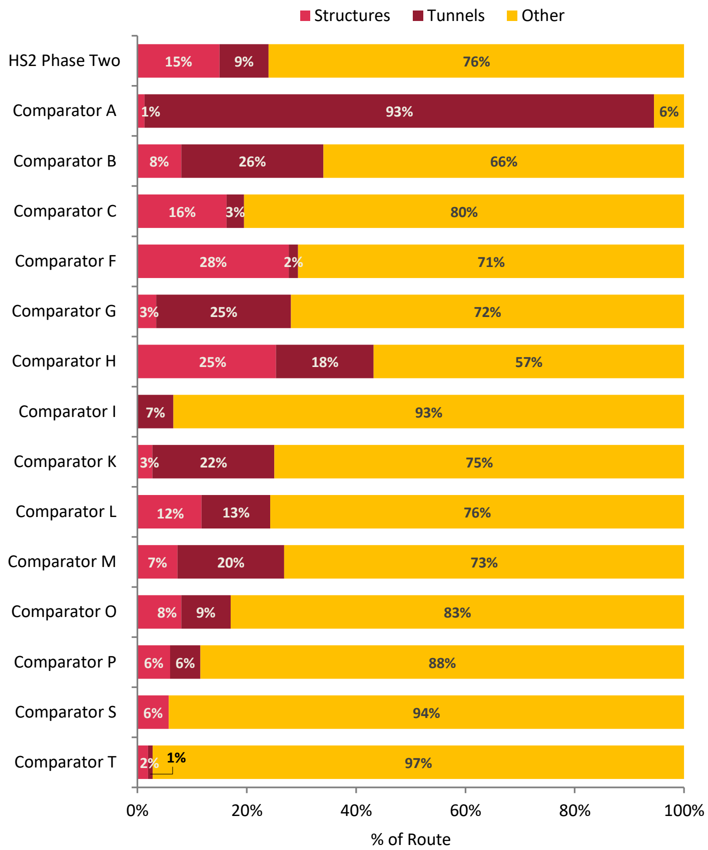
This partly explains the greater proportions of viaducts, tunnels and bridges on HS2 Phase Two than on some comparator schemes, compounded by the locations of Sheffield Meadowhall and East Midlands Hub stations in relatively challenging locations. These station locations dictate a route alignment with relatively tight curves, requiring through-trains to reduce speed – a situation that most comparators have avoided. These requirements drive costs higher, but do not present an opportunity to reduce costs without changing the station locations.

There are a number of other factors that can contribute to greater numbers of expensive assets, but this study concludes they do not have an exceptional impact on the HS2 Phase Two scheme:

1. Vertical and horizontal alignment characteristics: These are driven by speed and acceleration, with higher speeds requiring shallower curves and demands for acceleration commonly driving gradients. However, through benchmarking with comparator projects, this study finds that HS2 Phase Two's alignment characteristics are not exceptional, albeit they are more stringent than those of railways that are designed for slower speeds.

2. Sensitive environmental features pose similar issues for comparators as they do for HS2 Phase Two. In California, the Grasslands Ecological Area north of Merced posed a significant enough risk of planning delay and compensation payments that the high speed rail project selected a longer and more costly route. The route of HSL Zuid in the Netherlands passes through one of the last undisturbed natural landscapes in the country which required the construction of a 7.2km tunnel at a cost of £218m. The route from Milan to Bologna in Italy includes sections of landscaped "green tunnel" through sensitive areas.

Route characteristics breakdown



Source: Comparators

In the French and Italian high speed rail schemes that this study has reviewed there was a significant emphasis on assessing all options against cost or affordability limits. There is an opportunity to review the route alignment, while maintaining station locations, and explore options to reduce cost through localised route and scope refinements. Such savings can only be quantified through a rigorous process of design, costing and value analysis, and assessed against environmental and schedule impacts.

City centre dedicated lines

One of the most significant differences between HS2 Phase Two and European comparators relates to the way that cities are served by high speed rail. In its Command Paper for High Speed Rail, the Government made a case to focus on complete journey times as a passenger priority.[15]

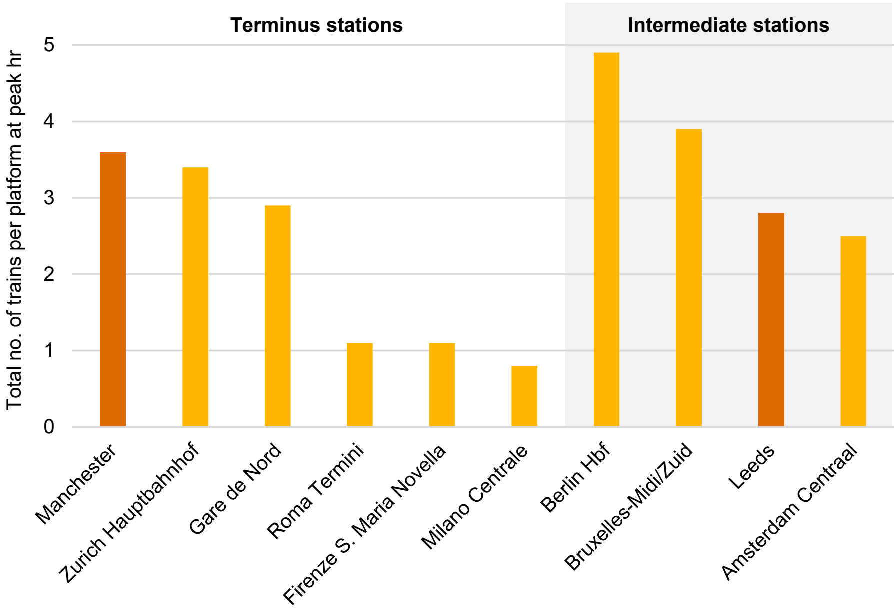
Like the railways in China and Japan, HS2 Phase Two is defined as a dedicated network. Constructing dedicated high-speed lines into city centre stations in Manchester and Leeds, to achieve the required journey times and capacity, increases costs when compared with some international schemes. A number of comparators in France, Italy, Germany, Belgium and the Netherlands use existing railways and stations to serve city centres with high speed services.

This study identifies that some comparators have been able to share railway connections with other services, even with high speed train frequencies above the levels currently proposed to serve Manchester and Leeds. Others have taken additional steps to remove slower services from existing lines to release

[15] High Speed Rail, Department for Transport, March 2010

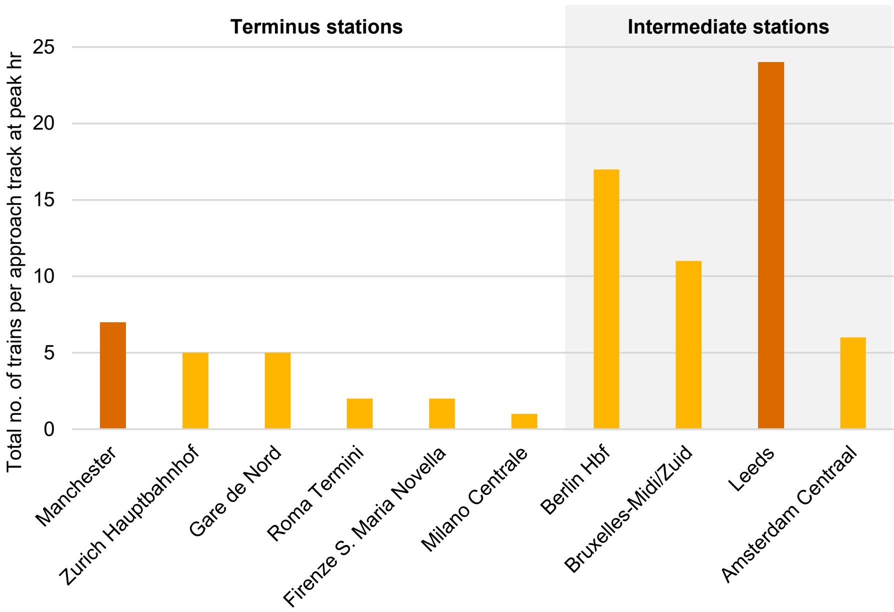
capacity for new high speed services. During this study, HS2 Ltd expressed that taking a similar approach is not considered viable due to there being insufficient capacity in the existing conventional network, and the need to meet journey time and reliability requirements. Benchmarking supports this view, indicating that the approaches to stations and platforms are more constrained in Manchester and Leeds when compared to many European cities, based on current service demands. These challenges will be further increased if the forecasts for significant growth in regional services[16] materialise.

Station platform capacity[17]



Source: HS2 Ltd and comparators

Station approach track capacity



Source: HS2 Ltd and comparators

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[16] Growth estimated by Network Rail for regional services at the existing Leeds station is 2.15 times current services, at the time HS2 Phase Two becomes operational

[17] In both charts, the number of trains at Manchester includes the forecast 5 HS2 trains per hour, and the number of trains at Leeds New Lane includes the forecast 5 HS2 trains per hour

Case Study – City Connectivity – LGV Bretagne Pays de la Loire

The LGV Bretagne Pays de la Loire line provides eight junctions – one junction to another high speed line and seven to the conventional network. This arrangement enables the existing stations at Rennes, Laval and Le Mans to be used by high speed services before re-joining either the conventional or high speed network to further destinations.

Source: http://www.rff.fr/fr/gestion-page-d-accueil/actualites/visite-de-chantier

Case Study – City Connectivity – LGV Sud-Est Atlantique

The line LGV Sud-Est Atlantique (Tours to Bordeaux) provides similar junctions to service the main cities of Tours and Bordeaux and the intermediate towns along the route using the existing stations and conventional network.

Source: http://www.lgvsudeuropeatlantique.org/les-atouts-du-projet/leproject

The study has seen extensive use of phasing the delivery of new schemes by comparators

Schedule and phasing

In its requirements, the DfT has set a completion date for opening the entire HS2 Phase Two route. In the other countries considered by this study, high speed railways are often commissioned in phases. Such phasing often fulfils one or more of the following objectives for those high speed rail projects:

- To achieve earlier primary benefits from the high speed line, most often by opening the main stretches of new lines, in advance of opening dedicated connections to city centres. High speed trains temporarily reach cities on existing railway lines.
- To test the demand and growth forecasts for the new high speed lines, by opening main stretches of a line before investing in city centre connections, or by utilising existing railway assets such as depots until growth justifies new assets.
- To enable continuous improvement through step-and-repeat delivery, with learning from each phase captured and applied to the next, resulting in improved efficiency through the supply chain.

In the USA, the construction of the new high speed line in California will initially be limited to the main route outside of city centres. The more expensive sections into the cities will be built once the patronage forecasts of the scheme have been proven. In France, LGV Est is being constructed in two phases. The first phase connects a number of major cities along the route bringing early benefits to these areas. The second phase, which extends the line to Strasbourg and the German border, has been deferred to reduce the scale of public subsidy required for construction.

It should be noted that comparator projects normally make full provision for later phases in their planning approvals and strategic planning. The primary opportunities that phasing could unlock for HS2 Phase Two relate to achieving benefits sooner by opening parts of the railway early, but there might also be opportunities to reduce costs through scope reductions, if actual demand does not justify the planned scope. However, this study also considers that any options to defer investment or construction should be carefully assessed so that the deferment itself does not become a reason for the failure to attract passengers.

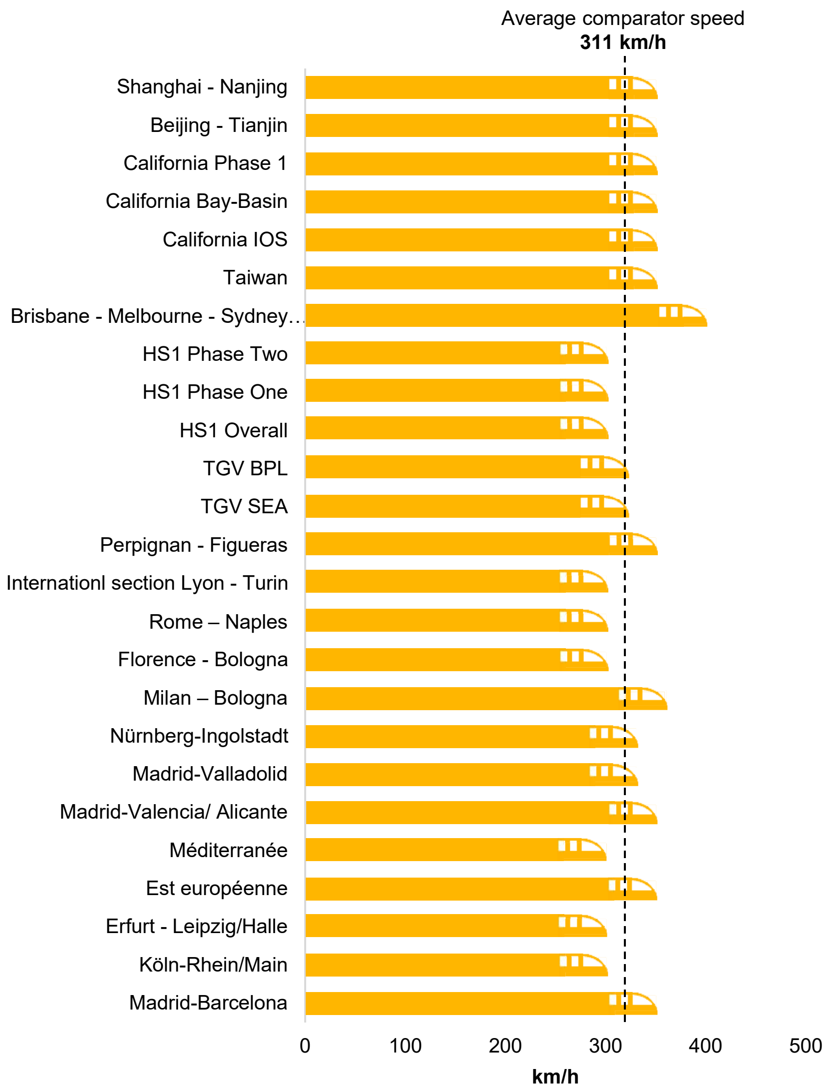
Speed

The maximum operating speed of HS2 Phase Two is 360kph where alignment and environmental impact allows, with a normal operating speed of between 320kph and 340kph. Such speeds are necessary to meet the journey time requirements set by the Sponsor.

These speeds are higher than many comparators but not unique, with operating speeds across comparators varying between 250kph and 350kph. At the time of writing, none are known to be operating above 350kph in normal service. In France, Spain and Italy, typical operating speeds are 300kph to 320kph, with alignments historically designed for 350kph. However, recently constructed lines, including LGV Est in France and the line from Milan to Bologna in Italy, have alignments designed for 400kph. Italy is planning to increase the operating speed on this route to 360kph. In European countries with shorter distances between cities, including Germany, Belgium and the Netherlands, speeds can be as low as 250kph.

HS2 Phase Two is future-proofing the route by accommodating an alignment design speed of 400kph where possible, which is consistent with many high speed railways in Italy, China and other parts of Asia. Higher operating speeds are known to drive cost higher in two ways. Firstly, dynamic loading and aerodynamic effects drive marginally greater costs in assets such as viaducts and tunnels. Secondly, a higher speed reduces flexibility in the vertical and horizontal alignment of the railway, making it more difficult to avoid costly assets like tunnels and viaducts, driving more significant costs. HS2 Ltd is assessing whether alternative speeds would provide cost saving opportunities[18].

Comparator maximum speeds



Source: Comparators

Land costs

This study has not sought to analyse the drivers of land and property costs across comparators, but benchmarking concludes that it is an area of cost difference, although it does not present an opportunity without changes to the legal system. However, as set out below under *Driver 3: Delivery model and the UK industry,* alternative compensation schemes in mainland Europe have been shown to give promotors greater flexibility to pay compensation in lieu of

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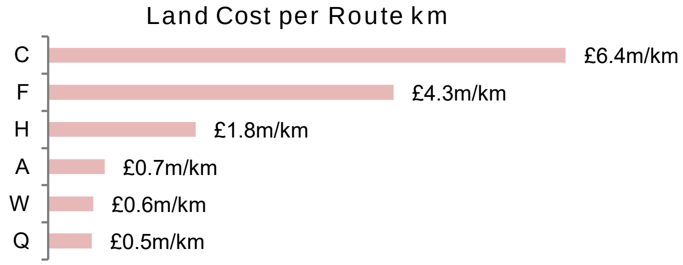
[18] Since the completion of this study, HS2 Ltd has assessed the impact of different speeds on capital cost, and concluded that the cost of building the Phase One consulted route designed for 200kph would be 9% lower than the cost of a route designed to 360kph.

changing the scheme and to potentially reduce periods of petitioning. It should also be noted that changes to the alignment discussed above could also lead to reduced land costs.

Average land cost per kilometre



Source: Comparators

Driver 3: Delivery model and the UK industry

The UK has a unique legal framework that governs the development and delivery of HS2 Phase Two. Comparator countries commonly adopt planning processes that encourage greater levels of cost optimisation and afford greater levels of freedom for the sponsor, promotor and contractors to optimise the route, and improve efficiencies in design and construction.

Comparators commonly have long-established organisations responsible for delivering projects

The UK has a shorter history in delivering new railways than comparators in mainland Europe. These comparators commonly have long-established organisations responsible for delivering projects that integrate the ownership, construction, maintenance and operation of existing railway infrastructure with the delivery of new high speed schemes.

High speed rail projects in mainland Europe are typically part of a long term strategy that has often been set out for decades. This has enabled the promotor organisations to develop expertise and to provide the supply chain with longer-term incentives to invest in growth and innovation.

The analysis of international benchmarks has identified that HS2 Phase Two faces higher supply chain and productivity related costs than some European comparators.

Together these differences lead to cost saving opportunities for HS2 Phase Two, as well as greater potential savings in the longer-term for future UK infrastructure projects, as set out below.

Planning processes

This study has not uncovered evidence that the costs of going through the Hybrid Bill process are greater than those in countries with similar legal systems. However, it has concluded that costly commitments are made during the process that others incur to a lesser extent.

The HS2 Phase Two scheme went to public consultation in 2013, and is expected to seek approval through the Hybrid Bill process leading to Royal Assent in 2019. The study has found that other European high speed rail projects are required to pass through similar planning junctures, but have differing requirements.

In France, such projects are required to obtain a Declaration of Public Utility (Déclaration d'Utilité Publique – DUP) which allows land to be purchased and design, financing and procurement to progress. This study, and specifically a review of the process that the LGV Est project went through, has identified the following characteristics of the French process that differ from those in the UK:

- Before commencing consultation, designs tend to include fewer features to mitigate potential objections;
- More flexible compensation arrangements; and
- More flexible processes that allow scope to be optimised after government approval.

The Hybrid Bill process in the UK is more consultative than the process in France. HS2 Phase Two has been subject to route consultation and has therefore been subject to early public influence. Schemes in France are not typically subject to such early consultation, nor do they tend to be consulted upon when the definition of the route, designs and cost estimates are at such an early stage of development.

This study has identified that features to mitigate the risk of potential objections have been included in the design for HS2 Phase Two, prior to the scheme going to consultation. Although a degree of up front mitigation is not uncommon on such schemes, there is evidence that the extent to which this practice has been applied to HS2 Phase Two is greater than on other international schemes, or on HS1 in the UK. Up-front mitigation has, at least in part, been committed to without a detailed and robust understanding of the cost implications. Comparison with high speed lines in France show that, where objections are foreseen, there is greater access to historic cost data to be able to assess the impact of such decisions, and greater flexibility to mitigate costs through compensating those affected instead.

In the current UK system, monetary compensation directed at individuals is widely viewed as inadequate.[19] Comparators face similar risks associated with public objections through their respective planning processes, however there is evidence that their compensation schemes are more generous and consequently completed more quickly. The French and Dutch planning systems are widely regarded as more successful than the UK system.[20] In France, there is evidence of a more generous compensation scheme being used, which opens up the ability to avoid having to make expensive scope changes where issues can be mitigated more cheaply through compensation.[21]

In France, there is greater flexibility to amend the route and technical design after approval at DUP. In the UK, once the Hybrid Bill has been submitted, the level of change permitted to the design and scope is more restricted, locking in scope at an early stage in the design development process and reducing the ability to optimise the design. The French have further advantages over the UK in that the organisations developing high speed rail schemes have greater access to historical cost data to make decisions around designs.

This study concludes that, although there is no evidence that the UK planning process itself is more costly to pass through, it does drive earlier route and scope decisions that increase costs when compared to others. It is recognised that changing major decisions on scope to reduce cost would be difficult at this

[19] Investing for Prosperity, Report of the LSE Growth Commission

[20] Confidential paper prepared by a credible UK organisation that focusses on contributing to the long-term growth strategy in the UK

[21] Decree of the President of the Republic 321/2007 on land expropriation for public works, and its modifications

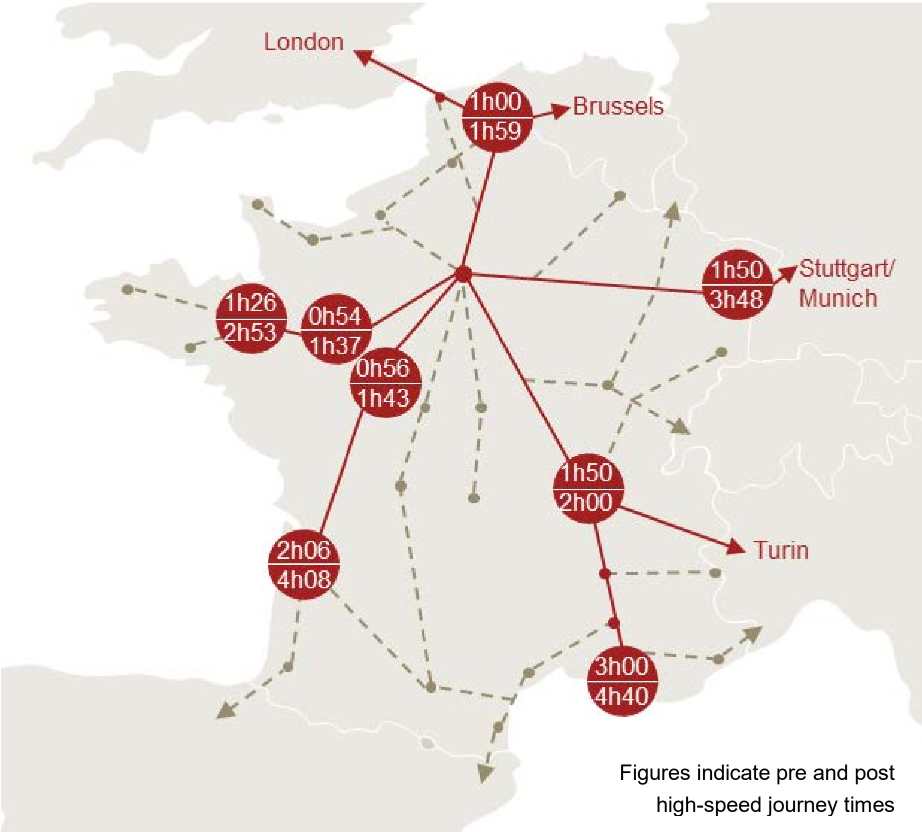
stage of the development. However, this study considers that HS2 Ltd should revisit any decisions that were made in anticipation of challenges during public consultation and consider opportunities to optimise the route and scope, whilst balancing its planned timetable for delivering the scheme. Government should also consider how it might draw on the lessons learned from HS2 Phase One and other recent experiences to fully unlock opportunities for future infrastructure projects.

Planning for high-speed rail

Some European countries, in particular Italy and France, have strategic long term plans for high speed rail. The figure below depicts France's strategic plan of 1992, setting out its vision for the continued growth of high speed rail across the country. This plan was approved by the French government under decree in 1992. Although in France this strategic plan does not negate the need for planning consent and consultation for each new limb of the network, there is evidence that it unlocks a number of key enablers to delivering high speed railways at lower cost. These are:

- The ability for the sponsors (Ministries) and promotors (SNCF Réseau, formerly RFF) of high speed rail in France to develop organisations with long-term capability and higher levels of integration with existing railway infrastructure programmes, operations and maintenance.
- Improved confidence of investors and the supply chain to invest, consolidate and grow capability.

Summary of France's strategic high speed rail plan



Source: Ministère de l'Équipement, du Logement et des Transports '92, reproduced by PwC

The UK's strategic long-term vision for high-speed rail and the plan for delivering it are not as developed as those of others in Europe. This was recognised as a central theme of the Higgins Review, as was the need for a national transport strategy and the way in which HS2 could contribute to, but not substitute, such a strategy.

There is a significant opportunity for the Government to unlock potential cost savings for future infrastructure projects through the development of a national infrastructure plan, and a specific high speed rail strategy. It should seek to take lessons from other countries that have developed such plans and should engage with the supply chain to identify the key commitments that would be required to unlock efficiencies, including those associated with reducing fragmentation in the supply chain.

Network and service integration

Comparator projects commonly develop high speed lines that share existing railway assets, integrate closely with services on existing lines and that are developed in conjunction with a primary service and network operator

International comparator projects commonly develop high speed lines that share existing railway assets, integrate closely with services on existing lines and that are developed in conjunction with a primary service and network operator.

In France, Spain and Italy, SNCF, ADIF and FS respectively own and manage both the conventional and high-speed networks, and develop these networks according to their strategic plans set by the European Rail Agency and their respective governments. These organisations, commonly through their subsidiaries, support the design and delivery of these projects as programme managers. SNCF Réseau in France[22] and Ferrovie dello Stato in Italy have broader obligations for the existing network infrastructure as well as new infrastructure and services. These organisations are well placed to identify opportunities to share existing assets and optimise new assets. They commonly share depot and maintenance facilities, run high speed trains on older networks and constrain the infrastructure to specific service requirements.

High speed rail – current market organisation

Country	HSR network administration	HSR network operations	HSR network maintenance	HSR passenger train operations
France	SNCF Réseau	SNCF Réseau	SNCF Réseau	SNCF Mobilités
Germany	DB Netze	DB Netze	DB Netze	DB Bahn
Italy	RFI	RFI	RFI	Trenitalia NTV
Belgium	Infrabel	Infrabel	Infrabel	Thalys Fyra
Netherlands	Infraspeed	Infraspeed	Infraspeed	Thalys
Spain	Adif	Adif	Adif	Renfe
UK	HS1	Network Rail	Network Rail	Eurostar Southeastern

Source: PwC

HS2 Phase Two is expected to be delivered by HS2 Ltd on behalf of DfT as the project sponsor. HS2 Ltd has been set up as a new entity. It does not own or manage the existing UK railway infrastructure – a role held by Network Rail. It does not yet have clarity on its role in the operation of the future high speed network.

Opportunities to reduce capital costs through scope optimisation can only be fully realised with an upfront decision on who the network operator will be and

[22] SNCF Réseau was Réseau Ferré de France until 2015

with greater alignment in incentives between HS2 Ltd, Network Rail and the future operator.

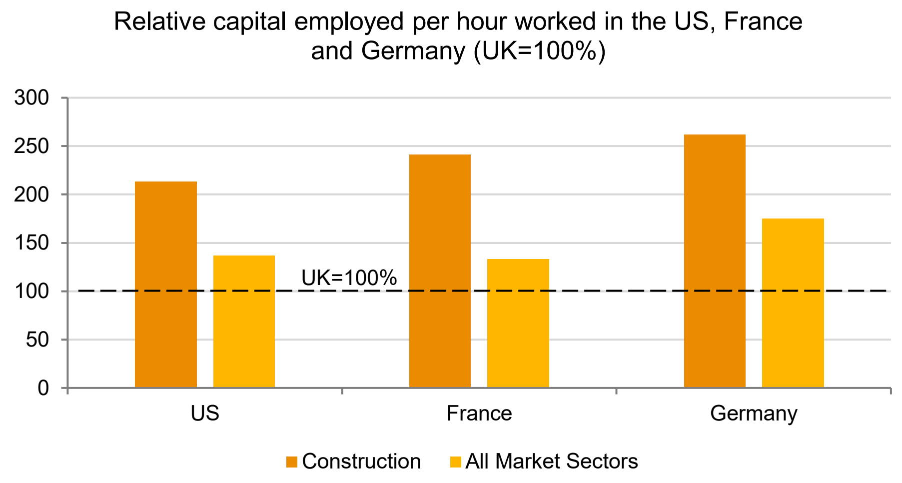
Supply chain costs

Infrastructure projects in the UK suffer from greater layering of supply chain overheads, profits and risk premiums than in some mainland European countries owing to greater fragmentation of the supply chain in the UK. Previous research and this study have identified that the UK suffers consequential increases in cost of anything up to 14%. [23]

The following factors are inherently linked and have been identified through this study and others as primary contributors to this difference in cost:

- There is evidence that the UK uses a greater number of smaller contract packages than international comparators, which increases administration and interface burdens and reduces economies of scale. Public sector procurement in the UK has a greater emphasis than elsewhere on encouraging small to medium enterprises.
- UK contractors do not have the same levels of confidence in the pipeline of work to commit to the same levels of investment in skills, innovation and plant, or to consolidate as much as mainland European contractors do.
- Mainland European contractors employ higher proportions of labour directly than is typical in the UK, where transient contract labour is more common, resulting in the additional burden associated with an unfamiliar workforce.
- Construction contractors in the US, France and Germany invest more in plant and equipment (capital per hour worked) than contractors in the UK.

Comparison of relative capital employed per hour worked



Source: IUK / NIESR (2008)

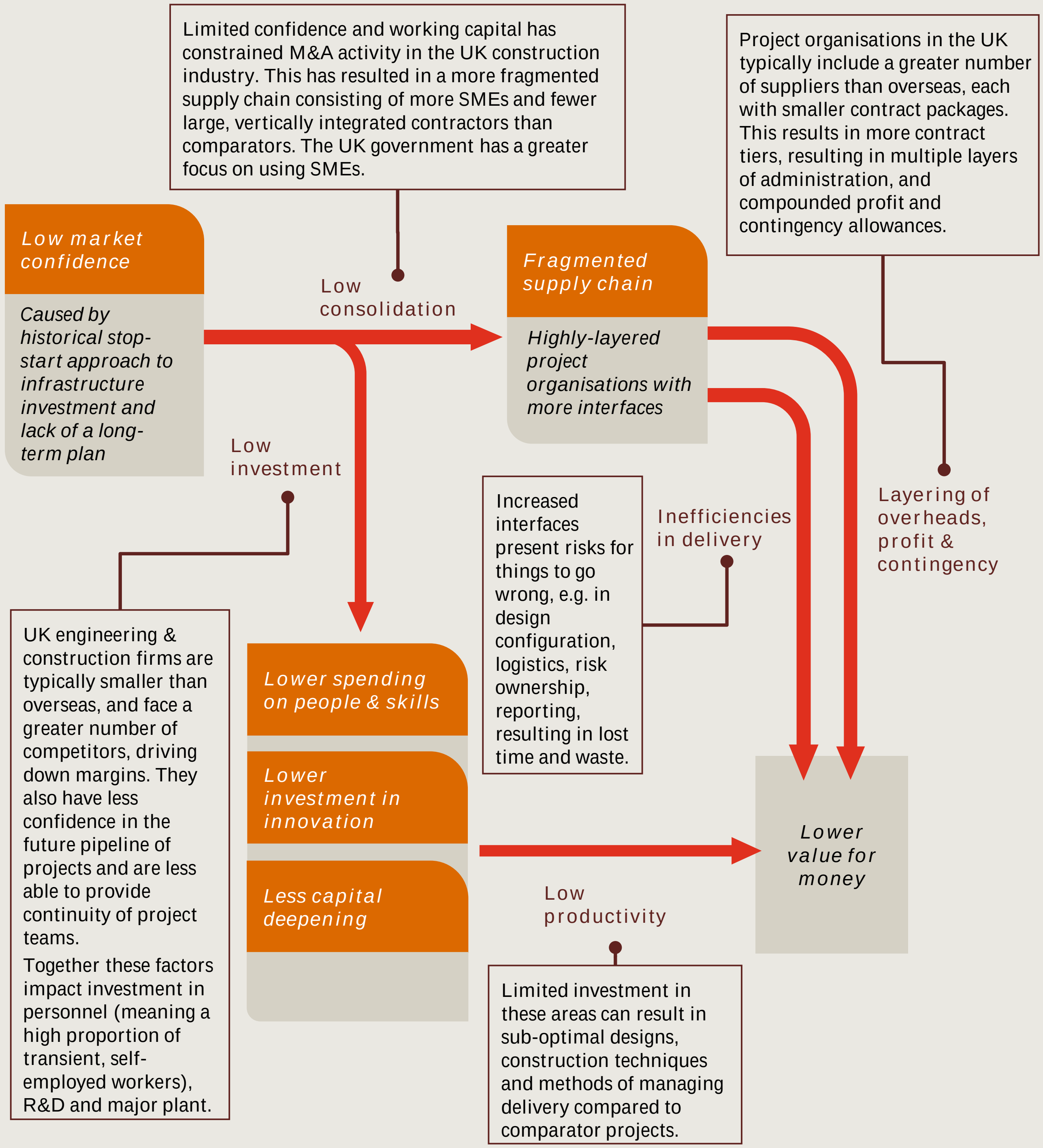
[23] International cost efficiency benchmarking of Network Rail by ORR, 2010, identified that contracting strategy accounted for 14% of the differences in maintenance and renewal costs between Network Rail and international peers.

However, a recent trend has begun to emerge of large mainland European construction contractors participating in UK joint ventures and consortia, and this is anticipated to be prevalent with HS2 Phase One.

There are opportunities for cost and schedule reduction through the application of delivery, contracting and procurement models that reduce layering and which encourage investment in staff development, innovative designs and construction equipment. There is an opportunity for HS2 Phase Two to benefit from the improvements in these areas that are realised through Phase One.

As set out above, to unlock greater efficiencies for future infrastructure projects, Government must consider its ability to commit to a long term infrastructure and high speed rail plan. This would enable the UK supply chain to consider longer-term investments in people and technology, partnerships and potentially encourage a greater degree of vertical integration across design and construction, as has been observed with a number of European high speed rail suppliers. Continuity of supplier and client teams across major projects will also support the delivery of greater efficiencies.

How the UK industry environment drives higher supply chain costs



Source: PwC

The study has identified a number of differences between the design and specification of HS2 Phase Two and the comparators that increase cost

Driver 4: Design requirements and assets

HS2 Ltd is in the process of developing a new suite of design requirements and technical standards. Many comparators differ in that they have developed optimised and stable requirements and standards over many years, as a consequence of having integrated organisations with extensive experience of developing, operating and maintaining high speed rail networks. For instance, HS2 Ltd.'s decision to operate at 360kph drives a difference to most European comparators because it puts HS2 Phase Two beyond the specifications in the European Technical Standards, placing it at the leading edge of high-speed rail design.

The opportunity for HS2 Ltd to optimise the design to reduce cost is limited due to the level of detail and relative inflexibility in the Sponsor's requirements. Comparators are typically able to optimise their schemes to a greater degree, driving out cost. The cost of HS2 Phase Two is also increased by the decision for HS2 to operate as a largely independent railway, with no existing facilities that can be utilised to service the network.

The study has identified a number of differences between the design and specification of HS2 Phase Two and the comparators that increase cost. These include the provision of standalone rolling stock and infrastructure maintenance depots, the choice of engineering solutions and the specifications of assets such as tunnels and viaducts. While HS2 Ltd has not specified its methodologies for construction, comparators typically utilise innovative techniques to drive cost and programme efficiencies, enabled by the standardisation of designs and multi-year experience across the client, design and construction value chain.

Depots

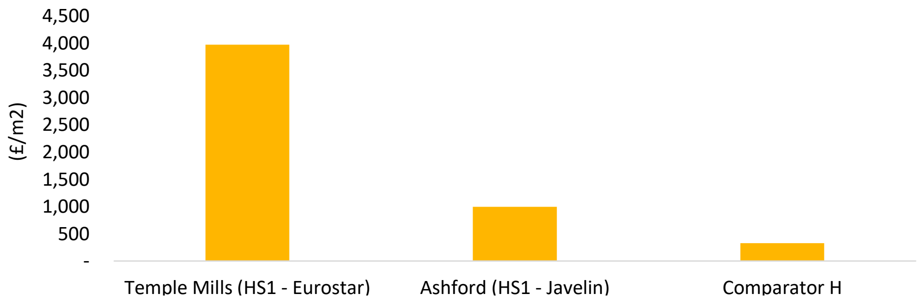
The HS2 Phase Two design includes four bespoke standalone depot facilities, two for rolling stock and two for infrastructure. These depots also require significant infrastructure, including junctions and viaducts, to provide access to the chosen depot locations, which have been selected primarily due to the size of depots specified.

Mainland European countries commonly use existing rolling stock depot facilities, upgrading and expanding them as required, rather than constructing new bespoke facilities for each high speed line. In France, for LGV Méditerranée, there was an upgrade of an existing depot costing €200m and the construction of simple lineside sidings for stabling purposes. The LGV Est project in France included scope for a €75m upgrade of an existing rolling stock depot. The new depots for HS1 at Temple Mills and Ashford cost £397m and £67m respectively. The new depot for the high-speed lines serving Comparator H cost £66m (see figure below).

Mainland European comparators also make use of existing infrastructure maintenance facilities which are shared across their high speed and conventional rail networks. Projects that required new facilities, including the Milan to Bologna line in Italy, chose to construct smaller maintenance compounds at intervals along the route. There are examples of comparators converting and downsizing their construction compounds into lineside maintenance compounds and sidings at the end of construction.

As set out above under *Driver 3: Delivery model and the UK industry*, there is an opportunity for HS2 Phase Two to integrate more with the existing railway. Specifically in respect of depots there is an opportunity for HS2 Phase Two to revisit its maintenance strategy and depot requirements and unlock the potential to utilise existing depot facilities and review depots specifications, sizing and locations. Consistent with opportunities set out above under *Driver 2: UK Infrastructure* Context and Sponsor requirements, HS2 Phase Two should consider options for phasing construction of new depots if passenger demand materialises.

Comparison of rolling stock depot costs per m^2

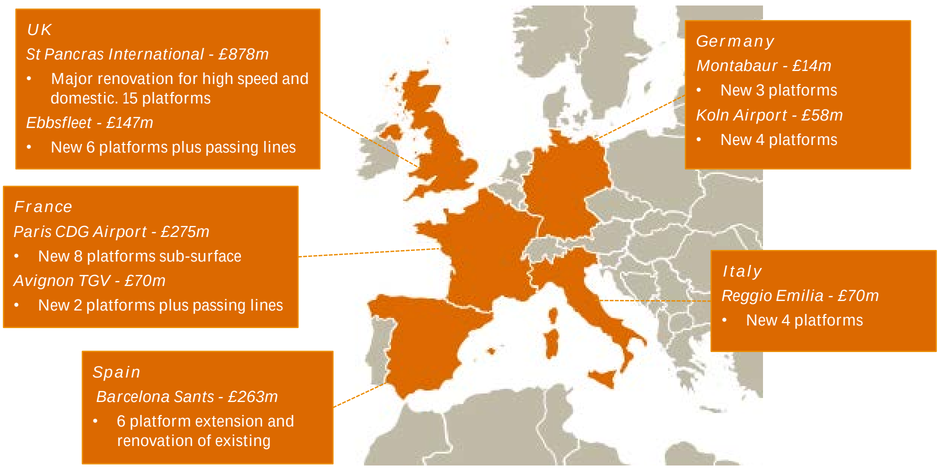


Source: Comparators

Stations

This study indicates that there is only limited opportunity for HS2 Phase Two to reduce station sizes to achieve cost reductions, as the proposed stations are broadly comparable in size with those of international comparators. However, as indicated in the figure below, the cost of railway stations varies significantly around the world, suggesting an opportunity to save cost through applying the principles of cost-led design to stations. Recent changes to environmental and security standards could be increasing the cost of more recent station construction. There may be an opportunity to value engineer station design to meet these standards in an efficient manner.

Comparator stations



Source: PwC

Managing environmental impacts

HS2 and its European comparators must comply with similar environmental legislation and there is evidence from the scale of noise and environmental mitigations applied by other high speed projects that such requirements are held in equal regard across nations. In fact, the UK is understood to have less protected areas than France and Italy (8% in the UK compared with 13% in France and 19% in Italy)[24].

The need to mitigate the noise and visual impact of high speed rail lines is a common theme amongst comparator railways. A key influence on the level of mitigation required is the speed of the line and its proximity to conurbations and other sensitive areas. While a train travelling at 200kph or 350kph creates a similar visual impact, the noise generated increases with speed, particularly above 300kph.

HS2 Phase Two's primary approach to mitigating the environmental impacts by lowering the railway and making greater use of cuttings is similar to the approach taken on HS1 and on some comparator schemes. However, this study has identified that many international comparators make greater use of cheaper lineside and train-borne mitigations.

European comparators make extensive use of lineside noise and visual screening in sensitive areas. HSL Zuid in the Netherlands, which passes close to many dwellings, made extensive use of transparent noise screening to mitigate the impacts on people living nearby. Italy also makes extensive use of screening in sensitive areas, with low height lineside barriers extending for much of the length of the Milan to Bologna route.

Other European comparators, including in France and Germany, are employing innovative track technology including dampers and under-sleeper pads to reduce noise and the need for screens. There are also examples of civil structures being designed to provide mitigation. These design features include U-shaped viaduct sections which lower the tracks in the structure and combine parapet protection with noise and visual screening. Such viaducts have again been employed in Italy, but these are largely regarded as being a particularly expensive, yet attractive solution.

Noise barrier

Source: PwC

While not as prevalent in Europe, rolling stock design in Asia places significant emphasis on providing train-based mitigation including improving aerodynamic design and introducing pantograph wells, bogey shrouds, spoilers and inter-car seals.

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[24] http://www.eea.europa.eu/data-and-maps/figures/proportion-of-terrestrial-land-covered

There is an opportunity for HS2 Phase Two to review its approach to mitigating the noise and visual impacts and potentially realise cost savings and construction schedule benefits by adopting the lineside and train-borne mitigation measures of comparators. Local engagement and agreement to solutions could also support this approach.

Asset specifications

The current technical requirements and specifications for HS2 Phase Two differ in a number of areas in comparison to international benchmarks

The current technical requirements and specifications for HS2 Phase Two differ in a number of areas from those of international schemes, and in some cases have resulted in larger, more costly assets. The drivers of these differences include the lack of a stable set of optimised requirements and standards from previous projects, and the design being developed for the Hybrid Bill to ensure it gives adequate powers as opposed to being an optimised design for construction.

The lack of existing standards in the UK has required HS2 Ltd to develop its own technical standards and specifications on an iterative basis with limited precedent data. The latest standards have removed some of the conservatism in earlier iterations but some still prescribe larger assets than comparator equivalents, increasing costs. However, this study acknowledges that some of these differences may be required to allow for the higher operating and design speeds of HS2 Phase Two.

Tunnel diameters

Source: HS2 Ltd and Comparators

Trace widths

Source: HS2 Ltd and Comparators

The current emphasis in the design process is to develop a design for the Hybrid Bill process which sets the corridor of land that HS2 Ltd can obtain following Royal Assent. The width of a double track formation (trace width) was originally specified at 22m wide by HS2's Technical Directorate but this has been reduced to 18.9m. Work is ongoing to assess the potential to reduce it further to 16.5m. However, comparators in Europe typically reduce their widths to as low as 14m and there is an opportunity for HS2 to achieve cost savings by reducing the width to be in line with the minimum achieved by comparators.

Taking another example, HS2 Phase Two has a flood resilience requirement to enable full operation of the railway in a 1/1000 year flood event, which increases the use and length of viaducts passing over flood-plains. International comparators typically have a lower requirement of a 1/500 year flood event.

HS2 Ltd should continue to review and optimise its standards and specifications, with due regard for comparator standards and specifications, as the design develops.

As the technical standards have been developed iteratively, the design for HS2 Phase Two does not fully reflect HS2 Ltd.'s latest standards. Updating the design would reduce the sizes and therefore costs of some assets. HS2 Ltd is working to update the design and the cost estimate to reflect the latest standards and lessons from Phase One; and to increase confidence in the HS2 Phase Two estimate.

Efficient design and construction techniques

Comparators have invested in innovative machines and other technologies to increase the rate of construction and improve quality and safety

With Phase Two only being at the early stages of design the extent to which HS2 Ltd will use the latest technology and innovative construction methods to increase the efficiency of construction is currently not fully defined but do form part of the planned efficiencies.

Standardisation, modularisation and pre-fabrication have been used to accelerate construction and reduce cost on recent comparator projects, particularly in relation to concrete structures. 65% of the concrete structures on the LGV SEA Tours Bordeaux project were pre-fabricated off-site and other innovations including viaduct construction methodologies and track laying machinery have been used.

Projects in China (with high proportions of viaducts and tunnels) have used temporary casting facilities and bespoke plant for long lengths of repetitive viaduct construction and slab track, reducing unit rates and speeding up construction. Costs have been lowered through the standardisation of designs for embankments, track, viaducts, electrification, signalling, and communication systems. Similar techniques, with extensive use of precast viaduct construction, have been adopted in recent projects in Italy. This study has observed a wide range of different structural forms being adopted often on the same route, tailored to the specific access available, or to the preferences of the appointed contractors.

The HSL Zuid project made extensive use of mechanised and standardised track laying processes for its slab track sections, which included an innovative U-bed slab design.

Comparators have also employed technology and modelling software to optimise their alignments, construction schedules and designs. Crossrail has made extensive use of Building Information Modelling (BIM), particularly in the design of stations, to identify and eliminate interface issues at the design stage rather than later during construction.

There is an opportunity for HS2 Ltd to leverage the experiences and investments of comparators to maximise the use of efficient construction methodologies and realise significant cost and schedule savings.

Driver 5: Scope and estimate development processes

HS2 Ltd has applied a much larger contingency provision through the use of optimism bias than comparators would typically include in their estimates

HS2 Ltd has had to confirm its cost estimate for delivering Phase Two at an early stage in the lifecycle because of its impact on government spending plans and the Government's Comprehensive Spending Reviews. HS2 Ltd has developed a cost estimate and schedule for Phase Two which reflect the early stage of design, limited experience and lack of precedent data. As a result, the scope is only defined at a limited level of detail.

French and Italian international comparator projects are able to draw on recent experience of high speed rail development and construction and are consequently able to draw on cost, scope and risk data more readily than HS2 Ltd. HS2 Ltd has applied a much larger contingency provision, through the application of the Government's optimism bias method, than comparators would typically include in their estimates. In HS2 Phase Two, there is little visibility as to the levels of uncertainty, risk or opportunity that are embedded within the quantities and the unit rates that make up the HS2 Phase Two estimate. While HS2 Ltd cannot quickly recreate the multi-decade legacy that the French and Italians have in estimating scope and costs, it can take lessons from their approaches to help achieve greater certainty over the developed scope and costs, specifically:

- Giving greater consideration of the costs of decisions relating to setting specifications, route selection and adopting designs;
- Providing greater transparency as to how these decisions relate back to the original Sponsor Requirements; and
- Challenging Sponsor Requirements where alternatives can be shown to achieve better balances between cost and value.

Whilst this study is aware that HS2 Phase Two has not developed its chosen alignment in isolation of cost considerations, comparators tend to place a greater emphasis on cost when making significant decisions around scope, including route alignment options. On the French LGV Est project, numerous alignments were subject to multi-criteria assessments and selected on the merits of design, benefits, cost, risk, schedule and affordability, selecting the best value based on whole life cost rather than capital cost alone. The alignment and scope for the Australian high speed rail project was optimised for cost in its early development stage, using specialist software.

The HS2 Phase Two scheme was initially developed to achieve a strong benefit to cost ratio. It is not unusual for the scope of high speed rail projects to be reduced to meet affordability requirements. HSL Zuid and LGV Est were both scaled-down to meet affordability constraints. This study finds that affordability constraints are largely applied to comparator projects prior to the assessment of project options, and prior to public commitments on route and costs.

Findings and recommendations

HS2 Phase Two has a unique set of strategic objectives and constraints that are not typically present in comparator high speed rail projects

There are opportunities to reduce the capital cost of HS2 Phase Two

HS2 Ltd, DfT, HMT, UK Government and the UK industry all have a role to play

Findings

In summary, the study has found the following:

- HS2 Phase Two has a unique set of strategic objectives and constraints that are not typically present in comparator high speed rail projects.
- There are short to medium term opportunities to reduce the capital cost of HS2 Phase Two by up to 27%.
- Further capital cost reductions may be possible but would require the relaxation of the strategic objectives or sponsor requirements and their associated benefits.
- HS2 Ltd, DfT, HMT, UK Government and the UK industry all have a role to play in the realisation of the opportunities.
- HS2 Phase Two is at an early stage in the design process with an inherent level of immaturity in design, schedule and cost estimate.

As HS2 Phase Two develops, and with the lessons learnt from this study, these areas can be addressed. In addition, organisational capability and lessons learnt that will flow from Phase One should also result in a more optimised programme.

The study has also found the following options where innovation can be exploited in delivery to make substantial cost and schedule reductions:

- UK Infrastructure Context and Sponsor requirements: Options remain to save cost through localised route and scope refinements, and HS2 Ltd should evaluate these holistically based on estimates of costs and benefits that have been rigorously validated.
- Delivery model and the UK industry: There is an opportunity to improve efficiency within the supply chain, through consolidation of the currently fragmented market, including through partnering type arrangements and increased investment in people, plant and innovation. Continuity of the supply chain from Phase One to Phase Two will enable continuous improvement through a step-and-repeat approach to delivery.
- Design requirements and assets: There is an opportunity to optimise specifications, employ innovative designs and construction techniques used by international comparators to reduce construction time and costs for linear assets (e.g. viaducts, permanent way), as well as stations and maintenance depots, by taking a cost-led approach to design within affordability limits.
- Scope and estimate development process: There is an opportunity to improve the current scope and estimate development processes to enable better understanding of the costs of scope and design decisions, to provide transparency of how costs are driven by requirements, improve the traceability of requirements to their source, and to improve confidence in allowances for uncertainty and risk.

Recommendations

At the time of completion in 2015 the study recommended that HS2 Ltd, DfT and wider UK Government should undertake the following actions to realise the opportunities presented above. Many of these recommendations were taken forward in the work and reviews that followed the study:

HS2 Ltd

1. Validate the estimate

- Undertake a comprehensive review of the current scope of Phase Two, to validate and refine requirements, inclusions, exclusions and assumptions.
- Validate the quantities, rates and mark-ups (for indirect costs, overheads and profits) in the estimate, by:
  - verifying that quantities are aligned with the current scope and that the bases of rates are aligned with the current specifications
  - market-testing base construction rates and mark-ups
  - identifying assumptions, uncertainty, risk and opportunities within the rates
  - using information from Phase One, and ensuring consistency across the programme, driven by a centralised estimating function.
- Improve confidence in the application of top-down savings targets (e.g. value engineering and the efficiency challenge programme) by incorporating into the bottom-up estimate.
- Improve confidence in the allowance for uncertainties, risks and unallocated contingency through transition from an optimism bias approach towards quantitative risk assessment.
- Secure buy-in from stakeholders across HS2 Ltd, DfT and HMT through appropriate governance.

HS2 Ltd

2. Move to a more integrated operating model

- Design and implement an operating model that drives the progressive development of the programme and ensures integration and transparency across functions.
- Introduce management processes and systems, supported by organisational changes as necessary, to integrate the development of scope, cost, schedule and risk evaluation to ensure alignment across functions, with clear ownership of and accountability for each; and the estimate overall.
- Establish a clear link between scope, costs and benefits, by identifying the impact that each element of scope has on the benefits case.
- Evidence from the benchmarking study demonstrates that there is tighter integration between the infrastructure organisations, responsible for the design, construction and commissioning of High Speed Rail schemes, and the rail network operator. We have seen strong alignment through the design development phases (especially where the conventional network is used for either early phasing or the permanent solution); and in the design of the operational infrastructure and systems, with the Network Operator having accountability for decisions impacting the operational and whole-life cost aspects of the system.
- We recommend that the Operating Model between HS2 Ltd and Network Rail is reviewed to ensure that the appropriate strategic alignment is in place, compared with other international schemes.

HS2

3. Reinforce cost-led decisions on performance, scope and design

- Set budgets, at an appropriate cost breakdown level (for example, for each station site, for individual major structures, rates for common linear assets), based on comparator costs and within affordability limits agreed with the sponsor.
- Greater emphasis should be placed on decisions on specification, design and schedule being cost-led, with estimating and commercial functions being an integral part of the programme delivery teams.
- Review opportunities to reduce costs through revisiting sponsor's requirements, refining the scope and phasing delivery, enabled through a reliable baseline and integrated scope, cost, schedule and risk functions, and taking a value management approach with consideration of whole life costs.
- Exploit international experience to introduce engineering solutions that save money, cheaper asset designs, and more efficient construction methods, through engagement with overseas contractors and infrastructure managers, and adopting emerging practices from Phase One and other UK major projects.
- Programme development should be subject to a comprehensive delivery and governance process, with gateways that incorporate a holistic evaluation of scope, quality, cost, benefits and schedule against the agreed requirements for each. Any proposals to deviate from agreed requirements should be subject to rigorous change control with appropriate governance.

HS2 Ltd

4. Evaluate design decisions driven by the Hybrid Bill process

- Identify and review design decisions that have been made in anticipation of challenges during public consultation and the cost of the resulting elements of scope driven by these.
- Where appropriate, review opportunities to reduce cost, and secure buy-in from stakeholders across HS2 Ltd, DfT and HMT to the decisions made.

HS2 Ltd

5. Reduce supply chain inefficiencies

- Encourage continuity of suppliers from Phase One to Phase Two by signalling to the market that demonstrating cost efficiency through continuous improvement on Phase One could be considered in the Phase Two selection process.
- Incentivise the market to reduce inefficiencies in the supply chain by developing a procurement strategy, underpinned by contracting strategies and tender selection processes, that:
  - enables and encourages collaboration and vertical integration in the supply chain to reduce the impact of fragmentation on overheads
  - encourages the supply chain to innovate and invest in people and plant
  - optimises the balance between market-led innovation and efficiencies through programme-wide standardisation.

DfT

6. Support the efficient delivery of high speed rail, and wider industry improvements in the UK

- DfT should review the governance arrangements for defining and managing the strategic objectives and sponsor's requirements, including increased transparency and linkage between cost, value and scope - throughout the project lifecycle.
- Build on the work and progress of the Infrastructure Client Group to achieve greater integration between DfT, Network Rail and HS2 Ltd to optimise decision making and share assets, capabilities and experience.

UK Government & Wider Industry

7. Develop an integrated strategic national infrastructure plan for high speed and conventional rail

- UK Government should create a more integrated strategic national infrastructure plan including high speed and conventional rail with committed spend targets that would ideally command parliamentary support across parliamentary cycles, to realise:
  - a better integrated and more experienced supply chain, building on the work of IUK and ICG, increasing investment and innovation to drive efficiencies and productivity increases
  - greater continuity in project sponsor and promoter/development roles, with corresponding increases in experience and capability.

UK Government & Wider Industry

8. Avoid early lock-in for future projects

- UK Government should look at how other countries manage development agreement processes to avoid scope being locked-in early, before designs are sufficiently developed to permit robust cost-benefit analyses, and thus consider amending the Hybrid Bill process for future infrastructure projects.

UK Government & Wider Industry

9. Review guidance and application of optimism bias

- UK Government should review its guidance on the application of optimism bias to infrastructure projects and consider the introduction of a more quantitative approach, as used in other countries, as the UK builds a portfolio of major programmes that could provide a rich source of data to inform such an approach. UK Government should bring client groups together to ensure that such data is captured and shared to the maximum benefit of the country.

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