High Speed Two (HS2) Phase Two

Risk analysis for the economic case
Technical documentation

July 2017
CS866_F

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Department for Transport

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High Speed Two (HS2) Limited,
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA

Telephone: 08081 434 434

General email enquiries: HS2enquiries@hs2.org.uk

Website: www.gov.uk/hs2

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Contents

1 Introduction

1.1 Scope and purpose of this document

1.1.1 This document provides background information and additional technical detail on the methodology used to calculate the benefit-cost ratio (BCR) histograms in the report "High Speed Two: Economic Case Advice for the Department for Transport."

1.1.2 The BCR is calculated from estimates of transport user benefits, construction and operating costs, fare revenues and monetised externalities following standard procedures and assumptions, as set out in the Department for Transport's WebTAG guidance.

1.1.3 In the many business cases one scenario is presented as a 'central case' and the calculated BCR is presented as a certainty with little understanding of its robustness. Whilst this approach provides a good basis for comparison of proposals, it is ultimately only one view of the future. In an infrastructure project with a potential lifespan of over 100 years, a single point-estimate fails to capture the potential upside and downside risks to returns from the investment.

1.1.4 Therefore, for the HS2 economic case, we have adopted a different approach to assessing the strength of the case. This new approach is based on assessing the potential range of returns in a way that allows us to understand the resilience of the returns to a range of different futures.

1.1.5 The assumptions that are made when assessing the returns from transport infrastructure investments, such as the rate of growth in the demand for travel, and the strength of economic growth, can exert a strong influence on the results of the analysis. In order to inform the assessment of the resilience of the economic case we have tested the strength of the case under a wide range of different assumptions.

1.2 Document structure

1.2.1 There are three further chapters in this report. Chapter 2 outlines the aims of the risk analysis, chapter 3 details the methodology, and chapter 4 provides detail on the inputs and assumptions.

1.2.2 A glossary of terms is provided at the end of the document.

2 Our approach to analysing risk

2.1 Introduction

2.1.1 The HS2 Risk analysis is a Monte Carlo model that estimates the combined impact of multiple sources of quantifiable risk on an outcome. The approach relies on the definition of ranges of risk around key variables, and the repeated simulation of the impact of different combinations of those factors on the outcome in question. A key advantage of using such an approach is that it guards against excessive weight being placed on extreme outcomes that would require the coincidence of a set of unlikely events to occur.

2.1.2 For this analysis, the key output measure is a benefit-cost ratio of the HS2 scheme. The BCR is calculated by dividing the net transport benefits by the net cost to Government. For each simulation every variable within the risk analysis is randomly generated using its defined distribution. The simulated value is then entered into the BCR calculation. Afterwards all the models are recalculated and combined to produce a BCR for the simulation. Once all of simulations have been calculated they are used to produce key statistics (mean, median etc.) and also histograms for the Economic Case.

2.1.3 A large number of simulations are required to build a reliable distribution of possible outcomes. In order to achieve this, the model that is used to predict the outcome must be capable of running quickly and automatically. Even with a relatively fast model the number of runs required could still lead to an excessive total run time.

2.1.4 To reduce the time taken to accurately estimate the range of BCR values, the input variables are generated using the Latin-Hypercube sampling (LHS)[1]. "*The distinguishing feature of Latin Hypercube sampling is stratification of the input probability distributions. A sample is then chosen from each stratified layer of the input distribution. Sampling is forced to represent values in each layer and thus recreates the input distribution. Convergence tests show that this method of sampling converges faster on the true distributions compared with Monte Carlo sampling.*"

2.1.5 As in previous business cases, each risk analysis run uses 2000 simulations to assess the variability of the BCR. 2000 simulations provides a useful balance between reducing the run time and making sure that the BCR converges as much as possible to the true BCR. To test this the model was run multiple times using different initial random seeds and the variation in the median BCR measured for different numbers of simulations.

[1]Public sector business cases using the five case model: updated guidance (2015) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/469317/green_book_guidance_public_sector_business_cases_2015_update.pdf

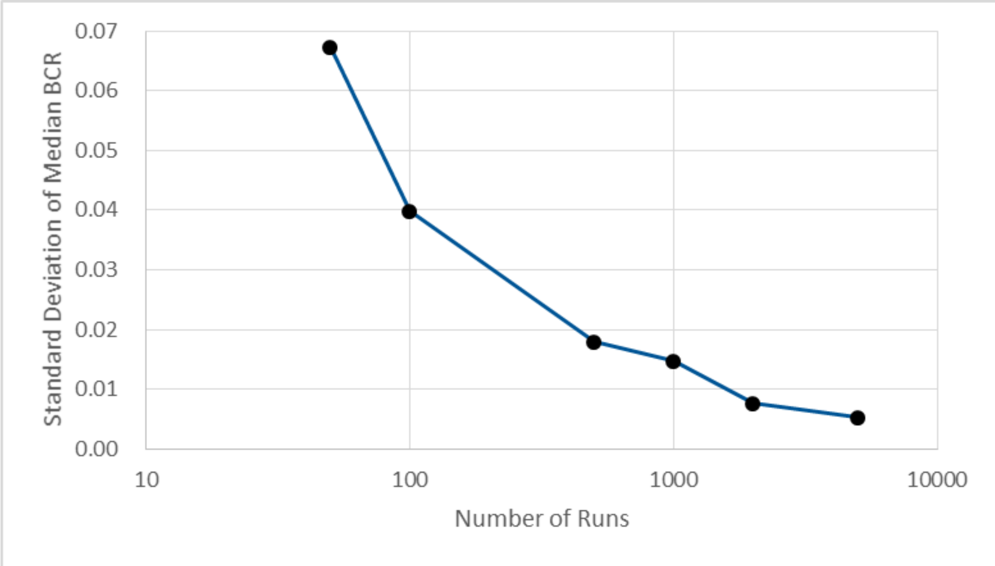

Figure 1: Graph of BCR variability against the number of model runs

2.1.6 This analysis suggests that below 2000 simulations the variations in the BCR would be two great to give a definitive answer. However increasing the number of runs does not appear to significantly reduce the variability. As a result it would not be economical to use 5000 simulations.

3 Model Methodology

3.1 Outline

3.1.1 One of the variables that has the largest impact on the economic appraisal of HS2 is the level of demand for long distance rail travel. This is calculated using the Exogenous Demand Growth Estimator (EDGE) model which then feeds into the Planet Framework Model (PFM) that assesses the impact of HS2. Further details on the modelling process can be found in PLANET Framework Model (PFM V7.1) – Model Description.

3.1.2 The runtime for both PfM and EDGE is significant and therefore it is not possible to include them in the risk analysis directly. To allow for the rapid estimation of demand and benefits two regression-based models have been constructed. The first acts as a meta-model for EDGE, estimating how long distance demand would change under various economic assumptions. The second estimates how levels of benefits and revenues changes as the level of demand changes. The process for doing this is outlined in the following sections.

3.2 Modelling demand growth

3.2.1 EDGE takes population, employment, fares levels, incomes and other data to provide forecasts of exogenous demand to PFM. The data comes from a wide variety of sources and is a mixture of regional and national data depending on the forecast year.

3.2.2 The meta-model takes EDGE results and estimates the model's relationships between the outputs and the variables for the risk analysis, to make analysis quicker and easier. To simplify the model it only works at a national level and it ignores many of the smaller factors that affect demand such as other public transport fares.

3.2.3 The model uses the following equation to calculate the overall cumulative demand growth for a given year :

$$D = C * AG^{t} * Pop^{p\ elast} * Fare^{f\ elast} * GDP^{GDP\ elast}$$

3.2.4 Where; *D* = Demand, *C* = a constant and *AG* = annual growth.

3.2.5 To simplify this equation we take the logarithm of both sides and then rearrange, taking advantage of the properties of the logarithm function;

$$\ln(D) = \ln(C * AG^{t} * Pop^{p\ elast} * Fare^{f\ elast} * GDP^{GDP\ elast})$$

$$\ln(D) = \ln(C) + \ln(AG^{t}) + \ln(Pop^{p\ elast}) + \ln(Fare^{f\ elast}) + \ln(GDP^{GDP\ elast})$$

$$\ln(D) = \ln(C) + t\ln(AG) + \text{p elast} * \ln(Pop) + Fare\ elast * \ln(Fare) + \text{GDP elast} * \ln(GDP)$$

3.2.6 The final equation is now in a linear form. To make this clearer the notation X′ is used to represent ln(x)

$$\mathrm{D}' = \mathrm{C}' + \mathrm{AG}'t + (\mathrm{p\ elast} * \mathrm{Pop}') + (f\ elast * Fare') + (GDP\ elast * GDP')$$

3.2.7 The terms in the equation are then estimated using regression analysis on outputs from a number of runs from the EDGE forecasting model: four variants on GDP and two variants on fares. Each sensitivity test produces a series of values from 2014 to 2037 (24 points). No sensitivities around population have been tested and so the population elasticity is assumed to be 1.00 which is consistent with the EDGE model.

3.2.8 Due to the underlying EDGE data coming from multiple sources it is hard to generate a single regression that accurately represents the EDGE outputs. To correct for this the dataset was separated with two regressions run, one for before 2026 and another for later years. This effectively separates the short term forecasts from the long term forecasts. The estimated elasticities, the constant term and the growth term are shown in Table 2 below.

	GDP Elasticity	**Fare Elasticity**	**Pop Elasticity**	**Constant**	**Annual Growth**
Before 2026/27	0.99	-0.88	1.00	1.00	1.01
After 2026/27	1.14	-0.95	1.00	0.98	1.01

Table 1: Estimated terms from regression analysis of EDGE model sensitivity tests

3.2.9 Furthermore, a comparison of the meta-model and the EDGE outputs confirms that the meta-model is suitable for the purposes of risk analysis. For all of the sensitivity tests the model has an accuracy of within 0.5% of the true value.

Sensitivity tests	**Long Distance Trips Index 2037 (2014/15 = 1)**		
	EDGE	**Meta-Model**	**Error %**
Reference Case	1.62	1.63	0.4%
RPI+0% (After 2020)	1.90	1.91	0.5%
RPI+2% (After 2020)	1.39	1.39	0.2%
GDP Growth -30%	1.38	1.39	0.5%
GDP Growth -15%	1.50	1.51	0.5%
GDP Growth +15%	1.76	1.76	0.1%
GDP Growth +30%	1.91	1.90	0.3%

Table 2: EDGE sensitivity test results

3.3 Estimating changes in benefits in response to changes in rail demand

3.3.1 The economic appraisal of HS2 uses two modelled years consistent with many other transport schemes. The first modelled year is 2026, the year of opening. In line with Webtag guidance the second modelled year is 20 years after the year of appraisal. For the 2017 Economic Case this is 2037.

3.3.2 For each modelled year, the transport planning model (in our case, PFM) is run twice – once with, and once without the investment (in this case HS2). The benefits and revenues for each of the modelled years can then be calculated by comparing the outputs from the model (demand, travel times, crowding etc.) for each of those scenarios. To calculate a profile of benefits and revenues over time all of the other forecast years are either an interpolation between 2026 and 2037 or a projection based upon the 2037 results and population growth. Due to this methodology the entire stream of benefits and revenues over the full appraisal period can be estimated by adjusting only the values for the two modelled years.

3.3.3 Therefore a simple linear regression was performed to identify the relationship between long distance demand and a measure of benefits, the extrapolation index (EI). The EI is calculated by subtracting the 2026 level of benefits and dividing by the difference between the 2026 and 2037 benefits. In the reference case the 2026 EI is 0 and the 2037 EI is 1.

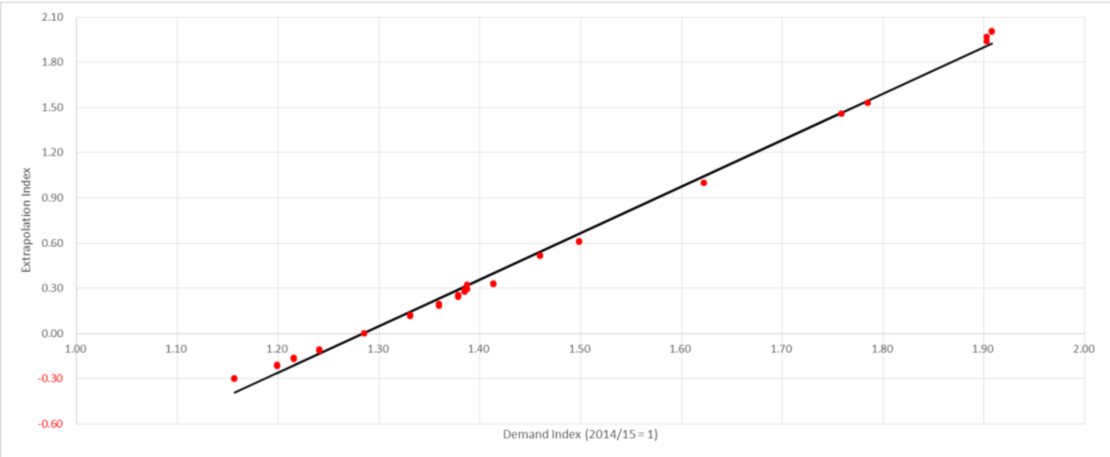

Figure 2: Graphing the relationship between the extrapolation index and the demand index

3.3.4 This regression then allows for an equation to be formed, EI = (3.09*DI) - 3.96, that defines the relationship between long distance demand and the required adjustment to benefits. The risk analysis model then takes the forecasted demand from the EDGE meta-model and calculates a new EI which is entered in the economic appraisal to compute the level of benefits and revenues for each simulation.

3.3.5 While this methodology is relatively simple, it has proven to be remarkably effective. As Figure 1 shows there is a very strong relationship between the level of long distance demand and the benefits and revenues of HS2.

3.4 Estimating Wider Economic Impacts

3.4.1 All BCR figures quoted in the economic case include Wider Economic Impacts (WEIs). The WEIs calculated for the HS2 scheme have three main components: Output change in imperfectly competitive markets, Agglomeration and Labour supply impacts. A full description of the method for calculating WEIs and what effects they measure can be found in Tag Unit A2.1[2] Due to methodological differences they are calculated differently and the details are outlined below;

3.4.2 Output Change in Imperfectly Competitive Markets: Under the standard case imperfect competition impacts are simply calculated as being 10% of the total business benefits; therefore calculating the variation in this element of the WEIs is done automatically by the Risk Analysis.

3.4.3 Agglomeration & Labour supply impacts: In the standard analysis this is calculated with the Department for Transport's Wider Impacts in Transport Appraisal (WITA) software. A small number of sensitivity tests have been run to attempt to estimate the relationship between long distance demand and the resulting WEIs.

3.4.4 The results of the sensitivity tests suggested that the Agglomeration & Labour supply impacts were relatively invariant to demand for both Phase One and Phase 2a. This is partly due to the lower levels of capacity provided by HS2 before Phase 2b. As such the Agglomeration & Labour supply impacts are held fixed relatively to demand and only the Phase 2b impacts are adjusted as the demand level changes.

3.4.5 Separately the WITA outputs are processed by a spreadsheet using a similar method to the main appraisal spreadsheet. This allows for the WITA benefits to be estimated by year and for the three phases of HS2 to be properly assessed. One of the inputs to this spreadsheet is GDP/capita which is used to grow benefits over time and as a result this is also varied in the risk analysis by using the GDP distribution.

[2] WebTAG Unit A2.1
http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/427091/webtag-tag-unit-a2-1-wider-impacts.pdf

4 Inputs/Data assumptions

4.1 Outline

4.1.1 Data has been collected from a variety of sources to inform the input distributions for the Risk Analysis model. In the vast majority of cases the mean of the distribution is set to equal the value used in the main appraisal process and the only additional data has been the estimate of the standard deviation.

4.1.2 The variables that have been selected for inclusion in the risk analysis have been chosen on the basis that they are key drivers of the BCR and that there are reliable sources of information for the parameter and its distribution. The full list of variables is outlined below.

Economic Variable	Benefits/Cost Impact	Included in Risk Analysis	Varied in Scenarios
GDP Growth Rate	Transport User Benefits Wider Economic Impacts Capital Cost Revenue	Yes	Yes
Fare Growth	Transport User Benefits Revenue	Yes	No
Value of Time	Transport User Benefits	Yes	No
VOT Elasticity	Transport User Benefits	Yes	No
GDP & Fares Elasticities	Transport User Benefits Revenue	Yes	No
Phase One Construction Cost Risk	Capital Cost	Yes	No
Phase 2a Construction Cost Risk	Capital Cost	No	Yes
Phase 2b Construction Cost Risk	Capital Cost	No	Yes
Phase One Rolling Stock Cost Risk	Capital Cost	Yes	No
Phase 2b Rolling Stock Cost Risk	Capital Cost	Yes	No
Car and Diesel Carbon Impacts	Other quantifiable benefits	Yes	No
Reliability Benefits	Transport User Benefits Revenue	No	Yes

Table 3: List of Risk Analysis variables

4.1.3 Clearly, these are not the only factors in the calculation of the BCR but they exert a strong influence over the results, particularly GDP growth. They are also the factors that are most amenable to analysis within our model. Most of the main elements of the HS2 BCR calculation have some variability modelled within the Risk Analysis. The only two exceptions are except are Operating Costs and Noise.

4.1.4 The addition of further variables into the analysis could either increase or decrease the variation in the scheme BCR, depending on the correlation with the other variables analysed.

4.2 UK GDP growth

4.2.1 In the appraisal of HS2, economic growth determines both how quickly demand grows in the model and how people value travel time-savings from the scheme. It is also used as a minor input in both the WEI's and Capital Cost calculations. As such it is the most critical input for the risk analysis.

4.2.2 The GDP projections used in the risk analysis are drawn from Office for Budget Responsibility (OBR) forecasts. These forecasts were published in the *Fiscal Sustainability Report* (January 2017) and the *Economic and Fiscal Outlook Report* (November 2016) and match the values used in PFM[3].

4.2.3 The OBR produces two sets of GDP forecasts - short-term forecasts and long-term forecasts. These are handled in the modelling in different ways.

4.2.4 The OBR short term forecasts are based on a split-normal distribution. The parameters, as provided by the OBR, are shown in Table 4.

Calendar year	2016	2017	2018	2019	2020	2021
Median	2.10	1.40	1.70	2.10	2.10	2.00
Skew	0.37	-0.12	-0.44	-0.64	-0.66	-0.67
Standard Deviation	0.73	1.22	1.82	1.92	2.02	2.12

Table 4: OBR Short term growth statistical parameters

4.2.5 These can be used to produce a fan chart of possible values for annual GDP growth. As part of their November 2016 forecast the OBR produced a fan chart of potential GDP growth rates over the next five years.

[3] Further details can be found in "PLANET Framework Model Version V7.1 Assumptions Report.

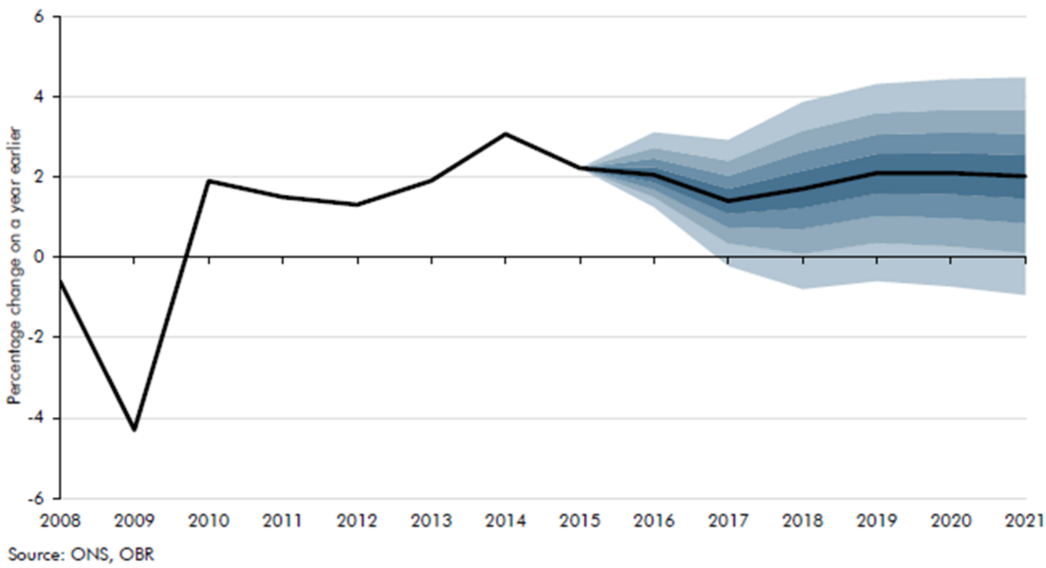

Figure 3: OBR GDP Fan Chart – Economic and Fiscal Outlook November 2016

4.2.6 The graph clearly shows the level of uncertainty around the GDP forecast increases with each year, which is to be expected given the difficulty of forecasting future GDP growth.

4.2.7 It is also worth noting that the OBR assumes that each year's forecast is independent of each other year. This is likely to be somewhat unrealistic, and may understate overall GDP volatility. However, there is a lack of data on the correlation between GDP forecasts in different years so the assumption is a necessary simplification.

4.2.8 The OBR do not publish a fan chart for their long-term GDP growth projection. As such the distribution for long-term growth is constructed in a different way. Long term GDP growth is assumed to be normally distributed and the mean value for each year is set to equal the OBR central GDP growth projection.

4.2.9 To estimate the standard deviation (SD) of long term GDP growth we have a assumed that there is a 95% chance that the OBR forecast is within +- 0.5% of the true long term average of GDP which is equivalent to a standard deviation of 0.26%. This assumption is very simplistic for calculating individual years but is appropriate for calculating the cumulative GDP growth between 2021 and 2037.

4.3 Value of Time

4.3.1 The value of time (VOT) research work[4] provided confidence intervals for the mean value of time. This allows for an estimate of the SD to be calculated by assuming that the value of time is normally distributed about the mean. In the case of business value of time the guidance has suggested a distance weighted approach where the value of time is different depending on the distance

[4] Available at https://www.gov.uk/government/publications/values-of-travel-time-savings-and-reliability-final-reports

travelled. It has not been possible to create a formula to adjust the SD for different distances.

4.3.2 As such the SD is used to model an adjustment factor, with mean 0, and the entire VOT curve is moved up or down depending on the value of this adjustment factor in each simulation.

4.3.3 As the distance-based approach as formally been accepted into guidance there is now more certainty over which VOT to use. Therefore no specific VOT sensitivity tests have been produced.

4.4 Non-business value of time elasticity

4.4.1 The standard deviation used in the analysis has not been updated since the 2013 economic case. Therefore the non-business VOT elasticity remains modelled by a Normal distribution with mean 1 and SD 0.135.

4.5 Fares & GDP Elasticities

4.5.1 In line with WebTAG guidance, the EDGE elasticities for GDP growth are based on evidence from PDFH5.1, whereas those for fares are based on PDFH4.

4.5.2 The fare elasticity of long-distance rail demand is divided into flows in or between three regional categories 'London', 'London and the South East' and 'Rest of Country', and information on variation is therefore available at this disaggregated level. Similarly the GDP elasticity is divided in "From London" and "to London" flow. To generate an overall variation, the variations for each regional category have been averaged together using weightings from the central case EDGE model run.

4.5.3 The resulting standard deviations included within the risk analysis are:

	Standard Deviation
GDP Elasticity	0.025
Fares Elasticity	0.041

Table 5: Standard deviation of GDP and fares elasticities

4.6 Capital Cost Risk

4.6.1 For Phase One, a quantitative cost risk assessment (QCRA) is used to determine the level of contingency that should be added to the base cost estimate. The QCRA includes threats that may or may not occur and tolerance ranges associated with the status of the price estimation and design development. Both threats and tolerances represent uncertainty to the base cost estimate.

The QCRA uses stochastic risk simulation to allow the cost uncertainties to be represented by ranges rather than single values, and the inclusion of events that may or may not occur. Each input is assigned one or more representative probability distributions which are sampled when the simulation is run.

4.6.2 The Phase 2a and Phase 2b construction cost risk is estimated using optimism bias (at 40%) rather than a QCRA. A sensitivity test with optimism bias set at 50% has been included in the economic case to compensate for the lack of QCRA.

4.6.3 A quantified risk analysis has also been developed for the rolling stock costs of both Phase One and Phase 2b of the HS2 scheme. As these will be procured separately the risks associated with each have also been determined separately. However, to reflect the fact that lessons will be learnt from Phase One, the level of risk is significantly lower for Phase 2b.

4.6.4 The QCRA simulation produces a range of possible estimates for contingency as a percentage of the base cost. These values are displayed in an S curve below. The S-curve shows the probability that a given cost will not be exceeded e.g. the P95 cost has a 95% chance of it not being exceeded.

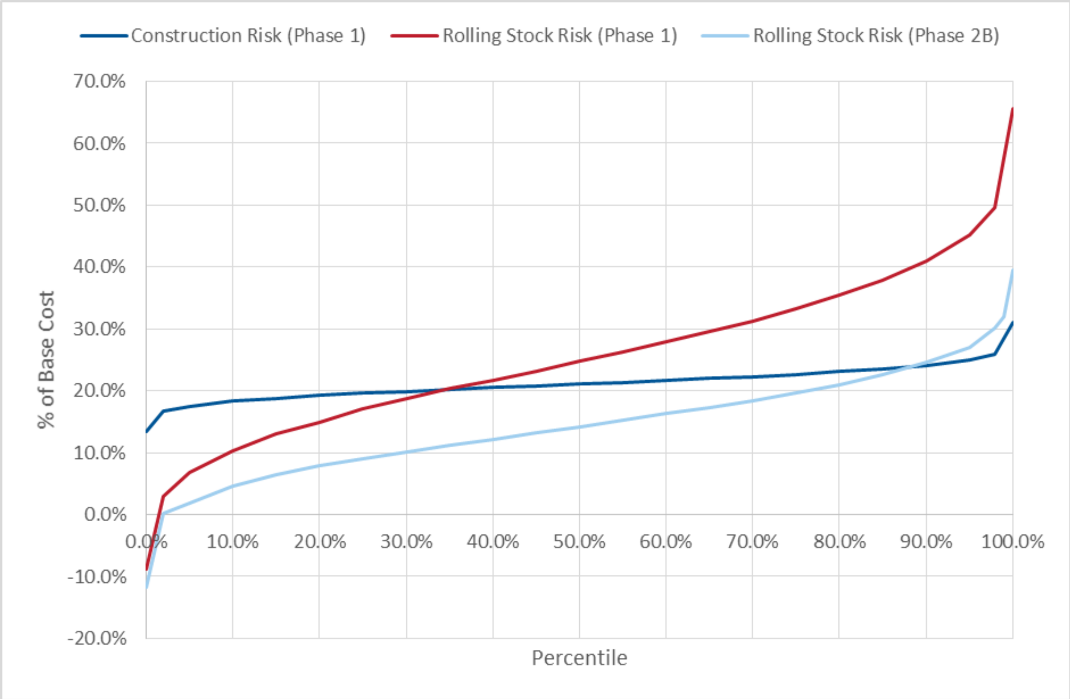

Figure 4: Cost QCRA curves

4.7 Carbon Models

4.7.1 Webtag guidance requires three estimates of carbon to be produced. A central case for use in the economic appraisal as well as a high and low sensitivity. Previously these sensitivities have not be used within the business case as they would not impact the BCR in a noticeable way.

4.7.2 In this version of the Risk Analysis these outputs have been included. By assuming the high and low estimates are maximum and minimum estimates for the value of the carbon impacts it is possible to create a triangular distribution to give a range of environmental impacts.

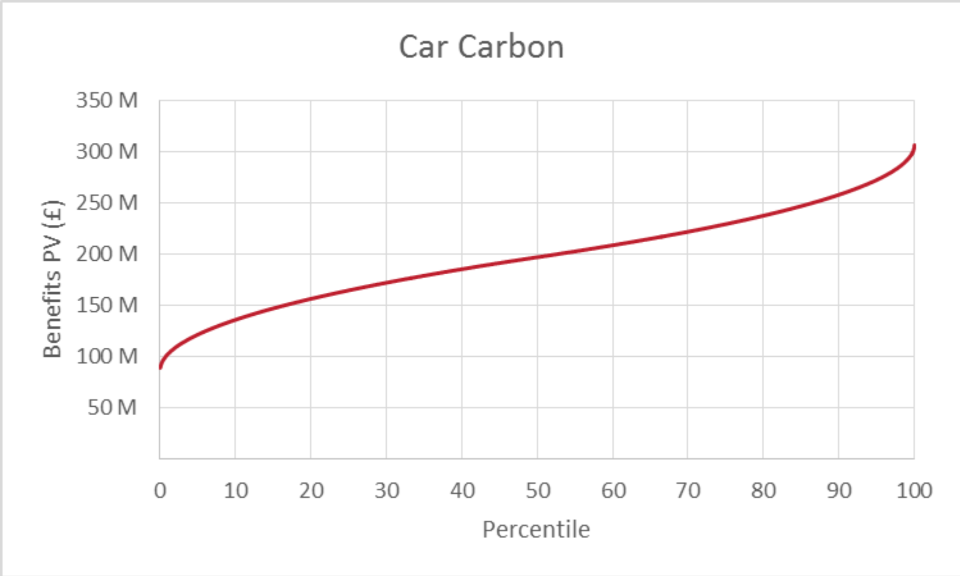

Figure 5: Distribution of car carbon benefits

5 Glossary

Definitions	Acronym	
Appraisal period	-	The assumed useful life of the assets for analysis. For the full network analysis it is 60 years from the opening of Phase 2b i.e. from 2033 to 2093.
Benefit cost ratio	BCR	The ratio of project benefits to project costs.
Capital costs/capital expenditure	CAPEX	The cost of acquiring the physical assets for HS2, including construction, land purchases and rolling stock.
Cost benefit analysis	CBA	The process of calculating and comparing the benefits and costs of a project, usually to generate the BCR.
Consumer price index	CPI	A measure of inflation, currently the government's official measure of price increases.
Demand cap year	-	The year in which the demand cap is reached.
'Do-Minimum'	DM	The set of train services and demand which are assumed to be in place if HS2 did not happen – the base case – against which the 'Do-Something' is assessed.
'Do-Something'	DS	The transport intervention – HS2 scheme – being considered.
Department for Transport	DfT	The government department responsible for the English (and some of the Scottish) transport network.
East Coast Main Line	ECML	The existing rail route connecting London King's Cross, Peterborough, Doncaster, Wakefield, Leeds, York, Darlington, Newcastle, Edinburgh and Aberdeen.
Elasticity	-	The responsiveness of a change in X as a result of a change in Y.
Full network	-	The extent of the HS2 network currently being planned for construction.
Gross domestic product	GDP	The market value of all officially recognised final goods and services produced in the UK within a given period.
Green Book	-	HM Treasury's guidance for public sector bodies on how to appraise options before committing funds to a policy, programme or project.
High-speed rail	HSR	A railway that can operate at speeds of over 150 mph.
Hybrid Bill	-	A option for new legislation that will provide the powers to build HS2.
Optimism bias	OB	A financial allocation to compensate for the systematic tendency for appraisers to be over-optimistic about key project parameters.
Office for Budget Responsibility	OBR	An independent body that analyses the UK's public finances.
Office of National Statistics	ONS	The UK's largest independent producer of official statistics.
Operating Costs	OPEX	The costs associated with running the railway including the maintenance of the track and trains and staff costs.
PLANET Framework Model	PFM	The suite of models used by HS2 Ltd to analyse the impact of HS2 on rail travel in the UK.
Passenger Demand Forecasting Handbook	PDFH	A summary of over 20 years of research on rail demand forecasting, service quality and fares.

Definitions	Acronym	
Phase One	-	The section of HS2 between London and the West Midlands with a connection via the West Coast Main Line at conventional speeds to the North West and Scotland. Phase One includes stations at London Euston, Old Oak Common (West London), Birmingham Interchange (near the National Exhibition Centre and Birmingham Airport) and Curzon Street.
Phase Two	-	The section of HS2 that extends beyond the West Midlands to Manchester and Leeds with connections to conventional railway lines via the West Coast and East Coast Main Lines. Phase Two includes stations at Manchester Airport, Manchester Piccadilly, East Midlands Hub (between Nottingham and Derby), Sheffield Meadowhall and Leeds. Phase Two is split between Phase 2a and Phase 2b.
Phase 2a West Midlands to Crewe	-	The section of HS2 between the West Midlands (Fradley) and Crewe.
Phase 2b Crewe to Manchester, West Midlands to Leeds	-	The section of HS2 from the West Midlands to Leeds (the Eastern leg), and from Crewe to Manchester (the Western leg).
Quantified risk assessment	QRA	A formal method of calculating the quantity of individual risks.
Real terms	-	The financial value, after removing the effects of inflation.
Released capacity	-	The availability of capacity on the conventional network created by the introduction of HS2.
Retail Price Index	RPI	An alternative measure of inflation previously adopted by the government as the official measure of price increases.
Service specification	-	The train service assumptions used in our modelling.
Standard case	-	Our scenario which most rigidly applies the assumptions in the Department for Transport's WebTAG guidance.
Train operating company	TOC	A company that holds an operating contract for a rail franchise.
Value of time	VoT	The implicit value people place on time.
Web Based Transport Analysis Guidance	WebTAG	The Department for Transport's guidance that provides guidelines on how to conduct transport studies.
West Coast Main Line	WCML	The existing rail route connecting London Euston, Birmingham, Manchester, Liverpool, Glasgow and Edinburgh. It is the busiest mixed-traffic railway route in Europe.
Wider economic impacts	WEIs	The agglomeration, imperfect competition and increased labour force participation benefits.
Wider Impacts in Transport Appraisal	WITA	Software that has been developed to estimate wider economic impacts (WEIs) of transport schemes, as explained in WebTAG Unit A2.1
Willingness to pay	WTP	The maximum value a consumer is willing to pay for a good or service.

High Speed Two (HS2) Limited,
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA

www.gov.uk/hs2