HS2 Carbon Implications Study Report

PARSONS BRINCKERHOFF

HS2 CARBON IMPLICATIONS STUDY REPORT

C240-PBR-OP-REP-000-000017 (P03)

Route Wide (C240 & C241)

HS2 Carbon Implications Study Report

Contents

Page number

List of figures

None Used

List of tables

List of acronyms

HS2	Project name for the High Speed 2 network (UK)
HS2 Ltd	Company Name for High Speed 2 client organisation
PB	Parsons Brinckerhoff
NR	Network Rail
ECML	East Coast Main Line
WCML	West Coast Main Line
AGV	Automotrice à Grande Vitesse (Alstom high speed reference train)
ECS	Empty Coaching Stock
EPS	Enhanced Permissable Speed (Tilting train speeds)
SA	Sectional Appendices (NR)
5MD	Five Mile Diagrams (NR)
TSS	Train Service Specification
TPC	Train Performance Calculator (Single Train runs)
SRT	Sectional Run-Time (time including margin used in the timetabling of trains)
TRT	Theoretical Run-Time (proposed by agreed uplift of all-out time)
TiPLoc	Timing Point Location (typically a passing time at a location for timetabling)
TE	Tractive Effort
IPD	Interim Preliminary Design
S&C	Switches and Crossings

References

Title	Reference
HS2 Project dictionary	HS2-HS2-PM-GDE-000-000001
[1] Phase One and Two timetables	Phase One = C240-PBR-OP-REP-000-200007, Phase Two = C240-PBR-OP-ASM-000-000004
[2] HS2 Phase Two Train Service Specification	HS2-HS2-SA-REP-000-000002 P02 (May 2013)
[3] Signalling design proposals received post-Hybrid Bill reporting	C240-PBR-RS-DMA-000-910001-FD
[4] Updated alignments and layouts for Curzon Street “Option 8E” by ARUP (no reference provided), post-Hybrid Bill Manchester Piccadilly “Base Case” layout from AECOM (no reference provided), and post-Hybrid Bill Leeds station “Option 6” layout (no reference provided)	
[5] Traction Energy Efficiency Report	C240-PBR-OP-REP-000-200013
[6] Euston station review of 7 platforms	C240-PBR-OP-REP-000-200012
[7] Modelling Parameters (Configuration Matrix Draft)	C240-PBR-SA-REG-000-200004
[8] Nominated Models	C240-PBR-DS-REP-000-000002

1 Executive summary

1.1.1 The purpose of this study is to support the determination by the Environmental Overview Consultants (EOC) of carbon emissions and the implications on HS2 Ltd's carbon footprint of operating trains at lower limiting speeds of 360-270kph in 30kph steps. This study has considered both single train journeys and full-day timetables for both Phases One and Two as defined in the HS2 Train Service Specification.

1.1.2 This report provides the results of simulations and further desktop timetable analyses to demonstrate timetable impacts, journey times, energy demand, train set sizing, and effects of delay for the Phase One & Two routes to/from London and Birmingham, Manchester, Leeds, Newcastle, Glasgow and Edinburgh, using the HS2 routes, dedicated West Coast Main Line and East Coast Main Line.

1.1.3 In order to ensure HS2 can function as a robust, operational railway, the design and modelling carried out to date has adopted internationally recognised best practice timetable planning methodology. As such, while the maximum operating speed on HS2 is 360km/h, trains are able to achieve normal timetabled operation (i.e. required journey times) while operating up to between 320 and 340km/h. This allows for a margin which, put simply, enables trains to "catch-up" on the planned schedule following delays. Such a margin is critical to the reliable operation of a railway.

1.1.4 As a result of this, operation at 330km/h is shown in this report to have no impact on achievement of the required journey times. However, were the train speed to be limited to 330km/h, the timetable would need to be changed to recreate the necessary margin which allows for reliable operation. A timetable designed for 330km/h maximum speed (or lower) would need to be based on longer journey times than are currently required for HS2 and under such a timetable, trains would normally operate at a lower speed, expected to be around 300km/h. Unless otherwise stated, the increases in journey time reported in this document therefore reflect the increased timetabled journey time (including margins derived at 360km/h) rather than the minimum achievable journey times. It is ultimately these timetabled journey times which will be published to the travelling public.

1.1.5 The results as expected demonstrate that the energy demands reduce and journey times increase as a result of each stepped reduction in speed limit within the timetable runs carried out. Table ES1 below indicates the journey time increases for Phase One of stepped speed reductions:-

Table ES1: Change in timetabled journey time (and % increase) in Phase One for varying maximum railway operating speed scenarios (minutes) compared with Final ES

From	To	Final ES	330 kph	300 kph	270 kph
Euston	Handsacre	0 (0%)	2 (4.6%)	4 ½ (11.0%)	8 (19.8%)
Euston	Curzon St	0 (0%)	1 ½ (3.5%)	3 ½ (8.5%)	6 ½ (15.4%)
Handsacre	Euston	0 (0%)	2 (4.4%)	4 ½ (11.1%)	8 ½ (20.4%)
Curzon St	Euston	0 (0%)	1 ½ (3.2%)	3 ½ (8.3%)	6 ½ (15.4%)

1.1.6 Where extended running time leads to inadequate turnround time at termini, this results in trains "stepping down" at termini, introducing additional units into the rolling stock circulation, and thus adding to the fleet size. The change in fleet sizes following timetable review for Phases One and Two is listed below in Table ES2:-

Table ES2 – Additional 200m units needed in service for each maximum railway operating speed scenario compared with Final ES - Summary

Route	330 kph	300 kph	270 kph
Total (Phase One)	+2 CP, +1 CL	+2 CP, +2 CL	+2 CP, +2 CL
Total (Phase Two)	+2 CP, +5 CL	+4 CP, +5 CL	+8 CP, +8 CL

CP = Captive HS2 Stock, CL = Classic compatible for Network Rail operation

1.1.7 This "stepping down" at termini also adds to the platform occupation, as at the point at which an extra unit is introduced, what was a minimum turnround become well above minimum. Availability of additional platforms is forecast to be required:

- Phase 1:
  - Manchester Piccadilly, in the 300 kph and 270 kph scenarios, HS2 services would need to use three platforms, reducing platform capacity available to other services.
- Phase 2:
  - Curzon St: Regular use of an additional platform is necessary in the 330kph, 300kph & 270kph speed scenarios, but this is already provided in the Final ES infrastructure
  - Manchester Piccadilly: For the 270 kph scenario, a fifth platform is essential
  - Leeds: A sixth platform is required in the 300 kph scenario, and then a seventh in the 270 kph scenario
  - Liverpool: in the 270 kph scenarios, availability of a third platform for HS2 trains is required, reducing capacity for other services
  - Glasgow: use of an additional platform is required in the 330kph, 300kph & 270kph scenarios, reducing capacity for other services
  - York: use of an additional platform is required in the 330kph, 300kph & 270kph scenarios, reducing capacity for other services
  - Newcastle: use of two additional platforms is required in the 330kph, 300kph & 270kph scenarios, reducing capacity for other services

1.1.8 It is possible that these requirements could be mitigated by redesign of the timetable and measures such as shunting trains out of a station after arrival and back again before departure, but it is not possible to confirm this without extensive detailed analysis.

1.1.9 Table ES3 below indicates the 'HS2-infrastructure only' train energy reductions (known colloquially as Captive trains) observed as an indicative sample of of all trains, where other trains on routes beyond HS2 infrastructure are detailed further in this report:-

Table ES3 – Mechanical Energy consumption for Captive HS2 trains

Scenario and train make-up	Max (all out) speed (km/h)	All-out service energy (kWh/km)	% energy of all-out 360km/h scenario	Max attained speed (timetabled run with margin) (km/h)	Timetabled service energy (kWh/km)	% Timetabled Energy to all-out energy
1 - 11 car	360	23.78	100%	317.9 for 330 limit	20.50	86%
2 - 11 car	330	21.89	92%	300 for 300 limit	19.90	91%
3 - 11 car	300	19.71	83%	270 for 270 limit	17.60	89%
4 - 22 car	360	45.33	100%	317.3 for 330 limit	38.81	86%
5 - 22 car	330	41.57	92%	300 for 300 limit	37.85	91%
6 - 22 car	300	37.32	82%	270 for 270 limit	33.63	90%

1.1.10 From a journey time and energy reporting perspective the results align with expectations for longer journey times and lower energy overall. Journey times for services that operate on the classic network as discussed later in this report observe lower overall impact since the classic network operates <270kph in any case. Where all energy demand is quoted in mechanical energy terms (excluding regen braking since receptivity is not known within this study), we would recommend based on other work for HS2 in this area that an approximate 11% uplift for electrical demand (including regen braking) is appropriate.

2 Abbreviations and descriptions

2.1.1 The abbreviations, descriptions and project terminology used within this document can be found in the project dictionary.

3 Background

3.1 General

3.1.1 HS2 Ltd submitted an Environmental Statement (ES) including an assessment of the carbon emission implications of the construction and operation of Phase One of HS2 alongside the hybrid Bill deposited to Parliament in 2013. In January 2014 the Environmental Audit Committee launched an inquiry into 'HS2 and the environment'. The inquiry intended to inform the House of Commons about route-wide environmental aspects of the project and subsequently recommended that HS2 Ltd should examine the carbon implications of limiting maximum operating line speed until the carbon intensity of UK grid electricity has reduced sufficiently. Limiting maximum operating line speed will not only have carbon emissions implications but could also have implications for journey time, timetable viability and hence associated lifecycle costs.

4 Introduction

4.1.1 HS2 Ltd has produced a remit to consider the carbon implication of limiting maximum operating line speed until the carbon intensity of UK grid electricity has reduced sufficiently. This requires assessment of the energy demanded for HS2 services, both for maximum currently proposed speed of operation and for potentially reduced speeds of trains from 360kph to 270kph in 30kph steps. This remit is provided in detail in Appendix B for clarity. PB have been commissioned by HS2 to undertake such tests as defined in

Appendix B via Rail network modelling to consider both the timetable implications and the energy output expectations of reducing the linespeeds in timetabled services, to enable the carbon implication of such changes for Phase One and Two to be derived using pre-defined timetable specifications and infrastructure models. The EOC has have been commissioned by HS2 Ltd to take these results and develop the expected levels of carbon output.

4.1.2 The baseline models to be used in responding to the carbon implications remit are those developed using PB's licensed and supported RailPlan V5.5 for Hybrid Bill stage, with the following amendments:-

- Updated to reflect signalling design proposals received post-Hybrid Bill reporting (ref 3)
- Updated (post-Hybrid Bill) alignments and layouts for Birmingham Curzon Street, Manchester Piccadilly layout and Leeds station layouts (ref 4)

4.1.3 No other amendments have been included at this stage of reporting. Note the only amendments reflecting a minor difference in journey time and hence energy demand are for 4.1.2 second bullet. Signalling updates have not affected the journey time of any train tested.

5 Assumptions

5.1 General based on HS2 Remit

5.1.1 The following assumptions and clarifications have been made over and above the remit in Appendix B, to provide further clarity over the bases for the study and the approach PB have agreed with HS2 Ltd and EOC.

5.1.2 Where the remit refers to 360kph operation, in practice through use of operating margins within the Phase One and Two timetables (Ref 1) the maximum speed reached by main Line HS2 trains may not generally be higher than around 320-340kph. This is to absorb operating margin in each Sectional Running Time (SRT) where a late running train would use this spare margin to recover delay.

5.1.3 For timetabled operation the remit refers to 90% operating at lower speed and 10% operating at higher speed. It has been agreed with HS2 Ltd that this can be managed as a post-processing activity by EOC and so no amendment to train performance in the operating timetables is required.

5.1.4 Only Phase One (10tph) and Two (18-tph) full-day timetables will be required for modelling the initial and ultimate stages of operation requested by the range of years that carbon implications analyses need to consider.

5.1.5 Section 4b of the remit requires confirmation of whether or not the existing frequency of service can be maintained with the stepped lowering of speed limits. The issue here is whether the proposed timetables will support train movements without delay to ongoing services. Ideally new timetables would be generated to make each speed pattern work if the limiting speed could not be accommodated in the journey operational margins. However the timescales for this work prohibit this from being carried out and so we have agreed with HS2 Ltd that the approach can be partly qualitative, based upon PB reviewing both the effects of speed reduction on full-day timetables and review of the implications of this on individual train service runs unhindered by other trains. These services are as defined in (ref 2) for Phase One and Two services including calculation of the TRTs that are used to derive SRTs. Please refer to Sections 7-9 for demonstration of these unhindered services, and a review for each Phase of the expected timetable implications.

5.1.6 Where the remit refers to derivation of kWh figures for train energy, this requires relative impacts of energy to be considered which precludes the need for detailed analyses to determine electrical loads. Instead we have agreed with HS2 Ltd that previous analyses to determine traction energy loads electrically for efficiency review (ref 5) can be used to define a working assumption of mechanical to electrical energy conversion, where mechanical energy is provided in Section 7 from the simulations undertaken for this study. All results for energy usage in this report are quoted for mechanical energy only. To clarify the mechanical energy figures provided exclude braking energy that could be used for regenerative braking, accepting that Line electrical receptivity is not known but also for the purposes of relative energy consumption this is sufficient to review comparative energy at the differing maximum speeds. Within the confines of this study, assessments based on the (ref 5) traction energy efficiency report indicates for Phase One services that the uplift from mechanical energy to electrical energy for timetabled services should be around 21-25% for absolute energy demand from DNO, with 7-16% uplift when taking account of a fully receptive Line and regen-fitted service. A reasonable approximation therefore from the above figures taking account of number spread in the Phase One sample would be 23% uplift without accounting for regen and 11% when accounting for regen to derive the equivalent electrical energy demands.

5.1.7 The remit refers to yearly operation and the results requested from EOC require this. We have been advised by HS2 Ltd that the standard year for operation calculations will be 350 days.

5.1.8 The remit refers to the HS2 Rolling Stock Specification, which latest edition also contains reference to conventional trains. We have agreed with HS2 Ltd for this activity that we have excluded conventional trains (non-articulated design) from our energy and timetable review, on the basis that a relative energy consumption assessment for differing speeds is what is needed for further assessment by EOC.

5.1.9 The remit refers to the working base case for fleet sizing as that included in the circulation and stabling plan provided for Hybrid Bill. For the purposes of this study we have agreed that only the operational fleet (i.e. excluding hot standby trains and trains in Depot for maintenance) will be considered for the fleet sizing assessment.

6 Methodology

6.1 General

6.1.1 In order to generate the required outputs for the carbon implications study, PB used Modelling and Simulations software RailPlan V5.5.0 and Excel 2010. The model generated for carbon implications review are identified for record purposes as “HS2-2A V22” dated 04/03/15, for both Phase One and Phase Two timetables. The input data is based upon above references and modelling parameters (ref 7).

6.1.2 The first stage of this process was to validate the Phase Two infrastructure model against the proposed timetable. This required minor functional amendment of the timetabled services to align with latest changes to the network model as described above, such as routing changes at Curzon Street, Manchester and Leeds.

6.1.3 Once satisfied the infrastructure model was working correctly, the next stage of the process was to verify the Baseline model function, and run the models for Phase One and Phase Two timetables, as well as running the range of single-train referenced services (identified in ref 2) in all-out performance mode for comparison of margin usage versus reduced speeds.

6.1.4 Following verification of the Baseline model, a key part of the PB remit was to test differential linespeed profiles in order to identify their impact on both the full-day timetable and TSS single-train runs and then translate the outputs into excel spreadsheet form. To achieve this objective, PB manually changed the speed profile of the rolling stock directly in RailPlan and re-ran models accordingly as single-train runs and “normal” timetable batch-runs. The incremental speed profiles tested were 360kph (Baseline); 330kph; 300kph and 270kph. The timetable and single run outputs were extracted from RailPlan in the form of text files and then transferred to their associated speed profile noted above in Excel.

6.1.5 A further requirement was to develop not only the timetabled service data sets referred above but also ‘all-out running’ data sets (not requiring trains to adhere to a set of arrival times at stations and so run ‘all-out’ in performance terms without application of operating margins). The all-out running results have been developed as required for the 300 / 330 / 360km/h scenarios, and reported in Section 7.

6.1.6 During verification of the Baseline models for Phase Two, a few empty stock movements were removed from the timetabled runs as these are defined at an early stage of timetable development and they were found in latest layout review to interfere with the way in which passenger services operated. These can be resolved as lower priority services when the timetables are fully ratified following refinements to design of the Phase One infrastructure.

7 Results

7.1 General

7.1.1 The results are presented below for Phase One only for energy review, as that was required by the EOC for this study, and both Phase One and Phase Two for timetable reviews.

7.1.2 The timetable reviews take the form of delay summaries, train type summaries, Single Train Performance Calculator runs (TPC), and full timetable assessments. Sample results from the full timetable results below have not been included, where PB has carried out review of those results and provided separate full timetable reviews contained herein.

7.1.3 Whilst speed scenarios do not change the distances run in service, where an increase in fleet size is identified (see Sections 8 and 9), the fact that additional units exists implies that some additional distance will be run as Empty Coaching Stock at the start and end of service. This is a minor effect and has not been assessed.

7.2 Energy Summary (Phase One only)

7.2.1 The calculation of energy summary results has been undertaken only for Phase One where this is the information stipulated as required by EOC for their analyses of HS2 carbon footprint based on the range of reducing speeds modelled herein. The following tables provide the information requested for total train kms per year; energy consumption in mechanical energy terms excluding regen braking (where the receptivity of the Line is not known for a 'mechanical only' simulation); and the number of train sets in service:-

Table 7.2.1 – Total train kms per year (Phase One infrastructure only at 360kph speed limit)

			Op Days per year:	350
	Captive trains			Hybrid trains
	200m	ECS (200m)	400m	200m
Total train kms	3,315,130.00	34,230.00	2,392,145.00	14,882,035.00

Table 7.2.2 – Mechanical energy consumption for Captive HS2 ECS trains (no change across speed ranges)

Scenario and train make-up	Max (all out) speed (km/h)	All-out service energy (kWh/km)	% energy of all-out 360km/h scenario	Max attained speed (timetabled run with margin) (km/h)	Timetabled service energy (kWh/km)	% Timetabled Energy to all-out energy
1 - 11 car	360	22.60	100%	58 for 330 limit	11.40	50%
2 - 11 car	330	22.60	100%	58 for 300 limit	11.40	50%
3 - 11 car	300	22.60	100%	58 for 270 limit	11.40	50%

Table 7.2.3 – Mechanical energy consumption for Captive HS2 trains

Scenario and train make-up	Max (all out) speed (km/h)	All-out service energy (kWh/km)	% energy of all-out 360km/h scenario	Max attained speed (timetabled run with margin) (km/h)	Timetabled service energy (kWh/km)	% Timetabled Energy to all-out energy
1 - 11 car	360	23.78	100%	317.9 for 330 limit	20.50	86%
2 - 11 car	330	21.89	92%	300 for 300 limit	[illegible]	91%
3 - 11 car	300	19.71	83%	270 for 270 limit	[illegible]	89%
4 - 22 car	360	45.33	100%	317.3 for 330 limit	[illegible]	86%
5 - 22 car	330	41.57	92%	300 for 300 limit	37.85	91%
6 - 22 car	300	37.32	82%	270 for 270 limit	33.63	90%

Table 7.2.4 – Mechanical energy consumption for Classic compatible HS2 trains (on Phase One infrastructure only)

Scenario and train make-up	Max (all out) speed (km/h)	All-out service energy (kWh/km)	% energy of all-out 360km/h scenario	Max attained speed (timetabled run with margin) (km/h)	Timetabled service energy (kWh/km)	% Timetabled Energy to all-out energy
1 - 11 car	360	22.35	100%	330 for 330 limit	20.20	90%
2 - 11 car	330	20.22	[illegible]	300 for 300 limit	17.79	88%
3 - 11 car	300	17.79	[illegible]	270 for 270 limit	15.59	88%

Table 7.2.5 – Number of train sets (*)

	Captive 200m	Classic 200m	TOTAL
Phase One	14 units	37 units	51 units

(*) Advice at 360 kph Limit only for Train sets in service (not maintenance / spares)

7.3 Delay Summary Phase One (basis for timetable review)

7.3.1 The delay summary results simulated a total of 349 trains operating at differential speed profiles, these being 360kph; 330kph; 300kph and 270kph. The assessment identified no delays being incurred by those trains travelling at 360kph and 330kph. However, several services operating below the 330kph threshold were delayed, with most of these happening at 270kph. Overall delays increased as speeds decreased. For further discussion of journey time increases please refer to Section 10. A summary of the full timetabled delays for Phase One are shown below, with % of delayed trains against total in brackets:-

Table 7.3.1 – Phase One Delay Summary results

	360kph	330kph	300kph	270kph
Highest recorded end delay	00:00:00	00:00:00	00:02:22	00:07:15
Highest recorded start delay	00:00:00	00:00:00	00:02:22	00:05:43
Total no. trains delayed (start of journey)	0 (0.0%)	0 (0.0%)	45 (12.9%)	136 (39.0%)
Total no. trains delayed (end of journey)	0 (0.0%)	0 (0.0%)	202 (57.9%)	276 (79.1%)

7.4 Delay Summary Phase Two

7.4.1 In general terms, the simulation outputs noted very few minor delays for the 964 trains simulated for Phase Two under the 360kph speed profile, although some services operating in the Birmingham and Manchester area were delayed due to the tightly constrained infrastructure and timetable operation, but this did not amount to anything significant. However, as the train speeds were incrementally reduced, overall delays increased and these reached their peak as services were tested at the lowest speed profile of 270kph for several parts of the network. A summary of the full timetabled delays are shown below, with % delayed trains against total in brackets:

Table 7.4.1 – Phase Two Delay Summary results

	360kph	330kph	300kph	270kph
Highest recorded end delay	00:02:15	00:02:19	00:10:26	00:34:59
Highest recorded start delay	00:00:00	00:00:00	00:02:25	00:26:36
Total no. trains delayed (start of journey)	0 (0.0%)	0 (0.0%)	46 (4.8%)	99 (10.3%)
Total no. trains delayed (end of journey)	18 (1.9%)	45 (4.7%)	534 (55.4%)	714 (74.1%)

7.5 Train Type Summary Phase One

7.5.1 A further output of RailPlan was the "train type summary" data, which was extracted directly from RailPlan and imported into excel. The data is too large to include here, but in summary, PB were able to ascertain the energy used in kWh by each service for the simulated timetable and their associated speeds.

7.5.2 Two examples from the TPC runs have been shown below for an AGV-11 car set and AGV-22 car set operating on the HS2 network:

Table 7.5.1 – Phase One Train Type Summary results

Length	Train ID	360kph	330kph	300kph	270kph
AGV-22	PH1_1_2	7210.2 kWh	7061.8 kWh	6694.8 kWh	5964.4 kWh
AGV-11	PH1_1_5	3766.6 kWh	3721.0 kWh	3535.2 kWh	3150.3 kWh
AGV-22	PH1_R2_10	6751.0 kWh	6635.0 kWh	6571.4 kWh	6198.5 kWh
AGV-11	PH1_R2_4	3569.1 kWh	3514.8 kWh	3407.8 kWh	3109.5 kWh

7.5.3 The kWh energy used by a 22-car AGV set was almost double in most cases compared to an 11-car AGV set. However, as the speed was decreased in the experiments, the energy consumed also decreased with the trains running at 270kph proving to be the most energy efficient per train-km, but their journey times and delay minutes increase as a consequence due to the reduced speed profile.

7.5.4 The sampled output demonstrates that as a train reduces its speed, the energy demanded by it also reduces too and this is almost halved when an AGV-11 train length is used for the service. However, by comparison with section 7.6 for Phase Two the results also note that there is a very little difference in energy demand for a 11 or 22-AGV for PH2_R2_10 and PH2_R2_4 at 360 and 330kph.

7.6 Train Type Summary Phase Two

7.6.1 A further output of RailPlan was the "train type summary" data, which was extracted from RailPlan and placed into excel. The data is too large to include here, but in summary, PB were able to ascertain the energy used in KWh by each service by the simulated timetable and its associated speeds. Two example random outputs for each direction have been tabulated below for reference to demonstrate our timetabled simulation results:

Table 7.6.1 – Phase Two Train Type Summary results

Length	Train ID	360kph	330kph	300kph	270kph
AGV-22	PH2_1_2	7057.3 kWh	6921.8 kWh	6407.5 kWh	5657.6 kWh
AGV-11	PH2_1_5	3711.1 kWh	3667.6 kWh	3389.6 kWh	2999.8 kWh
AGV-22	PH2_R2_10	6564.1 kWh	6586.4 kWh	6554.1 kWh	5722.4 kWh
AGV-11	PH2_R2_4	3494.2 kWh	3498.3 kWh	3294.6 kWh	3031.6 kWh

7.6.2 The sampled output demonstrates that as a train reduces its speed, the energy demanded by it also reduces too and this is almost halved when an AGV-11 train length is used for the service. However, the results also note that a very little difference in energy demand for a 11 or 22-AGV for PH2_R2_10 and PH2_R2_4 at 360 and 330kph, in fact the energy used is slightly higher according to the analysis.

7.7 TPC Timetable Results for TRTs Phase One

7.7.1 The next part of PB's analysis and associated results/outputs refer to the TPC timetable run for the Theoretical Run-Times (or TRTs) where we calculated the impacts on theoretical operating margins to be used, were a full timetable to be analysed at a later date. The TPC results were tested at 360kph; 330kph; 300kph and 270kph with each category being applied with a % margin to the journey times depending on where the trains travelled i.e. using the HS2 infrastructure (5%) or the classic Network Rail routes (7.5%) in terms of total journey time uplift. It is worth noting that the Phase One results only focus on services using the HS2 network out of Euston towards Handsacre Junction, Curzon Street and the WCML and fringes (no services to Leeds, Newcastle or ECML).

7.7.2 Due to the physical quantity of output data generated, two detailed sample outputs have been tabulated below for illustrative purpose to compare the impacts on journey time and TRT calculation and the full set of single-train results are summarised in Appendix A. These samples comprise one service for each direction running between Euston and Glasgow using HS2 and the WCML and the second one running between Euston and Curzon Street using the HS2 network throughout only. Note naming convention TP refers to Timing Point Locations (TiPLocs) used for timetable development and pathing:-

Table 7.7.1 – Phase One TPC results – Euston to Glasgow

	Margin (%)	360kph	330kph	300kph	270kph
EUSTON	5.0%				
OLDOAK	5.0%	00:04:58	00:04:58	00:04:58	00:04:58
INTCHANG	5.0%	00:28:56	00:30:30	00:32:40	00:35:41
TP-DND	5.0%	00:01:36	00:01:44	00:01:54	00:02:07
TP-MLJ	5.0%	00:04:04	00:04:15	00:04:35	00:05:01
JNHANDS	5.0%	00:02:00	00:02:00	00:02:00	00:02:00
JNCOLW	7.5%	00:03:03	00:03:03	00:03:04	00:03:03
STAFFORD	7.5%	00:05:06	00:05:06	00:05:05	00:05:06
JNCREWE	7.5%	00:13:56	00:13:56	00:13:56	00:13:56
CREWE	7.5%	00:00:33	00:00:33	00:00:33	00:00:33
TP-CWJ	7.5%	00:09:03	00:09:03	00:09:04	00:09:04
WARRINGT	7.5%	00:04:31	00:04:31	00:04:30	00:04:30
JNGOLB	7.5%	00:06:15	00:06:15	00:06:15	00:06:15
WIGAN	7.5%	00:01:45	00:01:45	00:01:46	00:01:46
PRESTON	7.5%	00:09:24	00:09:24	00:09:23	00:09:23
LANCASTE	7.5%	00:12:43	00:12:43	00:12:43	00:12:43
OXENHOLM	7.5%	00:10:55	00:10:54	00:10:55	00:10:55
PENRITH	7.5%	00:22:54	00:22:55	00:22:55	00:22:55
CARLISLE	7.5%	00:12:55	00:12:55	00:12:55	00:12:54
LOCKERBI	7.5%	00:17:08	00:17:07	00:17:07	00:17:08
CARSTAIR	7.5%	00:29:46	00:29:47	00:29:46	00:29:46
MOTHERWE	7.5%	00:10:49	00:10:49	00:10:50	00:10:50
GLASGOW	7.5%	00:13:38	00:13:38	00:13:37	00:13:37
Totals	Totals	03:45:58	03:47:52	03:50:33	03:54:12
	Totals Mins	226	228	231	234

7.7.3 Table 7.7.1 for the Euston to Glasgow service notes that as speed decreases, the journey time increases. However, the rate at which journey times fluctuate in line with speed changes is proportionally reduced when services use the classic network (E.g. WCML), since these routes only accommodate speed limits <270kph.

Table 7.7.2 – Phase One TPC results – Euston to Birmingham

	Margin (%)	360kph	330kph	300kph	270kph
EUSTON	5.0%				
OLDOAK	5.0%	00:04:53	00:04:53	00:04:53	00:04:53
INTCHANG	5.0%	00:30:10	00:31:40	00:33:50	00:36:48
TP-DJW	5.0%	00:03:21	00:03:20	00:03:21	00:03:20
WASHW-DEP	5.0%	00:02:24	00:02:24	00:02:24	00:02:24
CURZONST	5.0%	00:02:09	00:02:09	00:02:09	00:02:09
Totals	Totals	00:42:57	00:44:26	00:46:36	00:49:34
	Totals Mins	43	44	47	50

7.7.4 As per classic network, the rate at which journey times increase on HS2 is dependent on the location at which trains travel. For example in Table 7.2.2 which shows the Theoretical Run Times between each station (not including dwells), we can see that the journey from Interchange to South Delta timing point TP-DJW are all 2mins & 24secs compared to say other parts of the journey which have differences between them e.g. Old

Oak to Interchange. The reason we have not included dwell times is that these are consistent across all tests and mask the relative effect of stepped speed limit reductions.

7.7.5 A similar result can be concluded for the Euston to Glasgow journey. The subtle difference with this journey compared to Curzon Street is that it uses Network Rail infrastructure north of Handsacre Junction to Glasgow and operates at a slower speed, which means the intermediate TRTs do not fluctuate as much between the various speed profiles.

7.7.6 Similar patterns are seen for services travelling in the opposite direction as shown below for sample Glasgow to Euston and Curzon Street to Euston services. Other services across the HS2 network have similar results i.e. TRTs increase as the speed reduces, but there intermediate points which operate on the Network Rail infrastructure at 7.5% so much as expected.

Table 7.7.3 – Phase One TPC results – Glasgow to Euston

	Margin (%)	360kph	330kph	300kph	270kph
GLASGOW	7.5%				
MOTHERWE	7.5%	00:13:27	00:13:27	00:13:27	00:13:27
CARSTAIR	7.5%	00:11:13	00:11:13	00:11:13	00:11:13
LOCKERBI	7.5%	00:29:51	00:29:51	00:29:51	00:29:51
CARLISLE	7.5%	00:17:15	00:17:15	00:17:15	00:17:15
PENRITH	7.5%	00:12:48	00:12:48	00:12:48	00:12:48
OXENHOLM	7.5%	00:22:45	00:22:45	00:22:45	00:22:45
LANCASTE	7.5%	00:11:19	00:11:19	00:11:19	00:11:19
PRESTON	7.5%	00:12:59	00:12:59	00:12:59	00:12:59
WIGAN	7.5%	00:09:24	00:09:24	00:09:24	00:09:24
JNGOLB	7.5%	00:01:39	00:01:39	00:01:39	00:01:39
WARRINGT	7.5%	00:06:23	00:06:23	00:06:23	00:06:23
TP-CWJ	7.5%	00:04:12	00:04:12	00:04:12	00:04:12
CREWE	7.5%	00:09:00	00:09:00	00:09:00	00:09:00
JNCREWE	7.5%	00:00:22	00:00:22	00:00:22	00:00:22
STAFFORD	7.5%	00:13:37	00:13:37	00:13:37	00:13:37
JNCOLW	7.5%	00:05:29	00:05:29	00:05:29	00:05:29
JNHANDS	7.5%	00:02:53	00:02:53	00:02:53	00:02:53
TP-MLJ	5.0%	00:02:01	00:02:01	00:02:01	00:02:01
TP-DMU	5.0%	00:04:57	00:04:59	00:05:1[illegible]	00:05:31
INTCHANG	5.0%	00:01:21	00:01:28	00:01:36	00:01:47
TP-NT	5.0%	00:23:42	00:25:20	00:27:42	00:30:46
OLDOAK	5.0%	00:04:20	00:04:20	00:04:28	00:04:41
EUSTON	5.0%	00:05:00	00:05:00	00:05:00	00:04:59
Totals	Totals	03:45:57	03:47:45	03:50:33	03:54:21
	Total Mins	226	228	231	234

Table 7.7.4 – Phase One TPC results – Birmingham to Euston

	Margin (%)	360kph	330kph	300kph	270kph
CURZONST	5.0%				
WASHW-DEP	5.0%	00:02:16	00:02:16	00:02:16	00:02:16
INTCHANG	5.0%	00:05:17	00:05:17	00:05:17	00:05:17
TP-NT	5.0%	00:26:06	00:27:27	00:29:33	00:32:22
OLDOAK	5.0%	00:04:20	00:04:20	00:04:28	00:04:41
EUSTON	5.0%	00:05:07	00:05:07	00:05:07	00:05:07
Totals	Totals	00:43:06	00:44:28	00:46:41	00:49:44
	Total Mins	43	44	47	50

7.8 TPC Timetable Results for TRTs Phase Two

7.8.1 As per Phase One TPC results Phase Two timetabled services and TPC tests were undertaken at 360kph, 330kph, 300kph and 270kph and applied a % margin to the journey times depending on if the trains were using the HS2 infrastructure (5%) or the classic Network Rail routes (7.5%). two detailed sample outputs have been tabulated below for illustrative purpose to compare the impacts on journey time and TRT calculation and the full set of single-train results are summarised in Appendix A. These samples comprise for each direction Euston to Manchester and Euston to Newcastle via HS2 Phase Two routes and WCML and ECML respectively:

Table 7.8.1 – Phase Two TPC results – Euston to Manchester Piccadilly

	Margin (%)	360kph	330kph	300kph	270kph
EUSTON	5.0%				
OLDOAK	5.0%	00:04:58	00:04:58	00:04:58	00:04:58
INTCHANG	5.0%	00:30:15	00:31:44	00:33:49	00:36:44
TP-DND	5.0%	00:03:26	00:03:26	00:03:26	00:03:26
TP-MLJ	5.0%	00:04:26	00:04:28	00:04:39	00:05:02
TP-MSD	5.0%	00:15:50	00:17:11	00:18:51	00:20:53
TP-MED	5.0%	00:01:53	00:01:52	00:01:52	00:01:53
MANCAIR	5.0%	00:02:35	00:02:36	00:02:35	00:02:35
MANCPICC	5.0%	00:05:59	00:05:59	00:05:59	00:05:59
Totals	Totals	01:09:23	01:12:14	01:16:10	01:21:31
	Total Mins	69	72	76	82

Table 7.8.2 – Phase Two TPC results – Euston to Newcastle

	Margin (%)	360kph	330kph	300kph	270kph
EUSTON	5.0%				
OLDOAK	5.0%	00:04:58	00:04:58	00:04:58	00:04:58
INTCHANG	5.0%	00:28:56	00:30:30	00:32:40	00:35:41
TP-DND	5.0%	00:01:59	00:02:01	00:02:06	00:02:12
JNEM	5.0%	00:00:37	00:00:36	00:00:36	00:00:37
TOTON	5.0%	00:10:09	00:10:34	00:11:15	00:12:14
MEADOW	5.0%	00:11:56	00:12:23	00:13:06	00:14:18
TP-CDJ	5.0%	00:06:20	00:06:27	00:06:45	00:07:10
TP-YBJ	5.0%	00:01:16	00:01:23	00:01:31	00:01:41
JNULLE	5.0%	00:06:14	00:06:15	00:06:17	00:06:22
YORK	7.5%	00:07:18	00:07:18	00:07:18	00:07:18
DARLINGT	7.5%	00:24:53	00:24:53	00:24:53	00:24:54
DURHAM	7.5%	00:13:41	00:13:40	00:13:41	00:13:40
NEWCASTL	7.5%	00:10:39	00:10:40	00:10:40	00:10:40
Totals	Totals	02:08:54	02:11:38	02:15:47	02:21:45
	Total Mins	129	132	136	142

7.8.2 Table 7.8.1 shows that for a service operating from Euston to Manchester under TPC conditions reducing speed profiles take longer as the speed decreases. However, the rate at which journey time's increase is dependent on the location at which trains travel. For example, we can see that the journey from Manchester Airport to Manchester Piccadilly are all 5mins & 59secs compared to say other parts of the journey which have a difference between them e.g. Old Oak to Interchange. This is due to trains already travelling at lower speeds than the degraded speed adjustments, which therefore have no impact on journey time for these sections of route. A similar result can be concluded from the Euston to Newcastle journey.

7.8.3 Similar patterns are seen for services travelling in the opposite direction as shown below for the Newcastle to Euston and Manchester Piccadilly to Euston. Other services across the HS2 network have similar results i.e. TRTs increase as the speed reduces, but there intermediate points which operate on the Network Rail infrastructure at 7.5% so much as expected.

Table 7.8.3 – Phase Two TPC results – Newcastle to Euston

	Margin (%)	360kph	330kph	300kph	270kph
NEWCASTL	7.5%				
DURHAM	7.5%	00:10:39	00:10:39	00:10:39	00:10:39
DARLINGT	7.5%	00:13:36	00:13:36	00:13:36	00:13:36
YORK	7.5%	00:24:56	00:24:56	00:24:56	00:24:56
JNULLE	7.5%	00:06:56	00:06:56	00:06:56	00:06:56
TP-YBJ	5.0%	00:06:38	00:06:38	00:06:38	00:06:39
TP-CDJ	5.0%	00:01:33	00:01:33	00:01:38	00:01:49
MEADOW	5.0%	00:05:42	00:05:56	00:06:20	00:06:53
TOTON	5.0%	00:12:19	00:12:37	00:13:17	00:14:26
JNEM	5.0%	00:10:08	00:10:28	00:11:07	00:12:08
TP-DMU	5.0%	00:00:59	00:01:00	00:01:00	00:00:59
INTCHANG	5.0%	00:01:52	00:01:52	00:01:52	00:01:54
TP-NT	5.0%	00:23:57	00:25:26	00:27:42	00:30:45
OLDOAK	5.0%	00:04:20	00:04:20	00:04:28	00:04:42
EUSTON	5.0%	00:05:00	00:05:00	00:04:59	00:04:59
Totals	Totals	02:08:37	02:10:58	02:15:08	02:21:21
	Total Mins	129	131	135	141

Table 7.8.4 – Phase Two TPC results – Manchester to Euston

	Margin (%)	360kph	330kph	300kph	270kph
MANCPICC	5.0%				
MANCAIR	5.0%	00:06:03	00:06:03	00:06:03	00:06:03
TP-MED	5.0%	00:02:41	00:02:41	00:02:41	00:02:41
TP-MSD	5.0%	00:02:05	00:02:05	00:02:05	00:02:05
TP-MLJ	5.0%	00:16:15	00:17:22	00:18:54	00:20:54
TP-DMU	5.0%	00:04:14	00:04:29	00:04:51	00:05:20
INTCHANG	5.0%	00:02:39	00:02:39	00:02:39	00:02:39
TP-NT	5.0%	00:26:05	00:27:26	00:29:33	00:32:21
OLDOAK	5.0%	00:04:21	00:04:21	00:04:28	00:04:41
EUSTON	5.0%	00:05:07	00:05:07	00:05:06	00:05:07
Totals	Totals	01:09:30	01:12:12	01:16:19	01:21:51
	Total Mins	69	72	76	82

8 Timetable review Phase One

8.1 General issues (also applicable to Phase 2)

8.1.1 Rather than recalculating all Theoretical (TRTs) and subsequent Sectional Running Times (SRTs) for each scenario, which would introduce uncertainty due to the mass of individual judgements being made, this study has focused on the change versus the Final ES case which was based on a maximum speed of 360 kph.

8.1.2 In preparation for a full timetable exercise, individual SRTs would be identified to the nearest half-minute, each rounded up or down aiming to achieve a balance over the whole journey. Pragmatically in this case, the impact of the speed scenarios has been assessed by identifying the change in overall movement time and converting this to a change in the total of SRTs for a journey, or that part of a journey made on HS2 infrastructure.

8.1.3 The change to timetabled journey time that would be experienced by passengers can be taken into demand modelling to assess economic impacts.

8.1.4 This discussion is based on the timetable and rolling stock circulation developed for the Final ES Operation Plan. Since then a number of other developments, principally around the Euston Phase One infrastructure, have occurred. Whilst these cannot yet be part of the accepted planning as analysis is ongoing and final decisions not yet made, their further implications for the findings of this analysis are discussed separately.

8.1.5 The possible implications for rolling stock fleet size arise if terminal turnrounds in the Final ES timetable are eroded to the extent that trains have to “step down” at termini, that is, they arrive later whilst the originally planned departure opportunity has to be brought forward, so that the next-but-one departure opportunity has to be taken. This means that the overall time for a round trip increases by a time equal to the service interval, so that an additional unit has to be put into service to maintain the timetabled frequency.

8.1.6 This analysis encompasses units required in service to operate a weekday timetable. Any change to numbers of maintenance spares is in addition to the effects identified. The risk is that a small change in units in service may trigger an additional maintenance spare unit.

8.1.7 Quantified analysis of additional crew costs was not requested as part of this exercise, but this adds value in the further discussion of implications of reduced speed operation. This section provides a qualitative discussion of the issues underlying likely changes to crew costs.

8.1.8 Costs for train crew are essentially proportional to train-hours. Whilst the changes indicated above are small in the context of individual trips, modern rostering agreements will allow the effect of small changes to accumulate, and eventually trigger a requirement for an additional staff member. Short of actual rosters for routine operation, it is not possible to assess when that point is reached, but the cumulative extension to journey time for all trains over a year can be used to estimate additional annual staff costs. However, for other than minor changes this is likely to give an extreme best case answer.

8.1.9 In a case such as this where the changes to the rolling stock are significant, a better assumption would be, pragmatically, that as every unit in use has a crew, the percentage change to crew numbers and costs will be the same as the percentage increase in the fleet size.

8.1.10 This will be a slight over-estimate, as the use of an additional unit for peak strengthening to operate the given train service does not itself increase driver costs, but would require additional on-train service staff.

8.1.11 On the other hand, where additional rolling stock is in service due to longer turnrounds, the fact of an extra unit being in use implies that additional Empty Coaching Stock (ECS) moves will be made somewhere at some time, if only to take that unit to berth at close-down and from berth at start-up, and this will incur a cost for a driver but not for service staff.

8.1.12 Longer turnrounds deriving from stepping down may make the crew workings more efficient, if they allow a break to be taken when a shorter turnround did not. Equally, where turnrounds are simply eroded without requiring stepping-down of units, a break may become impossible where previously it was possible. These two effects are considered to be of equal and opposite impact in all scenarios and so are neglected.

8.2 Changes to journey times

8.2.1 In Phase One, only two sources of change to journey times occur:

- Euston to/from Curzon St with a call at Birmingham Interchange;
- Euston to/from Handsacre with no call at Birmingham Interchange, common to all other routes.

8.2.2 From RailPlan timetable output, the following data have been extracted for Phase One operations:

Table 8.2.1: Overall movement time for varying maximum speed scenarios

From	To	360 kph	330 kph	300 kph	270 kph
Euston	Handsacre	00:41:33	00:43:27	00:46:08	00:49:47
Euston	Curzon St	00:42:57	00:44:26	00:46:36	00:49:34
Handsacre	Euston	00:41:20	00:43:09	00:45:56	00:49:45
Curzon St	Euston	00:43:06	00:44:28	00:46:41	00:49:44

8.2.3 On this basis, the change to timetabled journey time required to preserve the same proportional margin, compared with Final ES, for each scenario would be:

Table 8.2.2: Change in timetabled journey time for varying maximum speed scenarios (minutes) compared with Final ES

From	To	Final ES	330 kph	300 kph	270 kph
Euston	Handsacre	0	2	4 ½	8
Euston	Curzon St	0	1 ½	3 ½	6 ½
Handsacre	Euston	0	2	4 ½	8 ½
Curzon St	Euston	0	1 ½	3 ½	6 ½

8.2.4 These journey time extensions are those that would be experienced by passengers and can be taken into demand modelling to assess economic impacts.

8.2.5 Implications for operational planning (scheduling and resources planning, and consequent implications for infrastructure whilst continuing to meet the Phase One Train Service Specification for each scenario are now discussed.

8.3 Timetable planning

8.3.1 Pathing has not generally been examined as:

- On the HS2 infrastructure, the effect is common to all trains, so that no impact on relative pathing of trains is expected;
- On the classic network, potential conflicts with classic trains were not examined for Final ES, and there is no reason of principle why they should be any more or less difficult if timings on the HS2 infrastructure change – with two exceptions.

8.3.2 The exceptions are:

- Terminus platform allocation, for which we have examined arrival and departure times that would result from the changed journey times to establish whether platform end conflicts would occur;
- Colwich Junction, where it is in effect a coincidence (but a very beneficial one) of the Euston turnround and running time to and from Euston that Down Manchester trains fall only 1½ minutes after the Up Manchester trains, in effect forming a parallel move that is very economical of capacity. Later times for the Down trains and earlier times for the Up trains will break this parallel move, so that capacity at this point cannot be used so economically, with the risk that the classic service specification may not be met.

8.4 Rolling stock

8.4.1 The Final ES timetable and rolling stock circulation was based on a standard turnround of 25 minutes at Euston, except for Glasgow trains which were given 46 minutes. This reflects the reality that the timetable was pragmatically "reverse engineered" out of the Phase Two timetable more for power analyses and costing than as a specific operational and commercial exercise, but it does represent an operationally-valid basis for analysis of the effects of changes.

8.4.2 The initial assumption is that the standard turnround at Euston is maintained, and any impact on turnround times is taken at country-end locations. This preserves the pattern of parallel arrivals and departures that can be accommodated within the Final ES track layout.

8.4.3 In the Final ES timetable and circulation, it was possible to confine units to specific routes within each day's work. Effects for each route are identified as:

- Euston - Curzon Street:
  - In the Final ES platform allocation plan for Curzon St., it was necessary to adopt a turnround of 17 minutes at Curzon St. Eroding this at each end by 1½ minutes leads to a turnround of 14 minutes, which is below the accepted minimum. It would therefore be necessary to step-down units at Curzon St, leading to turnrounds of 34 minutes, even for a reduction in maximum speed to 330 kph.
  - Once this step has been taken, further speed reductions have no further effect as even reduction to a 270 kph maximum would leave a turnround of 24 minutes which is robust.
  - On Curzon Street workings, strengthening of peak trains to 400-metre formations for peak services required an additional 7 units, as the round trip time enabled some units to work more than one peak trip. With the stepping down at Curzon St., as well as one extra unit in service to maintain the service frequency, one further unit would be required as a peak strengthener to work with that unit.
- Euston – Manchester:
  - In the Final ES platform allocation plan for Manchester Piccadilly, turnrounds of between 35 and 32½ minutes were allocated, depending on the inwards route and stopping pattern. There is thus at worst 7½ minutes excess over the identified required turnround time of 25 minutes. This turnround time would be breached by a journey time extension of any more than 3½ minutes, and this arises in the 300 kph scenario. At that point therefore, an additional unit in service is required.

  - In Phase One, no peak strengthening is involved, so no further additional units are required for strengthening.
- Euston – Liverpool:
  - In the Final ES platform allocation plan for Liverpool Lime St., turnrounds are either 25 ½ or 35 minutes, as the service interval to meet constraints on route to Euston is not even. Any extension to journey time would therefore breach the identified required turnround time of 25 minutes turnround once per hour, and require an additional unit in service.
  - Having put an extra unit into the circulation, further extensions to journey time can then be tolerated.
  - In Phase One, no peak strengthening is involved, so no further additional units are required for strengthening.
- Euston – Preston: In the Final ES platform allocation plan for Preston, a turnround time of 54 minutes is allowed. Extension to journey time in any scenario can therefore be tolerated without additional rolling stock.
- Euston – Glasgow: In the Final ES platform allocation plan for Glasgow Central, a turnround time of 74½ minutes is allowed. Extension to journey time in any scenario can therefore be tolerated without additional rolling stock.

8.4.4 Effects on fleet size are summarised as:

Table 8.4.1 – Additional 200m units needed in service for each speed scenario compared with Final ES Phase One

Route	Unit type	330 kph	300 kph	270 kph
Curzon St	CP	+1 in service +1 peak extra	+1 in service +1 peak extra	+1 in service +1 peak extra
Manchester	CL	-	+ 1	+ 1
Liverpool	CL	+ 1	+ 1	+ 1
Preston	CL	-	-	-
Glasgow	CL	-	-	-
Total		+2 CP, +1 CL	+2 CP, +2 CL	+2 CP, +2 CL

CP = Captive HS2 Stock, CL = Classic compatible for Network Rail operation

8.5 Traincrew

8.5.1 The increase in crew costs is estimated as being:

- 330 kph: 5.8%
- 300 kph: 7.8%
- 270 kph: 7.8%

8.6 Infrastructure

8.6.1 At Curzon Street in Phase One, seven platforms would be provided but only two required to operate the train service, which at that point operates on the Euston route only. With a turnround time of 17 minutes, this could operate off one platform only (although prudent operations would make use of more).

8.6.2 The worst case for turnround times would be under the 330 kph scenario, in which stepping down is just triggered so that the Final ES turnround of 17 minutes would become 34 minutes (17 – 1½ - 1½ +20 minutes). This could still be accommodated in two platforms. Further stages of speed reduction would then erode the extended turnround, but still require two platforms.

8.6.3 At Manchester Piccadilly, the Final ES Operation Plan envisaged use of two platforms for HS2 services. With longer turnrounds resulting when an additional unit is required (300 kph and 270 kph), this requirement would increase to three platforms. This does not imply a change to the Phase One infrastructure as at this point the classic station would be being used, but the additional platform requirement may have costs for changes to classic infrastructure.

8.6.4 At Liverpool Lime St., the Final ES Operation Plan envisaged use of two platforms for HS2 services. This could be maintained subject to adding pathing time (estimated at 1 minute) to one of the arriving services in each hour in the 330 kph scenario to achieve an adequate platform reoccupation margin. In further scenarios, the later arrivals by definition delay the arrivals so that pathing time is not needed.

8.6.5 As the Preston and Glasgow circuits do not involve additional rolling stock, there are no infrastructure implications.

9 Timetable review Phase Two

9.1 General

9.1.1 The maximum speed of 360 kph planned for the Final ES timetable supports efficient unit circuits for Euston – Curzon St, Euston – Glasgow/Edinburgh, Euston – Leeds/York, Euston – Newcastle and Curzon St – Newcastle. Any speed reduction scenario results in additional units being required to operate these services.

9.1.2 Reduction to 300 kph also requires additional units for Euston – Manchester and Heathrow[1] - Leeds.

9.1.3 Reduction to 270 kph requires further additional units for Euston – Manchester as well as additional units for Euston – Liverpool, Euston – Leeds, Curzon St – Manchester, Curzon St – Edinburgh/Glasgow, Curzon St – Leeds.

9.1.4 The overall effect on units in service is as follows (please refer to Table 9.7.1 for further breakdown of this detail):-

[1] Actually modelled as originating at Euston

Table 9.1.1 – Additional 200m units needed in service for each speed scenario compared with Final ES Phase Two - Summary

	Unit type	330 kph	300 kph	270 kph
Total additional in service	CP	+2 CP	+5 CP	+11 CP
	CL	+5 CL	+5 CL	+8 CL

CP = Captive HS2 Stock, CL = Classic compatible for Network Rail operation

9.1.5 Additional maintenance spares will be required to support this increase in fleet in service.

9.1.6 At Curzon St, it is likely that no additional infrastructure would be required in any scenario as a seventh platform is available but not used in the “standard hour” service, but feasibility of accommodating the critical start-up and close-down periods has not been demonstrated.

9.1.7 At Manchester Piccadilly, speed reductions to 300 kph and below make a fifth platform essential. Depending on the detail of any eventual timetable, there is a risk that speed reduction to 270 kph would make a sixth platform necessary.

9.1.8 At Leeds, the 300 kph scenario requires six platforms and the 270 kph scenario requires seven, even assuming that an acceptable track layout can be devised.

9.1.9 At classic stations it has not been possible to assess requirements as these depend on operation around the classic service. However wherever stepping down of units is required, the increase in platform occupation makes it likely that some cost of some sort will be incurred.

9.1.10 As per Phase One review, train crew costs are estimated to increase compared with Final ES:

- 330 kph: 4.8%
- 300 kph: 6.8%
- 270 kph: 13.0%

9.2 Timetabling implications

9.2.1 Data from RailPlan timetable output extracted for Phase Two operations, including the change to timetabled journey time compared with Final ES for each scenario, is shown in Appendix A.

9.2.2 Implications for operational planning (scheduling and resources planning) and consequent implications for infrastructure whilst continuing to meet the Phase Two Train Service Specification for each scenario are now discussed.

9.3 Timetable analysis

9.3.1 In Phase Two almost every planned train service from the specification is subject to potentially differing effects, due to differing stopping patterns even where the ultimate origin and destination are the same. A number of simplifying assumptions are made but the direction and level of effects identified will be valid.

9.3.2 Pathing has not generally been examined as:

- On the HS2 infrastructure, the effect is common to all trains, so that no impact on relative pathing of trains is expected, with the caveat in the case of the Leeds/York line discussed below;
- On the classic network, potential conflicts with classic trains were not examined for Final ES, and there is no reason in principle why they should be any more or less difficult if timings on the HS2 infrastructure are altered.

9.3.3 The exception is terminus platform allocation, for which we have examined arrival and departure times that would result from the changed journey times to establish whether platform end conflicts would occur leading to greater changes to journey time resulting from “pathing time” to avoid them.

9.3.4 On the Leeds/York line, journey time extensions for trains making stops at all stations are much less than for trains passing all stations. The risk is that the stopping trains will be forced to extend their journey times as much as the through trains in order to maintain passing at stations. Equally however, slowing the through trains may allow a stopping train to run one station further before being overtaken. This has not been explored in detail as it would require a full timetable development exercise to clarify. For this exercise the identified journey times have been taken at face value.

9.3.5 Table 9.3.1 below is taken from the Operation Plan for the Final ES case, and shows required minimum turnrounds for each service group:-

Table 9.3.1 – Minimum Turnrounds for each service Group

From <Station> to London Euston & back to <Station>	Required turnround time [min]
Birmingham Curzon Street	15
Manchester	20
Liverpool	25
Preston	25
Glasgow/Edinburgh	35
Leeds	20
York	20
Newcastle	25
From <Station> to Birmingham Curzon Street & back to <Station>	**Required turnround time [min]**
London Euston	15
Manchester	15
Glasgow/Edinburgh	35
Leeds	20
Newcastle	25

9.3.6 These turnrounds are taken to apply at each end of the route, but are interpreted pragmatically if a sub-standard turnround at one end is offset by a greater than standard turnround at the other, subject to maintaining the absolute minimum of 15 minutes.

9.4 Routes from Euston

9.4.1 The Final ES timetable and rolling stock circulation was based on a standard turnround of 25 minutes at Euston, except for Glasgow trains which were given 55 minutes (with some adjustments for specific purposes where feasible). The assumption is that the turnround at Euston is maintained, and any impact on turnround times is taken at country-end locations. In the Phase Two service, the standardised turnround at Euston is crucial to maximising efficiency of platform utilisation.

- Euston - Curzon Street:
  - In the Final ES platform allocation plan for Curzon St., it is necessary to adopt a turnround of 17 minutes at Curzon St. for one train in each hour. Eroding this at each end by 1½ minutes leads to a turnround of 14 minutes, which is below the absolute minimum. It would therefore be necessary to step-down units at Curzon St, even where turnrounds of other London trains within the hour remain compliant.
  - Greater journey time extension have no further effect as once turnrounds have been extended by stepping down, they can be further eroded without further adverse impact.
  - On Curzon Street workings, strengthening of peak trains to 400-metre formations for peak services required an additional 7 units, as the round trip time enabled some units to work more than one peak trip. With the stepping down at Curzon St., as well as one extra unit in service to maintain the service frequency, one further unit would be required as a peak strengthener to work with that unit.
- Euston – Manchester:
  - In the Final ES platform allocation plan for Manchester Piccadilly., turnrounds of between 29 and 30 minutes were allocated, depending on the inwards route and stopping pattern. There is thus at best 9 minutes excess over the identified

required turnround time of 20 minutes. This turnround time would be breached in the 300 kph scenario. At that point therefore, an additional unit in service is required.

- o In the 270 kph scenario, even this turnround time reduces below 15 minutes once per hour. This requires a second “stepping down”, and a further unit in service.
- o In Phase Two, although peak strengthening is incurred, further additional units would not be required for strengthening, as the planned fleet already provides an extra unit for all peak trains.

- Euston – Liverpool:
  - o In the Final ES platform allocation plan for Liverpool Lime St., turnrounds are either 37½ or 51 minutes, with the arrival via Stafford working back via Crewe and vice-versa. The greatest extension to round trip journey time that could be tolerated is thus 12 ½ minutes. This would be breached in the 270 kph scenario.
- **Euston – Preston**: In the Final ES platform allocation plan for Preston, a turnround time of 78½ minutes is allowed. Extension to journey time in any scenario can therefore be tolerated without additional rolling stock.
- **Euston – Glasgow/Edinburgh**:
  - o In the Final ES timetable, turnround times of 25 and 27 minutes at Edinburgh are allowed. For a journey of this length, a turnround of 35 minutes is required, and so the timetable is already deficient in this respect, but this has been accepted so far on the basis that the Euston turnround for these trains is well in excess of the minimum. Logically though, any extension to journey time would be unacceptable and thus incur additional rolling stock;
  - o At Glasgow, turnrounds of 37 and 39 minutes are achieved, and these would be infringed by any extension to journey time.
  - o Additional units would thus be required for both the Edinburgh and Glasgow portions, leading to +2 for the service group.
- **Euston – Leeds**: Services are to be provided by two trains per hour to Leeds, plus one train per hour which carries portions (each formed of a 200m CL unit) for Leeds and York. As the combined Leeds/York train is assumed to be worked by CL units, interworking of units at Leeds is already limited.
  - o For the dedicated Euston – Leeds trains, turnrounds of 36 and 53 minutes are achieved. For a journey of this length, 20 minutes is appropriate, so that an extension to round trip time of 16 minutes could be tolerated. As the 36-minute turnround results from both arrival and departure on Service 13 (from Ref 2) which calls at all stations, this is just tolerable in the 300 kph scenario, but not in the 270 kph scenario, resulting in an extra unit being required.
  - o Although peak strengthening is involved for Leeds services, a further additional unit would not be required to work with this on peak workings, as the planned fleet already provides an extra unit for all peak trains.
  - o With respect to the combined Leeds/York train, the situation is somewhat complex as part of the journey time is made up of dwell time at Meadowhall for the split and join operation. However, as the turnround for the York portion is only 21½ minutes, and this involves running onto the classic network, the prudent assumption is that any extension in journey time would lead to a requirement for an additional unit.
  - o The Leeds portion achieves a turnround of 33 minutes in the Final ES timetable. There is thus 13 minutes excess over the minimum, which is adequate to

absorb journey time extension in the 300 kph scenario, but in the 270 kph scenario would require an additional unit in service.

- Euston – Newcastle
  - Turnrounds of 24 ½ and 26 ½ minutes are achieved at Newcastle, so a minor infringement of the compliant turnround is already encountered. Thus any journey time extension would lead to the need for an additional unit.

9.5 “Heathrow” services

9.5.1 These trains fall into the standard pattern of turnrounds at Euston, even though their nominal London-end origin is not Euston. To fit the available paths, they form one circuit for the two routes, with an arrival from Leeds forming a departure to Manchester, and vice-versa.

- Given the turnround at the London end plus the running time to and from Manchester, a turnround of 55 ½ minutes is achieved at Manchester. This can clearly be eroded without adverse effect in any scenario.
- The Leeds turnround, by reason of the longer running time, is 31 minutes. The compliant turnround of 20 minutes is thus just infringed by the 300 kph scenario, requiring an additional unit in service.

9.6 Routes from Curzon Street

9.6.1 Analysis of the Curzon St route is complicated as there is no standardised turnround pattern such as is essential at Euston. Any additional running time could thus potentially be absorbed at either end of the route, to the extent that currently planned turnrounds allow. If a choice is available at the termini, the actual course of action will be determined by pathing on route, which cannot be explored short of a detailed timetable exercise. However, as trains from Curzon St are pathed in relation to trains from Euston when making connections or passing at stations, the assumption in this analysis is that the impact of extended running times will be felt at the remote terminus rather than at Curzon St.

- Curzon St – Manchester
  - These trains are already on short turnrounds of 15 or 16 minutes at Curzon St, so it is assumed the effect is felt at Manchester. Without infringing the absolute minimum turnround of 15 minutes, journey time extension can be tolerated in the 330 kph and 300 kph scenarios, but not in the 270 kph scenario which would require an extra unit in service.
- Curzon St – Glasgow or Edinburgh
  - Turnrounds are 43 minutes at Edinburgh and 41 minutes at Glasgow. These would become significantly substandard in the 270 kph scenario, but remain compliant in the 330 kph scenario. For 300 kph, the Edinburgh turnround remains complaint but the Glasgow turnround becomes substandard. In practice this would probably be tolerated as the Curzon St turnround is above the minimum.
- Curzon St – Leeds
  - The Leeds turnrounds of 20 or 22 minutes remain compliant in the 330 kph and 300 kph scenarios, but become non-compliant in the 270 kph scenario.
- Curzon St – Newcastle

- o The turnround achieved at Newcastle is only 22 ½ minutes so is already substandard, but this has been accepted as the Curzon St turnround at 35 minutes is above the minimum. The best judgement is that for all scenarios an additional unit would be triggered, in view of the risk identified earlier that stopping trains would be forced to match the journey time extension of through trains to maintain passing relationships at stations.

9.7 Rolling stock

9.7.1 Effects on fleet size are summarised as:

Table 9.7.1 – Additional 200m units needed in service for each speed scenario compared with Final ES Phase Two - Detail

Route	Unit type	330 kph	300 kph	270 kph
Euston to/from:				
Curzon St	CP	+1 in service +1 peak extra	+1 in service +1 peak extra	+1 in service +1 peak extra
Manchester	CP	-	+1	+2
Liverpool	CL	-	-	+ 1
Preston	CL	-	-	-
Glasgow/E'boro'	CL	+2	+2	+2
Leeds	CP	-	-	+1
Leeds/York	CL	+1 York	+1 York	+1 York +1 Leeds
Newcastle	CL	+ 1	+ 1	+ 1
Heathrow to/from:				
Manchester	CP	-	-	-
Leeds	CP	-	+ 1	+ 1
Curzon St to/from				
Manchester	CP	-	-	+ 1
Glasgow/E'boro	CL	-	-	+ 1
Leeds	CP	-	-	+ 1
Newcastle	CL	+ 1	+ 1	+ 1
Total additional in service	CP	+2 CP	+4 CP	+8 CP
	CL	+5 CL	+5 CL	+8 CL

CP = Captive HS2 Stock, CL = Classic compatible for Network Rail operation

9.8 Infrastructure

- Curzon St.:
  - o A specific complication arises in the 330 kph scenario. As one of three trains per hour passes Interchange, it arrives at Curzon St 4 minutes quicker than the other two. Similarly, one train per hour to London runs more quickly to Euston by delaying its departure from Curzon St. In the 330 kph scenario when, after stepping down, turnrounds are longest, this leads to a need to spread London services across three platforms instead of two.
  - o This need not necessarily lead to a requirement for an additional platform, as seven platforms are available but only six used in the "standard hour" service.

However, it frustrates the ambition to retain a platform for unplanned moves such as set-swaps, and imposes an additional operating burden in the start-up and close-down periods - whether this can be accommodated without impact on other services, with possible infrastructure implications elsewhere, is not clear at this level of analysis.

- The problem could be overcome by standardising the Curzon – Euston trains so that all call at Interchange. This would frustrate the ambition to offer the lowest possible headline journey time once per hour.
- In other scenarios, where journey time extensions are greater and turnround shorter, the need to use a seventh platform is removed, but platform utilisation overall remains higher than in the 360 kph scenario as a result of the stepping down.

- Manchester:
  - 330 kph: No change
  - 300 kph: No change
  - 270 kph: The second "stepping down" leads to a point in the hour at which three London trains are in the station simultaneously. Stepping down of the Curzon St trains leads to these also overlapping in the station, so that two platforms are occupied. The precise effect remains to be determined, but the likelihood is that a fifth platform would become a requirement.
- Liverpool
  - 330 kph: No change
  - 300 kph: No change
  - 270 kph: The "stepping down" leads to a point in the hour at which three London trains are in the station simultaneously. It is not clear whether this can be accommodated with respect to other services, or what costs might be involved in accommodating it.
- Preston
  - No change in any scenario
- Glasgow/Edinburgh
  - In both cases the stepping down of London trains in all scenarios leads to trains overlapping in the platforms, which may present costs for accommodating other services.
  - With respect to Curzon St trains, as the service is planned to alternate between Glasgow and Edinburgh stepping down does not lead to overlapping in the platform, although the longer occupation at each location in excess of an hour may cause conflicts with other platforming requirements, potentially resolved at a cost.
- Leeds
  - 330 kph: No change
  - 300 kph: Stepping down of the Heathrow trains leads to overlapping occupations, which requires a sixth platform
  - 270 kph: The "stepping down" leads to a point in the hour at which three London trains are in the station simultaneously. Stepping down of the Curzon St trains leads to these overlapping in the station, so that two platforms are occupied. Along with stepping down of the Heathrow trains, the total number of platforms

required is seven. Feasibility of operating the service even on seven platforms also depends on the resulting track layout.

- York
    - In all scenarios, trains "step down" at York. This would lead to turnrounds potentially in excess of an hour, which would be difficult to accommodate in the station with respect to other trains. Presumably the HS2 service would shunt out of the station to an unspecified location, and back again for departure. Feasibility of this and associated costs have not been assessed.
- Newcastle
    - The journey time extensions for London trains in all scenarios and Curzon St trains in the 300 kph and 270 kph scenarios would lead to up to four HS2 trains at once at Newcastle station. It is not obvious how this would be handled and what the costs of handling it would be, but it is more likely that shunt moves would be made to and from the station than that additional platforms would be provided. Feasibility of this and associated costs have not been assessed.

9.9 Traincrew

9.9.1 The increase in crew costs is estimated as being:

- 330 kph: 4.8%
- 300 kph: 6.8%
- 270 kph: 13.0%

10 Discussion of results

10.1 General

10.1.1 From a journey time and energy reporting perspective the results align with expectations for longer journey times and lower energy overall.

10.1.2 Clearly the TRTs increase as the speed reduces since the net effect of these runs is to increase journey time, which would otherwise erode margin. In addition, the rate at which TRTs increase as the speed reduces is less when services operate on the classic network, where in some cases, there are no differences at all as the speed reduces. This is due to the fact trains have to operate more slowly and so the net impact is marginal.

10.1.3 In terms of energy, there is less being used if trains operate at slower speeds as expected. With regard to electrical loads on the network as a whole, as proposed in Section 5.1.6 we would suggest use of the 11% mark-up for routes to consider electrical demand when taking account of regen braking. Depending on the sensitivity of the output that uses this mark-up, it would be prudent to undertake 'high & low' calculations of demand or cost based on this figure with +/- 2% tolerance given the limited sample size (18 trains) that was used, to include the range of costs expected.

10.1.4 At the outset of this study very little if any difference was expected for both energy demand and journey time variance between the 330kph and 360kph speed-limited full timetable runs. This is because the normal full-day timetables for both Phases One and Two contain a robust level of operating margin on both SRTs and in many cases turnround time at the termini. While the latter has no direct bearing on journey time the former still requires each train to use this margin in normal unhindered journeys to arrive on time at the next station / TiPLoc. We have ageed the mechanism for ensuring this in RailPlan for HS2 is to apply reduction in speed and braking profiles (not acceleration at this time though this function is available if required, since the operating margin should always be saved for the end portion of any journey if possible to best enable catch-up in the event of delay). In normal operation therefore the trains typically operate below 360kph (Captive trains operate around 325km/h and Classic Compatible trains at 335km/h on highest speed sections based on defined operating margins) and so there are limited if any locations or scenarios where the 330kph speed reduction will have an effect in these results.

10.1.5 However it is critical to emphasise from 10.1.4 above that the operating principle of all HS2 timetables requires that the timetables can recover from any significant delay as quickly as possible, and maintain sufficient reliability when minor delays are experienced. This is achieved via operating time margin which extends the minimum journey times, and these times are used to generate the timetables. If trains are planned to be operated at any speeds below 360 km/h, increases in minimum journey times would require new margin calculations which would necessitate new timetables to be developed.

10.2 Phase One Timetable Review – Alternative plans

10.2.1 As part of analysis for operation of the Phase One service on six platforms at Euston, a platforming plan (ref 6) has been drawn up that features allocation of a 15-minute turnround at Euston to Curzon Street services. This leaves a 27-minute turnround at Curzon Street. Whilst this is prudent in view of the short London-end turnround, in planning terms it could tolerate the 330 kph scenario, although there would clearly be a risk to robustness.

10.2.2 In the 300 kph scenario, the turnround time would drop to 20 minutes. At this point, where the turnround time is identical to the service interval, a platform-end conflict would occur for alternate trains, making the scenario unachievable regardless of robustness, so that the Final ES plan would have to apply.

10.2.3 In the 270 kph scenario the turnround would drop below 15 minutes so that stepping down would become necessary.

10.3 Phase Two Timetable Review – Alternative plans

10.3.1 This analysis has not considered the possible early extension of HS2 services to Crewe. However, it must be noted that from separate analysis on the operational feasibility of that extension, it appears that it will be critical to place the Up and Down Manchester services in parallel at Crewe North Junction. It is likely that any more than a slight (one or two minutes) extension to journey times will frustrate this.

10.3.2 The analysis above identifies that the long turnround at Preston would tolerate journey time extension arising from any of the speed reduction scenarios. However, this long turnround has been viewed as a potential opportunity to extend the service beyond Preston, and this opportunity is jeopardised by journey time extension. As detailed timetabling to exploit the opportunity has not yet been undertaken, it is not possible to say at what point this risk becomes real.

10.3.3 This analysis has been based on the Final ES train Service Specification which includes Heathrow services from Manchester and Leeds. The future of these services is not certain, but should they not operate to and from Heathrow it would be a reasonable assumption that some other services of some sort would operate in their place, and that similar effects would be found.

Appendix A – Changes to movement time and timetable journey time for each speed scenario

Changes to movement time and timetable journey time for each speed scenario
Down direction

Final ES timetable, Down direction			On HS2 infrastructure		Uplifted train movement time						Change in train movement time			Change in timetabled journey time (mins)		
Service	From	To	Calling Old Oak and ...	HS2 to:	Trip ref	360 kph	Trip ref	330 kph	300 kph	270 kph	330 kph	300 kph	270 kph	330 kph	300 kph	270 kph
1	Euston	Curzon St	None	Throughout	**Trip PH2_1**	00:40:42	Trip TPC2 _1	00:42:15	00:44:28	00:47:30	00:01:33	00:03:46	00:06:48	1.5	4	7
2	Euston	Curzon St	Interchange	Throughout	**Trip PH2_2-3**	00:42:58	Trip TPC2 2_3	00:44:26	00:46:36	00:49:34	00:01:28	00:03:38	00:06:36	1.5	3.5	6.5
3	Euston	Curzon St	Interchange	Throughout	**Trip PH2_2-3**											
4	Euston	Manchester	Interchange, Airport	Throughout	**Trip PH2_7**	01:09:15	Trip TPC2 _7	01:12:08	01:16:09	01:21:32	00:02:53	00:06:54	00:12:17	3	7	12.5
17	Heathrow	Manchester	Interchange, Airport	Throughout	**Trip PH2_7**											
5	Euston	Manchester	None	Throughout	**Trip PH2_9**	01:03:50	Trip TPC2 _9	01:07:11	01:11:41	01:17:29	00:03:21	00:07:50	00:13:39	3.5	8	13.5
6	Euston	Manchester	Airport	Throughout	**Trip PH2_8**	01:05:26	Trip TPC2 _8	01:08:48	01:13:16	01:19:06	00:03:22	00:07:50	00:13:40	3.5	8	13.5
7	Euston	Liverpool	None	Crewe	**Trip PH2_5**	01:22:57	Trip TPC2 _5	01:25:45	01:29:33	01:34:33	00:02:48	00:06:36	00:11:36	3	6.5	11.5
8	Euston	Liverpool	None	Handsacre	**Trip PH2_4**	01:35:47	Trip TPC2 _4	01:37:41	01:40:22	01:44:01	00:01:54	00:04:35	00:08:15	2	4.5	8.5
9	Euston	Preston	None	Crewe	**Trip PH2_6**	01:26:00	Trip TPC2 _6	01:28:48	01:32:36	01:37:36	00:02:48	00:06:36	00:11:36	3	6.5	11.5
10	Euston	Glasgow/E'boro'	None	Golborne	**Trip PH2_11**	03:28:05	Trip TPC2 _11	03:31:03	03:35:52	03:42:08	00:02:58	00:07:48	00:14:04	3	8	14
11	Euston	Glasgow/E'boro'	Interchange	Golborne	**Trip PH2_10**	03:31:54	Trip TPC2 _10	03:34:23	03:38:44	03:44:34	00:02:30	00:06:50	00:12:41	2.5	7	12.5
12	Euston	Leeds	Toton	Throughout	**Trip PH2_20**	01:14:08	Trip TPC2 _20	01:16:45	01:20:49	01:26:29	00:02:38	00:06:41	00:12:21	2.5	[illegible]	12.5
13	Euston	Leeds	Interchange, Toton, Meadowhall	Throughout	**Trip PH2_19**	01:19:05	Trip TPC2 _19	01:21:29	01:25:15	01:30:36	00:02:24	00:06:10	00:11:31	2.5	6	11.5
18	Heathrow	Leeds	Interchange, Toton, Meadowhall	Throughout	**Trip PH2_19**											
14	Euston	Leeds	Toton, Meadowhall	Throughout	**Trip PH2_22**	01:16:09	Trip TPC2 _22	01:18:42	01:22:43	01:28:19	00:02:33	00:06:35	00:12:11	2.5	6.5	12
15	Euston	Newcastle	None	York Branch Jn	**Trip PH2_23**	02:08:54	Trip TPC2 _23	02:11:38	02:15:47	02:21:45	00:02:44	00:06:53	00:12:51	2.5	7	13
16	Euston	Newcastle	None	York Branch Jn	**Trip PH2_23**											
21	Curzon St	Manchester	Airport	Throughout	**Trip PH2_13-14**	00:36:53	Trip TPC2 _13-1	00:38:13	00:40:01	00:42:22	00:01:20	00:03:08	00:05:29	1.5	3	6.5
22	Curzon St	Manchester	Airport	Throughout	**Trip PH2_13-14**											
23	Curzon St	Glasgow/E'boro'	None	Golborne	**Trip PH2_15a**	02:59:34	Trip TPC2 _15A	03:01:11	03:03:18	03:06:06	00:01:38	00:03:45	00:06:33	1.5	4	6.5
24	Curzon St	Leeds	Toton, Meadowhall	Throughout	**Trip PH2_16-17**	00:46:36	Trip TPC2 _16-1	00:47:29	00:49:07	00:51:30	00:00:53	00:02:31	[illegible]	1	2.5	5
25	Curzon St	Leeds	Toton, Meadowhall	Throughout	**Trip PH2_16-17**											
26	Curzon St	Newcastle	Toton, Meadowhall	York Branch Jn	**Trip PH2_18**	01:46:47	Trip TPC2 _18	01:47:45	01:49:31	01:52:01	00:00:58	00:02:44	[illegible]	1	2.5	5

Code 1 - Accepted

Up direction

Final ES timetable, Up direction			On HS2 infrastructure		Uplifted train movement time							Change in train movement time			Change in timetabled journey time (mins)		
Service	From	To	Calling Old Oak and ...	HS2 to:	Trip ref		360 kph	Trip ref	330 kph	300 kph	270 kph	330 kph	300 kph	270 kph	330 kph	300 kph	270 kph
1	Curzon St	Euston	None	Throughout	Trip PH2_1	R	00:40:41	Trip TPC2 _1 R	00:42:09	00:44:26	00:47:37	00:01:28	00:03:45	00:06:56	1.5	4	7
2	Curzon St	Euston	Interchange	Throughout	Trip PH2_2-3	R	00:43:06	Trip TPC2 2_3 R	00:44:28	00:46:41	00:49:44	00:01:22	00:03:35	00:06:38	1.5	3.5	6.5
3	Curzon St	Euston	Interchange	Throughout	Trip PH2_2-3	R											
4	Manchester	Euston	Interchange, Airport	Throughout	Trip PH2_7	R	01:09:30	Trip TPC2 _7 R	01:12:12	01:16:19	01:21:51	00:02:43	00:06:49	00:12:21	2.5	7	12.5
17	Manchester	Heathrow	Interchange, Airport	Throughout	Trip PH2_7	R											
5	Manchester	Euston	None	Throughout	Trip PH2_9	R	01:03:47	Trip TPC2 _9 R	01:07:00	01:11:37	01:17:37	00:03:13	00:07:49	00:13:50	3	8	14
6	Manchester	Euston	Airport	Throughout	Trip PH2_8	R	01:05:32	Trip TPC2 _8 R	01:08:45	01:13:22	01:19:22	00:03:13	00:07:49	00:13:50	3	8	14
7	Liverpool	Euston	None	Crewe	Trip PH2_5	R	01:24:10	Trip TPC2 _5 R	01:26:48	01:30:37	01:35:43	00:02:38	00:06:26	00:11:33	2.5	6.5	11.5
8	Liverpool	Euston	None	Handsacre	Trip PH2_4	R	01:36:32	Trip TPC2 _4 R	01:38:21	01:41:08	01:44:57	00:01:49	00:04:36	00:08:25	2	4.5	8.5
9	Preston	Euston	None	Crewe	Trip PH2_6	R	01:25:43	Trip TPC2 _6 R	01:28:20	01:32:10	01:37:16	00:02:38	00:06:27	00:11:33	2.5	6.5	11.5
10	Glasgow/E'boro'	Euston	None	Golborne	Trip PH2_11	R	03:28:21	Trip TPC2 _11 R	03:31:50	03:36:47	03:43:14	00:03:29	00:08:26	00:14:52	3.5	8.5	15
11	Glasgow/E'boro'	Euston	Interchange	Golborne	Trip PH2_10	R	03:32:19	Trip TPC2 _10 R	03:35:17	03:39:46	03:45:43	00:02:58	00:07:27	00:13:24	3	7.5	13.5
12	Leeds	Euston	Toton	Throughout	Trip PH2_20	R	01:14:18	Trip TPC2 _20 R	01:16:35	01:20:29	01:26:22	00:02:16	00:06:11	00:12:03	2.5	6	12
13	Leeds	Euston	Interchange, Toton, Meadowhall	Throughout	Trip PH2_19	R	01:19:08	Trip TPC2 _19 R	01:21:07	01:24:44	01:30:13	00:01:59	00:05:36	00:11:05	2	5.5	11
18	Leeds	Heathrow	Interchange, Toton, Meadowhall	Throughout	Trip PH2_19	R											
14	Leeds	Euston	Toton, Meadowhall	Throughout	Trip PH2_22	R	01:16:11	Trip TPC2 _22 R	01:18:22	01:22:12	01:27:58	00:02:11	00:06:01	00:11:48	2	6	12
15	Newcastle	Euston	None	York Branch Jn	Trip PH2_23	R	02:08:37	Trip TPC2 _23 R	02:10:58	02:15:08	02:21:21	00:02:21	00:06:31	00:12:44	2.5	6.5	12.5
16	Newcastle	Euston	None	York Branch Jn	Trip PH2_23	R											
21	Manchester	Curzon St	Airport	Throughout	Trip PH2_13-14	R	00:36:48	Trip TPC2 _13-1 R	00:38:06	00:39:57	00:42:23	00:01:18	00:03:09	00:05:35	1.5	3	5.5
22	Manchester	Curzon St	Airport	Throughout	Trip PH2_13-14	R											
23	Glasgow/E'boro'	Curzon St	None	Golborne	Trip PH2_15a	R	03:00:04	Trip TPC2 _15A R	03:01:38	03:03:51	03:06:42	00:01:34	00:03:47	00:06:38	1.5	4	6.5
24	Leeds	Curzon St	Toton, Meadowhall	Throughout	Trip PH2_16-17	R	00:46:27	Trip TPC2 _16-1 R	00:47:06	00:48:31	00:50:58	00:00:39	00:02:04	00:04:3[illegible]	0.5	2	4.5
25	Leeds	Curzon St	Toton, Meadowhall	Throughout	Trip PH2_16-17	R											
26	Newcastle	Curzon St	Toton, Meadowhall	York Branch Jn	Trip PH2_18	R	01:46:02	Trip TPC2 _18 R	01:46:47	01:48:21	01:51:00	00:00:45	00:02:20	00:0[illegible]:58	1	2.5	5

Appendix B – HS2 Carbon Implications Remit

Introduction

The Environmental Audit Committee (EAC) recommended that *'While the impact of lower maximum train speed on reducing emissions is currently not seen as substantial, the legally binding commitment to reduce emissions makes even a small reduction desirable. HS2 Ltd and the Department should therefore examine the scope for requiring a reduced maximum speed for the trains until electricity generation has been sufficiently decarbonised to make that a marginal issue, and publish the calculations that would underpin such a calculation.'*

The Government response to the EAC states that ***"HS2 Ltd will undertake further examination of the possible emissions benefits of changing the operational specification.*** *However, HS2 Ltd is clear that operating at lower speed would reduce carbon emissions from the operation of rolling stock by only a relatively small degree, and would increase journey times, making HS2 a less attractive option to customers on roads and using flights. This is likely to result in less mode shift and potentially less carbon benefit associated with the operation of HS2, which could lead to an overall increase in UK carbon emissions compared to the existing proposed operating speed."*

Background

Greengauge 21 has previously proposed[1] that the maximum operating speed of HS2 could be reduced from 360 kph **to 300 kph prior to the 2030's** to improve the carbon impacts of HS2. Greengauge 21 also conclude that *'as electrical power generation is more fully decarbonised and the HSR network is extended, the journey time improvements on HS2 become even more important in delivering mode shift, and so a top speed of 360 kph is more likely to be needed and justified by the carbon savings from reduced air and private car travel'.*

More recently, the Campaign to Protect Rural England has, in their petition, called for *'limiting the maximum operational speed of services on High Speed 2* ***to 300 kph until the carbon Intensity of UK grid reaches 50gCO_2/kWh'*** (i.e. 2040 – based on DECC projections).

The Environmental Statement included line speed sensitivity testing based on changes to maximum speed (see table below). Permanently reducing the maximum speed to 300 kph from 330-360 kph was calculated to reduce the carbon emissions from the operation and maintenance of rolling stock by approximately 7% (approximately a 2% reduction to the total carbon emitted during construction and operation).

Assumed maximum speed (kph)	Total operational footprint (tCO_2e)[2]	Variance to 330/360 kph
360	2,380,000	4.8%
330-360	2,270,000	N/A
330	2,250,000	-0.9%
300	2,110,000	-7%

However, the carbon implications of limiting the maximum operating speed to 300 kph, prior to sufficient grid decarbonisation, has not been fully investigated.

[1] Greengauge 21: Carbon impacts of HS2. http://www.greengauge21.net/wp-content/uploads/The-carbon-impacts-of-HS2-final-2012.pdf

[2] It is important to note that energy consumption data for the train sets is based on today's technology and does not include expected improvements in system efficiency and management.

Remit

Parsons Brinckerhoff and Arup/URS are requested to submit quotes to undertake specific work tasks in a high level investigation of the service and carbon implications, for Phase One of HS2, of alternative operational scenarios. Whilst the carbon implications will, largely, be considered in the context of the Phase One carbon footprint it will also be necessary to consider the implications of the alternative operational scenarios on destinations north of Birmingham (e.g. journey time to Manchester and Leeds).

1. The study will focus on the carbon implications of the following scenarios:
    a. Maximum operating speed 360 kph
    b. 330/360 kph (maximum operating speed 330 kph for 90% of service, maximum operating speed 360 kph for 10% of service – the current HS2 assumed operational specification)
    c. 300/330kph (maximum operating speed 300 kph for 90% of service, maximum operating speed 330 kph for 10% of service)
    d. 270/300 kph (maximum operating speed 270 kph for 90% of service, maximum operating speed 300 kph for 10% of service)

2. The study will quantify the carbon implications associated with the construction[3], operation and maintenance of HS2 rolling stock. Journey times will be quantified for each scenario to enable a qualitative discussion of the carbon implications associated with mode shift and the resultant impact on per passenger kilometre carbon emissions.

3. The service and carbon implications should be assessed over 60 years with scenarios 1.a – 1.d applied from day 1 of operation (i.e. 2026) to the following years (after which the current HS2 assumed operational specification should be applied):
    a. 2030 (to align with the Greengauge 21 'Carbon impacts of HS2' report and to reflect the year in which the Committee on Climate Change project the carbon intensity of UK grid electricity to reach 50 gCO_2/kWh).
    b. 2040 (to align with the timescales set out in The Campaign to Protect Rural England's petition and to reflect the year in which DECC project the carbon intensity of UK grid electricity to reach 50 gCO_2/kWh).
    c. 2050 (to align with Climate Change Act 2008 timeframes).

4. Parsons Brinckerhoff shall report the following information for each operational scenario in bullet point one and, where relevant, for each time scenario identified in bullet point, for each journey (both directions) within the Phase One and Phase Two timetables:
    a. Journey time
    b. Confirmation of whether the existing frequency of service can be maintained given the current railway design (Yes/No), if yes:
        i. Rolling stock fleet size required to maintain frequency of service (including turn around time)
        ii. Kilometres travelled from operation of rolling stock fleet (train km)
        iii. Variance to 330/360 kph (kWh/train set km and %)

[3] Only the carbon implications associated with changes to the rolling stock fleet size should be considered in relation to construction carbon emissions.

5. Arup/URS shall report the following information for each operational scenario in bullet point one and, where relevant, for each time scenario identified in bullet point three:
    a. Embedded carbon emissions associated with rolling stock fleet (tCO_2e)
    b. Carbon emissions from operation of rolling stock fleet (tCO_2e)
    c. Carbon emissions from maintenance of rolling stock fleet (tCO_2e)
    d. Total carbon footprint from construction, operation and maintenance of rolling stock (tCO_2e)
    e. Variance to 330/360 kph (tCO_2e and %)

6. The following assumptions should be adopted:
    a. The existing train service specification (HS2-HS2-OP-DAS-000-000001) is to be used along with current modelling parameters.
    b. The base case fleet size is as per the circulation and stabling plan (C240-PBR-OP-PLN-000-200003 [P01]).
    c. Rolling stock will not require replacement before 2050 but will require maintenance.

Deliverable

Parsons Brinckerhoff shall deliver an interim paper/technical note, followed by a final draft, to HS2 Ltd to include the information listed in bullet point four for the scenarios listed in bullet point one.

Arup/URS shall deliver an interim report, followed by a final draft, to HS2 Ltd to include the following:

a. The context and purpose of the study
b. The approach and assumptions adopted
c. Relevant calculations and quantified findings
d. Qualitative discussion of the likely impact on carbon benefits from mode shift and resultant impact on per passenger kilometre carbon emissions
e. Discussion of the findings in the context of the total carbon emissions from construction, operation and maintenance
f. Discussion of the findings in the context of timetabling, engineering, cost, etc. implications
g. Consideration of areas of further investigation.

Timescales

Parsons Brinckerhoff shall submit the interim paper/technical note to HS2 Ltd by XXXX.

The final draft paper/technical note shall be submitted to HS2 Ltd by XXXX.

Arup/URS shall submit the interim report to HS2 Ltd by XXXX.

The final draft report shall be submitted to HS2 Ltd by XXXX.