SECOND OPINION CALCULATED COST

High speed rail in Sweden

25 May 2016

GÖTEBORG TO BORÅS
LINKÖPING TO BORÅS
JÖNKÖPING TO MALMÖ
EAST LINK

ARUP

CONTENTS

Stockholm is one of the three principle cities on the proposed HSR network

Section 1

EXECUTIVE SUMMARY

Trafikverket has been commissioned by National Negotiation on Housing and Infrastructure to perform a second opinion on the evaluation of costs reported in December 2015.

Arup has been commissioned by Trafikverket to provide this second opinion. It has been achieved by analysing benchmark cost data from comparable projects, considering the application of the Successive Principle and providing an independent estimate, including an alternative method of monetising cost uncertainty. The main findings of this report can be summarised as follows.

BENCHMARK AGAINST COMPARABLE PROJECTS (SECTION 3 OF THIS REPORT)

The estimates for all the proposed routes sit within the range of other European High Speed Rail Projects that have been delivered since 2000.

The proposed Swedish schemes sit at the higher end of the range, which may reflect the specific characteristics of the proposed project including the relatively high proportion of tunnels, structures and earthworks on the scheme.

HIGH LEVEL ESTIMATES (SECTION 4 OF THIS REPORT)

Arup has undertaken high-level cost estimates for one option in each of the four proposed routes. These are:

1. Goteborg to Borås,
2. Linköping to Borås (Alt 1)
3. East Link and
4. Jönköping to Malmö (US2)

To these estimates, Arup has applied allowances for cost uncertainty at P_{50}, P_{80} and P_{90}[1] confidence limits using guidance from the United Kingdom's (UK) Department for Transport (DfT).

As the ranges in the Successive Principle reports are expressed at P_{50} and P_{85} levels, Table 1.1 provides a comparison of Arup estimates at P_{50}, P_{80} and P_{90} and the equivalent Trafikverket estimates at P_{50} and P_{85}.

Table 1.1 Arup Estimates and Equivalent Trafikverket estimate at P50 and P85

		P_{50} (bn SEK)	P_{80} (bn SEK)	P_{85} (bn SEK)	P_{90} (bn SEK)
All Routes	**Trafikverket**	256		320	
	Arup	264	312		351
Göteborg to Borås	**Trafikverket**	33		40	
	Arup	28	32		38
Linköping to Borås	**Trafikverket**	79.4		103.4	
	Arup	90	108		122
East Link	**Trafikverket**	53		68	
	Arup	63	71		84
Jönköping to Malmö	**Trafikverket**	86		112	
	Arup	83	91		107

SUCCESSIVE PRINCIPLE (SECTION 5 OF THIS REPORT)

Arup has reviewed the way in which the Successive Principle has been applied. The Successive Principle has been used by Trafikverket to judge the contribution of uncertainty to project cost estimates. All four applications broadly comply with Successive Principle guidance. Considerable effort appears to have been spent preparing for and conducting each of the two-day workshops. The assessment results are clearly illustrated and properly interpreted. The fact that the estimates that have been generated from the Successive Principle process are broadly similar to the independent estimate carried out by Arup, would support the view that this process has generated an appropriate range of estimates for this stage of the project.

However, this report highlights a small number of issues concerning input data collection which has the potential to undermine the reliability of the assessment results. Firstly, workshops were attended by experienced persons, but there is no indication as to what disciplines were represented. Secondly, only four general uncertainties have been considered in the assessment of East Link. Thirdly, it is not clear from the Successive Principle reports why, for selected general uncertainties (e.g. New Technologies and Laws/Rules) with the same planning reference scenario descriptions, some values are negative and some are positive. Recommendations to address these issues are included in the report.

1 P50 is the monetary value that has a 50% chance of being exceeded. P80 is the monetary value that has a 20% chance of being exceeded P90 is the monetary value that has a 10% chance of being exceeded

Section 2

INTRODUCTION

SCOPE

The scope of this report is to:

1. Provide an analysis of where the total cost of the route per km of the proposed project, as described in the Successive Principle reports, sit against other high speed rail schemes
2. Provide an alternative high-level independent cost estimate of the proposed routes between Göteborg to Borås, Linköping and Borås (Alt 1), Jönköping to Malmö (US2) and East Link for comparison to the estimates and other information provided by Trafikverket.
3. Review and critique the application of the Successive Principle studies for the proposed route sections.

METHODOLOGY

Benchmarking methodology

For the benchmarking exercise data was gathered from a range of comparable High Speed Rail in Europe. This was initially gathered from a combination of Arup data and published reports[2].

Although "high level" cost data was available for a wide range of projects, only some of these had sufficient detail to enable a detailed analysis. The chosen projects were selected because:

1. They were all completed after the year 2000
2. They all have a design speed of 300kph or more
3. They are all in Europe, constructed under comparable safety standards

Other projects were also considered for the benchmark, including High Speed rail schemes in Asia, the United States and other proposed schemes in the UK, but were eventually discounted because they did not have enough detail to provide a useful comparison, the schemes were too dissimilar to the proposed Swedish schemes (for example heavily urbanised), or the projects are still at planning or design stage.

To provide like for like comparisons, all the projects were normalised by inflating to 4th Quarter 2015 and converted from UK Stirling to Swedish Krona by a conversion factor of 11.5.

As part of this process data for potential adjustments for geographical location were considered, specifically the possible difference in cost of construction in the UK and Sweden. In this analysis it was considered that published data was limited and too generic to arrive at a realistic location factor that is specific enough to apply to the construction of a High Speed Rail project. However Trafikverket were able to supply accurate cost data for bridge construction and it was found that the overall cost for comparable construction in the UK was very similar. On this basis, and without any evidence to the contrary, it was decided for the purpose of this exercise not to apply a location factor adjustment.

High Level Cost Estimate

The documents used as the basis for the analysis are listed in Appendix B. In addition to these documents, Trafikverket was able to clarify any queries on the main quantities for the routes and these formed the basis for the estimate.

To arrive at an estimate, the quantities were applied to Arup's generic rates for the main elements of the work including railway systems, earthworks, tunnelling and structures.

Due to lack of scope definition, costs for stations and property were taken from the Successive Principle reports and applied to the estimate.

Arup has applied a percentage to the base construction cost for client costs and design, in the region of 15% or as advised by Trafikverket

Contractor's preliminaries and profit are applied to the estimate at 21% (12% preliminaries and 9% profit) as advised by Trafikverket, although it is noted that this level of preliminaries are lower than currently experienced in the UK for this type of scheme.

2 See Appendix C list of references

Cost Uncertainty Review Method

Arup has reviewed the uncertainty analysis in order to (a) judge whether the analysis process accords with good practice, and (b) test whether the analysis results are appropriate. To understand whether or not the risk analysis process is in line with good practice, the *Successive Principle* and its application have been reviewed (see 'Successive Principle Application'). Our review has addressed:

1. The input data used for analysis, including impact range scenarios and their substantiation;

2. How input data have been modelled, including the use of probability distributions;

3. The risk analysis software that has been used;

4. How the analysis results have been interpreted, using probability density, cumulative probability and tornado charts.

To form a second opinion, the following documents have been reviewed:

Ref 1. *A Brief Explanation of the Successive Principle in Practice*

Ref 2. *Successive Principle in Baseline*

Ref 3. *The East Link Project – Cost Assessment Using the Successive Method* (November 12-13, 2014)

Ref 4. *Linköping-Borås Uncertainty Analysis – A Cost Analysis Using the Successive Principle*

Ref 5. *The Successive Principle – Proactive Management of Uncertainty*

Ref 6. *Uncertainty Analysis: A Time and Cost Analysis of the Göteborg-Borås double-track railway line, based on the Successive Principle*

Uncertainty Analysis – a cost analysis using the successive principle for the high-speed line for the Jönköping-Malmö stretch

Over the course of the commission, Arup has made two separate Optimism Bias (OB) assessments. The first was based on HM Treasury's *Green Book Supplementary Guidance.* The second uses the British Department for Transport (DfT), *Procedures for Dealing with Optimism Bias in Transport Planning.* The latter document is the result of a joint consultancy assignment between Bent Flyvbjerg and COWI. To obtain statistically significant samples, the DfT's guidance includes data from the Flyvbjerg Database on international projects to add to UK samples. For this reason, coupled with the fact that DfT's guidance provides uplift percentages that equate to specific confidence limits to enable comparison with Trafikverket estimates (see Table 2.1), Arup cost estimates are based on DfT guidance only (see Section 4).

The DfT guidance recommends that the established uplifts for OB should be applied to estimated budgets at the time of decision to build a project. The approval stage is equivalent to the time of presenting the business case for a project to the DfT with a view to obtaining the "go" or "no-go" for that project. Whilst it is recognised that the UK and Swedish project phases to not align exactly, Arup understands that none of the four projects have yet to reach an "equivalent" business case stage, at the time the Successive Principle reports were written. The OB uplifts are therefore considered not to be conservative. There is no scope in DfT guidance for adjustment of uplifts to account for increasing levels of certainty.

Table 2.1 - Applicable Capital Expenditure Uplifts for Selected Percentiles. Constant Prices (Source: DfT, Procedures for Dealing with Optimism Bias in Transport Planning)

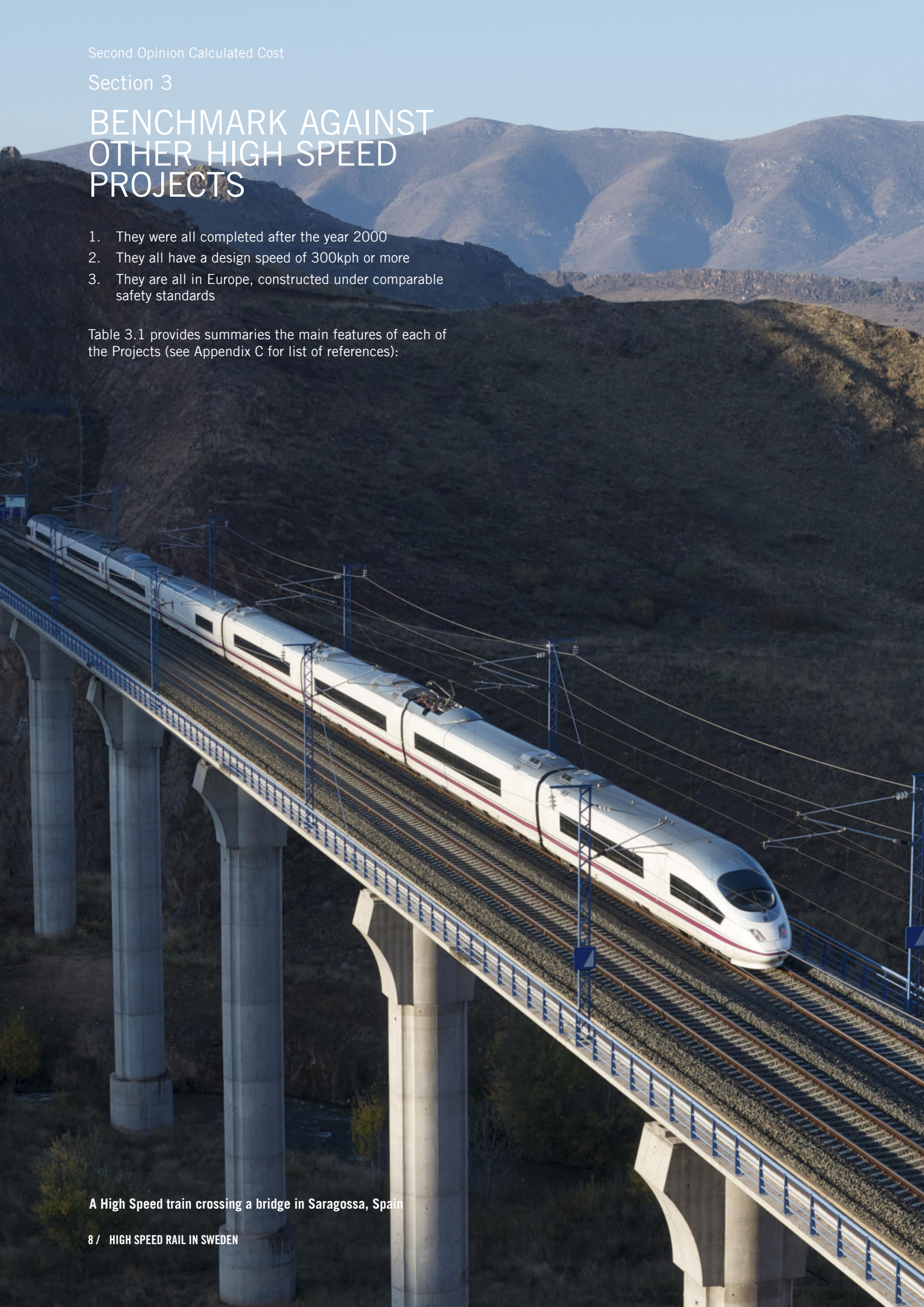
Category	Type of projects	Applicable optimism bias uplifts				
		50% percentile	60% percentile	70% percentile	80% percentile	90% percentile
Roads	Motorway Trunk Roads Local roads Bicycle facilities Pedestrian facilities Park and ride Bus lane schemes Guided buses on wheels	15%	24%	27%	32%	45%
Rail	Metro Light rail Guided buses on tracks Conventional rail High speed rail	40%	45%	51%	57%	68%
Fixed links	Bridges Tunnels	23%	26%	34%	55%	83%

Section 3

BENCHMARK AGAINST OTHER HIGH SPEED PROJECTS

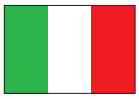
1. They were all completed after the year 2000
2. They all have a design speed of 300kph or more
3. They are all in Europe, constructed under comparable safety standards

Table 3.1 provides summaries the main features of each of the Projects (see Appendix C for list of references):



A High Speed train crossing a bridge in Saragossa, Spain

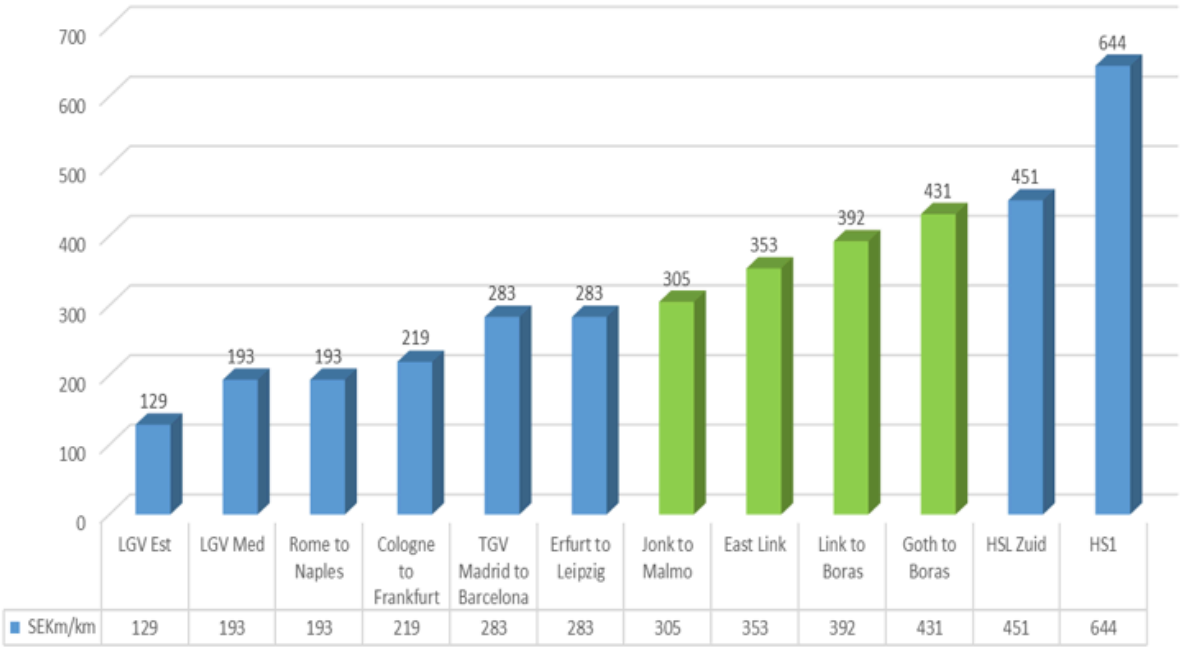
Table 3.1 Description of routes used for benchmark analysis

Project	Description of Routes
LGV Est European 	A High Speed Rail connecting Vaires-Sur-Maine near Paris to Baudrecourt, opened in 2007 Route length: 301km % of route in tunnel: 1% % of route on structures: 2% Track: Ballast
LGV Mediterrannee 	A High Speed Rail connection the regions of Provence-Alpes-Côte d'Azur and Languedoc-Roussillon to the LGV Rhône-Alpes, and then to Lyon and north, opened in 2001 Route length: 250km % of route in tunnel:: 6% (TBM) % of route on structures: 6% Track: Ballast New stations: 5nr
Rome to Naples 	A High Speed Rail connecting Roma Termini to Gricignano di Aversa, opened in 2005 Route length: 205km % of route in tunnel: 18% % of route on structures: 19% Track: Ballast New stations: 2nr
Cologne to Frankfurt 	A High Speed Rail connecting Cologne and Frankfurt, opened in 2002 Route length: 219km % of rout in tunnel: 22% (some TBM) % of route on structures: 3% Track: 95% slab, 5% ballasted New stations: 2nr
Madrid to Barcelona 	A High Speed Rail connecting Madrid and Barcelona, opened in 2008 Route length:126km % of route: in tunnel: 9% % of route on structures: 6% Track: Ballast New Stations: 3nr
Leipzig to Erfurt 	A High Speed Rail connecting Erfurt and Leipzig/Halle., opened in 2015 Route length:123km % of route in tunnel:: 13% % of route on structures: 12% Track: Approx. 75% slab, 25% ballast New Stations:3nr
HSL Zuid 	A High Speed Rail in the Netherlands to the Belgian Border, opened in 2009 Route length: 125km % of route in tunnel:: 14% % of route on structures: 2% Track: Slab
High Speed 1 	A High Speed Rail in the UK connecting St Pancras to the Channel Tunnel, opened in 2007 Route length: 109km % of route in tunnel:: 26% (TBM) % of route on structures: 8% Track: 85%ballast, 15% slab New Stations: 3nr plus major work at St Pancras

COMPARISON TO THE PROPOSED SWEDISH ROUTES

The following chart summarises P50 cost per km for Jönköping to Malmö (US2) and Linköping to Borås (Alt1), Göteborg to Borås and East Link from the Successive Principle report (green bars) against the projects listed above (blue bars).

Chart 3.1 Comparison of Cost per km of proposed Swedish High Speed Projects against benchmarked sample



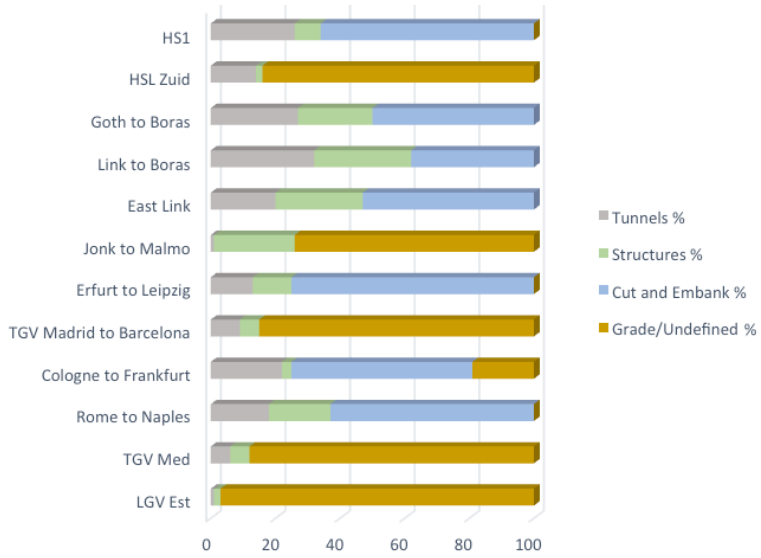
Cost Drivers

There are many factors that influence the cost of a High Speed Rail scheme, but some of the major factors includes:

- **Proportion of tunnels along the route**
- **Proportion of structures, including viaducts**
- **Extent of cuttings and embankments**
- **Other major factors, such as station construction or major redevelopment**

Chart 3.2 shows the reported proportion of tunnels, structures (e.g. bridges), cuttings and embankments along the route of all the sampled projects, including the proposed Swedish Projects (see Appendix C for sources of information). Note the most expensive project per km is at the top (HS1) and the least expensive per km at the bottom of the chart (LGV Est European)

Chart 3.2 Proportion of Tunnels, Structures, Cuttings and Embankments



OBSERVATIONS

- **Although there are many factors that can influence cost, it is noted that a high proportion of tunnels and structures tends to be reflected in a higher overall average cost per km. This is certainly true in the case of High Speed 1, with a high proportion of tunnels, cuttings, embankments and structures when compared with other sampled benchmark projects.**
- **The four sections of the Swedish route have different costs per km, but these appear broadly proportionate to the number of tunnels, structures, cuttings and embankment, with Göteborg to Borås being the most expensive and Jönköping to Malmö the least.**
- **The proposed Swedish Schemes sit towards the higher end of the sampled benchmark projects (at P50). This may appear appropriate given the high proportion of tunnels on some of the schemes, high number of structures, and proportion of cutting and embankment.**

Section 4

ESTIMATES

HIGH LEVEL ASSUMPTIONS

An independent estimate has been prepared for each of the routes. In preparing the estimate a number of generic assumptions were made, applicable to all estimates

Element	Assumption
Environmental Mitigation	An allowance of 11m SEK per km is made to cover environmental mitigation, which may include fencing, landscaping, noise barriers etc.
Rail	Includes for new slab track, overhead lines and signalling systems. Note cost for power from the Distribution Network Operator are excluded.
Tunnels	An allowance per km for drill and blast is included
Highways	Based of quantities derived from the Successive Principle reports or confirmed by Trafikverket
Bridges and structures	Based of quantities derived from the Successive Principle reports or confirmed by Trafikverket
Earthworks	Based of quantities derived from the Successive Principle reports or confirmed by Trafikverket
Stations and Property	As not possible to independently assess based on the information available, an allowance approximate to the P50 value from the Successive Principle reports is included
Client Costs	Based on client costs in the UK, a normal percentage that might be applied at an early stage of a project to cover client organisations and client design is 10 – 20%. Trafikverket's percentage additions fall within this range and this has been applied
Contractor Preliminaries, Overhead and Profit	Contractor's preliminaries, covering site set up and management costs are applied at 12%. Contractor's overhead and profit are included at 9%, as advised by Trafikverket.

HIGH LEVEL ESTIMATES

The following tables summarises Arup independent estimate of the proposed routes. Further detail is included in Appendix A

Entire Route combined

Element	Total Including Client Costs	Arup P50	
Environmental Mitigation	10,397	40%	14,555
Rail	51,764	40%	72,469
Stations, buildings	7,014	40%	9,820
Tunnels	33,770	40%	41,537
Highways	3,267	40%	3,757.31
Bridges, structures, walls	61,664	40%	75,847
Earthworks	27,985	40%	39,179
Property and other	4,792	40%	6,708
Total	200,652		263,873

	SEK (bn)	
Arup total at P50	264	Total plus percentile
Arup total at P80	312	Total plus percentile
Arup total at P90	351	Total plus percentile
Trafiverket	256	

Göteborg to Borås

Element	Total Including Client Costs	Arup P50	
Environmental Mitigation	1,010	40%	1,414
Rail	5,147	40%	7,206
Stations, buildings	561	40%	785
Tunnels	5,291	40%	6,508
Highways	61	40%	70
Bridges, structures, walls	6,145	40%	7,558
Earthworks	3,468	40%	4,855
Property and other	29	40%	41
Total	21,712		28,438

	SEK (bn)	
Arup total at P50	28	Total plus percentile
Arup total at P80	32	Total plus percentile
Arup total at P90	38	Total plus percentile
Trafiverket	33	

Linköping to Borås (Alternative 1)

Element	Total Including Client Costs	Arup P50	
Environmental Mitigation	3,172	40%	4,441
Rail	16,112	40%	22,557
Stations, buildings	2,551	40%	3,572
Tunnels	19,312	23%	23,753
Highways	2,363	15%	2,717.15
Bridges, structures, walls	18,815	23%	23,142
Earthworks	5,863	40%	8,208
Property and other	1,201	40%	1,682
Total	69,389		90,072

	SEK (bn)	
Arup total at P50	90	Total plus percentile
Arup total at P80	108	Total plus percentile
Arup total at P90	122	Total plus percentile
Trafiverket P50	79.4	

Jönköping to Malmö (US2)

Element	Total Including Client Costs	Arup P50	
Environmental Mitigation	3,918	40%	5,486
Rail	19,275	40%	26,985
Stations, buildings	3,179	40%	4,450
Tunnels	662	23%	814
Highways	202	15%	232
Bridges, structures, walls	20,958	23%	25,778
Earthworks	11,589	40%	16,225
Property and other	1,850	40%	2,589
Total	61,632		82,560

	SEK (bn)	
Arup total at P50	83	Total plus percentile
Arup total at P80	91	Total plus percentile
Arup total at P90	107	Total plus percentile
Trafiverket P50	85.5	

East Link

Element	Total Including Client Costs	Arup P50	
Environmental Mitigation	2,296	40%	3,214
Rail	11,230	40%	15,722
Stations, buildings	724	40%	1,013
Tunnels	8,505	23%	10,461
Highways	642	15%	738
Bridges, structures, walls	15,747	23%	19,368
Earthworks	7,065	40%	9,891
Property and other	1,712	40%	2,396
Total	47,919		62,804

	SEK (bn)	
Arup total at P50	63	Total plus percentile
Arup total at P80	71	Total plus percentile
Arup total at P90	84	Total plus percentile
Trafiverket P50	53.4	

OBSERVATIONS AND RECOMMENDATIONS

- **The percentage uplifts for uncertainty have been applied in line with the DfT guidance referred to in Table 2.1, in section 2 of this report. These have been used to arrive at the P50, P80 and P90 values. The percentage has generally been applied in line with the recommendation for High Speed Rail, unless the guidance recommends alternative uplifts for other assets, for example tunnels and highways.**
- **At P50, Arup's estimate is higher than the estimate generated by the successive principle for Linköping to Borås and East Link but lower than the estimates generated for Göteborg to Borås and Jönköping to Malmö. However the combined Arup total is within 3% of the entire route estimate generated by Trafikverket.**
- **The main variance is generated by the difference in rate applied to Rail (a combined rate for slab track, signalling and overhead lines), where Arup's rate per km is significantly higher than Trafikverket's. Part of the reason for this is that Arup's rate includes the cess that runs alongside the rail corridor, whereas Trafikverket allow for this within roads. However, as there is also a difference in the cost per km for slab track, it is recommended that this rate is investigated further to ensure that an adequate and realistic allowance has been made for this element.**

Section 5

SUCCESSIVE PRINCIPLE APPLICATION

At the teleconference between Trafikverket and Arup on Tuesday, 3 May, Arup was asked not to critique the Successive Principle *per se*, but to review how the method has been applied to the different route sections. Notwithstanding, from Ref 1 and Ref 2, the rationale behind the Successive Principle is clear. Using probability distributions to describe risk and uncertainty is widely recognised as good practice, certainly in the UK, and is a fundamental element of Quantitative Risk Analysis (QRA), using Monte Carlo simulation.

CATEGORISATION OF SECOND OPINION OBSERVATIONS

Where our review has identified that the report is not fully auditable or substantiated, this is highlighted in an appropriate recommendation. The recommendations are categorised to give an indication of their importance as follows:

Category 1 - Resolution considered essential to support the estimated cost.

Category 2 - Further details required to establish effect on the estimated cost

Category 3 - Minor comments - no effect on the estimated cost

THE EAST LINK PROJECT (REF 3)

The Successive Principle method is referenced and broadly followed. The following observations are made:

1. Workshop Group: The report states that the attendees "are presumed to have the necessary knowledge and experience". Evidence to that effect, however, is not provided. An indication of what disciplines are represented, including estimators, would help to provide assurance [*Recommendation #1; Category 2*];
2. Brainstorming general uncertainties: it is not clear what method of identification has been used. Ref. 1 refers to, for example, a pre-set list of general uncertainties. An explanation of what method has been used would help to judge whether or not the list of uncertainties is likely to be comprehensive. It would also help to identify risk themes at a programme/portfolio level which, in turn, would facilitate uncertainty analysis at the programme level [*Recommendation #2; Category 2*];
3. General uncertainties: Ref 3 acknowledges that only four general uncertainties were assessed at the workshop. These were considered by attendees to be the most important and have large negative minimum values. Two observations are made here. Firstly, there should be some record of why the group considered these four uncertainties to be the most significant. Secondly, it could be that the remaining general uncertainties counter the (negative) effect of the four assessed uncertainties, such that the P50 and P80 values increase. [*Recommendation #3; Category 1*];
4. Relationship between General Uncertainties and Basic Entries: The final sentence of the penultimate paragraph in Section 13 is not understood. Because general uncertainties can affect numerous basic entries, the Successive Principle applies them to the total project cost. But this sentence suggests that they have been applied to individual basic entries [*Recommendation #4; Category 3*];
5. Basic entry categories: Ref 1 mentions breaking down basic entry categories into sub-categories in order to improve the reliability of category estimates. Section 12 of Ref 3 states that this has yet to be done. It should be confirmed whether this is an activity that should be completed at this stage of a project's lifecycle [*Recommendation #5; Category 3*];
6. Modelling and analysis: The East Link analysis has used the *Multirisk* software program. It is a recognisable tool for quantifying cost uncertainty via the Successive Principle method. The report, however, does not describe how general uncertainties or basic entries have been modelled, so the reviewer cannot judge whether it accords with the Successive Principle. But, given the probability density graph on page 9, a normal probability distribution would appear to have been used to combine general uncertainties and basic entries, which is consistent with the Successive Principle. Furthermore, Arup has completed a high level analysis and the results are broadly consistent.
7. Output graphs: A probability density curve is presented to illustrate the uncertainty profile. Although not specified in Ref 1, it would be helpful to see a cumulative probability graph (S-Curve) to view other confidence values (e.g. P50). The *Top Risks* chart is not as useful as the equivalent charts in Refs 4, 6&7. The latter provide relative contributions in percentages, and also indicate the variance of each uncertainty relative to the output modal value [*Recommendation #6; Category 3*];

LINKÖPING-BORÅS (REF 4), GÖTEBORG-BORÅS (REF 6), JÖNKÖPING-MALMÖ (REF 7)

These reports differ from the equivalent East Link report (Ref 3). However, some of our observations still apply. Certainly, the output graphs (cumulative probability, tornado and overlays) are better illustrated and provide a better understanding of cost uncertainty profiles and their dominant contributors. The following observations are made:

1. General Uncertainties: the three tables of general uncertainties and their subcategories are broadly the same, but the list in Ref 7 appears more extensive. The latter happens to be the most recent assessment and might therefore have accounted for lessons learnt from the two previous assessments. Whilst learning lessons is reassuring, they may also highlight deficiencies in historical assessments (i.e. Ref 6 & Ref 7). Alternatively, the differences between the three reports may be caused by having different workshop facilitators or not using a pre-set list of general uncertainties. We would argue that a pre-set list of uncertainties (and their subcategories) would provide greater assurance that all uncertainties had been considered in the assessment. It would not preclude the assessment of additional uncertainties [*Recommendation #7; Category 2*];
2. In accordance with the guidance, all four reports[3] describe a *planning reference* or assumed base case assumption for each identified uncertainty. This forms the basis for describing alternative scenarios or deviations from the planning reference. They are termed *Green World* (i.e. upside scenario) and *Red World* (i.e. downside scenario). This is good practice: uncertainty and risk should always be viewed relative to a reference case.

   However, the magnitude of the monetary values, especially the most likely (i.e. planning reference) values, and the *skewness*[4] of the ranges sometimes differ between the four applications for the same general uncertainty. Whilst differences in the monetary amounts can partly be explained by the different total estimated cost for each project/route section, the same is not necessarily true of differences in skewness and most likely values. If descriptions of the planning reference and Green and Red Worlds are the same or similar, we would argue that the skewness and most likely values should also be similar. But, from the different reports, this is not always the case. The following bullet points highlight some apparent inconsistencies, which could undermine the reliability of the assessment results [*Recommendation #8; Category 1, Recommendation #9, Category 1*]:

   - **Laws/Rules: Linköping-Borås (LB) has a planning reference value of -1.1 Billion SEK. With the same description, the Jönköping-Malmö (JM) report and the Göteborg-Borås (GB) have planning reference values of +0.5 Billion SEK and +2 Billion SEK respectively. It is not understood why (a) planning reference values should be different for the same scenario description, and (b). Given the planning reference description that "current laws/ legislation apply", why there should be a cost reduction (i.e. *possibility*) as the planning reference value, as is the case for LB;**
   - **New Techniques: Similar observations of #1 also apply here. For the same planning reference description, the values for LB (-1.9 Billion SEK) and JM (-2.5 Billion SEK) are similar, but the equivalent value for GB is +6 Billion SEK. It is not clear why (a) the value for this planning reference should be negative (b) why the range in planning reference values is so broad, and (c) the skewness differs markedly between GB and LB/JM**

3. Risk Analysis Software: These project analyses have used *Futura Nova*. Like *Multirisk* it is a recognisable software program for quantifying cost uncertainty. The output graphs included in this report are considered to more accessible and useful compared to the equivalent graphs in the East Link Report (Ref 3). However, the content of the tornado graphs has not been translated, so it's difficult to conclude whether or not the significant contributors are reasonable. The cost comparison graph is illustrative and helps to distinguish between the respective cost uncertainty profiles Alt 1 and Alt 2;
4. Workshop Group: The report states that the group was "highly qualified ….with a combined total of approximately 360 years in the profession". Again, there is no indication as to whether the right blend of skills was present at the workshop. An indication of what disciplines were represented, including estimating, would help to provide assurance [*Recommendation #1; Category 2*];
5. Modelling and analysis: The report does not describe how general uncertainties or basic entries have been modelled, so the reviewer cannot judge whether basic entries and general uncertainties have been modelled in accordance with the Successive Principle. However, Arup has independently modelled Linköping-Borås input data to gauge the reasonableness of Trafikverket analysis results. The table below presents the input data and a comparison of Trafikverket and Arup results. The values for P50, mean and standard deviation are broadly similar.

3 The relevant sections in the Göteborg to Boras report have not been translated into English. However, there is sufficient evidence to conclude that the same process has been followed.

4 Skewness indicates the degree of asymmetry in a distribution. Skewed distributions have more values to one side of the most likely value — one tail is much longer than the other refers to the tail of a probability distribution. Positively skewed means there a longer tail to the right of the distribution. Negative skewness means the distribution is skewed to the left.

Identifier	Basic Entry/ General Uncertainty	Min	Most Likely	Max	Cost Dis (Billion SEK)	Forced Sampling (Billion SEK)	Mean Values (Billion SEK)
01	Building Contractor	4	10.6	22	11.2	11.2	11.4
02	Property	0.1	1	4	1.3	1.3	1.3
03	Environment	0.6	3.2	10	3.7	3.7	3.9
04	Digging Railway	2.5	8	18	8.6	8.6	8.8
05	Other Land	0.2	1.8	7	2.3	2.3	2.4
06	Construction	3	23	40	22.6	22.6	22.5
07	Tunnels	7.7	15.2	30	16.1	16.1	16.4
08	BEST	4.7	9.3	16.2	9.6	9.6	9.7
09	Urban Passages	0.4	2.2	8.2	2.7	2.7	2.9
01	Vendor Market	-20	-1.2	15	-1.5	-1.5	-1.6
02	Laws, Rules	-20	-1.1	20	-0.8	-0.8	-0.7
03	New Techniques	-20	-1.9	10	-2.7	-2.7	-2.9
04	Mother Earth	-17	1.4	20	1.4	1.4	1.4
05	Opinion, Politics	-10	0.4	20	1.6	1.6	1.9
06	Project Org	-15	0.1	20	0.7	0.7	0.9
07	Line of Investigative Area	-20	-0.4	20	-0.3	-0.3	-0.3
					P50	**Mean**	**Std Dev**
			Arup		76.5	76.5	20.2
			Trafikverket		79.4	79.4	23.2

CONCLUSION

The four applications of the Successive Principle are similar and broadly comply with related guidance. The more significant observations relate to the input data rather than uncertainty modelling and analysis. To provide assurance that the results of any analysis is reliable, it is necessary to firstly identify a comprehensive list of uncertainties and then to ensure that their related cost impact ranges are justifiable and consistent.

For a data gathering workshop to be effective, it needs to be attended by a quorum of suitably qualified and experienced persons representing different railway project disciplines. Each assessment report states that workshop attendees are very experienced, but there is no mention of what disciplines they represented.

Assessment reports describe planning reference scenarios. They also describe Green World and Red World scenarios as a basis for assessing the range of cost outcomes from each general uncertainty. This is good practice because it clarifies assessment assumptions, which provide for challenge and audit. However, there are a few related issues that need further clarification. The first relates to the list of general uncertainties that have been assessed. East Link has currently only assessed four, which would suggest its current provision for uncertainty is underestimated.

Secondly, the planning reference for several general uncertainties is described in the same way, yet the cost ranges, planning reference values and distribution skewness can differ markedly. The reasons for these apparent inconsistencies are not understood. Finally, it is not clear why planning reference values are negative for selective uncertainties, for example *laws and rules*.

RECOMMENDATIONS

Category 1

Recommendation #3: *Clarify why only four general uncertainties have been considered in the assessment of East Link, what justification there is for concluding they are the most significant uncertainties, and what plan is in place to assess a more comprehensive list of uncertainties.*

Recommendation #8: *For selected general uncertainties (e.g. New Technologies and Laws/Rules), explain why some planning reference values should be negative and some positive for the same scenario description.*

Recommendation #9: *For the New Technologies general uncertainty, explain why the cost impact ranges and skewness for projects GB, LB and JM differ so markedly, given the same planning reference description has been used.*

Category 2

Recommendation #1: *Indicate the disciplines that were represented at Successive Principle workshops*

Recommendation #2: *Clarify what method was used to identify uncertainties at individual workshops and provide assurance that a comprehensive list of uncertainties was identified.*

Recommendation #7: *Consider using a pre-set list of uncertainties (and their subcategories) to provide greater assurance that all significant uncertainties have been considered in the assessment.*

Category 3

Recommendation #4: *For East Link, clarify whether the contributions from general uncertainties has been applied to individual basic entries or to the total of the basic entries.*

Recommendation #5: *Confirm whether breaking down basic entry categories into subcategories is an activity that should be completed at this stage of a project's lifecycle.*

Recommendation #6: *Present a cumulative probability graph (S Curve) to illustrate other confidence limits and the spread between them.*

APPENDIX A: ESTIMATE SUMMARIES

All routes combined

Element	Base Cost	Allocation of Prelim	Arup Total (m) SEK	Client Costs	Total Including Client Costs	Arup P50	
Environmental mitigation	7,480	1,571	9,051	1,346	10,397	40%	14,555
Rail	37,236	7,820	45,056	6,708	51,764	40%	72,469
Stations, buildings	5,048	1,060	6,108	906	7,014	40%	9,820
Tunnels	24,060	5,053	29,112	4,657	33,770	23%	41,537
Highways	2,324	488	2,812	455	3,267	15%	3,757.31
Bridges, structures, walls	44,340	9,311	53,651	8,013	61,664	23%	75,847
Earthworks	20,176	4,237	24,413	3,572	27,985	40%	39,179
Property and other	3,451	725	4,176	616	4,792	40%	6,708
Total	144,114	30,264	174,378	26,274	200,652		263,873

Element	Total Including Client Costs	Arup P80	
Environmental mitigation	10,397	57%	16,323
Rail	51,764	57%	81,269
Stations, buildings	7,014	57%	11,013
Tunnels	33,770	55%	52,343
Highways	3,267	32%	4,313
Bridges, structures, walls	61,664	55%	95,579
Earthworks	27,985	57%	43,936
Property and other	4,792	57%	7,523
Total			312,299

Total Including Client Costs	Arup P90	
10,397	68%	17,466
51,764	68%	86,963
7,014	68%	11,784
33,770	83%	61,799
3,267	45%	4,737
61,664	83%	112,845
27,985	68%	47,015
4,792	68%	8,050
		350,659

	SEK (bn)	
Arup total at P50	264	Total plus percentile
Arup total at P80	312	Total plus percentile
Arup total at P90	351	Total plus percentile
Trafiverket P50	256	

Linkoping to Boras (Alternative 1) 204km

Element	Base Cost	Allocation of Prelim	Arup Total (m) SEK	Client Costs (16.82%)	Total Including Client Costs	Arup P50		Trafikverket "50% ile"	Variance	% Variance	Arup assumption
Environmental mitigation	2,244	471.2	2,715.24	457	3,172	40%	4,441	4,743	-302	7%	Allowance of 11m SEK per km
Rail	11,398	2,393.7	13,791.99	2,320	16,112	40%	22,557	11,413	11,144	-49%	216km total. Arup allowance per km includes double track (204km) and Single Track (12km), Overhead Lines (no power), signalling and communications and rail Cess
Stations, buildings	1,805	379.1	2,184.05	367	2,551	40%	3,572	3,575	-3	0%	Used allowance in line with Trafikverket
Tunnels	13,662	2,869.0	16,531.02	2,781	19,312	23%	23,753	19,497	4,256	-18%	Rate reviewed. Based on 66km Drill and blast
Highways	1,672	351.0	2,022.55	340	2,363	15%	2,717.15	2,956	-239	9%	Approx 51000m roads. Cess inlcluded in "rail"
Bridges, structures, walls	13,311	2,795.2	16,105.72	2,709	18,815	23%	23,142	26,156	-3,014	13%	
Earthworks	4,148	871.0	5,018.86	844	5,863	40%	8,208	10,420	-2,212	27%	Assumed 25.5km cutting and 62.5k embankment. Average width 20m and average deph 5m. Enhanced rate for cutting through rock
Property and other	850	178.5	1,029	173	1,201	40%	1,682	1,671	11	-1%	Used allowance in line with Trafikverket
Total	49,089	10,309	59,398	9,991	69,389		90,072	79,441	10,630.98	-12%	

Element	Total Including Client Costs	Arup P80	
Environmental mitigation	3,172	57%	4,980
Rail	16,112	57%	25,296
Stations, buildings	2,551	57%	4,006
Tunnels	19,312	55%	29,933
Highways	2,363	32%	3,119
Bridges, structures, walls	18,815	55%	29,163
Earthworks	5,863	57%	9,205
Property and other	1,201	57%	1,886
Total	69,389		107,587

Total Including Client Costs	Arup P90	
3,172	68%	5,329
16,112	68%	27,068
2,551	68%	4,286
19,312	83%	35,340
2,363	45%	3,426
18,815	83%	34,431
5,863	68%	9,850
1,201	68%	2,019
69,389		121,748

	SEK (bn)	
Arup total at P50	90	Total plus percentile
Arup total at P80	108	Total plus percentile
Arup total at P90	122	Total plus percentile
Trafiverket P50	79.4	

Jonkoping to Malmo 260km

Element	Base Cost	Allocation of Prelim	Arup Total (m) SEK	Client Costs (13.23%)	Total Including Client Costs	Arup P50		Trafikverket "50% ile"	Variance	% Variance	Arup assumption
Environmental mitigation	2,860	600.6	3,460.60	458	3,918	40%	5,486	7,802	-2,316	42%	Allowance of 11m SEK per km
Rail	14,069	2,954.4	17,022.92	2,252	19,275	40%	26,985	12,183	14,802	-55%	260km total. Arup allowance per km includes double track (260km), Overhead Lines (no power), signalling and communications and rail Cess
Stations, buildings	2,320	487.2	2,807.20	371	3,179	40%	4,450	4,484	-34	1%	Used allowance in line with Trafikverket
Tunnels	483	101.4	584.43	77	662	23%	814	1,347	-533	65%	Rate reviewed. Based on 1.2km Drill and blast
Highways	148	31.0	178.53	24	202	15%	232	3,601	-3,369	1449%	Approx 4.5m roads. Cess inlcluded in "rail"
Bridges, structures, walls	15,297	3,212.3	18,509.09	2,449	20,958	23%	25,778	28,353	-2,575	10%	
Earthworks	8,459	1,776.3	10,234.90	1,354	11,589	40%	16,225	20,347	-4,122	25%	Based on 8,800,000m3 cut; 14,831,000m3 fill.
Property and other	1,350	283.5	1,634	216	1,850	40%	2,589	2,593	-4	0%	Used allowance in line with Trafikverket
Total	44,984	9,447	54,431	7,201	61,632		82,560	85,450	-2,890.49	4%	

Element	Total Including Client Costs	Arup P80	
Environmental mitigation	3,918	57%	6,152
Rail	19,275	57%	30,262
Stations, buildings	3,179	57%	4,990
Tunnels	662	57%	1,039
Highways	202	55%	313
Bridges, structures, walls	20,958	32%	27,664
Earthworks	11,589	55%	17,963
Property and other	1,850	57%	2,904
Total	61,632		91,288

Total Including Client Costs	Arup P90	
3,918	68%	6,583
19,275	68%	32,382
3,179	68%	5,340
662	83%	1,211
202	45%	293
20,958	83%	38,353
11,589	68%	19,469
1,850	68%	3,107
61,632		106,739

	SEK (bn)	
Arup total at P50	83	Total plus percentile
Arup total at P80	91	Total plus percentile
Arup total at P90	107	Total plus percentile
Trafiverket P50	85.5	

East link 150km

Element	Base Cost	Allocation of Prelim	Arup Total (m) SEK	Client Costs (15%)	Total Including Client Costs	Arup P50		Trafikverket "50% ile"	Variance	% Variance	Arup assumption
Environmental mitigation	1,650	346.5	1,996.50	299	2,296	40%	3,214	2,897	317	-10%	Allowance of 11m SEK per km
Rail	8,070	1,694.8	9,764.99	1,465	11,230	40%	15,722	7,665	8,057	-51%	150km total. Arup allowance per km includes double track (150km), Overhead Lines (no power), signalling and communications and rail Cess
Stations, buildings	520	109.2	629.20	94	724	40%	1,013	1,007	6	-1%	Used allowance in line with Trafikverket
Tunnels	6,112	1,283.6	7,395.82	1,109	8,505	23%	10,461	10,074	387	-4%	Rate reviewed. Based on 27.5km Drill and blast
Highways	461	96.8	557.85	84	642	15%	738	1,545	-807	109%	Approx 4.5km roads. Cess inlcluded in "rail"
Bridges, structures, walls	11,316	2,376.4	13,692.65	2,054	15,747	23%	19,368	24,733	-5,365	28%	Originally based on on 25.5km possible value bridges. New assumption 40km
Earthworks	5,077	1,066.2	6,143.47	922	7,065	40%	9,891	7,798	2,093	-21%	Assumed 11km aptoc 25 75 cut/embankment. Av 5m depth
Property and other	1,230	258.3	1,488	223	1,712	40%	2,396	2,364	32	-1%	Used allowance in line with Trafikverket
Total	34,437	7,232	41,669	6,250	47,919		62,804	53,399	9,404.57	-15%	

Element	Total Including Client Costs	Arup P80	
Environmental mitigation	2,296	57%	3,605
Rail	11,230	57%	17,631
Stations, buildings	724	57%	1,136
Tunnels	8,505	57%	13,353
Highways	642	55%	994
Bridges, structures, walls	15,747	32%	20,785
Earthworks	7,065	55%	10,951
Property and other	1,712	57%	2,687
Total	47,919		71,142

Total Including Client Costs	Arup P90	
2,296	68%	3,857
11,230	68%	18,866
724	68%	1,216
8,505	83%	15,565
642	45%	930
15,747	83%	28,816
7,065	68%	11,869
1,712	68%	2,875
47,919		83,994

	SEK (bn)	
Arup total at P50	63	Total plus percentile
Arup total at P80	71	Total plus percentile
Arup total at P90	84	Total plus percentile
Trafiverket P50	53.4	

Gothenburg to Boras - 66km

Element	Base Cost	Allocation of Prelim	Arup Total (m) SEK	Client Costs (15%)	Total Including Client Costs	Arup P50		Trafikverket "50% ile"	Variance	% Variance	Arup assumption
Environmental mitigation	726	152.5	878.46	132	1,010	40%	1,414		1,414		Allowance of 11m SEK per km
Rail	3,699	776.8	4,475.76	671	5,147	40%	7,206		7,206		70km total, 66k km double track and 4km single traack. Overhead Lines (no power), signalling and communications and rail Cess
Stations, buildings	403	84.6	487.63	73	561	40%	785		785		Used allowance in line with Trafikverket
Tunnels	3,803	798.5	4,601.13	690	5,291	23%	6,508		6,508		Rate reviewed. Based on 18.4km Drill and blast
Highways	44	9.2	52.88	8	61	15%	70		70		Approx 2km roads. Cess inlcluded in "rail"
Bridges, structures, walls	4,416	927.4	5,343.36	802	6,145	23%	7,558		7,558		Based on 16km structures
Earthworks	2,492	523.4	3,015.52	452	3,468	40%	4,855		4,855		21km cut, 13 km fill. Average depth 5m
Property and other	21	4.4	25	4	29	40%	41		41		Used allowance in line with Trafikverket
Total	15,603	3,277	18,880	2,832	21,712		28,438		28,437.55		

Element	Total Including Client Costs	Arup P80	
Environmental mitigation	1,010	57%	1,586
Rail	5,147	57%	8,081
Stations, buildings	561	57%	880
Tunnels	5,291	57%	8,307
Highways	61	55%	94
Bridges, structures, walls	6,145	32%	8,111
Earthworks	3,468	55%	5,375
Property and other	29	57%	46
Total	21,712		32,481

Total Including Client Costs	Arup P90	
1,010	68%	1,697
5,147	68%	8,647
561	68%	942
5,291	83%	9,683
61	45%	88
6,145	83%	11,245
3,468	68%	5,826
29	68%	49
21,712		38,178

	SEK (bn)	
Arup total at P50	28	Total plus percentile
Arup total at P80	32	Total plus percentile
Arup total at P90	38	Total plus percentile
Trafiverket P50	33	

APPENDIX B: LIST OF DOCUMENTS SUPPLIED BY TRAFIKVERKET REFERRED TO IN THIS REPORT

Cost Analysis Using the Successive Principle – Linköping to Borås

Cost Assessment Using the Successive Principle – East Link

East Link Project Report about Cost and Time

Uncertainty Analysis based on the Successive Principle Gothenburg to Borås

Project Gothenburg to Borås Additional Costs December 2015

Uncertainty Analysis using the Successive Principle Jönköping to Malmö

A Brief Explanation of the Successive Principle in Practice

Successive Principle in Baseline

APPENDIX C: OTHER EXTERNAL SOURCES

1. **High Speed Rail: International Comparisons.** Commission for Integrated Transport
2. **Comparison for High Speed Capex**. Lloyds Register, 2009
3. **Construction Output Price Indices:** Office for National Statistics
4. **Global Construction Cost 2016 (16th ed).** Compass International Consultants Inc.
5. **International Construction Costs 2016.** Arcadis
6. **Procedures for Dealing with Optimism Bias in Transport Planning.** Department for Transport

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