New Main Lines

Cost Benchmarking Study

March 2021

Jacobs TRAFIKVERKET

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1. Executive Summary

Trafikverket has been tasked by the Swedish Government to develop new rail infrastructure connecting Stockholm with Gothenburg and Malmö via dedicated high-speed rail lines. A key element of the 'Nya Stambanor' (New Main Lines) programme involves producing cost estimates on an aggregated level for the planning, design and construction of the scheme.

To support cost planning and identify a suitable range of cost estimates for the New Main Lines, Trafikverket commissioned Jacobs to carry out an analysis to compare construction costs at the overall project level. These types of analyses are frequently carried out at the early planning phase – the current stage of the majority of New Main Lines route sections - to provide a 'sense check' on the overall cost estimate.

The objectives of the study were as follows:

1) Collect and present high-level construction cost per kilometre benchmarks for relevant international high-speed rail schemes and compare to the most recent published Trafikverket cost estimates;
2) Collect cost element level benchmark data from relevant international schemes and develop indicative cost estimates for New Main Lines based on route length quantities (at grade, tunnel, structures) and cost element level benchmarks, produced independently in December 2020 and without knowledge of Trafikverket's updated cost estimates (published in February 2021) to provide a 'sense check' for Trafikverket's cost estimate for the full New Main Lines network; and
3) Collect and present evidence from previously constructed international high-speed lines on the extent to which cost estimates can escalate during planning process stages and towards the final cost outturn.

1) High level comparison of international cost benchmarks and published Trafikverket cost estimates for New Main Lines

The purpose of the high-level comparison was to understand the extent to which existing published TRV estimates fall within a typical range of comparable international HSR schemes.

HSR benchmark schemes were selected according to criteria designed to ensure comparability of benchmark schemes to the Sweden context. These included selecting only schemes from high income countries, and schemes under construction or in operation since 2000.

The sample of international benchmark schemes vary in technical specification, number of stations and route length, ranging from ABS Leipzig/Halle - Berlin in Germany - a substantial high-speed upgrade scheme at the low end of the cost per km range (2 stations, 187 km), to the UK High Speed 2 scheme (Phase 1) which is a new 214 km high-speed line designed for 330 km/h operation with 4 new stations.

The average (mean) construction cost across the benchmark range was 415 million SEK per km. The median construction cost is 373 million SEK per km. All values are reported in Swedish Krona (SEK) in 2017 prices.

Trafikverket's cost estimate for the planning, design and construction of the New Main Lines network is SEK 295 billion (+/- SEK 50 billion, 2017-02 prices) equivalent to 428 million SEK per km. The high-level benchmark comparison illustrates that the latest Trafikverket cost estimate for the full network lie close to the average level for comparable international high-speed rail schemes.

2) Construction cost estimates for New Main Lines based on element level cost benchmarks

Trafikverket requested Jacobs to produce estimates of the construction cost of New Main Line based only on cost element level benchmark values and route length quantities. The purpose of this exercise was to provide a 'sense check' for Trafikverket's cost estimates.

Jacobs established a central 'most likely' benchmark rate for each of the cost elements (for methodology, see section 5 of this report) and applied the rates to relevant route length quantities provided by Trafikverket, with appropriate client development cost and contingency rates applied.

Based on this approach, using the same confidence level as Trafikverket, the total cost of the full network is estimated at SEK 271 billion +/- 48 billion (2017 prices). Table 1-1 below summarises the indicative construction cost estimates.

Table 1-1 Indicative Construction Cost Estimate for New Main Lines based on element level cost benchmarks, 2017 prices

	Route section length (km)	Benchmark P50 Estimate, billion SEK	Cost per km, million SEK
Full Network	690	271	393

3) Evidence on cost overruns in the construction of high-speed rail lines

Numerous academic studies have identified a systematic tendency for large infrastructure projects to have significant overruns and delays. The tendency for project construction cost at the early planning phase to be consistently underestimated has been termed project optimism bias.

Evidence from Flyvbjerg et al (2012) found that the average cost overrun experienced by NW European high-speed rail schemes was 26%[1]. According to a 2011 study by the Centre of Transport Studies Stockholm, the average cost overruns in Sweden is estimated at 21% for rail projects[2]. Evidence from French LGV schemes indicate a wide variation in cost overruns between schemes ranging from minus 10% to plus 25%.

The reasons for cost overruns are various but the most common issues are changes to the programme scope and design, an inadequate planning process, unforeseen ground conditions, scheme complexity, lack of resource in planning, optimism bias leading to under-estimation of construction, programme and schedule risks.

The international evidence on the prevalence and scale of cost overruns normally experienced by High Speed Rail Schemes highlight the need for Trafikverket to carefully account for unforeseen cost uncertainty and scope changes through an appropriate 'Optimism Bias' risk provision to counter the systematic tendency for large infrastructure projects for significant overruns and delays to occur.

[1] Cantarelli, C. C., Flyvbjerg, B, and Buhl, S. L. 2012. Geographical Variation in Project Cost Performance: The Netherlands versus Worldwide. Journal of Transport Geography, 24: 324–331

[2] *Cost overruns in Swedish Transport Projects, Centre for Transport Studies Stockholm, 2011, Lundberg et al.*

2. Purpose and objectives of the study

To support cost planning for the New Main Lines programme, Trafikverket commissioned Jacobs to carry out an analysis to compare construction costs at the overall project level. These types of analyses are frequently carried out at the early planning phase – the current stage of the majority of New Main Lines route sections - to provide a 'sense check' on the overall cost estimate.

At the time of carrying out the analysis for this study (December 2020), a revised baseline design estimate was being prepared by Trafikverket. To maintain independence of the cost benchmarking analysis, no details of the Trafikverket revised baseline design estimate was made available to Jacobs while the analysis was being carried out. The revised Trafikverket estimate has since been released in a new report[3] published in February 2021.

The revised baseline design estimate is SEK 295 billion (+/- SEK 50 billion, 2017-02 prices). For this system, sections of the route are designed for a maximum speed of 320 km/h with slab track construction while other sections are designed for 250 km/h with ballast track construction. The scheme length of the New Main Lines is approx. 690km and includes 13 new or redeveloped stations.

While no two infrastructure schemes have the same specifications and economic conditions, it is possible to minimise the differences by selecting and comparing schemes that have similar characteristics to the reference system and normalising their cost data points by conversion to a route-kilometre metric to allow a consistent comparison to be made between schemes of varying route length.

With these applications in mind, the benchmarking study has the following objectives:

1) Collect and present high-level construction cost per kilometre benchmarks for relevant international high-speed rail schemes and compare to the latest Trafikverket cost estimate for the full New Main Lines network.
2) Collect cost element level benchmark data from relevant international schemes and develop indicative cost estimates for New Main Lines based on route length quantities (at grade, tunnel, structures) and cost element level benchmarks, produced independently and without knowledge of Trafikverket's updated cost estimates (December 2020) to provide a 'sense check' for Trafikverket's cost estimates; and
3) Collect and present evidence from previously constructed international high-speed lines on the extent to which cost estimates typically escalate over planning process stages and final cost outturn.

[3] Report available at: http://trafikverket.diva-portal.org/smash/get/diva2:1532016/FULLTEXT01.pdf

3. Study methodology and data collection

3.1 Methodological approach

The methodological approach of the study has been developed to meet the objectives of the study as set out by Trafikverket. Two approaches have been applied:

1) Develop high level total cost per kilometre benchmarks from comparable schemes and compare to published cost estimates for New Main Lines.

2) Develop indicative cost estimates by using cost element benchmarks from schemes for which detailed breakdowns are available, determining 'most likely' or central values from the benchmark ranges and apply route length quantities from New Main Lines provided by Trafikverket.

3.2 Data collection and HSR benchmark database

The data collection process involved sourcing published information, studies and technical documents collected from a variety of public and private sources, including information sourced through schemes for which Jacobs is currently or previously involved in. This process supplemented benchmarks already available to Jacobs from previous cost benchmark studies.

Jacobs maintains a database containing high-speed rail construction cost benchmark data from 80+ operational, under-construction or advanced planning phase international high-speed rail schemes or scheme sections.

Limited information is published on the outturn construction costs for the majority of High-Speed Rail schemes. Data in a format suitable for detailed cost element level benchmarking are only available for a small number of schemes so additional cost element level data were collected specifically for this study to extend the data sample.

3.3 High level benchmark selection criteria

Upon completion of the data collection process, relevant HSR schemes were selected based on the following selection criteria:

- Construction of the schemes has been completed in the last 20 years or schemes are currently under construction.
- Schemes in high-income countries with a cost of living within a similar range to Sweden.

Scheme costs were converted to Swedish Krona (SEK) in 2017 prices using the Eurostat construction cost index[4] and the most recent exchange rates[5]. For non-EU countries, the IMF GDP deflator[6] was used to convert to 2017 prices.

Technical and construction cost information for the benchmarked HSR schemes selected based on the above criteria are presented in Table 3-1.

[4] Construction producer price and construction cost indices overview, Eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php/Construction_producer_price_and_construction_cost_indices_overview

[5] Exchange rates. OECD: https://data.oecd.org/conversion/exchange-rates.htm

[6] International Monetary Fund, World Economic Outlook Database, October 2017: https://www.imf.org/en/Publications/WEO/weo-database/2017/October

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Table 3-1 Comparator HSR schemes used in the study (sorted high to low construction cost per km)

Country	Project	Scheme status	Year of operation	Route length, km	Construction cost million SEK per km, 2017 prices
UK	UK HS2 Phase 1	Under Construction	2026	214	992
UK	UK HS1	Operational	2007	109	822
Italy	Florence-Bologna	Operational	2009	79	774
USA	California High Speed Rail CVS	Under Construction	2029	192	667
Italy	Turin-Milan	Operational	2009	125	614
Spain	LAV Leon-Asturias	Under Construction	2021	50	583
Germany	Stuttgart - Munich	Under Construction	2022	267	468
Italy	Milan - Venice	Under Construction	2027	273	412
Germany	NBS Köln-Rhein/Main	Operational	2002	177	400
Germany	ABS Nuremberg-Ebensfeld	Operational	2011	83	394
Italy	Milan - Bologna	Operational	2008	182	353
Germany	NBS Ebensfeld - Erfurt	Operational	2017	107	349
Spain	LAV Madrid-Valladolid	Operational	2007	180	241
France	LGV Méditerranée	Operational	2001	244	228
Germany	NBS Erfurt-Leipzig/Halle	Operational	2015	123	227
France	LGV Sud-Europe Atlantique	Operational	2018	340	222
Belgium	HSL network	Operational	2007	314	183
Spain	LAV Madrid-Barcelona-Girona	Operational	2013	804	152
France	LGV Est Européenne (Phase 1)	Operational	2007	300	123
Germany	ABS Leipzig/Halle-Berlin	Operational	2006	187	88
Total - route km				**4,350**	
Average construction cost SEK million per km, 2017 prices					**415**
Median construction cost SEK million per km, 2017 prices					**373**
Standard deviation construction cost SEK million per km, 2017 prices					**254**

3.4 New Main Line cost estimates and system route length quantities

Sections of the baseline design system are designed for a maximum speed of 320 km/h with slab track construction while other sections are designed for 250 km/h with ballast track construction. The scheme length of the New Main Lines is approx. 690km and includes 13 new or redeveloped stations.

For the purposes of comparison with international benchmarks, the New Main Lines estimate was converted to 2017 values using the industry cost index and presented as cost million SEK per km. The cost estimates are summarised in Table 3-2.

Table 3-2 Trafikverket cost estimate for the full New Main Lines network, 2017 prices

Scheme	Route length, km	Construction cost, billion SEK, 2017 prices	Construction cost. million SEK per km, 2017 prices
Full New Main Lines network	690	295	428

System route length quantities were provided by Trafikverket for use in the cost element level benchmark analysis. Route length quantities broken down by at-grade, tunnels, and bridges & structures are summarised in Table 3-3.

Table 3-3: New Main Lines Route Sections – Route Length Quantities Summary

Section	Total length, km	Tunnels, km	Bridges and structures, km	At grade, km
Full New Main Lines network	690	96	73	521

4. High level comparison of international cost benchmarks and Trafikverket New Main Lines programme

4.1 Benchmark comparison with Trafikverket New Main Lines programme

An analysis was carried out to compare the cost per kilometre of Trafikverket's baseline design estimate for the full New Main Lines network with international benchmark schemes at the total scheme construction cost level.

The analysis highlights the wide variation across the range of international benchmarks. The unit cost of construction ranges from 992 million SEK per km (UK High Speed Two) to 88 million SEK per route km (Germany ABS Leipzig/Halle-Berlin).

There exist many factors that influence the variation in construction costs between high speed rail schemes. There is a strong correlation between the scale of civil works construction and the cost per kilometre however this is not the only important driver. Some common factors influencing the cost of high-speed rail construction are listed in Table 4-1.

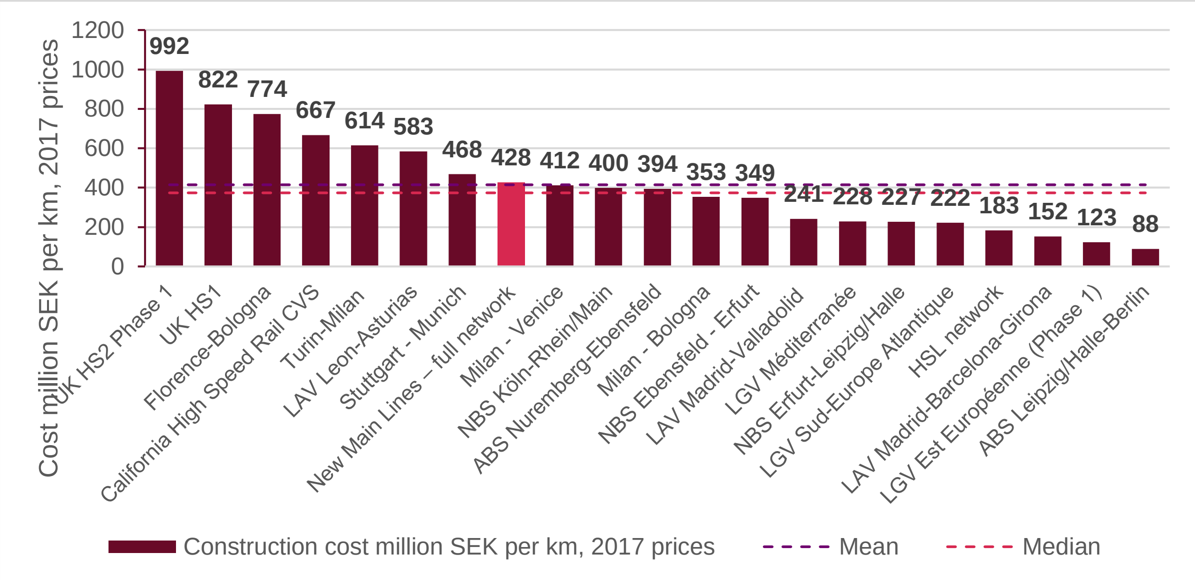
Table 4-1 Common factors influencing HSR construction cost

Common factors influencing HSR construction cost	Description of influence on construction cost
Scheme specification & design requirements	Higher technical specification driven by operating speed requirement and capacity can lead to higher construction costs in several areas e.g. slab track construction, traction power supply, station platform capacity etc.
Route topography / geography	Greater variation in vertical distance along the route alignment can drive higher excavation volume of earthworks, longer tunnel sections and greater number of structures
Number and scale of stations	A greater number of stations in the scheme specification directly drives cost, but also influences costs in other areas e.g. civils, systems, connections to existing network
Station location	The requirement for central urban locations can drive costs in several ways - urban tunnels & structures are substantially higher cost than non-urban locations, land acquisition and compensation in city centres compared to peripheral locations
Contracting and procurement model	Some procurement models can lead to compounded risk, overheads and profit within the supply chain driving higher overall scheme costs
Cost of construction (price level)	The general price level drives labour and materials costs which are key elements of overall construction cost
Land and property costs	The cost of land, level of compensation for compulsory purchase and cost of environmental/ noise / visual mitigation can vary, with route alignments through lower density areas typically resulting in lower costs

The average (mean) construction cost of the benchmark sample is 415 million SEK per km. The median construction cost is 373 million SEK per km. All values have been adjusted to Swedish Krona (SEK) in 2017 prices.

As can be observed in Figure 4.1, the current Trafikverket cost estimate for the full New Main Lines network on a per kilometre basis is 428 million SEK per route km (highlighted in yellow) lies slightly above the mean (average) and median levels of the benchmark sample of international schemes.

Figure 4.1 Construction cost per km – TRV estimate and International HSR Benchmarks, million SEK, 2017 prices



4.2 Cost Overruns

One of the objectives of this study is to present evidence on the extent to which cost estimates for high-speed rail schemes typically escalate over planning process stages and final cost outturn. This is important for the purposes of understanding the extent to which the risk of outturn costs exceeding planning phase cost estimates are accounted for in the current phase of New Main Lines scheme design and planning.

Numerous academic studies have identified a systematic tendency for large infrastructure projects for significant overruns and delays to occur. The tendency for project construction cost at the early planning phase to be consistently underestimated has been termed optimism bias. Optimism Bias (OB) is the systematic tendency for appraisers to underestimate, exclude from scope or be overly optimistic about key parameters.

Two types of error are typically embedded within the early stage scheme cost estimate, which are in addition to the standard contingency risk provision:

1) Under and over estimation (cost rates, quantities and risk provision)

2) Exclusion of unforeseen scheme elements which lead to future stage scope change

Actual costs are defined as real, accounted outturn construction costs determined at the time of project completion. Estimated costs are defined as forecasted construction costs during the planning and construction stages.[7] Cost overrun is measured as final outturn costs minus planning phase cost estimate as a percentage of planning phase cost estimate.

[7] Cantarelli, C.., Flyvbjerg, B, and Molin J*, 2010, Cost Overruns in Large-Scale Transportation Infrastructure Projects: Explanations and Their Theoretical Embeddedness, European Journal of Transport and Infrastructure Research.*

According to a 2011 study by the Centre of Transport Studies Stockholm, the average cost overruns in Sweden is estimated at 21% for rail projects[8]. The paper notes that this average overrun in rail projects is lower than the average in other countries. However, the standard deviation for rail projects was found to be higher than other scheme types.

The cost overruns in road and rail projects in Sweden have been constant for the 13-year period and cost estimates have not improved over time. Evidence from Flyvbjerg et al (2012) found that the average cost overrun experienced by NW European high-speed rail schemes was 26%[9].

Table 4-2 presents the difference between early stage, final estimate and actual outturn construction costs for high-speed rail (LGV) schemes in France as well as the published explanation for the cost overrun.

Table 4-2 Comparison of early & final planning stage cost estimates and actual outturn – France LGV Schemes[10]

Scheme	Year	Early Phase Estimate, EUR m 2009 prices	Final Phase Estimate, EUR m 2009 prices	Actual Outturn, EUR m 2009 prices	Cost Overrun - outturn as % of early phase estimate	Cost Overrun - outturn as % of final phase estimate	Reason for cost overrun (if any)
LGV Atlantique	1990	2,369	2,409	2,941	24.2%	22.1%	Change in rolling stock spec. and knock-on impact on infr. Costs
LGV Nord	1993	2,981	3,705	3,729	25.1%	0.6%	-
LGV Interconnexion Ile de France	1996	1,346	1,686	1,562	16.0%	-7.4%	-
LGV Rhone Alpes	1994	1,159	1,422	1,410	21.6%	-0.8%	-
LGV Méditerranée	2001	4,848	4,700	4,778	-1.4%	1.7%	-
LGV Est Phase 1	2007	3,940	3,905	4,655	18.1%	19.2%	Change in programme scope
LGV Sud Europe Atlantique	2017	7,100	6,484	6,379	-10.2%	-1.6%	-

Source: see footnote 13

[8] *Cost overruns in Swedish transport projects, Centre for Transport Studies Stockholm, 2011, Lundberg et al.*

[9] Cantarelli, C. C., Flyvbjerg, B, and Buhl, S. L. 2012. Geographical Variation in Project Cost Performance: The Netherlands versus Worldwide. Journal of Transport Geography, 24: 324–331

[10] The evidence quoted in Table 4-2 is sourced from the official 'Bilan LOTI' ex post evaluations for each LGV scheme. These documents are published by SNCF/ RFF with the exception of LGV Sud Europe Atlantique which is published by LISEA, the concession company for the new LGV line.

The evidence from France LGV schemes illustrates the scale and extent of cost overruns that can occur on high speed rail schemes. Five out of the seven LGV schemes in the sample observed a cost overrun compared to the early phase estimate of greater than 10%. The remaining schemes observed either a cost overrun close to zero or a large negative deviation. The latter example may have occurred due to overprovisioning of risk in the early phase estimate.

Specific quantitative evidence on the most typical causes of cost overrun in high-speed rail schemes is not available. However, based on review of available ex-post evaluations produced for French LGV lines, the most common issues driving cost overruns are changes to the programme scope and design, an inadequate planning process, lack of resource in planning and optimism bias leading to under-estimation of construction, programme and schedule risks. Unforeseen ground conditions and scheme complexity are two other common factors observed to drive cost overruns on other high-speed schemes. Table 4-3 presents a synthesis of the typical causes for cost overruns on major infrastructure projects identified within the academic literature.

Table 4-3 Synthesis - typical causes for cost overrun

Cost overrun cause	Causes
Technical	Forecasting errors – price rises, poor project design and incompleteness of estimates Scope changes Uncertainty Inadequate planning process
Economic	Lack of resources in planning Poor financing / contract mgmt. Lack of incentives Inefficient use of resources
Psychological	Cognitive bias leads to optimistic forecasts Cautious attitude towards risks Optimism bias
Political	Deliberate cost underestimation Manipulation of forecasts Private information

Source: Cantarelli C, 2012, 'Cost Overruns in Large-Scale Transport Infrastructure Projects - A theoretical and empirical exploration for the Netherlands and worldwide', PhD Dissertation - Delft University of Technology.

5. Cost estimates for New Main Lines based on element level cost benchmarks

5.1 Classification of cost elements

Trafikverket requested Jacobs to produce indicative cost estimates using cost element benchmarks from schemes for which detailed breakdowns were available, determining 'most likely' or central values from the benchmark ranges and applying route length quantities from New Main Line provided by Trafikverket. The analysis described in this chapter was carried out in December 2020.

Several meetings were held with the Trafikverket cost estimation team in order to establish a suitable cost element classification that could align with available cost element benchmark data and scheme route length quantities. The meetings also established suitable assumptions regarding the infrastructure specification which could be used for the cost element benchmarking exercise.

In advance of commencing the analysis, it was recognised that benchmark data at the cost element level are more difficult to attain than high level data with the risk that smaller benchmark samples might be available for the individual cost elements. To mitigate this risk and ensure a sufficient sample size, it was agreed with the Trafikverket cost estimation team that schemes in the planning phase as well as completed schemes would be included in the cost element benchmark samples.

For each cost element, the mean (average) benchmark value rather than the median value is used as the 'most likely' value in the element level cost estimate. The mean is used rather than median for the purposes of ensuring that the influence of outlier benchmark schemes are captured in the cost estimates and that the tail risk of scheme complexity is fully recognised – the programme is currently at low design maturity with only 25% of New Main Lines route sections at design phase.

Following consultation with Trafikverket and after a thorough review of documentation available for international HSR schemes, the following key cost elements were identified and summarised as in Table 5-1.

Table 5-1 Cost element classification, infrastructure assumptions

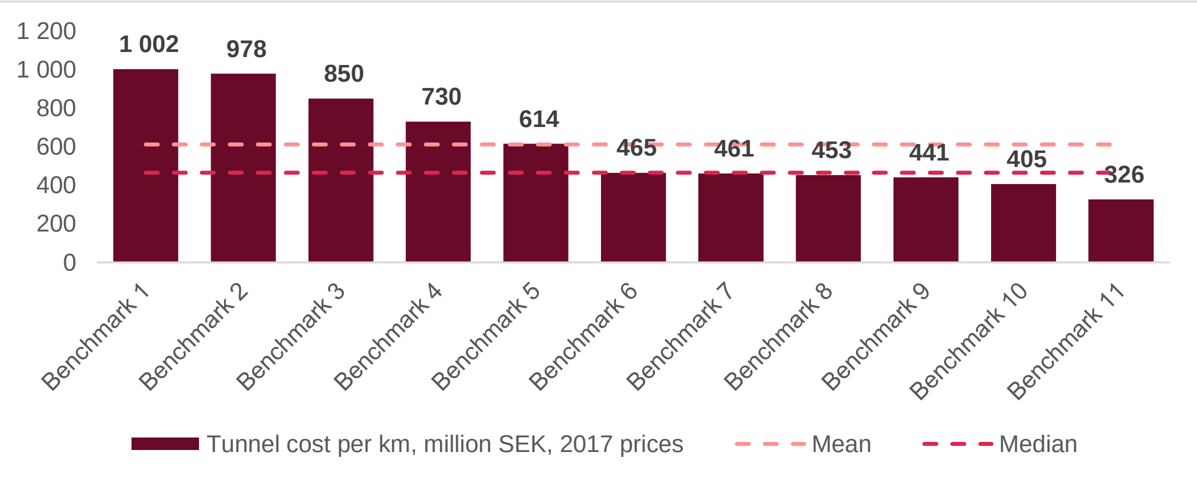
Cost element	Description	Benchmark Unit	Benchmark data source
Tunnels	Twin bored tunnels	Million SEK per route km, mean value	Best available comparators (own research)
Bridges	Constructions such as overbridges, underbridges, footbridges and viaducts	Million SEK per route km, mean value	Best available comparators (own research)
Earthworks	General earthworks - embankments and cuttings	Estimate based on a sample of earthworks benchmarks	Bespoke analysis carried out by Jacobs earthworks expert, see section 5.1.3
General civil works	Civil works not elsewhere classified e.g. ground preparation, demolition, fencing, utilities relocation	Million SEK per route km, mean value	Best available comparators (own research)
Stations	Station cost for station assets for which TRV are responsible: platforms including the roof and platform equipment, structures within the station environment that support track facilities, platform connections	Million SEK per platform km, mean value	Best available comparators (own research)

Cost element	Description	Benchmark Unit	Benchmark data source
Track, OHLE, Signalling, Communications, Power	Overhead line electrification (OHLE) and traction power, signalling and communications. Both ballasted and slab track permanent way unit prices have been cross-checked and benchmarked against international rail projects	Million SEK per route km, mean value	Best available comparators (own research)
Client development cost	Planning and programme support, pre-phase and preliminaries, design and procurement, construction and commissioning.	% of direct construction costs, mean value	Best available comparators (own research)
Land acquisition	Cost of land to be acquired permanently or temporarily for site works.	% of direct construction costs, mean value	Best available comparators (own research)
Contingency	Contingency allowances are applied to cover uncertainties in the scope of works or costs.	% of all costs	Best available comparators (own research)

5.1.1 Tunnels

Tunnel costs are driven by several factors such as tunnel diameter, geological complexity, rock type and tunnel length. However, via a simplified approach by estimating an average cost per km, it is possible to identify an average cost rate across a sample. A sample of 11 schemes where tunnel cost information and tunnel length are available was sourced. Tunnel construction was limited to twin bore or greater to align with the anticipated requirements for New Main Lines as indicated by Trafikverket. Benchmark values range from 326 million SEK per route km to 1,002 million SEK. The mean value across the sample is 611 million SEK per route km and the median value is 465 million SEK per route km. Figure 5.1 below illustrates the normalised tunnel construction cost per kilometre benchmark values in million SEK adjusted to 2017 price base.

Figure 5.1 Tunnel construction cost per km, million SEK, 2017 prices

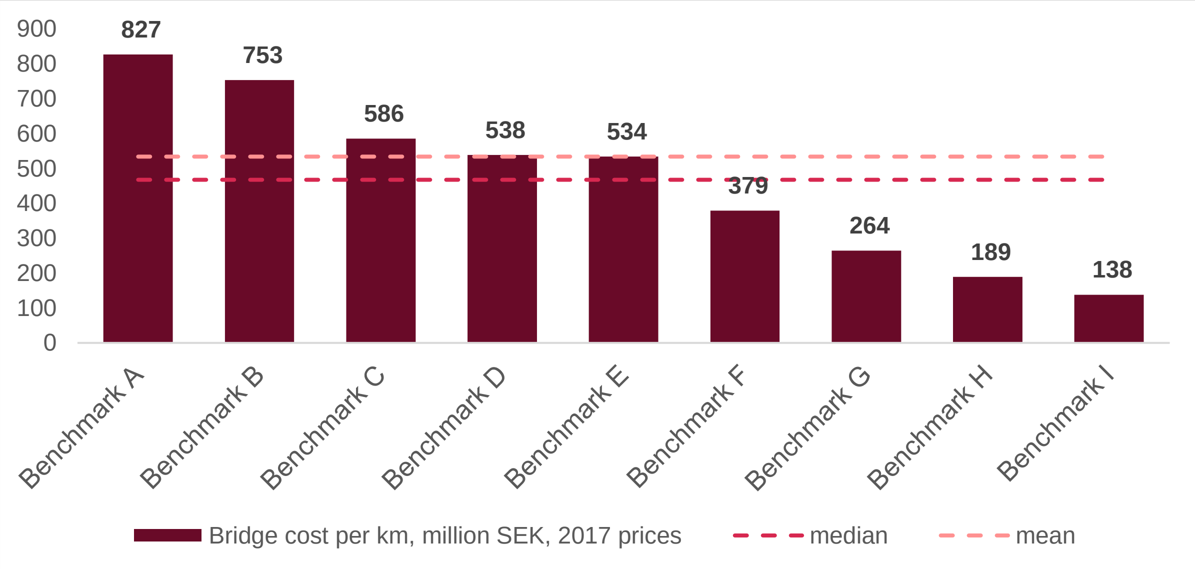


5.1.2 Bridges & structures

For long span bridges and other structures such as overbridges, underbridges, footbridges and viaducts, several comparator schemes were selected which provide compatible benchmark data points.

Benchmark values range from 138 million SEK per route km to 827 million SEK per route km. The average value across the sample is 468 million SEK while the median is 534 million SEK per route km. Figure 5.2 below shows the normalised cost per kilometre benchmark bridge construction cost in million SEK adjusted to 2017 prices.

Figure 5.2 Bridges construction cost per km, million SEK, 2017 prices



5.1.3 Earthworks

Earthworks comprise the processes and activities involved with the excavation, treatment, movement & placement of soil and rock on site to form cuttings and embankments and providing a suitable platform for the railway. They also involve ground improvement and treatment to address poor ground conditions and retention measures to provide steepened earthworks. The main factors affecting the earthworks cost of High-Speed Rail schemes are listed in Table 5-2 ranked in order of importance.

Table 5-2 Main factors affecting earthworks costs in High Speed Rail schemes

Rank	Item	Issues
1	**Earthworks Quantities and Type**	▪ Rock cutting: excavation costs are high, and the fill extracted normally requires processing. In most cases, the rock extracted will be good quality and can avoid the need to import stone from elsewhere. ▪ Soil cutting - normal plant machinery is required. It is not always possible for the extracted material to be reused as fill for construction – it may need to be used as landscape fill or disposed off-site. ▪ The cut / fill balance must be assessed to determine if there is a surplus (take off site or buy extra land) or deficit requiring import or a borrow pit requiring additional land. ▪ Mass-haul of materials can be an issue if material needs to be moved from one end of the route section to another. ▪ Import of specialist fills – for example, drainage stone – can result in increased costs if it cannot be sourced locally.
2	**Line speed**	▪ Costs can increase exponentially once train speed goes over 200kmh, and German experience is that railways should avoid line speeds at or above 300km / hour because of the construction and maintenance costs involved.

Rank	Item	Issues
		▪ Line speed affects the vertical alignment (permitted gradient): cutting depth, land take, cut/fill balance, etc ▪ Earthworks quality: high quality foundation treatment and fill stiffness to manage differential settlement and geodynamics from high speed loadings ▪ It is critical to agree the line speed early in the development of a project as it will have a significant impact on many factors including the land take and cost.
3	**Contract form / ownership of ground risk**	▪ Understanding the ground conditions includes inherent uncertainties and therefore risk. ▪ Adopting an appropriate risk share mechanism has a significant impact on the cost. ▪ If the Contractor owns all the risk, then they will price for all possible risks and the scheme will not be affordable. ▪ The risk is often managed using a Geotechnical Baseline Report. ▪ The geotechnical design approach also has an influence– conservative or realistic
4	**Geological conditions**	▪ Foundation treatment under embankments is a substantial additional cost item that needs to be priced carefully (e.g. to address quick clays in Sweden) ▪ Geological Hazard / Ground risk management: remedial measures may be required for any ground issue under or adjacent to the earthworks e.g. existing landslides.
5	**Population density along the route**	▪ Extent of existing infrastructure along the route e.g. roads, rail, utilities that need to be addressed ahead of and in parallel with the earthworks.
6	**Whether the project enters large cities**	▪ Affects retaining walls, junctions, construction adjacent to existing buildings etc.
7	**Environmental constraints**	▪ Measures required to address archaeology, noise / visual impact, ecology either in the permanent works or during construction.

Key to the earthworks costing of any project is the volume and type of material to be excavated and placed and the nature of the ground conditions present. Therefore, the earthworks cost is difficult to benchmark accurately to other projects with approaches used for other cost elements. The earthworks volume and ground conditions vary significantly between projects and the exercise cannot be completed based on a simple typical cost per kilometre method.

The standard approach to establishing an accurate earthworks cost is to undertake a full bottom up estimate based on cut/fill quantities by material type and to include for any special measures such as ground improvement to address poor ground conditions and high fill quality to address high speed loading, and constraints present along the route. As this study is aimed at producing indicative cost estimates based on benchmarks from international schemes, this was considered to not fit the objectives of the study.

Instead of producing a detailed bottom up estimate, a separate earthworks benchmarking analysis was carried out by a Jacobs geotechnics expert team. A technical report detailing the earthworks benchmarking analysis has been produced and has been issued separately to this report.

A methodology was developed to benchmark the earthworks costs to other projects using a three-phase process as set out below.

Phase 1: Benchmark Projects Based on Earthworks Volume & Construction Cost

1) Collect data on excavated volume and total earthworks cost of 19 earthworks schemes (conventional and HSR) together with an indication of the relative complexity of the earthworks.
2) Determine the relationships between:
   i. earthworks cost and volume extracted
   ii. earthworks cost and total construction cost (excluding cost for any tunnels)

Phase 2: Assess the relative complexity of the earthworks on the New Main Lines

1) Overlay the scheme alignment with geology maps to determine the terrain and rock /soil material through which the route alignment passes.
2) Provide a qualitative assessment on how the complexity of the New Main Lines compares with the complexity of the benchmarked schemes from Phase 1. Complexity varies substantially across the route length. This assessment is summarised in Table 5-3.

Table 5-3 Qualitative assessment of earthworks complexity of New Main Lines

Project	Length (km)	Length of earthworks (km)	Geological Domain A: Rock (%)	Domain B: Glacial Soils (%)	Domain C: Post Glacial Soils (%)	Domain D: Peat & Soft Clay (%)	Overall Complexity of Earthworks
Overall	690	521	14	55	10	21	High

Phase 3: Assess the benchmarked cost for the New Main Lines earthworks

1) Based on the total volume of earthworks estimated for the New Main Lines, the relative complexity of the earthworks and the estimated total construction cost (excluding tunnels) estimate the cost of the New Main Lines earthworks in two approaches:
   i. Based on cost per m^3 of material excavated
   ii. Based on percentage of the total construction cost

The benchmarked costs estimated using approaches A and B are 43,500M SEK and 47,000M SEK respectively which is less than 10% variance providing a good level of alignment.

Based on the findings of the analysis, the recommended P50 (most likely) and P90 values for use in the cost benchmarking estimate as follows:

- P50: 47,000M SEK
- P90: 73,000M SEK

5.1.4 General civil works

General civil works encompass a variety of activities which are likely to be required on a linear basis along the entire length of the alignment, excluding tunnels and bridges. Definitions of general civil works vary across schemes and countries, making it more difficult to develop appropriate comparable benchmarks.

Benchmark values range from 8 million SEK per route km to 30 million SEK. The average cost across the sample is 28 million SEK per route km and the median cost is 27 million SEK per route km.

5.1.5 Stations

Station cost benchmarks have been sourced from 8 schemes where station construction has been an element of the high-speed rail projects – half of the benchmarks are operational schemes and half are under construction. Station configurations varied depending on the number and length of platforms, facilities provided, level and location – central or suburban. Station benchmarks were classified into 'Minimal', 'Intermediate' and 'Intermediate+' stations which reflect different characteristics of stations and the complexity of construction. Minimal stations generally mean fewer platforms, narrower platform width, shorter platform length, fewer customer facilities.

Platform length of all stations was taken to establish cost per platform meter, which was then averaged for each of the station categories. Additionally, due to one of the stations being elevated while other seven were at-grade, one more category was introduced – 'Intermediate+' – to emphasise that above-grade stations would require a larger investment contribution.

It should be acknowledged that aggregating the costs across stations which are distinct in their nature may lead to substantial variation. However, this approach was necessary in the absence of design information or quantities of the stations.

Table 5-4 Station categories based on cost benchmark values

Station category	Cost per platform metre, SEK, 2017 prices
Minimal	206,500
Intermediate	538,800
Intermediate+	1,366,300

Proposed New Main Line stations have been studied and classified based on a description provided by Trafikverket[11]. The following characteristics have been used to define the scale of stations:

- Type and platform quantity.
- Level of the station.

The primary cost driver for the purpose of the analysis is total platform length. It is assumed that the middle platform requires twice as much investment as a side platform, hence for middle platforms the length of platforms has been multiplied by two.

Based on the total platform length, New Main Lines stations were classified into 'Minimal' and 'Intermediate', where minimal stations were the stations with the platform length under 1000m. Additionally, Jönköping station was classified as 'Intermediate+' because it is planned to be constructed on a bridge according to the TRV documentation, thus which would involve higher costs of construction.

Landvetter airport station is proposed to be built underground at the airport. Based on platform length this station would be classified as 'Minimal' however given the substantially higher cost of underground station construction, it has been classified as 'Intermediate'.

These assumptions are summarised in Table 5-5.

[11] Description of assumptions made. Annex to Overall System Design 3.0. Trafikverket

Table 5-5 New Main Lines: stations classification

Station	Calculated platform length in metres (side platforms * length + middle platforms * length * 2)	At grade / elevated / below grade	Type
Vagnhärad	510	At grade	Minimal
Nyköping	1,120	At grade	Intermediate
Skavsta	1,275	At grade	Intermediate
Norrköping	1,640	At grade	Intermediate
Linköping	1,640	At grade	Intermediate
Tranås	510	At grade*	Minimal
Jönköping	2,460	Elevated	Intermediate+
Borås	1,640	At grade	Intermediate
Landvetter airport**	510	Below grade	Intermediate
Mölndal	1,530	At grade	Intermediate
Värnamo	820	At grade	Minimal
Hässleholm	820	At grade	Minimal
Lund	3,280	At grade	Intermediate

*No information available - assumed to be at grade; ** Underground station, classified 'Intermediate'

Following this classification, benchmarked cost rates from comparator schemes were applied to the New Main Lines stations' calculated platform lengths which are used for the purpose of classification.

Trafikverket is only responsible for the construction and long-term maintenance of station assets at the platform level and up to and including elevators, escalators and stairwells to platform. Trafikverket is not responsible for assets related to the station concourse area, ticket offices and related floorspace within the station building which will be the responsibility of others.

Platform level assets including roof and platform equipment, structures within the station environment that support track facilities and platform connections are assumed to be within the responsibility of Trafikverket. Waiting areas, public and commercial areas etc. are assumed to be funded by another party and therefore has only half of the total station construction costs been taken into consideration in this benchmark.

Table 5-6 below illustrates estimated construction cost for 'Minimal', 'Intermediate' and 'Intermediate+' stations, allocated to New Main Line route sections.

Table 5-6 Benchmark-based estimates of New Main Lines station costs

New Main Line Sections	Cost per 'Minimal' stations, million SEK 2017 prices	Cost for 'Intermediate stations, million SEK 2017 prices	Cost for 'Intermediate+' station, million SEK 2017 prices	Total, million SEK 2017 prices
Total	**275**	**3,404**	**1,681**	**5,359**

5.1.6 Track, OHLE, Signalling, Communications & Power

Infrastructure cost benchmarks associated with overhead line electrification (OHLE), traction power, signalling and communications have been collected from 15 relevant comparable schemes.

The influence of slab versus ballast track construction substantially affects the track costs, which is a significant component of this cost element. Due to the level of detail available, it was not possible to isolate the influence of varying track specifications in this cost estimate.

Benchmark values range from 27 million SEK per route km to 112 million SEK. The average value across the sample is 57 million SEK per route km and the median value is 52 million SEK per route km.

5.1.7 Client Development Costs

Client development costs comprise an important component of the total cost of high-speed rail construction and vary significantly based on the country and scale of the scheme.

The assumption of this study is that client development costs are associated with:

- Planning and programme support: costs within this category include the route studies, alternative scenario calculations and cost estimations.
- Pre-phase and preliminaries: costs within this category include costs of legal and political aspects, consultation, land development, feasibility studies, environmental impact assessment and insurance;
- Design and procurement: costs within this category include the design for the approval framework and procurement process strategy; and
- Construction and commissioning: costs within this category include project management, compensations, preparatory works, supervision, testing, approval, consultation, documentation and compliance.

While the level of detail which can be obtained for client development costs is limited, it has been possible to establish benchmarks for 10 schemes.

The benchmark values ranges from 8% to 21% of the direct construction cost. The average and median values across the sample are 13% of the direct construction cost.

5.1.8 Land

Land acquisition costs are associated with the land to be acquired for temporary and permanent purposes for construction, development and operation of the high-speed rail. Usually, the estimates would vary based on the route corridor reservation, areas dedicated for stations, and potential need to reallocate existing facilities.

A detailed description of in-scope land acquisition costs is required to obtain more accurate land cost estimates. In the absence of this information, a benchmark has been developed based on land costs as a % of direct costs from several comparator schemes across the world.

The benchmark values range from 3% to 8% of the direct construction cost. The average and median rates across the sample are 6% of the direct construction cost.

5.1.9 Risk contingency

Contingency allowances are applied in cost estimates to cover uncertainties in the scope including quantities and cost unit rates. The cost benchmarks used in this study have been derived from schemes at planning phase, construction phase and from final cost outturn.

Approximately 50% of the cost estimate by value has been derived from planning and construction phase benchmark schemes. The estimated costs normally include an embedded contingency or Quantitative Risk Analysis (QRA) based risk allowance but are unlikely to incorporate an Optimism Bias (OB) adjustment to account for project cost overruns as mentioned in Section 4.2, which are present in the majority of planning phase estimates.

For schemes where OB is accounted for, it is listed as a separate risk provision and is not embedded in the cost element estimates. For example, the for baseline construction cost estimate for the UK's HS2 Phase 1 programme is £6.7bn with QRA-based construction risk added equivalent to 22.5% and Optimism Bias risk added at 34.3% of estimated cost, bringing total risk provision to 64% of estimated cost[12]. This level of risk provision is considered too high to apply to benchmark schemes as they are drawn from outturn costs or represent estimates in a latter phase of planning (single option development or detailed design).

To account for persistent underestimation of cost estimates at planning phase and ensure comparability with outturn costs representing approximately half of the benchmark schemes, a risk contingency adjustment of 26% derived from the published evidence on cost overruns on high speed rail schemes in NW Europe has been used (see Section 4.2).

Cost outturn data for completed schemes represent 49% of element cost by value and hence are not subject to risk. Applied to the planning and construction phase, schemes the risk contingency adjustment applied is 13.2% of scheme costs including land and client development costs.

5.1.10 Uncertainty

The benchmark-based cost estimate represents the central 'most likely' forecast for the full scheme cost. It is consistent with a P50 confidence level which indicates the cost level that has a 50% chance (probability) of being exceeded. Typical confidence intervals used internationally are P80 and P90.

It is not advisable or appropriate to calculate confidence levels using the cost element benchmark data given the very low sample size and considering they would not account for project or programme risks specific to Sweden.

The revised baseline design estimate for the full scheme previously published by Trafikverket in February 2021 is SEK 295 billion +/- 50 billion (2017 prices).

This is considered an appropriate basis to account for the uncertainty range around the benchmark-based cost estimates, in the absence of better information.

The approach to calculating cost estimates at higher confidence levels is as follows:

- Estimate a standard deviation for each cost element based on the Trafikverket estimate cost uncertainty range.
- Assume a normal distribution of risks for each cost element (excluding contingency) except earthworks where a separate P50 and P90 estimate has been estimated via a bespoke analysis.
- Calculate unit cost rates / proportions at each P-level using the inverse normal distribution and apply in the benchmark – based cost estimate calculation. No adjustment is applied to quantities.

[12] HS2 Limited, 2012, HS2 Cost and Risk Model Report – March 2012.

6. Summary of benchmark-based cost estimates for New Main Lines

The table below presents the benchmark values across each cost element along with the P70, P80 and P90 confidence levels implied by the uncertainty ranges established in Section 5.1.10.

Table 6-1 Cost element per unit at P50, P70, P80 and P90 confidence levels, SEK in 2017 prices

Cost element	Benchmark Unit	P50 Benchmark per unit	P70 Benchmark per unit	P80 Benchmark per unit	P90 Benchmark per unit
Tunnels	Million SEK per route km, mean value	611	699	770	853
Bridges	Million SEK per route km, mean value	468	535	589	652
Earthworks	Bespoke estimate, % of direct construction costs excl. tunnels	30.4%	31.0%	32.1%	33.9%
General civil works	Million SEK per route km, mean value	28	32	35	39
Stations	Million SEK per platform km (average across station categories)	352	461	558	685
Track, OHLE, Signalling, Communication, Power	Million SEK per route km, mean value	57	66	72	80
Client development cost	% of direct construction costs, mean value	13.4%	15.1%	16.6%	18.2%
Land acquisition	% of direct construction costs, mean value	5.6%	6.4%	7.0%	7.7%
Risk contingency	% of all costs	13.2%	13.2%	13.2%	13.2%

Table 6-2 summarises the cost estimates for the New Mail Lines based on the P50 median benchmark values for each cost element, route quantities for the full New Main Lines network.

The benchmark-based cost estimate for the New Main Lines scheme at the P50 confidence level is 271 billion SEK in 2017 prices.

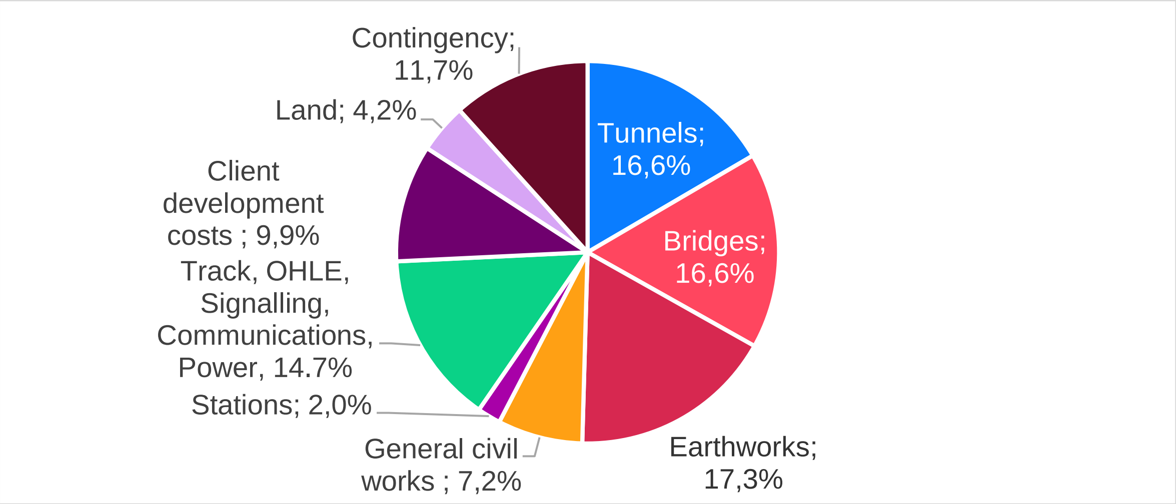
Table 6-2 Benchmarked P50 construction cost estimate for New Main Lines, million SEK, 2017 prices

Cost element	Benchmark-based P50 construction cost estimate, SEK million	Cost element as % total
Tunnels	44,900	16.6%
Bridges	44,900	16.6%
Earthworks	46,800	17.3%
General civil works	19,500	7.2%
Stations	5,400	2.0%
Track, OHLE, Signalling, Communications, Power	39,700	14.7%
Client development costs	26,900	9.9%
Land	11,300	4.2%
Contingency	31,600	11.7%
Total	270,900	100%
Total per km	393	
Total length, km	690	

A pie chart illustrating the breakdown in total costs across the cost elements is shown in Figure 6.1.

Earthworks costs comprise the largest share (17.3%) of total estimated cost of the full New Main Lines network, followed by tunnels (16.6%) and bridges (16.6%).

Figure 6.1 Benchmark-based P50 construction cost estimate – breakdown across cost elements



Estimates have been produced for the New Main Lines Full Network at the P50 and higher confidence levels. Using the same confidence level as Trafikverket for its cost estimates, the total cost of the full network based on international cost benchmarks is estimated at **SEK 271 billion +/- 48 billion** with a P70-P30 confidence interval.

Estimates for the full network at higher confidence levels are presented in Table 6-3.

Table 6-3 Summary of benchmark cost estimates at P50, P70, P80, P90 confidence levels - Full Network

	P50	P70	P80	P90
Full Network	271	319	360	413

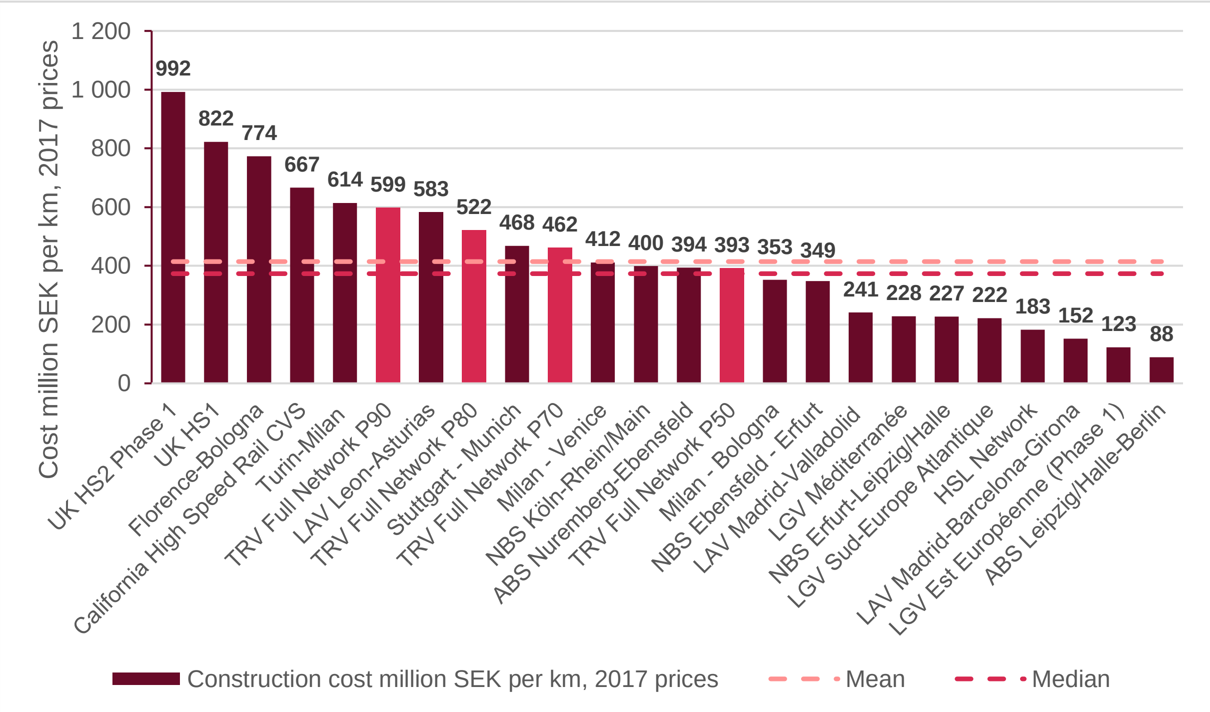
6.1 Comparison of benchmark estimates to international HSR schemes

A useful further comparison is to compare P50, P70, P80 and P90 Full Network estimates to international HSR scheme per route km benchmarks.

As observed in Figure 6.2, the P50 benchmark-based estimate lies between the mean and median levels and the P70 estimate lies just above the benchmark mean. Cost estimates at the P70, P80 and P90 remaining within one standard deviation of the international cost benchmark sample.

From this illustration, it is not inconceivable for total network costs could increase substantially compared to current estimates and still lie close to or within the central range of international HSR benchmarks.

Figure 6.2 Benchmarked estimates compared against international HSR schemes



7. Key limitations to the study

Several limitations were identified during the course of the study which are highlighted here:

- Limited detail was available to this study on the design and specification of the New Main Lines as only 25% of the route sections are at design phase. The remainder of sections do not have an outline design and as such, quantities data available for the analysis was limited to route length split by at grade, tunnel and structures, and the number of stations. This limitation restricted the ability to tailor the analysis to the specific characteristics of the New Main Lines e.g. where costs are likely to be at the high or low part of the benchmark range.
- The availability of data on general civil works and earthworks is very limited. Earthworks is considered the most uncertain cost element. For this reason, a bespoke earthworks analysis was commissioned and carried out by an experienced Jacobs geotechnics team. Carrying out this analysis has reduced the level of uncertainty around earthworks costs and provided useful information around how earthworks complexity varies across the route network. A technical report outlining the methodology and findings of the analysis have been submitted separately to Trafikverket.
- Station costs have been produced based on a high-level assumption regarding station configuration in the absence of more detailed information on required construction works. This increases the uncertainty around any cost estimates related to stations. A high-level assumption that 50% of stations assets by value will be funded by Trafikverket. There is substantial risk that this assumption is incorrect however tangible information to the contrary has not been provided.
- Land acquisition costs are also subject to substantial uncertainty as the costs can vary based on the corridor reservation, areas dedicated for stations, and potential requirement to reallocate existing facilities. However, the overall risk to the estimate is lower as this cost element makes up a much smaller proportion of the scheme total costs.

8. Conclusions

Trafikverket commissioned a cost benchmarking study to support cost planning for the New Main Lines programme and assist in identifying a suitable range of cost estimates for the New Main Lines.

A high-level comparison of the construction costs of comparable international HSR schemes with TRV cost estimates for New Main Lines full network indicates that TRV estimates lie slightly above a central range of international cost benchmarks.

No firm conclusions can be made from this comparison as the construction cost of each scheme is driven by its design characteristics including the scale of tunnels and earthworks along with the number and location of stations in the network.

A second cost element level benchmarking analysis was carried out to produce a benchmark-based cost estimate that reflected the varying characteristics of the TRV New Main Lines.

Indicative P50, P70, P80 and P90 cost estimates were produced which applied cost element level cost benchmarks to the specific design characteristics (e.g. tunnels, structures, stations) and quantities.

The central (P50) estimate of total construction cost for the New Main Lines full network using this method lies within the central range of international HSR schemes with cost estimates at the P70, P80 and P90 remaining within one standard deviation of the international cost benchmark sample.

A conclusion can be derived from this analysis that full network construction costs could rise above their current level and still lie within a central range of international HSR benchmarks. Further design detail of route sections which are at an early stage will assist in reducing the uncertainty around the construction cost of the New Main Lines programme.