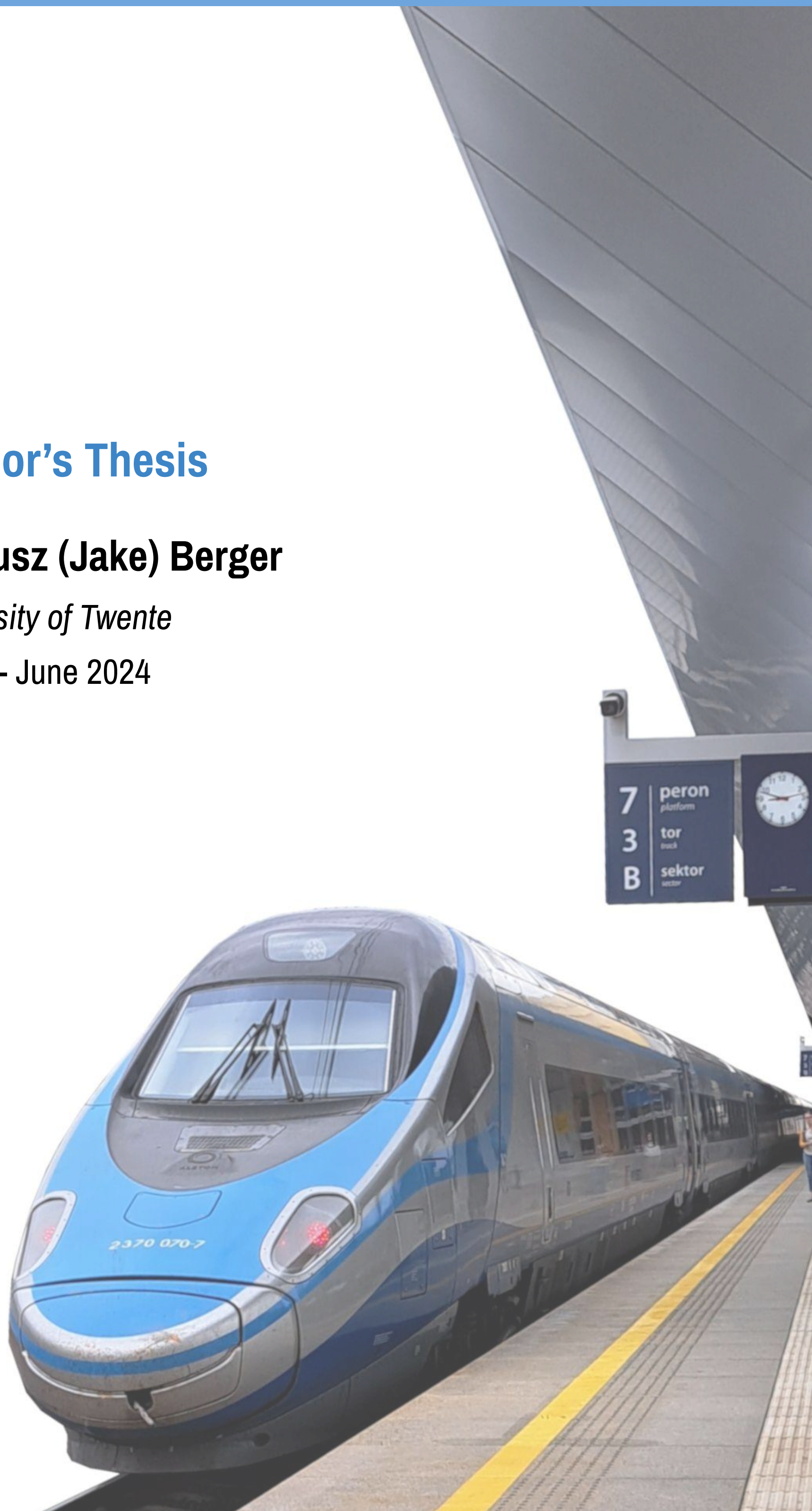
NORTH SEA - BALTIC EXPRESS

TRAVEL TIME, COSTS AND BENEFITS OF A DIRECT TRAIN CONNECTION ON THE AMSTERDAM - BERLIN - WARSAW CORRIDOR IN RELATION TO NATIONAL AND EUROPEAN PLANS



Bachelor's Thesis

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Preface

I travel on the Amsterdam - Berlin - Warsaw corridor regularly myself and, as a student in the field of transport, I have often wondered how the national and the European plans will influence the travel time on this route. What was also interesting for me, as an enthusiast of high-speed railways, was *the Metropolitan Network*, which proposes such services for every major city of the European Union. Therefore, in my bachelor thesis I have wanted to research how the plans included in the Trans European Transport Network and the vision of *the Metropolitan Network* will (or would) reduce travel time on the corridor and how different alternatives for a direct Amsterdam - Warsaw connection compare.

I would like to thank Royal HaskoningDHV for the opportunity of realising my own thesis topic, while being supported by many professionals in the field. In particular, I would like to thank my supervisors - Christiaan Végh for his great help in finding access to knowledge and advising me in my assignment and Karst Geurs for his guidance, which allowed the results of my thesis to be more insightful. I would also like to thank Wouter Leyds for answering sometimes quite complicated technical questions and Barth Donners for his help with operating the Royal HaskoningDHV’s travel demand model.

Summary

The North Sea - Baltic Express is a direct railway connection between Amsterdam, Berlin and Warsaw that is proposed by this thesis with scenarios of different time scopes and infrastructure. The aim of this research is to assess and compare the main impacts of the scenarios, which are based on creating the proposed direct connection and existing plans and proposals (national and Trans-European Transport Network (TEN-T) plans, *the Metropolitan Network* proposal), on railway travel time, costs and travel time benefits. Although the scenarios are compared with benefit-cost ratios, a full cost-benefit analysis is outside the scope of this work. The research questions consist of one main question and three sub-questions, namely:

RQ1: How do the NSBE scenarios (S1: direct train on current infrastructure; S2: plans until 2050 finished; S3: *the Metropolitan Network* proposal finished) compare, based on benefit-cost ratios, on the Amsterdam - Berlin - Warsaw railway corridor?

RQ1.1: What are the effects of the scenarios on travel time?

RQ1.2: What investment costs (in €) and operation costs (in €/year) do the scenarios induce?

RQ1.3: What are the benefits due to travel time saved (in €/year) that the scenarios bring?

The answer to the main research question was found by answering the sub-questions first. Firstly, an analysis of the current Dutch, German and Polish railway networks and a review of national and European plans and proposals for the corridor were carried out with collecting the appropriate data. This allowed for the determination of routings and stops for *the North Sea - Baltic Express* in the given scenarios. Next, the travel time for each scenario was determined with the routing information in *OpenTrack* (2024), a professionally used programme for simulating rail systems in time. Investment and operation costs were estimated with the EU toolset for estimating costs of railway EU projects (Attinà et al., 2018), relevant literature and, if available, public data on future projects. Benefits due to the travel time saved were calculated with the railway demand coming from the RHDHV random regret minimisation model (RHDHV, 2018), values of travel time savings and the saved travel time. The cost and benefit results were used to determine benefit-cost ratios, which allowed for comparisons of the scenarios with one another and across the three countries.

The results for the three sub-questions coming from the aforementioned process are summarised in Table A. Although the benefit-cost ratios are presented, these are not a result of a full cost-benefit analysis and do not allow for a recommendation on whether to realise the scenarios, but can be for a comparison of them.

Table A. Summary of results for RQ1.1, RQ1.2 and RQ1.3

		S1 *(direct train on current infrastructure, 2025)*	**S2** *(TEN-T and national plans being finished, 2050)*	**S3** *(the Metropolitan Network, 2050)*
Travel time (RQ1.1)	**Amsterdam - Warsaw** (13:24*)	10:49	8:11	6:38
	Amsterdam - Berlin (5:52*)	5:35	4:42	3:25
	Berlin - Warsaw (5:32*)	5:14	3:29	3:13
Costs (RQ1.2)	**Investment** [million €]	56 - 69	7,300 - 9,300	8,900 - 11,900
	Operation [million € per year]	22	102	109
Benefits (RQ1.3)	**Travel time savings** [million € per year]	4.7 - 9.3	33.9 - 87.2	49.4 - 122.5
BCRs (RQ1)	**Benefit-cost ratios**	0.19 - 0.39	0.08 - 0.26	0.10 - 0.31

*current time including transfer in Berlin for Amsterdam - Warsaw travel

It was concluded that all scenarios bring significant travel time results, but S1 is the most beneficial, scoring the highest among the three scenarios with its BCR. However, for the two scenarios for 2050, scenario 3 (*the Metropolitan Network*) may be more recommended than the already planned-to-be-realised scenario 2 (the TEN-T). From the comparison between the countries, it seems that for the Netherlands scenario 3 is the most beneficial, for Poland it is scenario 1, while for Germany all three scenarios are comparable.

As scenario 1 can be realised shortly, it is advisable to investigate and consider its introduction, either as a day or a night train. Significant travel time reductions between Amsterdam, Berlin and Warsaw are indeed feasible, and with the plans for the TEN-T, they are to be realised, indicating major benefits for the travellers on this corridor in the future. *The Metropolitan Network* should be studied further, as inclusion of its elements may bring significant benefits, also in terms of reduction of the modal split of aviation. However, full cost-benefit analyses need to be conducted, as the definition and estimation of costs and benefits in this work was not broad enough to give a robust recommendation for or against the scenarios on economic basis.

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Abbreviations

ABW corridor	Amsterdam - Berlin - Warsaw corridor
BCR	Benefit-Cost Ratio
BWE	Berlin-Warszawa Express (train service linking Berlin and Warsaw)
CBA	Cost-Benefit Analysis
CPK	Centralny Port Komunikacyjny (central communication hub)
CEE	Central and Eastern Europe
DE	Germany
ECTS	European Train Control System
EIP	Express Intercity Premium
ERTMS	European Rail Traffic Management System
EU	European Union
GDP	Gross Domestic Product
HSL	High-Speed Line
HSR	High-Speed Railway
HT	Horizontal Timetable
ICB	InterCity Berlijn (train service linking Amsterdam and Berlin)
ICE	InterCity Express
NL	The Netherlands
NSBC	North - Sea Baltic Corridor
NSBE	North - Sea Baltic Express
OD	Origin-Destination
PL	Poland
PPS	Purchasing Power Standards (in relation to the EU average)
STH	Solidarity Transport Hub (hub of the CPK)
TEN-T	Trans-European Transport Network
VTTS	Value of Travel Time Savings

1. Introduction

The train travel time between Amsterdam, Berlin and Warsaw is currently approximately 11 hours, excluding the 2-hour-long transfer time in Berlin. The only high-speed railway (HSR) lines lying on this route are Berlin - Hannover and Minden - Löhne, while most of the corridor uses conventional speeds.

However, there are several plans for the railway lines on this corridor included in the North Sea - Baltic Corridor (NSBC) of the Trans-European Transport Network (TEN-T), such as Warsaw - Łódź - Poznań HSL. Deutsche Bahn with other EU's national carriers proposed *the Metropolitan Network*, which envisions the corridor of the three capitals to be fully high-speed. These plans and proposals have the aim of increasing the demand for railways, including the international EU connections.

Royal HaskoningDHV, the company hosting this thesis, conducted an investigation into travel time between Amsterdam and Berlin in 2018. With the vast investments in the European railway network due to the TEN-T that is to be finished by 2050, it is worthy to investigate how the Amsterdam - Berlin connection extended towards Warsaw would look. This thesis aims to assess and compare the main impacts of scenarios (based on existing plans) on railway travel time, and the associated infrastructure and operational costs and travel time benefits.

1.1. Background

1.1.1. Quick overview of railway plans and proposals

The Trans-European Transport Network policy is meant to develop a high-quality transport infrastructure in the European Union. It has several goals, among which are economic, social and territorial cohesion and the creation of 'seamless transport systems across borders, without physical gaps, bottlenecks or missing links' (European Commission, 2023b). The legal basis of the TEN-T was established as a regulation in 2013, whose revision was approved by the European Parliament in 2024. The revision strives to improve the network and align it with the European Green Deal.

The Metropolitan Network is a proposal made by Deutsche Bahn and other European rail carriers, which has the aim of connecting two-thirds of the EU's population by HSR by 2050. As the authors of the report mention (Deutsche Bahn, 2023), their study has the European Green Deal as a starting point. *The Metropolitan Network* connects all 230 metropolitan regions of the EU with an HSR service at least every hour (Deutsche Bahn, 2023).

Germany and Poland plan investments that are to change the way railways operate in these countries. Germany is in the process of development of *Deutschlandtakt*, a project of transformation to a timetable-based infrastructure. Poland develops a big-scale transport project called *CPK* (*Centralny Port Komunikacyjny*), which involves a brand-new international airport connected by ca. 2,000 km of newly constructed HSR lines and 3,700 km upgraded existing lines.

The Netherlands have a policy for the whole country's public transport - *OV 2040*. It is the most important national policy regarding future development of the Dutch railways. It includes an improvement of connectivity of the biggest cities in the west of the country and of other parts of the country to this area. For international long-distance trains, it proposes faster connections to Germany (Ministry of Infrastructure and Water Management, 2021).

1.1.2. International railway connections in the European Union

High-speed railway is a service that runs at significantly higher speeds than conventional passenger trains. In the context of the trans-European system, it encompasses the criterion of being able to serve services with 250 km/h or more if newly built, 200 km/h if upgraded from conventional railway or being a high-speed line that has especially adapted features due to topographical or city-planning constraints (Eurostat, 2023). Concepts of a Europe-wide HSR network emerged in the second half of the twentieth century. The institutionalisation of actions for such a network came with the publishing of guidelines for the development of the TEN-T in 1998 (European Parliament & Council of the EU, 1996). This network became a strategic investment for increasing the EU's competitiveness (Pomykała & Engelhardt, 2022).

In terms of international connections, there were significant differences between Western Europe and Central Eastern Europe. International services in Western Europe have focused on relatively high-frequent short- or medium-distance connections on the most developed railway corridors, while other services, such as trains running very long distances and night trains have been reducing or disappearing. However, recently ÖBB (Austrian Railways) have been reversing that trend with the introduction of new international night connections (Seidenglanz et al., 2021; Vrána, 2023).

Seidenglanz et al. (2021) has identified recent patterns in international railways services in the V4 group (Poland, Czechia, Slovakia and Hungary) - the long-distance international services have been focusing more on frequent trains mainly on short and medium-distance routes offered in a cyclic schedule (schedule that has departure times in consistent time intervals, e.g. 12:11, 12:41, 13:11, etc.), the travel time has been shortening and the direction of the services has reorientated towards Western Europe, while in the past it used to connect these countries to Eastern Europe better. Moreover, the new long-distance carriers, such as *LeoExpress*, *Regiojet* and *Arriva*, have created competition, bringing more innovation and proactiveness to the market, which has also mobilised the national carriers (Seidenglanz et al., 2021).

In 2023, the European Commision announced that 10 pilot railway projects will receive its support (3 out of 10 partially using the NSBC). These projects are meant to create new or improve existing cross-border connections across the EU (Directorate-General for Mobility and Transport, 2023). This demonstrates the Commission's will and effort in establishing such services, to which the NSBE could be a potential candidate.

1.1.3. State of the research field

Currently, there is no research published that would directly address a direct connection of Amsterdam, Berlin and Warsaw. However, there are various investigations into parts of that route, effects of the designed future infrastructure, and current (high-speed) railway infrastructure. There are also numerous policies and plans regarding this area.

In terms of investigations into parts of the route, the most significant piece of research is the report of AT Osborne and Royal HaskoningDHV (2018) investigating what different investments and changes in the current train connection Amsterdam - Berlin would bring in terms of travel time and costs. The effects of the designed infrastructure included in the TEN-T plans were studied in the '2nd Study on the North Sea - Baltic TEN-T Core Network Corridor for the European Commission' (SIA "Ernst & Young Baltic" et al., 2017).

The studies on construction of high speed railway and implementation of international train connections in the area include e.g. Seidenglanz et al. (2021), Pomykała and Engelhart (2023) and Vrána et al. (2023). The costs of construction of high speed infrastructure are also a studied subject, e.g. by Campos and de Rus (2009). The value of travel time savings, that is to help to estimate the benefits of the travel time reduction on the route, is widely studied, e.g. in the meta-analysis of Shires and de Jong (2009).

1.2. Research dimensions

1.2.1. Problem statement

Comparison of how different plans and proposals would affect the travel time between Amsterdam, Berlin and Warsaw can be perceived as a problem, as the EU wants to shift more passengers to sustainable modes of transport and make the transport network safer, faster and more convenient (European Commission, 2023a). Moreover, the railway travel time between the three capitals can be seen uncompetitive in relation to aviation (11:08 vs. 5:21 h between Amsterdam Centraal and Warszawa Centralna excluding transfers; see Appendix A). The comparison is also important in terms of the 2050 climate neutrality goal. Travel time reductions may attract more passengers to this sustainable mode of transport, satisfying one of the goals of the TEN-T. This is why it would be worthy to get an insight into how the plans and *the Metropolitan Network* proposal are to influence this travel time, and how scenarios resulting from these plans and proposals compare (for RQs, see Section 1.2.4).

1.2.2. Research goal

The aim of this research is to assess and compare the main impacts of the scenarios, which are based on creating the proposed *North Sea - Baltic Express* connection and existing plans and proposals (national and TEN-T plans, *the Metropolitan Network*), on railway travel time, infrastructure and operational costs and travel time benefits.

1.2.3. Research scope

The scope of the research of this thesis is limited to the Amsterdam - Berlin - Warsaw corridor itself. However, as it has many connections to other big and significant cities (like Hamburg or Wrocław), these will be considered in considering the stops of the new international connection.

For example, to provide passengers from Gdańsk and Wrocław with the opportunity to travel conveniently in the direction of Amsterdam, the train should stop in Poznań. Freight trains, local trains and suburban trains will lie beyond the scope of the research, as the thesis will focus only on the international connection stopping in the largest cities.

The costs will be based on investment and operation costs, while external costs such as environmental costs will lie beyond the scope. Similarly, the benefits will not include other benefits than those expressed in the total value of travel time savings.

The time scope varies in different scenarios. For the first scenario, the current infrastructure is assumed, so the train is assumed to run from the next year's (2025) timetable. For the second and third scenarios, the year of the train running is assumed to be 2050, as that is the date of the TEN-T plans and *the Metropolitan Network* proposal being finished.

1.2.4. Research questions

This thesis has one main research question and three sub-questions. The main research question is as follows:

RQ1: How do the NSBE scenarios* compare, based on benefit-cost ratios, on the Amsterdam - Berlin - Warsaw railway corridor?

***Scenarios**:
Base scenario: Current train connection

Scenario 1 (S1): Implementation of a direct train connection on the current infrastructure

Scenario 2 (S2): TEN-T and national plans for the North Sea-Baltic corridor being finished and a direct connection

Scenario 3 (S3): Additional propositions from *the Metropolitan Network,* and the TEN-T and national plans having been implemented and a direct connection

In addition to that, three sub-questions are specified, namely:

RQ1.1: What are the effects of the scenarios on travel time?

RQ1.2: What investment costs (in €) and operation costs (in €/year) do the scenarios induce?

RQ1.3: What are the benefits due to travel time saved (in €/year) that the scenarios bring?

2. Methodology

In this section, the methodology of the research behind this thesis will be presented. Firstly, Figure 1 the research framework is shown, which helps to visualise the steps behind the research. Secondly, in the upcoming sections (also marked on Figure 1), the steps will be described in detail with the theory behind them.

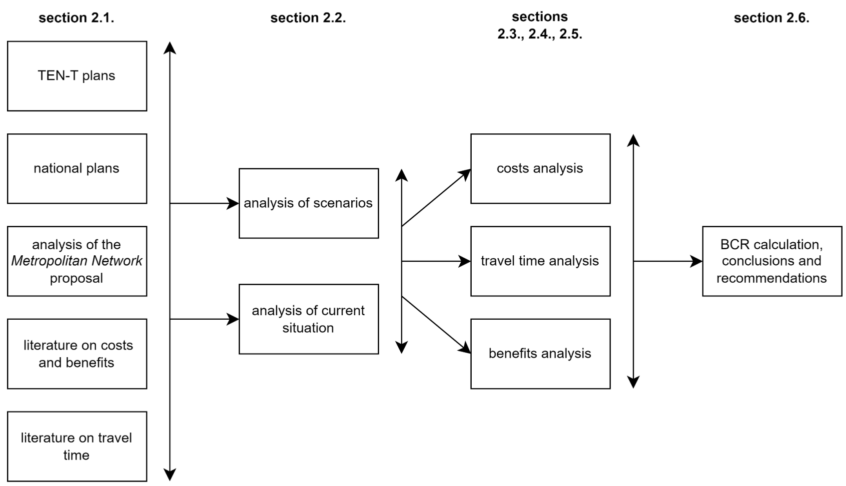

Figure 1. Research framework

On the first (leftmost) level, TEN-T plans, national policies and plans will be analysed and information on the works on the Amsterdam-Berlin-Warsaw corridor will be gathered. The proposal of *the Metropolitan Network* will be inspected, and if there is lacking information (on e.g. what exactly the parameters of new HSLs will be), assumptions will be made. Literature on costs, benefits and railway travel time will also be studied on this level.

On the second level, the information gathered in the first step will be assigned and analysed, including additional data, such as parameters of the assumed stock to be used as the *North Sea - Baltic Express*. On the third level, the outcomes directly answering the research sub-questions will be worked on, that is, travel time, costs and benefits. This will lead to the fourth level, that is, answering the main research question, the conclusions and recommendations.

2.1. Literature review

The research methods used in this thesis will be desk research with the combination of several methods of data collection and calculations. Firstly, data concerning the parameters of the planned railway developments will be collected from TEN-T and national plans, so that there is information on e.g. maximum speeds for scenario 1 and scenario 2. For scenario 3, the data from *the Metropolitan Network* proposal will be gathered. Moreover, literature on costs, benefits and travel time will be reviewed at this stage. This analysis of railway plans and proposals is located in Section 3.

2.2. Initial analysis of scenarios

After the literature review, the routing and stops of the trains in each scenario will be determined. The stops currently included in the plans (such as *Deutschlandtakt* or *CPK*) for international connections on the corridor will be considered. The principle is that the *North Sea - Baltic Express* should stop only on major nodes and in the biggest cities. Moreover, in order to obtain the travel times and running costs, the rolling stock for the base scenario and the three scenarios will be determined. The results of this step can be found in Section 4.

2.3. Travel time (RQ1.1)

RQ1.1*: What are the effects of the scenarios on travel time?*

Travel time is significant in accessibility and connectivity of regions, but also is an important factor in the determination of mode of transport in a travel (van Wee et al., 2013). Furthermore, travel time is also a very important factor in the competitiveness of HSR with aviation (Dobruszkes, 2011).

The Metropolitan Network report argues that shorter travel time due to a connected European HSR is to enable much better connectivity and accessibility, which is to increase the attractiveness of train travel in the EU. As the authors of the report state, the travel time reductions would result in a major effect on the travel demand (Deutsche Bahn, 2023). Due to construction of the TEN-T, on the NSBC the rail passengers will save 26.1% of their travel time. The passenger transport activity on that corridor will grow by 3.2% in 2030 (Schade et al., 2018).

Travel time of a train is mainly dependent on the speed with which the train operates, the number and length of its stops, and how the train can be scheduled in the timetable. The influence of the timetable is especially significant when the traffic is dense on the corridor, as then the arrival and departure times of different trains are highly dependent on each other (Khoshniyat and Peterson, 2015).

The method of obtaining travel time differs for all three scenarios. As scenario 1 is based on the same (or similar) train composition as *Intercity Berlijn* and *Berlin-Warszawa Express* (Vectron MS and 9 wagons), variations in terms of addition or removal of stops will be added to / deducted from the travel time of the two currently run trains. For each deducted stop there will be a simulation made in OpenTrack (OpenTrack RT & ETH Zürich, 2024), which is a software that is professionally used for simulating rail systems in time. The simulation will include the actual speed parameters, and two trains will be run - one with stopping on the station and one without. The difference of travel time between them will be the time saved by skipping the stop. The data for all sections will be gathered and summed in Excel.

Scenarios 2 and 3 have a similar procedure. However, these involve major changes to the current railway network and skipping multiple stops. Therefore, an estimation in OpenTrack software will be made based on characteristics of the (new) infrastructure and of the rolling stock. The data for ETR 1000 (chosen due to its ability to use all the parameters present on the corridor in 2050) accelerating and braking time will be gathered. The most important factors in the calculation of travel time are the maximum speeds over given sections, where the train will stop and over what section it will need to accelerate or decelerate. The travel time over given sections will also include an additional margin (e.g. for the train to catch up if some delay is encountered earlier). All relevant data will be gathered in Excel, but calculation of the travel time based on this data will be done by an OpenTrack simulation. The results of this travel time step can be found in Section 5.

2.4. Costs (RQ1.2)

RQ1.2: *What investment costs (in €) and operation costs (in €/year) do the scenarios induce?*

In the context of this thesis, construction of HSLs, upgrades of conventional lines and purchase of rolling stock are considered in the investment costs. For the operation costs, the costs of operating the lines and operating the railway service itself are accounted for. The visualisation of factors determining the investment costs and the operation costs can be seen on Figure 2.

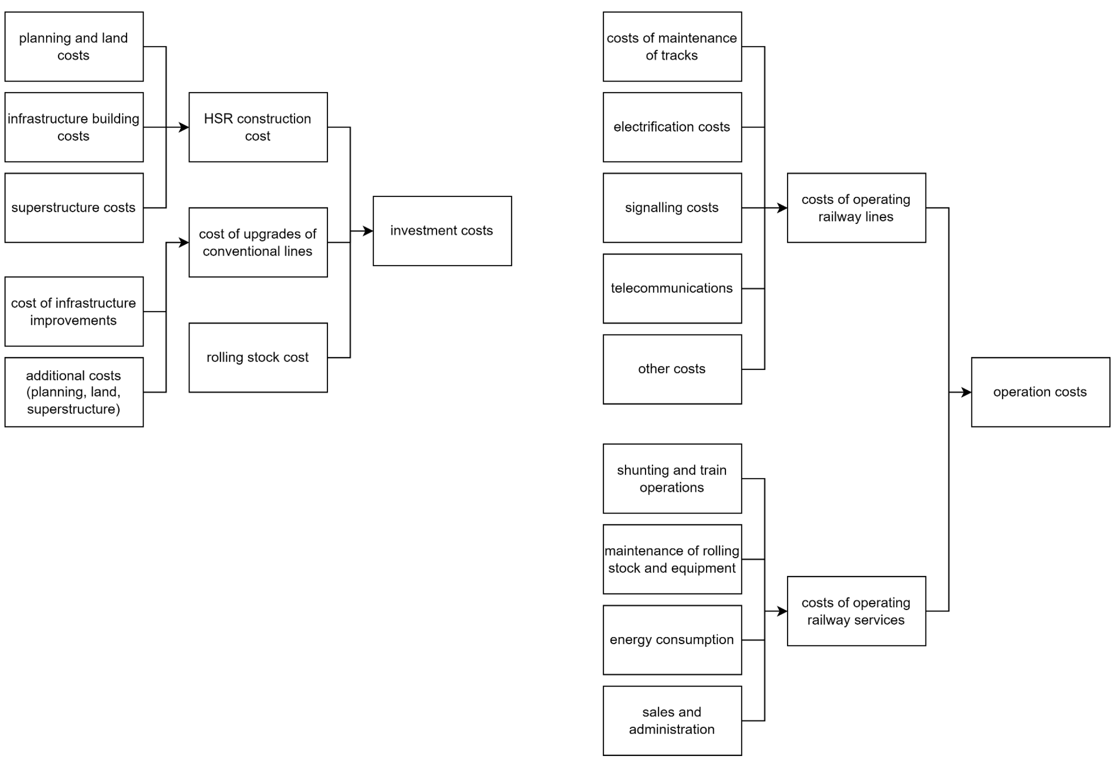

Figure 2. Diagram visualising the factors of investment and operation costs

Three major costs are involved in building HSR infrastructure - planning and land costs (5-10%), infrastructure building costs (usually 10-25%) and superstructure costs (UIC, 2005, as cited in Campos and de Rus 2009). The cost of upgrades of conventional lines consists mainly of the cost of infrastructure improvements (most frequently in capacity or speed (Attinà et al., 2018), connected to e.g. installation of ERTMS). Another investment cost is the purchase of rolling stock that will make use of the parameters of the infrastructure.

For HSR construction and upgrades of conventional lines, the costs per kilometre will come from the official document with toolsets for estimating costs of railway EU projects (Attinà et al., 2018). If data on a given part of the project is available, like in the case of many TEN-T investments, it will be used directly. Then, the cost in €/km will be multiplied by the length of sections with given characteristics. It needs to be remembered that scenarios 2 and 3 will include parts of costs of building/upgrading railway lines, which will not solely serve the direct connection, but also other international and national trains. To account for this, percentages of split between national (regional express and intercity) and international trains on given lines will be assumed based on national plans, and the final investment cost will be the total cost multiplied by the percentage of international trains serving the ABW corridor. For the rolling stock cost, data will come from previous purchases.

The costs of operating railway lines mainly consist of maintenance of track costs (40-67%), electrification costs, signalling costs and telecommunications (HSR: 10-35%, conventional: 15-45%). The electrification costs do not differ significantly between high-speed and conventional railways (Campos and de Rus, 2009). For this thesis, the values of costs of railway line operation will be taken from literature (in €/km; taking into account national data or countries with lines with similar railway characteristics) and multiplied by lengths of given sections. This part will also account for the international-national connection split.

In terms of the cost of operating railway services, it is split mainly into shunting and train operations, maintenance of rolling stock and equipment, energy consumption and sales and administration. While the cost of (ticket) sales and administration is dependent on how the train operators function, the other three factors are dependent on the train models used and the model of functioning of railways in a given country (Campos and de Rus, 2009). In this thesis, the costs of operating railway services will be estimated with cost data per train per year.

After that, the costs will be split between three countries, as funding of railway infrastructure is not only on the EU level, but also on the national level. Other possible costs, such as social cost, will be specified and shortly described based on previous research. The result of this step is presented in Section 6.

2.5. Benefits (RQ3)

RQ1.3: *What are the benefits due to travel time saved (in €/year) that the scenarios bring?*

A part of the benefits coming from a shorter travel time of a connection can be expressed in the value of travel time savings. Value of travel time savings (VTTS) is the monetary value of the travel time being saved by a faster connection. According to Shires and de Jong (2009), it is 'often used in cost–benefit analysis of transport projects and policies, and also to compute generalised travel costs'.

In order to arrive at the final numbers for the total value of travel time savings, there are a few major factors involved, visualised on Figure 3 below.

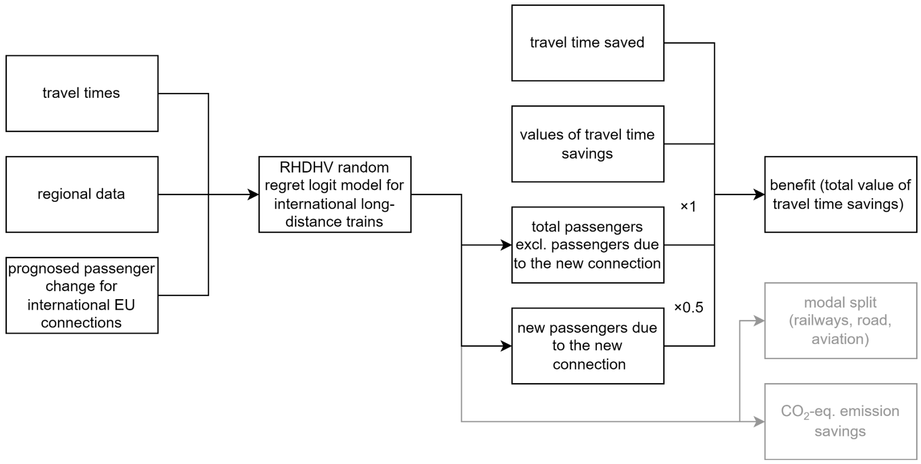

Figure 3. Diagram visualising the estimation of total value of VTTS

To arrive at the final numbers, the values of travel time savings need to be multiplied by the number of passengers (trips) on the connection. To obtain these numbers, the RHDHV random regret minimisation model (RHDHV, 2018) will be used. This model needs 3 inputs (travel times between origin-destination pairs, regional data and prognosed passenger change) to generate OD matrices, modal splits along the routes and CO_2-eq. emission savings. It uses regret minimisation for the mode choice, so that the modal shift is more dependent on all modes.

Total passengers (excluding the new ones) given by the model, will be multiplied by the travel time saved for different scenarios on given sections and the values of travel time savings. The passengers that appeared only due to the new connection account for only half the benefit that would occur if they were there without the changes (due to the rule of half used in CBAs). These passengers will also be multiplied by the travel time saved and the VTTS.

Then the results will be corrected for cities that the RHDHV model does not include (but are relevant for the NSBE) by calculating what percentage of population is included by the model and dividing the results by this percentage. The sum of the values for all sections will be the total benefit for the given scenario. As with costs, the benefits will be also split between the three countries. Afterwards, other benefits such as social benefits will be described based on literature. The results of this step can be sound in Section 7.

2.6. Final stage

RQ1: *How do the scenarios compare, based on benefit-cost ratios, on the ABW corridor?*

At the end of relevant stages, the data on travel time, cost and benefits will be presented and compared across scenarios. Benefit-cost ratios will be calculated for all scenarios (and countries) assuming a discount rate of 3.25% and a span of 100 years, which two values come from the current advice of Rijkswaterstaat (2021) and assumption for infrastructure determined by the Ministry of IenW (2018). The comparison between BCRs will be the answer to the main research question (Section 8). Moreover, when possible, the results of this thesis will be compared with the study done by RHDHV and AT Osborne (2018; in Section 9). The discussion, conclusion and recommendations arising from this thesis will follow (Sections 10, 11 and 12).

3. Analysis of railway networks, plans and proposals

Analysis of railway networks, plans and proposals is done to obtain the context for the further steps in this thesis. With this analysis it will be possible to determine the routing of the NSBE, which will be crucial for answering the research questions. In this chapter, the current HSR in the Netherlands, Germany and Poland will be presented and the results of the analyses of the national plans, the TEN-T plans and the Metropolitan Network will be given.

3.1. Current HSR

High-speed railway is currently used in all three countries, albeit with different intensity and aims. The HSR networks are described below and presented on Figures 4, 5 and 6.

The HSR in the Netherlands was introduced in 2009. Currently, there are two lines on which high speeds can be reached - *HSL-Zuid* (Amsterdam-Rotterdam-Belgian border; 300 km/h) and *Hanzelijn* (Lelystad-Zwolle; 200 km/h). These two lines can be seen on Figure 4. *HSL-Zuid* is currently used with high speeds by international trains by Eurostar, while *Hanzelijn* is not used with such speeds. However, domestic high-speed services are planned with the introduction of new ICNG stock (NS, 2024).

Figure 4. HSR in the Netherlands (*HSL-Zuid* in purple, *Hanzelijn* in orange)

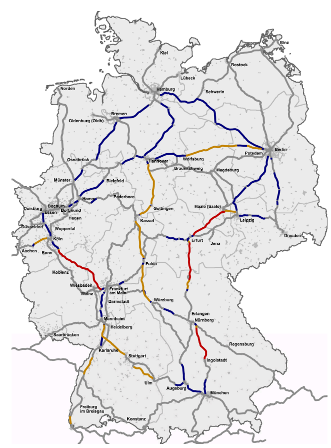

Figure 5. HSR in Germany (HSR in blue, yellow and red; "ICE Network," 2022)

The German HSR was introduced in 1991. It consists of multiple extensive lines ranging across the country, creating the fifth longest HSR network in the world (The Globalist, 2018) with the fastest speed of 300 km/h (see Figure 5). High-speeds are used both domestically (by ICE) and internationally (mainly by ICE and Eurostar).

The HSR in Poland was introduced in 2014. There are two Polish high-speed lines - the *Central Railway Line* (*CMK*) and *E65 north*, which are represented on Figure 6. *CMK* links Warsaw with Krakow and Katowice and has a limit of 200 km/h. It is currently being upgraded to 250 km/h. E65 north has a limit of 200 km/h and links Warsaw with Tricity (agglomeration of Gdańsk). High-speed services are both national (mainly EIP) and international (IC and EIC).

Figure 6. HSR in Poland (CRL in green, E65 north in purple)

3.2. Analysis of the national railway plans

The national railway plans described underneath do include a general description of the plan, however, the measures described are only those that are relevant to the ABW corridor.

3.2.1. The Netherlands

As the document ‘Ontwikkelagenda Toekomstbeeld OV’ (Ministry of Infrastructure and Water Management, 2021) specifies, the goals of *OV 2040* are to create a metro-like connection between the ring of cities (Amsterdam - Zwolle - Arnhem/Nijmegen - Breda/Eindhoven - the Hague/Rotterdam with Utrecht in the ring’s centre), good connectivity of this ring to other parts of the Netherlands, a faster train connection to Germany and an introduction of new forms of public transport to the Netherlands (such as bus rapid transit and light railway). An overview of the plans relevant to this thesis can be found in Appendix B. The most relevant plans are that the international railway passenger numbers are prognosed to grow, the ICB is to be possibly rerouted via Arnhem or Zwolle, night trains are to provide an attractive international service up to 1250 km and Amsterdam Zuid is to become the international train station of the Netherlands.

The final report under the name ‘Landelijke Netwerkuitwerking Spoor 2040. Toekomstbeeld OV’ (Kernteam Landelijke Netwerkuitwerking Spoor, 2020) is a document specifying what measures regarding railways need to be taken to meet the country’s public transport goals for 2040. As the report specifies, the measures described are not decisions yet. There are specific changes to the infrastructure on the ABW corridor, as seen in Appendix B. The measures on the ABW corridor mainly include speed upgrades.

3.2.2. Germany

Germany is in the process of development of *Deutschlandtakt*, which sets the goal of serving twice as many railway passengers by 2030 and increasing the market share of rail freight transport by at least 25% by 2030 (in comparison to 2020; Deutschlandtakt, 2020). The railways in Germany will function based on a cyclic schedule. The final report of *Deutschlandtakt*, including the target timetable for 2030, was published in 2022.

Deutschlandtakt is based on supply-oriented concepts, such as fixed intervals of time on the served lines and frequent service. Its plans strive to optimise transfer connections, reduce travel time in passenger and freight transport and eliminate bottlenecks. The changes on the ABW corridor mainly include speed upgrades on both conventional and high-speed lines and an expansion of train services (Deutschlandtakt, 2022). For a more comprehensive list of infrastructural changes, see Appendix B. Moreover, German authorities envisage the employment of ERTMS on the full network by 2040 (European Commission, 2022).

Nevertheless, the *Deutschlandtakt* also introduces plans for international services for the ABW corridor. The most impactful change is nearly twice as frequent services. Table 1 below provides an overview of these changes.

Table 1. *Deutschlandtakt* train service changes for the ABW corridor: Amsterdam - Berlin

Part of the corridor	***Measure***
Amsterdam - Berlin	Two two-hourly types of services - FV34.a (faster) starting at Berlin Südkreuz and stopping at Berlin Hbf, Berlin-Spandau, Hannover Hbf, Osnabrück Hbf and Rheine on the way to Hengelo - FV34.b (slower) will run from Berlin Ostbahnhof, stopping at Berlin Hbf, Berlin Zoo, Berlin-Spandau, Hannover Hbf, Minden, Bünde, Osnabrück Hbf, Rheine and Bad Bentheim on the way to Hengelo
Hengelo - Berlin Hbf	Shorter travel time (FV34.a: 3:50 h, FV34.b: 3:29 h; currently 4:00 h)
Amsterdam - Arnhem - German border	Hourly service to Köln Hbf, extended to Frankfurt (Main) Hbf every 2 hours
Berlin - Warsaw	Two two-hourly types of services, both with German routings of Berlin Zoo - Berlin Hbf - Berlin Ostkreuz - Frankfurt (Oder) - Polish border - FV28.a: Berlin - Warsaw connection - FV28.b: Berlin - Poznań - Warsaw/Gdańsk/Wrocław (only in peak hours)

3.2.3. Poland

The CPK project, including both a major international aviation hub and numerous high-speed lines, has the aim of connecting the largest urban areas and serving major international corridors through Central and Eastern Europe (CPK, 2024). The ‘White Book on Railway Development’ (CPK, 2023) is a report describing the approach to reforming the Polish railway infrastructure and services. It describes that the holistic planning for the railway component of the CPK project is to include, among others, the development of a horizontal timetable, local mobility hubs, intermodal terminals network and several passenger models and planning tools.

The *Horizontal Timetable* (HT) is to be used as a basis for determining the need for railway infrastructure investments, being a cyclic timetable with well-defined train routes. It is to also include minimum frequencies for different types of services and consistency of connections. The HT is meant for the timetable 2030/31, but an outlook timetable for 2049/50 is to be prepared as well. As of June 2024, only a draft of the outlook timetable for 2049/50 for long-distance traffic without travel times is publicly available. The train service changes for the international connections on the ABW corridor coming from this outlook timetable can be seen in Table 2.

Table 2. Overview of changes on the ABW corridor by 2050 (CPK, 2023)

Relevant part of the ABW corridor	Measure
Berlin - Warsaw	To be served by a part of the new *Y-line*, instead of the conventional Warsaw - Poznań line via Kutno
Berlin Hbf - Warszawa Wschodnia	Hourly connection of Warsaw and Berlin (KDP01 in the current 2049/50 draft of the *Horizontal Timetable*) calling at Warszawa Wschodnia, Warszawa Centralna, Warszawa Zachodnia, CPK (STH), Łódź Fabryczna, Poznań Główny, Zbąszyń, Świebodzin, Frankfurt (Oder), Berlin Ostbahnhof and Berlin Hbf

While the CPK project is currently being revised due to detection of irregularities in the process of its preparation, the *Y-line* (Warsaw - Łódź - Poznań/Wrocław HSR) is not a part of this revision and will be continued regardless (Madrjas, 2024b). The *Y-line* is the only HSR line coming from the CPK project to be used on the ABW corridor, therefore it is clear what infrastructural changes will occur on the route of the NSBE.

When it comes to ERTMS, the whole route between Warsaw and the German border has it under implementation. In Poland, trains cannot technically and legally operate above 160 km/h without ERTMS. Therefore, new high-speed lines will already be built with ERTMS (Ministry of Infrastructure, 2023).

3.3. Analysis of plans in the Trans-European Network

The TEN-T policy is meant to develop a high-quality transport infrastructure in the European Union and does not only include railways, but also roads, waterways, airports, ports, urban nodes and rail-road terminals. Different TEN-T layers have different time of completion, however, the whole network is to be finished by 2050.

The different lines that can be used to route the NSBE are all included in the TEN-T (with the exception of some short in-city connecting lines). The overview of these can be found in Appendix C, along with their types of network and service. As previously mentioned, all these lines lie on the North Sea - Baltic Corridor. The NSBC is one of 9 corridors of the TEN-T and runs from Belgium and the Netherlands to Estonia, Finland and Sweden via Germany, Poland, Lithuania and Latvia.

According to the 2nd study on the NSBC, its completion from 2016 to 2030 will consume 96 billion €2015 in investment and create 715 billion €2015 of additional GDP. In 2050, passenger transport activity on rail on the NSBC is to grow by 61% (in comparison to 2015), while the emissions per passenger-kilometre are to fall by 34% (SIA "Ernst & Young Baltic" et al., 2017).

3.3.1. The 2024 revision of the 2013 regulation

The 2013 regulation is under revision, in order to improve the network and align it with the European Green Deal (European Commission, 2023b). The revision has been approved by the Council of the European Union twice and by the European Parliament. It awaits signatures of the presidents of the Council and the Parliament to be legally binding (Legislative Observatory of the European Parliament, 2024). Because the 2024 revision is at a very advanced stage, in this thesis it is assumed to be already binding. The revision is to bring additional 2.37% GDP growth and 0.47% growth in employment by 2050 on the EU scale. The transport activity on rail is to rise additionally by 3.5% in 2050 (Schade et al., 2018). The overview of the major changes introduced can be seen in Table 3.

Table 3. Overview of changes introduced by the 2024 revision (European Commission, 2023b)

Change	Description
Addition of the extended core network to the two 2013 layers	Two 2013 layers: - Core network - most significant connections, to be completed by 2030 - Comprehensive network - meant to connect all EU regions to the core network, to be completed by 2050 Additional 2024 layer: - Extended Core network - an in-between goal, to be completed by 2040
New minimum speed requirement	Minimum 160 km/h for all passenger core network lines
Obligation of multimodal hubs	Each urban node with multimodal hub(s) (1 hub until 500,000 inhabitants, one more per each additional 500,000 inhabitants)
New ERTMS deadline	ERTMS on all the lines of the TEN-T by 2040

3.4. Analysis of *The Metropolitan Network*

The authors of *the Metropolitan Network* (2023) explain that the EU set the target of reducing carbon emissions in the transport sector by 90% by 2050, which involves two milestones - doubling the volume of European HSR traffic by 2030 and tripling this volume by 2050 (compared to 2015). They claim that HSR traffic will only grow by ca. 60% of the target growth if only planned infrastructure measures are undertaken, therefore more investments are needed.

The authors assumed hourly service between metropolitan regions (defined as agglomerations of more than 250,000 inhabitants) in 2050 on the new HSLs. (Deutsche Bahn & PTV Group, 2023). Their model was created with Deutsche Bahn, cooperating with other national carriers.

Construction of *the Metropolitan Network* and HSR planned until 2030 would almost quadruple Germany's HSR infrastructure and increase the Dutch HSR sevenfold and the Polish HSR tenfold. The visualisation of new infrastructure can be seen on Figure 7 below.

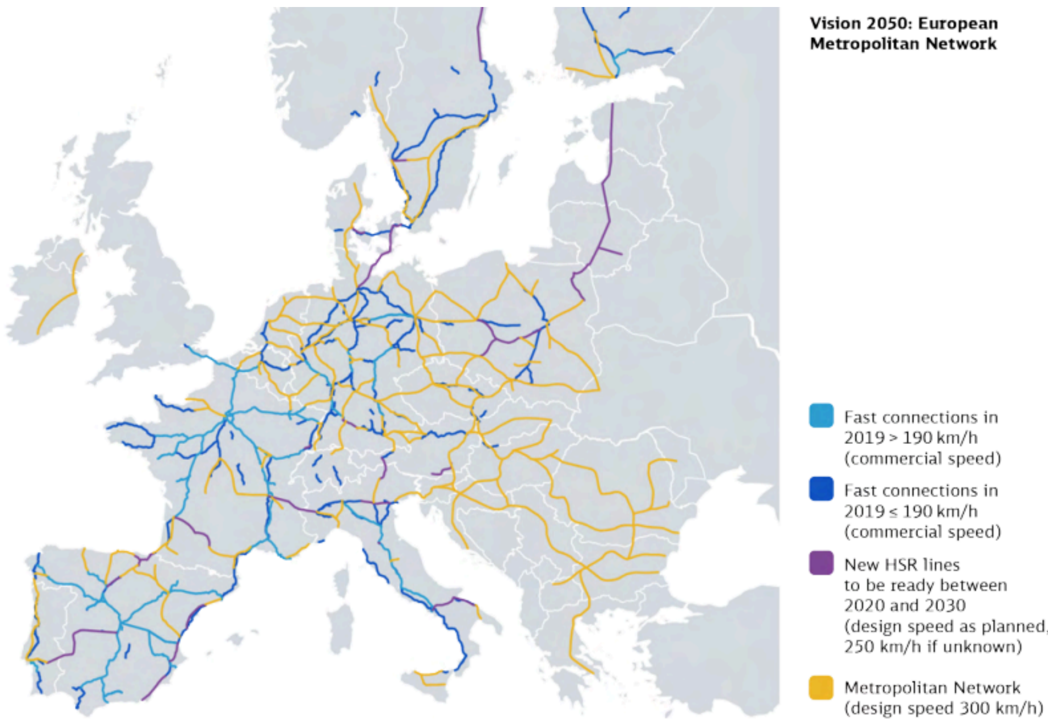

Figure 7. Vision of *the Metropolitan Network* (*note that fast connections are not always HSR as defined by Eurostat*; Deutsche Bahn & PTV Group, 2023)

3.5. Conclusion on railway network and plan analysis

As results from the analysis done for this chapter, HSR is used in all three countries, while Germany uses it the most broadly. The Dutch railway plans concentrate on improving the current network, the German plans strive to introduce a country-wide railway cyclic schedule and the Polish plans aim to create a country-wide HSR network with a cyclic schedule. The TEN-T plans focus on the performance of transport across the whole EU, while the Metropolitan Network proposes an upgrade of the TEN-T plans in order to create a EU-wide HSR network. While the plans differ in their aims, they are generally consistent with one another. The results of the analysis have various implications for the routing of the NSBE in all scenarios.

4. NSBE routing

Routing of the North - Sea Baltic Express needed to be determined for each scenario to be able to calculate the travel time in the following step. Firstly, the outcome of AT Osborne and RHDHV's research (2018) will be shown. Next, the routings for each scenario will be determined, connecting the information from the Section 3 document analysis with rules corresponding to each scenario (e.g. that the NSBE should stop only on major nodes and in big cities).

4.1. Research of AT Osborne and Royal HaskoningDHV

The research of AT Osborne and Royal HaskoningDHV (2018) specified 4 possible future routes for the connection of Amsterdam with Berlin. These can be seen on Figure 8. The first one, which is the current route of *IC Berlijn*, leads through Deventer and Osnabrück (in black). The second one leads through Zwolle instead of Deventer (in yellow). The third possibility deviates from the current route until Hannover by running through Utrecht, Emmerich and Essen (in red). The fourth possibility is similar to the third one, but instead of passing through Essen, it traverses Gelsenkirchen (in orange). In this thesis, the alternative route through Zwolle will be referred to as *Alternative A*, the one through Essen as *Alternative B1* and the one via Gelsenkirchen *as B2*.

Figure 8. Possible routes according to AT Osborne and Royal HaskoningDHV (2018)

The routing via Arnhem and Emmerich can bring up to 1:20 h reduction in travel time, while the current routing and the one via Zwolle can reduce the travel time by up to 1 hour (in comparison to 2018). The alternative routings are uncertain due to major interventions in the current railway networks. Very significant reduction achieving 4:40 h of travel time between Amsterdam and Berlin would need a high-speed line between Amsterdam and Hengelo/Enschede, which would cost around 4.7 to 6.9 billion €. Possible travel time estimations for the routes in the future are 5:28, 5:21, 5:04 and 5:03 h for current route and alternatives A, B1 and B2 respectively (AT Osborne & Royal HaskoningDHV, 2018).

4.2. Scenario 1: the route

Scenario 1 assumes merging the two current services on the ABW corridor - *IC Berlijn* and *Berlin-Warszawa Express* with the possibility of omission of some of their current stops. The current route of these two can be seen on Figure 9.

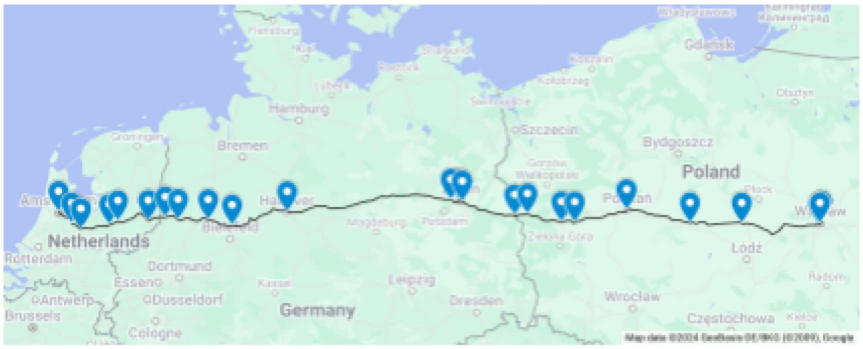

Figure 9. Current routes of *ICB* and *BWE* and their stops

As shown on Figure 9, both train services have a large number of stops. As aforementioned, the principle is that the NSBE should stop only on major nodes and in the biggest cities. However, Hilversum should be excluded due to its relatively small size and great connectivity to Amersfoort. If a given city of more than 500,000 inhabitants has multiple stops, they should be kept, in order to avoid overcrowding the main station.

In terms of major nodes, it can be argued that Frankfurt (Oder) and Kutno should remain as stops. Frankfurt (Oder) is an important junction connecting different areas of east Brandenburg and can also serve as a transfer stop for passengers from Gorzów Wlkp. and Zielona Góra in the direction of Berlin. Kutno can serve as a transfer point towards Berlin for passengers from Łódź (a metropolitan area of over a million). As of 2025, Bad Bentheim has to remain at least a technical stop, as the switch of voltages there needs to be made on standstill.

While the area of Amsterdam has only one stop, the agglomerations of Berlin and Warsaw have 3 stops each. This is due to policies on long-distance train stops and infrastructural constraints. Thus keeping 3 stops also makes the NSBE more feasible to realise. Moreover, it needs to be mentioned that both Berlin and Warsaw are bigger cities than Amsterdam, with their populations being 1.8 and 3.6 times larger in 2021 (Eurostat, 2024).

Therefore, the stops of the NSBE in scenario 1 are:

1. Amsterdam Centraal
2. Amersfoort Centraal
3. Hengelo
4. Bad Bentheim (voltage switch)
5. Osnabrück Hbf
6. Hannover Hbf
7. Berlin-Spandau
8. Berlin Hbf
9. Berlin Ostbahnhof (Berlin East)
10. Frankfurt (Oder)
11. Poznań Główny (Poznań Main)
12. Kutno
13. Warszawa Zachodnia (Warsaw West)
14. Warszawa Centralna
15. Warszawa Wschodnia (Warsaw East)

4.3. Scenario 2: the route

Scenario 2 is realised in 2050. Each of the three countries' national railway plans gives their more or less detailed vision on connections to Berlin in the future, as seen in Table 4.

Table 4. Summary of each country's vision on connections to/from Berlin

The Netherlands *(OV 2040)*	**Germany** *(Deutschlandtakt)*	**Poland** *(CPK)*
Amsterdam Zuid (not Centraal) as the Dutch international station.	Train service from **Berlin to Amsterdam every hour**, but with 2 stopping schemes.	**Warsaw - Berlin** train to be routed **via the *Y-line*** with different stops.
Amsterdam - Berlin train via Zwolle (more emphasised) or via Arnhem and Emmerich (less emphasised).	Direct train service Berlin - Warsaw every other hour, in peak hours additional 2-hourly train service from Berlin to Poznań, continuing towards Warsaw/Wrocław/Gdańsk.	**KDP01**: Berlin Hbf - Berlin Ostbf - Frankfurt (Oder) - Świebodzin - Zbąszyń - Poznań Gł. - Łódź Fabryczna - CPK - Wwa Zach. - Wwa Centr. - Wwa Wschodnia
	The Ruhr is extremely busy. Ruhr - Hanover line incapable of handling 2030 traffic plans.	
	FV 34.b: Berlin Südkreuz - Berlin Hbf - Berlin-Spandau - Hannover Hbf - Osnabrück Hbf - Rheine - Hengelo	

When the visions are compared, the routing can be determined. As the Netherlands want the connection to Berlin to run via Zwolle or the Ruhr, and according to the German plans the Ruhr is overloaded with trains, routing via Zwolle seems much more feasible. As Amsterdam has only one stop in *IC Berlijn*, Amsterdam Zuid will be served. The TEN-T plans have Frankfurt (Oder) - Poznań HSL being finished by 2050, so it will be used. The route can be seen on Figure 10.

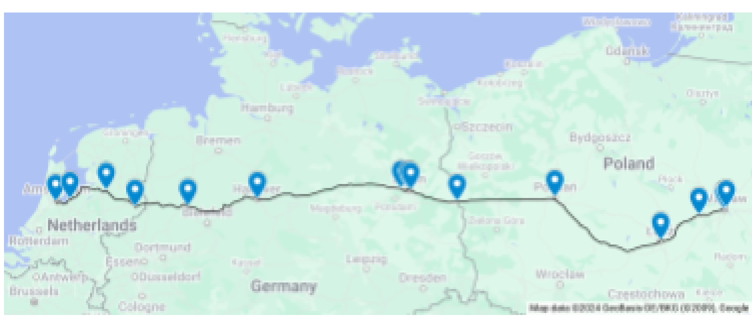

Figure 10. Routing of NSBE in scenario 2

In terms of the logic, it follows the same rules as in Section 4.2. FV34.b and KDP01 give the possible stops in Germany and Poland. Rheine, Świebodzin and Zbąszyń should be skipped, as they are neither big cities nor would allow for a significantly better accessibility thereof. Berlin Südkreuz cannot be served easily due to alignment of tracks in Berlin, so it is also skipped.

For the stops in the Netherlands, Hengelo, Zwolle and Amsterdam satisfy the metropolitan area criterion. In order to avoid overcrowding Amsterdam Zuid in the agglomeration of Amsterdam, Almere Centrum will also be a stop. Therefore, the list of stops is:

1. Amsterdam Zuid (Amsterdam South)
2. Almere Centrum
3. Zwolle
4. Hengelo
5. Osnabrück Hbf
6. Hannover Hbf
7. Berlin-Spandau
8. Berlin Hbf
9. Berlin Ostbahnhof (Berlin East)
10. Frankfurt (Oder)
11. Poznań Główny (Poznań Main)
12. Łódź Fabryczna *(main station of Łódź)*
13. CPK (Solidarity Transport Hub)
14. Warszawa Zachodnia (Warsaw West)
15. Warszawa Centralna
16. Warszawa Wschodnia (Warsaw East)

4.4. Scenario 3: the route

The Metropolitan Network report (2023) only gives rough routings of the new HSLs, but the new lines are meant to connect metropolitan regions of more than 250,000 by 2050. It seems that the possible NSBE routing in S3 roughly overlaps with the routing in S2. The major differences are that there would be new HSLs on corridors Frankfurt (Oder) - Berlin, Wolfsburg - Hannover, Hannover - Osnabrück - Hengelo and Hengelo - Zwolle - Almere (see Figure 11).

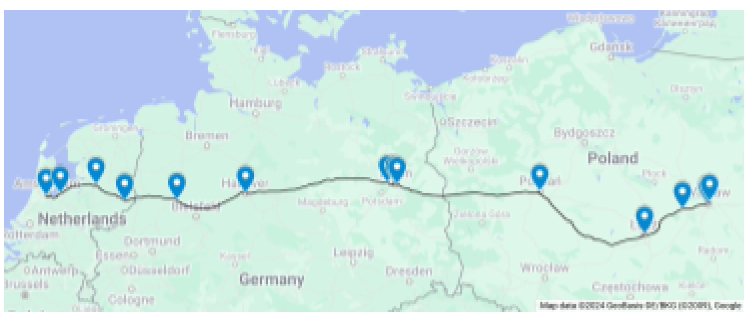

Figure 11. Routing of NSBE in scenario 3 (several new partial routings assumed)

The logic behind the selection of stops is similar to the one from S1 and S2 (Section 4.2. and 4.3.), however, the major railway node criterion is skipped, as the principle of *the Metropolitan Network* is that it serves metropolitan areas of more than 250,000 inhabitants. Only Frankfurt (Oder) is therefore skipped, as the rest of the stops lie in such areas. Hence the stops in S3 are:

1. Amsterdam Zuid (Amsterdam South)
2. Almere Centrum
3. Zwolle
4. Hengelo
5. Osnabrück Hbf
6. Hannover Hbf
7. Berlin-Spandau
8. Berlin Hbf
9. Berlin Ostbahnhof (Berlin East)
10. Poznań Główny (Poznań Main)
11. Łódź Fabryczna *(main station of Łódź)*
12. CPK (Solidarity Transport Hub)
13. Warszawa Zachodnia (Warsaw West)
14. Warszawa Centralna
15. Warszawa Wschodnia (Warsaw East)

As the NSBE in all 3 scenarios could also be attractive to transfer over from connections from other agglomerations and countries, these are presented for each NSBE stop in Appendix D.

5. Travel time determination

As scenario 1 has a different method than scenario 2 and 3, the process of their travel time determination will be presented separately. Afterwards, the travel time results will be presented along with the current travel time between Amsterdam and Warsaw via Berlin.

5.1. Scenario 1

For scenario 1, only maximum speed data for the sections around the skipped stations and lengths of these sections were collected, in order to determine what travel time saving skipping the particular station would bring. For each of the stations a simple simulation in OpenTrack was prepared, and later the time of a train skipping the station was subtracted from the time of a train stopping at the station. The time of the stopping train included the stop duration that was equivalent to the duration *IC Berlijn* or *Berlin-Warszawa Express* currently use. Nevertheless, there were also assumptions made in order to make the simulation realistic and feasible, and obtain a realistic travel time for the train. These can be found in Appendix E. The most significant assumptions are that the NSBE has planning priority in the schedules, is served with Vectron MS and wagons and it is planned with 90% of its performance. With these, the travel time for NSBE in scenario 1 was obtained. It is presented along with results for other scenarios in Table 5.

5.2. Scenarios 2 and 3

For scenarios 2 and 3, maximum speed, length and voltage data for all the sections (defined as lengths of tracks with the same maximum speed) was collected in Excel. Some of the routings had to be assumed, which is described in Sections 4.3 and 4.4. The infrastructure for S2 and S3 is different, so the section data was different as well. These sections, along with the placement of stations used by the NSBE were created in OpenTrack, and then the simulation was run for both scenarios with ETR 1000 train, whose performance data was collected from Trenitalia (2012) and Canetta (2015) and can be seen in Appendix F. A summary of assumptions for S2 and S3 can be found in Appendix E. The most significant ones out of these are the planning priority, ETR 1000 as the rolling stock, 90% performance and speed parameters on the new lines (if unknown). With these, the travel times for NSBE in scenarios 2 and 3 were obtained. They are presented in Table 5.

5.3. Comparison of travel time results

In order to present a quick overview of how the travel time results compare in-between scenarios and with the current travel time between Amsterdam and Warsaw via Berlin, Table 5 is presented underneath. “A” means arrival time and “D” is the departure time from a station, while the | symbol means the given station is not served. In order to make the travel time saved between Berlin and Warsaw more visible, it is presented in Table 6.

Table 5. Travel time results for all scenarios and the current travel time

Station		**current time*** (excl. transfer time)	**S1** (direct train on current infrastructure)	**S2** (national and European plans until 2050)	**S3** (*the Metropolitan Network*)
Amsterdam Centraal	**D**	00:00	00:00	|	|
Amersfoort Centraal	**A**	00:35	00:32	|	|
	D	00:37	00:34	|	|
Amsterdam Zuid	**A**	|	|	|	|
	D	|	|	00:00	00:00
Almere Centrum	**A**	|	|	00:18	00:18
	D	|	|	00:20	00:20
Zwolle	**A**	|	|	00:51	00:40
	D	|	|	00:53	00:42
Hengelo	**A**	01:52	01:41	01:25	01:01
	D	01:53	01:42	01:28	01:04
Bad Bentheim	**A**	02:10	01:59	|	|
	D	02:13	02:02	|	|
Osnabrück Hbf	**A**	02:52	02:39	02:13	01:29
	D	02:55	02:42	02:16	01:32
Hannover Hbf	**A**	04:02	03:45	03:12	02:05
	D	04:05	03:48	03:15	02:08
Berlin-Spandau	**A**	05:31	05:14	04:28	03:11
	D	05:33	05:16	04:30	03:13
Berlin Hbf	**A**	05:52	05:35	04:42	03:25
	D	05:56	05:39	04:46	03:29
Berlin Ostbahnhof	**A**	06:02	05:45	04:52	03:35
	D	06:06	05:49	04:56	03:39
Frankfurt (Oder)	**A**	06:52	06:35	05:33	|
	D	06:52	06:36	05:36	|
Poznań Główny	**A**	08:30	08:05	06:16	04:43
	D	08:41	08:09	06:21	04:48
Kutno	**A**	10:03	09:28	|	|
	D	10:06	09:31	|	|
Łódź Fabryczna	**A**	|	|	07:16	05:43
	D	|	|	07:19	05:46
CPK (STH)	**A**	|	|	07:40	06:07
	D	|	|	07:42	06:09
Warszawa Zachodnia	**A**	11:04	10:29	07:54	06:21
	D	11:07	10:32	07:57	06:24
Warszawa Centralna	**A**	11:12	10:37	08:00	06:27
	D	11:18	10:43	08:06	06:33
Warszawa Wschodnia	**A**	11:24	10:49	08:11	06:38
total travel time (incl. 2h transfer for S0)		**13:24**	**10:49**	**8:11**	**6:38**
travel time saved		**-**	**2:34**	**5:12**	**6:45**
(excl. 2h transfer for S0)		-	(0:34)	(3:12)	(4:45)

*not all stops shown; data from last week of 2024 timetable (DB, 2024))

Table 6. Partial travel time results Berlin - Warsaw for all scenarios and the current travel time

Station		**current time*** (excl. transfer time)	**S1** (direct train on current infrastructure)	**S2** (national and European plans until 2050)	**S3** (*the Metropolitan Network*)
Berlin Hbf	**A**	00:00	00:00	00:00	00:00
	D	00:04	00:04	00:04	00:04
Berlin Ostbahnhof	**A**	00:10	00:10	00:10	00:10
	D	00:14	00:14	00:14	00:14
Frankfurt (Oder)	**A**	01:00	01:00	00:51	|
	D	01:00	01:01	00:54	|
Poznań Główny	**A**	02:38	02:30	01:34	01:18
	D	02:49	02:34	01:39	01:23
Kutno	**A**	04:11	03:53	|	|
	D	04:14	03:56	|	|
Łódź Fabryczna	**A**	|	|	02:34	02:18
	D	|	|	02:37	02:21
CPK (STH)	**A**	|	|	02:58	02:42
	D	|	|	03:00	02:44
Warszawa Zachodnia	**A**	05:12	04:54	03:12	02:56
	D	05:15	04:57	03:15	02:59
Warszawa Centralna	**A**	05:20	05:02	03:18	03:02
	D	05:26	05:08	03:24	03:08
Warszawa Wschodnia	**A**	05:32	05:14	03:29	03:13
total travel time		**5:32**	**5:14**	**3:29**	**3:13**
travel time saved		**-**	**0:18**	**2:03**	**2:19**

*not all stops shown; data from last week of 2024 timetable (DB, 2024))

It can be stated that all scenarios bring significant reductions in the travel time between the stations Amsterdam Centraal/Zuid and Warszawa Wschodnia. Even if the 2-hour-long transfer in Berlin is ignored, scenario 1 brings more than 0.5 h time reduction. Moreover, such a connection could be more attractive due to the lack of a transfer. National and European plans are also to contribute to the travel time reduction - the difference between S2 and S1 is more than 2.5 hours. As expected, the biggest travel time reduction comes with *the Metropolitan Network* in S3 - it is 1.5 h shorter than S2, more than 4 hours shorter than S1, and more than 6.5 h shorter than the current connection.

Moreover, ignoring the 2-hour saving due to a lack of transfer, it can be observed that what saves the most time in S2 is the new HSR infrastructure in Poland (about 2-hours). Between Berlin and Warsaw there is limited time difference between S2 and S3 - this is due to the fact that on this part of the route only Berlin - Frankfurt (Oder) needs to be upgraded for *the Metropolitan Network*. On the ABW corridor, the current plans for Polish HSR in 2050 are already compliant with *the Metropolitan Network*, while the plans for German HSR are partially compliant and those for Dutch HSR are not compliant.

6. Cost determination

Cost determination was needed to obtain the benefit-cost ratios, which were to allow for scenario comparisons. The costs, which are split into investment and operation costs, are also presented separately. Afterwards, a description of the unquantified costs is given.

6.1. Investment costs

If investment costs were known (e.g. for *Y-line*), these were included directly in the calculation of total investment costs. If not, data from the toolset developed for the European Commission ‘Assessment of unit costs of rail projects’ (Attinà et al., 2018) or data from TEN-T documents itself (like Schade et al. (2018)) was taken. The data from the toolset included interval values (e.g. 5.4 ± 60% M€/km), therefore the end result for investment costs is an interval.

Further on, in order to obtain investment costs per country, the data was not only summed for total values, but also for total values per country. Rolling stock costs could not be split directly, therefore it was calculated what percentage of route by length takes place in each country. These percentages were then assumed as parts of the stock costs.

The investment costs had to be corrected for the fact that the new infrastructure is not to only serve international connections. For this the future service plans were analysed, arriving at the splits of national and international connections (serving the ABW corridor) on every section of the corridor. For the national connections on high-speed lines, regional trains were not taken into account (but German and Polish regional expresses were, as these are to utilise HSR). For the Netherlands it was assumed that new (high-speed) railway lines would benefit both Intercity and regional Sprinter trains, as the Dutch railway network is very busy and capacity would increase significantly. The international connection percentage was used to determine what part of the investment is to be attributed to the scenarios of the NSBE.

The rolling stock costs are assumed for two trains - one in the direction of Warsaw and one in the direction of Amsterdam each day. Siemens Vectron MS with wagons for S1 and ETR 1000 for S2 and S3 were assumed earlier as the stock serving the connection. The wagons had to be further specified at this step. The NSBE in S1 could serve either as a day train or a night train, therefore two alternative compositions were chosen. For the day train it was noticed that one of the national carriers (PKP Intercity) has recently bought new wagons that are to be used on international routes (Madrjas, 2024a). These were also assumed, as they are designed to increase the passengers’ comfort. For the night train, the new ÖBB NightJet composition was chosen due to this carrier’s role as a European pioneer of night connections (Seidenglanz et al., 2021; Railvolution, 2021). Such a composition could provide the needed comfort for night travellers, contributing to the NSBE’s possible popularity.

If the value given by a source was not current (as of 2024), it was corrected for the cumulative value change. Calculations per scenario, along with sources for different values and changes overview, are in Appendix H. In Table 7, the total investment costs have an overview along with the operation costs. On Figure 12, the results are split by country monetarily and by percentage.

6.2. Operation costs

Costs of operation of the NSBE were split into two categories - train services cost and railway lines cost. The costs of the upkeep of currently existing lines were not taken into account, as the calculation is meant to show what costs come with the scenarios and not what costs there are generally on the ABW corridor. This also implies that the only operation costs for S1 are those generated by providing the NSBE service.

For scenario 1, as the NSBE is served by both HSR and conventional railways, current operating costs per train-km per country (incl. stock maintenance) were gathered from a study on rail costs for the European Commission (Steer Davies Gleave, 2015). The results per country were then summed for the total cost per year.

For scenarios 2 and 3, the calculations were conducted similarly. Data for the operating cost per seat-km and maintenance cost per seat-km were collected from the study of Campos and de Rus (2009). There was no data directly for ETR 1000, therefore the costs of ICE 3 Multi-system were taken, as it has similar characteristics to ETR 1000. This data was multiplied by the number of seats and the number of kilometres per year to be run by the NSBE train.

For the railway line costs, data for the maintenance of HSR per kilometre had to be collected, as this will be the dominating train technology in S2 and S3. Unfortunately, such data could not be found directly for the three countries. Therefore, the data for Belgium (Campos & de Rus, 2009) was assumed to be the cost per kilometre, as this country has similar terrain and technical characteristics to the (plans for the) ABW corridor. Then, the cost per kilometre was multiplied by the total length of the new/upgraded railway lines and the international connection percentage on the new/upgraded lines to obtain the total railway line costs per year.

If the value given by a source was not in the current year (2024), it was corrected for the cumulative value change of Euro over years. The calculations per scenario, along with sources for different values and overview of changes, can be seen in Appendix H. In Table 7, the total operation costs are given an overview along with the investment costs. In Figure 12, the results are split by country monetarily and by percentage.

6.3. Comparison of cost results

The final results obtained for the research question 1.2 are compiled in Table 7 and Figure 12.

Table 7. Absolute cost results (in the value of Euro in 2024)

	Total investment costs (one-time) [M€]				**Operation costs per year** [M€/year]			
	NL	*DE*	*PL*	**TOTAL**	*NL*	*DE*	*PL*	**TOTAL**
S1	8 - 10	26 - 32	22 - 27	**56 - 69**	6.3	8.5	7.2	**22.0**
S2	280 - 400	590 - 820	6,420 - 8,110	**7,290 - 9,330**	15.6	44.5	41.6	**101.7**
S3	700 - 1,020	1,730 - 2,740	6,420 - 8,110	**8,850 - 11,870**	15.3	48.2	45.6	**109.1**

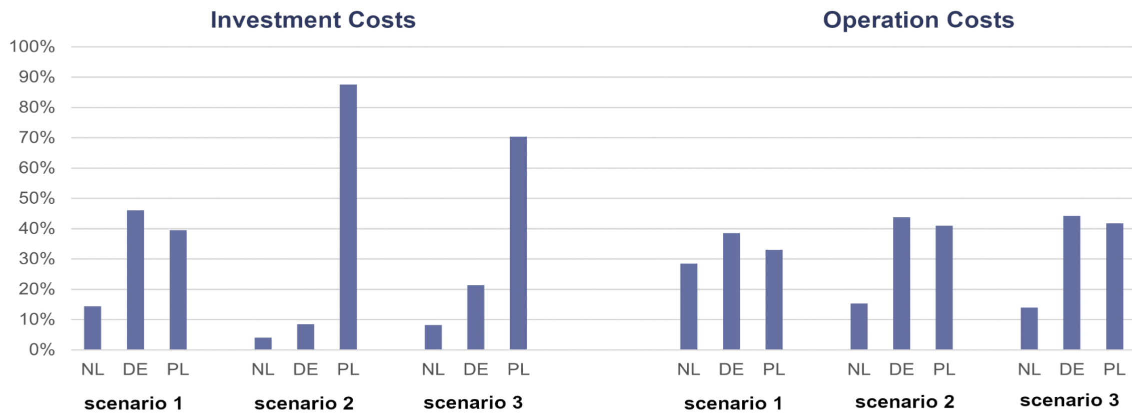

Figure 12. Comparison of percentage cost results by country

As one can see, S1 has very small costs compared to S2 and S3. This is because there is no change in the infrastructure in S1, which is the majority of costs for S2 and S3. It can also be noted that in S2 and S3 Poland pays the majority of the investment costs. This is because currently no Polish HSR is present on the ABW corridor, while 2050 plans include the whole Polish part of the corridor being high-speed. However, due to these plans, Poland's investment is the same in S2 and S3, as its plans are compatible with *the Metropolitan Network*.

Overall, the Netherlands require the least investment and operation costs due to the fact that the smallest share of the ABW corridor lies in this country (~15%). Although adapting the Netherlands for S3 requires the most intervention in the current plans, the absolute cost of investment is still estimated to be the smallest out of the three due to the smallest route share. To sum up, in S1 Germany and Poland require the most funds, while in S2 and S3 the most funds are needed for Poland. Whilst the costs for the other two countries in S2 and S3 are smaller, costs for Germany also have a big share in S3 (~21%).

6.4. Unquantified costs

Except for the costs of investment and operation, there are also external costs. Although quantifying these lies beyond this thesis' scope, such costs should not be ignored. In the study of van Essen et al. (2019) prepared for the European Commission, these were split into:

- accident costs,
- environmental costs, such as ones due to air pollution, noise, habitat damage, well-to-tank emissions and climate change,
- congestion costs (not present for railways and aviation),
- and other costs (e.g. barrier effects in cities)

From the results of van Essen et al. (2019), railways have the lowest external costs per passenger-kilometres compared to passenger cars and short-haul aviation (<1,500 km travel). These values for 2016 are 2.8, 12.0 and 4.26 €-cent/pkm, respectively. If the railways are split into HSR and conventional electric railways, HSR has even lower external costs (1.3 vs. 2.6 €-cent/pkm). Therefore, it may be that by attracting passengers from other modes to the NSBE due to a better connection, all modes' total external costs are actually reduced, not increased.

7. Benefit determination

Benefit determination was conducted with the RHDHV model (2018), whose outputs were translated into benefits. After description of these, benefit results will be compared both by scenario and countries, which will be followed by a description of benefits not quantified in this thesis.

7.1. Operating the RHDHV (2018) model

As is done with models, some assumptions had to be made in order to arrive at its outputs. An overview of them can be found in Appendix I. The most important assumptions are that medium-distance travels are not considered (so e.g. from Amsterdam to Hengelo), data for some stops (like Zwolle, see Appendix J) were omitted due to data unavailability, passenger numbers grow by 2.1% yearly and the NSBE can be used to transfer to from other cities. The data the model gave in return was then organised into Excel sheets. This included (new) passenger numbers, modal splits and CO_2-eq. emission savings.

7.2. Translating the outputs into benefits

In order to translate the passenger outputs into time savings benefits, values for travel time savings had to be found. The number for the Netherlands was taken from Kouwenhoven et al. (2023) for travels on trains. The numbers for Germany were taken from Axhausen et al. (2015) for travels on public transport. Unfortunately, data for the values of travel time savings for Poland was not available publicly, so an assumption was made. The GDP per capita in PPS for Poland and Germany (Eurostat, 2023) were divided by each other, giving a ratio (0.696), which was multiplied by the data for Germany, giving an estimation of the values of time savings for Poland. All the values, corrected for the cumulative change of the value of Euro over years, can be found in Appendix K. As there were only four cities outside the three countries considered, the values for them were assumed to be Polish for Prague and Ostrava, and Dutch for Antwerp and Brussels.

Then, each OD pair was assigned a value given its travel distance. As it was not possible to know the demographics, the country of the travel's origin was also the traveller's origin. These values were then multiplied by the numbers of passengers (accounting for the half-rule) and the travel time saved on the OD pair. The sums of all of these in one scenario were the final time savings benefits. The minimum benefits were those only for OD pairs of metropolitan areas the NSBE stops in, while the maximum benefits were for all considered areas.

Additionally, as the RHDHV model did not have all the cities that the NSBE is to stop in and all the cities that have the possibility of being well-connected to the NSBE (see Appendix D), the percentage of what population was included by the model was calculated. For the stop cities, it was between 97 and 99% and for the connected cities between 83 and 84%, depending on the scenario. The difference in these percentages for the three countries were also considered. These percentages allowed for an estimation of what total benefits there are for each scenario thanks to dividing the numbers from the model by the adequate percentages. These estimates can be found in Table 8.

Table 8. Time savings benefits

Time savings benefits [€2024/year]			
	S1 (direct train on current infrastructure)	**S2** (national and European plans until 2050)	**S3** *(the Metropolitan Network)*
Directly connected areas (min. benefits)	4,671,451	33,858,389	49,415,781
Indirectly connected areas	4,617,259	53,350,196	73,051,843
Total (max. benefits)	**9,288,710**	**87,208,585**	**122,467,624**

7.3. Comparison of benefit results

The benefit data can be seen in Table 9. The sums of the countries' parts are not analogical to total time savings benefit data due to the inclusion of Prague, Ostrava, Brussels and Antwerp in the model, which lie outside the three countries.

Table 9. Time savings benefits per year

Time savings benefits per year per country [million €2024/year]							
	Netherlands		**Germany**		**Poland**		**TOTAL**
S1	0.86 - 1.81	*19%*	2.43 - 4.59	*49-52%*	1.38 - 2.56	*28-30%*	**4.67 - 9.29**
S2	4.76 - 14.42	*14-17%*	14.52 - 37.50	*43%*	14.29 - 27.12	*31-42%*	**33.86 - 87.21**
S3	9.20 - 24.36	*19-20%*	24.65 - 56.82	*46-50%*	15.30 - 30.42	*25-31%*	**49.42 - 122.47**

As one can see, scenario 1 has the lowest, while scenario 3 has the highest values of time savings benefits. This goes in accordance with the fact that scenario 3 has the most interventions in infrastructure, while scenario 1 does not include any such alterations. However, it can also be seen that the creation of a direct connection in scenario 1 is very significant. The split of benefits for each country looks different for every scenario, as the travel time saved is dependent on the amount of interventions in the infrastructure of a given country. Generally, Poland has its highest split in S2, Germany in S1 and the Netherlands in both S1 and S3. This may be because Poland is the country to have the most investments in S2, much time is saved by skipping stops in Germany and the Netherlands in S1 and the most major investments in the Dutch infrastructure are made in S3 compared to other scenarios.

Nevertheless, it needs to be noted that the time savings benefits presented in this thesis are only those that are there for (very) long-distance passengers. This means that the benefit numbers presented are definitely not all time savings benefits due to the new infrastructure in S2 and S3.

7.4. Unquantified benefits

Benefits considered and quantified in this thesis are those due to travel time savings. However, these are definitely not the only benefits that are generated by new connections on (high-speed) railways. As Nash (2015) specifies, revenue coming from tickets, capacity release for other lines and external costs saved on other modes are significant in cost-benefit analyses of HSR. Moreover, the NSBE and infrastructure improvements considered in the three scenarios may also bring various other benefits and a list of these is in Table 10.

Table 10. List of benefits unquantified in this thesis

Unquantified benefit	Comment (if needed)
Revenue from tickets	
Benefits due to better international connectivity of cities on the ABW corridor	
Benefits due to increase in business attractivity of cities on the ABW corridor	
Capacity release for other lines	Construction of new HSLs can release capacity on alternative routes.
Travel time savings for freight	If the HSLs are to be also used by freight, e.g. at night, this can also bring time savings for freight railway transport.
Strategic military benefits	Faster railways may also mean faster transport for the military. Particularly important in the context of the TEN-T.
External costs saved on other modes	These include, but are not limited to, lower accident numbers (due to an accident rate lower than on roads), emission savings and lowering congestion on roads (Steer Davies Gleave, 2015). The estimated emission savings due to modal shift given by the RHDHV model are 47.7, 295.0 and 520.9 kilo tonnes CO_2-eq. per year in S1, S2 and S3, respectively. The modal shifts can be seen in detail in Appendix L. The shift from aviation and road transport is very visible for S3 and quite visible for S2. For Amsterdam-Warsaw, Amsterdam-Berlin and Berlin-Warsaw, the change in the railway part of the split is +2%, +5% and +5% for S1, +14%, +22% and +39% for S2 and +31%, +45% and +43% for S3. The largest significant falls in the modal split of aviation occur in S2 and S3 (S2: -12%, -16% and -24%; S3: -28%, -35% and -27%). This may mean S2 and S3 are particularly beneficial in striving towards the 2050 climate neutrality goal.

8. Comparison of costs and benefits

To compare the scenarios and how the countries are affected, an overview of benefit-cost-ratios is provided on Figure 13 (exact values are in Appendix M). These values were obtained by assuming a discount rate of 3.25% and a span of 100 years, which come from the current advice of Rijkswaterstaat (2021) and the assumption for infrastructure by the Ministry of IenW (2018). The ratios are given as intervals, as was the data for costs and benefits. The maximum benefits are if the NSBE is well communicated with trains from other big metropolitan areas.

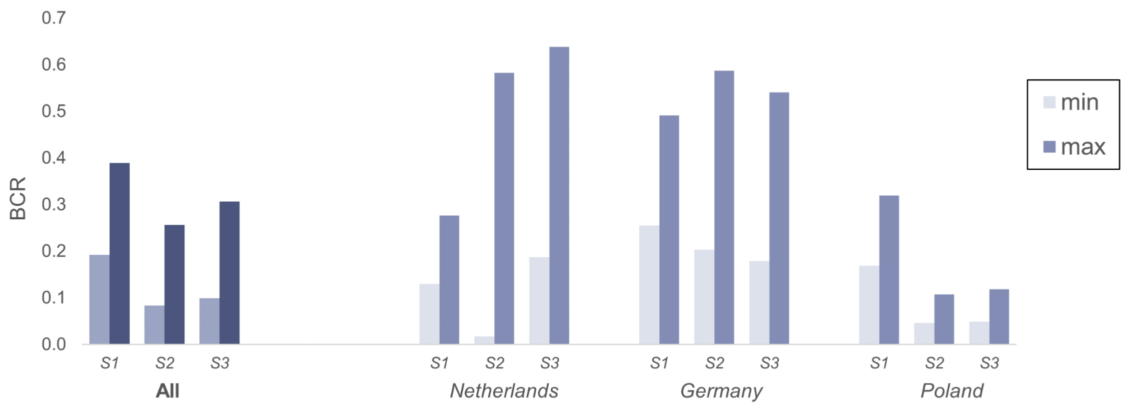

Figure 13. Benefit-cost ratio intervals for the scenarios (costs and benefits not fully estimated)

The BCR intervals are large and are all below 0.7. Taking it from the EU perspective, S1 has the highest benefit-cost ratio, while S2 has the lowest. For Poland it is similar, but it has much smaller upper limits for S2 and S3. The Netherlands have the lowest interval of values in S1 and the highest in S3. For Germany the values do not vary very significantly across scenarios.

However, this thesis does not aim to conduct a CBA of the infrastructure and its operation proposed in the scenarios. In CBAs, values above 1 usually indicate a recommendation to realise the investment. However, a value below 1 does not mean that a given project will not be realised, and multiple (HSR) projects have been conducted in spite of this (e.g. Turin - Milan HSL with 0.46 and British HS1 with 0.53 (Meyer de Freitas & Blum, 2023)). The calculation of costs in this thesis excluded external costs, while the calculation of benefits did not include many factors such as revenue from tickets or external costs saved on other modes (important for the EU railways due to the Green Deal). In the EU railway projects analysed by Kelly et al. (2015) travel time savings were only about 20% of the benefits (e.g. Madrid - Barcelona HSL), and for other realised HSR projects researched for this thesis it varied from 33% (Rome - Naples HSL; Beria & Grimaldi, 2016) to 62% (British HS1; Atkins et al., 2015). This may suggest that the benefit-cost ratios for the NSBE could change greatly if a proper CBA was done.

Moreover, the new infrastructure is not to be built solely for international connections, but, as appears from the policy analysis, mainly for national ones. This means that a CBA would have to include this use. Such analyses were already done for the TEN-T (S2) with a positive recommendation (e.g. Schade et al. (2018)). Therefore, although these numbers are all below 1, they should not be taken as a recommendation not to realise the scenarios, but as values allowing for the scenario comparison and a starting point for further research on the NSBE.

9. Comparison of the results with the 2018 study

Thanks to the research of RHDHV and AT Osborne (2018), the results of this thesis can be partially compared with results of another study. Scenario 1 is comparable with the scenario PLUS1 from the 2018 study between Amsterdam and Berlin. The routing of the train in the 2018 study's scenario L1.2 is similar to the one in scenario 2, however, the speed parameters in the 2018 study do not include parameter changes such as the minimum 160 km/h limit requirement on the TEN-T core network lines to be introduced in the 2024 revision of the TEN-T. Scenario 3 can be roughly compared to the 2018 study's high-end scenario of Amsterdam - Deventer - Hengelo HSL, although the HSL's routing is different (in S3 it is Amsterdam - Zwolle - Hengelo). The comparisons are summarised in Table 11.

Table 11. Comparison of this thesis' results with the 2018 study (RHDHV & AT Osborne, 2018)

	Pair of cities	Result of this thesis	2018 study result (comparable scenarios)	Difference in percentages
Scenario 1	Amsterdam - Berlin	5:35	5:29	2%
Scenario 2	Amsterdam - Berlin*	4:42	5:24	13%
Scenario 3	Amsterdam - Hengelo**	Reduction of 50 min.	Reduction of 1 hour	17%

*different railway line parameters; **different routing

From Table 11, it can be seen that scenario 1 has the smallest difference - it is also almost identical to the one in the 2018 study. In scenario 2 the difference is larger, but this is probably mainly due to differences in railway parameters taken in the two investigations. The biggest difference is in scenario 3, however, the routing of the line between Amsterdam and Hengelo is very different, and what connects these two investigations is only an HSL connecting the two cities. Comparing the stop stations determined in the two investigations, it can also be seen that scenario 1 has almost identical stations (except Amsterdam Zuid instead of Amsterdam Centraal) in both of them, although the results of the 2018 study in this matter were not taken as a starting point for the stop determination in this thesis.

Unfortunately, there can be no comparison made for the part between Berlin and Warsaw for scenarios 1 and 2, and for the part between Hengelo and Warsaw for scenario 3, as there was no comparable research conducted for these. The *Horizontal Timetable* from the CPK project will be able to provide a comparable result, but currently only a version without travel times is publicly available.

The costs already included known costs on the stage of their estimation. For the benefits, the 2018 study does not provide specific numbers, but only roughly compares its scenarios between each other. This also means that comparison of the time savings benefits in this thesis is not possible.

10. Discussion

The investigation made in this thesis ended successfully, albeit there are some strengths and limitations linked to the methodology used. These will be discussed in the same order as the four research questions in this thesis were answered.

When it comes to the research question 1.1 (the travel time determination) the main limitation was that there was no integration in timetable planning due to the limited time for this thesis. This would be particularly important for scenario 1, as it has a short time scope of realisation (2025). If timetable integration was made, then it would be known with greater certainty that the S1 travel time result was indeed feasible. In scenario 2 and 3 (2050), the routing and speed parameters of several railway lines were assumed due to data being unavailable. Because of this it also may turn out that the travel time is slightly underestimated, however, the assumptions were rough courses omitting terrain developments and buildings, and speed parameters were roughly derived from plans and proposals in order to reduce this possibility of underestimation. Moreover, the simulation run in OpenTrack was rather simplified with no presence of interaction with other railway lines, other trains on the line, and errors in train operating behaviour. This may also imply a slight underestimation of travel time. However, the programme used to estimate the travel time is professionally used, and the simulations were made after extensive analysis of national and European policies and plans and detailed collection of parameters needed to run the simulation effectively. This may suggest that the travel times arrived at in this thesis have the correct order of magnitude and are close to the real values.

For the research question 1.2, the cost determination, it may be stated that it was simplified, excluding external costs and uncertainties other than those given by the EU toolset by Attinà et al. (2018). If data was unknown about the cost of a given investment, quick assumptions were made with this toolset, while operation costs were taken from literature. This caused the final cost results to be in a form of rather broad intervals - if more time was available for this research question, more individuality of given investments could be considered. However, the actual toolset with percentages of uncertainty in costs was used, which may indicate that the actual cost lies in the interval arrived at in this thesis. The cost results were also split between international and national use, so the cost result is only for the NSBE and could be used for answering the main research question.

The research question 1.3, the benefit determination, included only the values of travel time savings. Benefits such as capacity release for other lines (due to investments), revenue from tickets, benefits due to increased international connectivity and external costs saved on other modes (particularly important in terms of the EU's climate neutrality goal) were not quantified. This most probably means that the benefit result only including the values of travel time savings is an underestimation of the total benefits and the benefit results from this thesis need to be always presented with this disclaimer. From the research done for this thesis, the travel time benefits seem to lie between 20 and 60% of total benefits in CBAs for railway projects (Kelly et al., 2015; Atkins et al., 2015). This also has another implication - the benefit-cost ratio presented in Section 8 cannot be taken as an answer on whether to implement the scenarios in reality, but allows only for a comparison of scenarios. In the RHDHV model (2018) medium-distance travels, very long-distance travels (e.g. Vilnius - Amsterdam) and complex international travels (two transfers with one of the transfer connections being extensive) were not considered, which may have led to a small but significant underestimation in the benefits.

However, the benefit determination had its strengths as well. Connectivity of the NSBE train with trains from other cities was considered in the results, giving a minimum benefit value if the NSBE is not well-integrated, and a maximum if it is. The model used was a regret minimisation one, suggesting that the results were more valid than if it was made with elasticities. If cities and areas were not included in the model, these were corrected for by estimation of what percentage of passengers is not included in the preliminary benefits.

The RHDHV model also provided modal split and CO_2-eq. emission savings estimations, which provide further context for the results of this thesis. For S1, the change in the railway part of the split is +2%, +5% and +5% for Amsterdam-Warsaw, Amsterdam-Berlin and Berlin-Warsaw respectively. For S2, it is +14%, +22% and +39%. For S3, it is +31%, +45% and +43%. The largest significant falls in the modal split of aviation occur in S2 and S3 (S2: -12%, -16% and -24%; S3: -28%, -35% and -27%). The possible emission savings due to modal shift are 47.7, 295.0 and 520.9 kilo tonnes CO_2-eq. per year in S1, S2 and S3, respectively.

The calculation of the benefit-cost ratios, although not offering an answer to whether to realise the investments or not due to the aforementioned reasons, allowed for a comparison of scenarios themselves and scenarios between countries. The travel time results of this thesis were also similar to the values found in the RHDHV and AT Osborne study (2018). If the scenarios between the two investigations were almost identical, then the results were very close. If they were only roughly comparable, then the difference was significant, but can be attributed to the significant differences in the railway parameters taken in the two studies. This may suggest that the results obtained in this thesis are valid.

11. Conclusion

The research question on travel time (RQ1.1) is answered that the first scenario shortens the travel time between Amsterdam and Warsaw to 10:49 hours, the second scenario to 8:11 hours and the third scenario to 6:38 hours. This implies travel time reductions of 2:34, 5:12, 6:45 hours (-19.3%, -38.9%, -50.5%) for the scenarios respectively compared to the current travel time of 13:24 h. All scenarios bring significant travel time reductions, and scenario 2 and 3 have a much larger impact on travel time than scenario 1.

The answer to the cost research question (RQ1.2) is that the investment costs are estimated to be 57 to 69 million €, 7.3 to 9.3 billion € and 8.9 to 11.9 billion € for S1, S2 and S3, respectively. The operation costs will be 22.0, 101.7 and 109.1 million € per year for S1, S2 and S3, respectively. The benefit research question (RQ1.3) is answered that the benefits due to travel time savings are 4.7 - 9.3, 33.9 - 87.2, 49.4 - 122.5 million € per year for S1, S2 and S3, respectively.

The answer to the main research question (comparison of scenarios with benefit-cost ratios) is that from the current point of view, scenario 1 (direct connection on current infrastructure) is the most beneficial, scoring the highest among the three scenarios with a BCR of 0.19-0.39. However, for the two time scope scenarios for 2050, scenario 3 (*the Metropolitan Network*) may be more recommended than the already planned-to-be-realised scenario 2 (the TEN-T) due to a higher BCR (0.10-0.31 vs. 0.08-0.26). From the comparison between countries, it seems that for the Netherlands scenario 3 is the most beneficial (0.19-0.64), for Poland it is scenario 1 (0.17-0.32), while for Germany all scenarios are comparable.

There were also several remarkable findings of this thesis. The completion of the TEN-T will bring a very major travel time improvement between Amsterdam and Warsaw. If even more investments are made, in line with *the Metropolitan Network*, the travel time could be further reduced to only 50% of the current travel time (towards 6.5 h). From the document analysis it also turns out that the current plans for Polish HSR on the ABW corridor are completely compliant with *the Metropolitan Network*, which indicates a high level of ambition in this country's plans for improvements in railways and may make realisation of *the Metropolitan Network* more feasible on the corridor.

To conclude, the investigation made in this thesis arrived successfully at answers to all four questions. Out of the three alternatives, a direct Amsterdam - Berlin - Warsaw connection on the current infrastructure is recommended to be realised, while it is also advised to further research the possibility of implementation of the *Metropolitan Network*'s solutions into national and TEN-T plans. Additionally, it was also concluded that the TEN-T and *the Metropolitan Network* will (or would) induce a very significant modal shift from aviation to railways on the ABW corridor. Significant travel time reductions between Amsterdam, Berlin and Warsaw are indeed feasible, and with the plans for the Trans-European Transport Network, they are to be realised, indicating major benefits for this corridor's travellers in the future.

12. Recommendations

Based on the results of this thesis, several recommendations can be formed. Firstly, it is known that the TEN-T will influence the travel time on the ABW greatly. This can and most likely will impact not only the possibility of creating the *North Sea - Baltic Express*, but also has implications for other medium- and long-distance train services, including the (successors of) *Intercity Berlijn* and *Berlin-Warszawa Express.*

Secondly, although the scenario's benefit-cost ratios emerging from this thesis are below 1, oscillating between 0.1 and 0.3-0.4, it needs to be remembered that neither the costs nor the benefits were fully estimated. Moreover, most of the infrastructure in the scenarios is to be mainly nationally used, thus the realisation of given infrastructural measures may mainly depend on benefits for national railway traffic. External costs saved on other modes are also a crucial benefit in terms of the 2050 EU goal of achieving climate neutrality, which benefit was excluded in this thesis. This suggests that it is advised to perform actual cost-benefit analyses, and the aforementioned benefit-cost ratios cannot provide a concrete and robust recommendation on whether to undertake measures from the scenarios.

Thirdly, although scenario 2 (TEN-T) and scenario 3 (*the Metropolitan Network*) have a long time scope (2050), scenario 1 was made for the current infrastructure. As could be seen in the results, a direct service between Amsterdam, Berlin and Warsaw stopping only in the largest cities has the potential to reduce the travel time on its route by up to 2.5 hours, bringing significant benefits to travellers. Even though the NSBE's integration into timetables was beyond the scope of this thesis, it may be the case that a night train with the NSBE's route can be easier to integrate, while being a better and more attractive product for travellers on very long journeys, such as from Amsterdam to Warsaw. Creation of international night trains up to 1,250 km already lies in the Dutch public transport strategy (Ministry of IenW, 2021), and the NSBE's route is shorter than this with its length of ~1,150 km. Such a service could be called, for example, the Hanseatic Sleeper and could already be a major improvement on the corridor. Therefore, it is worthy to further investigate the creation of such a service.

Fourthly, from the results it could also be concluded that *the Metropolitan Network* brings very major travel time reductions on this corridor not only compared to the current situation (Amsterdam - Warsaw by 50%, Amsterdam - Berlin by 40%), but also compared to the TEN-T in 2050 (Amsterdam - Warsaw by 19%, Amsterdam - Berlin by 26%). *The Metropolitan Network* also has the potential to reduce the modal split of aviation very significantly - by 28% between Amsterdam and Warsaw and by 35% between Amsterdam and Berlin. This also suggests that it could also be the case for other international travels in the European Union if *the Metropolitan Network* was to be constructed. Therefore, it can be concluded that further research into implementation of certain solutions proposed by *the Metropolitan Network* is advisable.

13. References

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14. Appendices

14.1. Appendix A: Current train vs. plane travel time

Table A.1. Amsterdam Centraal - Warszawa Centralna (based on NS, KLM and PKP PLK data and DB timetable for 18.06.2024)

Amsterdam Centraal - Schiphol airport	0:15	*train travel*
time for check-in, security control, embarking	2:00	*according to KLM*
Schiphol airport - Warsaw Chopin airport	2:00	*plane travel*
time to disembark, collect luggage	0:45	*assumption*
Warsaw Chopin airport - Warszawa Centralna	0:21	*train travel*
SUM	**5:21**	**hours**
Amsterdam Centraal - Berlin Hbf *(IC Berlijn)*	5:52	
Berlin Hbf - Warszawa Centralna *(Berlin-Warszawa Express)*	5:16	
SUM	**11:08**	**hours**

The calculations do not include time needed to transfer/wait for the connection (for aviation from/to airport station from/to the airport itself, for train 2-hour transfer time at Berlin Hbf).

14.2. Appendix B: Broadened overview of national railway plans

Table B.1. Relevant plans being a part of *OV 2040* (Ministry of IenW, 2021)

Part of *OV 2040*	**Comment (if applicable)**
Further development of ERTMS on the Dutch net to shorten headway times	Some lines until 2031, whole net towards 2050
Consideration of switching the current 1.5 kV DC electrification system to a new one	*E.g. 3 kV DC*
Possible growth towards 15 million and more international train passengers	
Great role of international connections for the competitive position of the Netherlands	*Creation of a sustainable, attractive and reliable alternative for short-distance flights*
Possible change of current connection of Amsterdam and Berlin	*Two alternative routings to the current one via Deventer - routing with a transfer in the Ruhr via Arnhem and a routing via Zwolle*
Night trains offering an attractive international product on routes up to 1250 km	
Amsterdam Zuid to become the international train station of the Netherlands	*Shifting focus of international railway connections from Amsterdam Centraal*

Table B.2. Infrastructural changes proposed by 'Landelijke Netwerkuitwerking Spoor 2040. Toekomstbeeld OV' (2020)

Relevant part of the ABW corridor	**Measure**
Amersfoort - Apeldoorn	Speed upgrade
Almere Oostvaarders - Lelystad	Speed upgrade to 160 km/h
Route of ICE Amsterdam - Frankfurt (Main) (Amsterdam - Utrecht - Arnhem - German border)	Speed upgrade to between 160 and 200 km/h
Amsterdam - Utrecht, Schiphol - Amsterdam - Almere - Lelystad	More frequent train services
Amsterdam - Twente	New intercity service via *Sallandlijn*, which is to be expanded to 2 tracks, shortening travel time by 15-20 minutes
Amsterdam - Berlin	Train services to Berlin with an alternative routing via Zwolle

Table B.3. Overview of Deutschlandtakt (2020) infrastructural changes for the ABW corridor

Infrastructural changes	
Relevant part of the ABW corridor	***Measure***
Arnhem - Oberhausen, Rheine - Osnabrück, Stendal - Wolfsburg; nodes of Hanover and Berlin	Headway times between trains to be shortened, capacity increase
Löhne - Osnabrück	Speed upgrade from 140 to 160 km/h
Wolfsburg - Berlin	Speed upgrade from most of the line being 250 km/h to mostly 300 km/h
Berlin - Frankfurt (Oder)	Expansion of train services
Hannover Hbf	Shortening of transfer times by 1 minute due to an additional passenger underpass
Bielefeld - Hannover	Additional HSL to be built as a priority *(the corridor between Hannover and the Ruhr is specified as extremely busy and unable to host the target timetable of 2030)*

14.3. Appendix C: Overview of the TEN-T lines on the ABW corridor

Table C.1. Current corridor

Line	Type of network	Type of service
Amsterdam Zuid/Amsterdam Centraal - German border (via Hilversum and Hengelo)	Core	Conventional
German border - Minden	Core	Conventional
Minden - Haste	Core	HS
Haste - Wunstorf	Core	Conventional
Wunstorf - Hannover Hbf	Core	HS
Hannover Hbf - Lehrte	Core	Conventional
Lehrte - Berlin-Spandau (via Rathenow)	Core	HS
Berlin-Spandau - Berlin Hbf (via Westkreuz)	Core	Conventional
Berlin Hbf - Polish border (via Erkner and Frankfurt (Oder))	Core	Conventional[1]
Polish border - Poznań Główny	Core	Conventional
Poznań Główny - Warszawa Gołąbki (via Konin, Kutno and Sochaczew)	Comprehensive	Conventional
Section around Warszawa Gołąbki station	Extended Core	Conventional
(Connecting line Warszawa Gołąbki - Warszawa Włochy)	(NA)	(NA)
Warszawa Włochy - Warszawa Wschodnia	Core	Conventional

[1] *To be upgraded to HS on the section Berlin Ostendgestell - Frankfurt (Oder) according to the regulation 2013, upgrade not present in the 2024 revision of the regulation*

Table C.2. Alternative A

Line	Type of network	Type of service
Weesp - Wierden (via Almere, Lelystad and Zwolle)	Comprehensive	Conventional

Table C.3. Alternative B1

Line	Type of network	Type of service
Amsterdam Zuid/Amsterdam Centraal - German border (via Utrecht and Arnhem)	Core	Conventional
German border - Oberhausen	Core	Conventional
Oberhausen - Dortmund (via Gelsenkirchen)	Comprehensive	Conventional
Section around Dortmund Hbf	Core	Conventional
Dortmund - Bielefeld	Core	HS
Bielefeld - Hannover[2]	Extended Core	HS (new construction)

[2]*Added in the revision of the regulation*

Table C.4. Alternative B2

Line	Type of network	Type of service
Oberhausen - Dortmund (via Essen)	Core	Conventional

Table C.5. Alternative C

Line	Type of network	Type of service
Frankfurt (Oder) - Poznań	Comprehensive	HS (new construction)

Table C.6. Alternative D

Line	Type of network	Type of service
Poznań - Sieradz	Core	HS (new construction)
Sieradz - Lublinek	Core	HS (new construction)
Lublinek - Łódź Retkinia	Extended Core	Conventional
Łódź Retkinia - Warszawa Gołąbki (via Łódź Fabryczna)	Core	HS (new construction)

14.4. Appendix D: NSBE stations as attracting nodes

Table D.1. Visualisations of “attracting nodes” - Amsterdam, Amersfoort/Alme., Zwolle, Hengelo

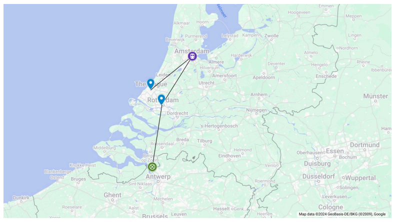
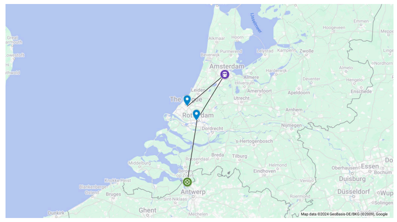
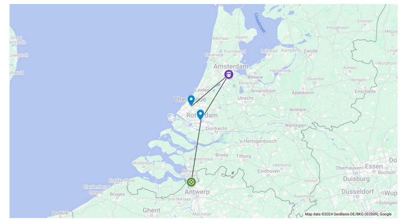
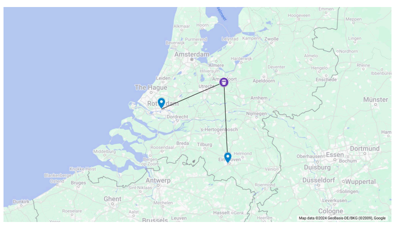
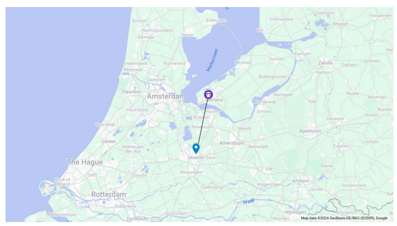
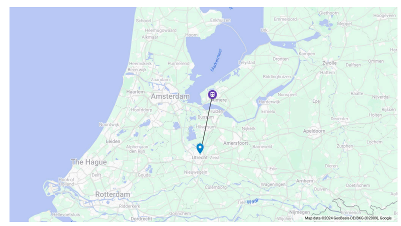
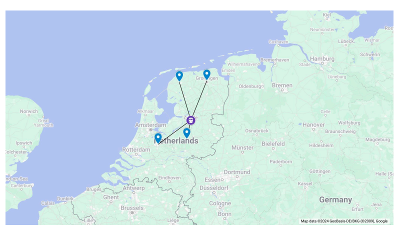
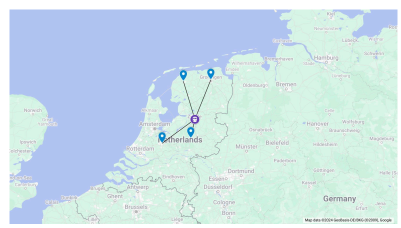
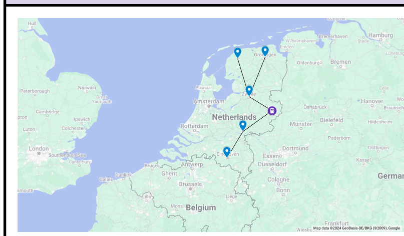
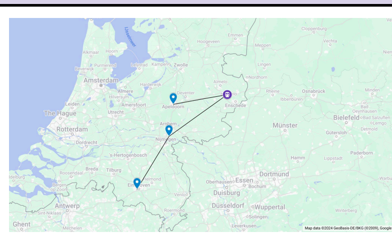
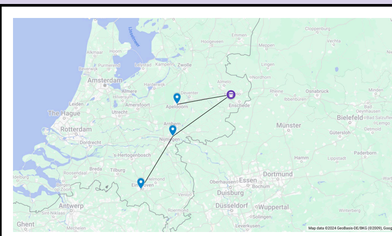
<table>
<tr><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th></tr>
<tr><td colspan="3">Amsterdam</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Areas: The Hague, Rotterdam; Countries: Belgium</td></tr>
<tr><td colspan="3">Amersfoort /Almere</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Areas (Amersfoort): Rotterdam, Eindhoven</td><td colspan="2">Areas (Almere): Utrecht</td></tr>
<tr><td colspan="3">Zwolle</td></tr>
<tr><td rowspan="2">stop not served in S1</td><td></td><td></td></tr>
<tr><td colspan="2">Areas: Leeuwarden, Groningen, Utrecht, Apeldoorn</td></tr>
<tr><td colspan="3">Hengelo</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Areas: Leeuwarden, Groningen, Utrecht, Apeldoorn, Eindhoven</td><td colspan="2">Areas: Apeldoorn, Arnhem-Nijmegen, Eindhoven</td></tr>
</table>

Table D.2. Visualisations of the “attracting nodes” - Osnabrück, Hanover, Berlin, Frankfurt (O)

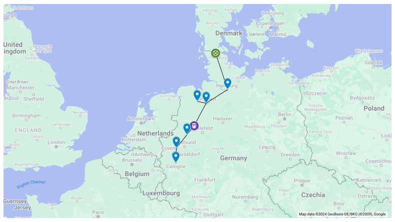
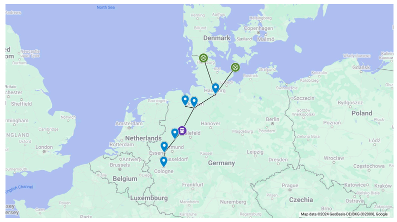
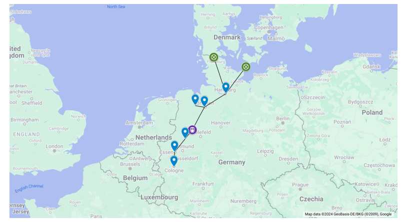
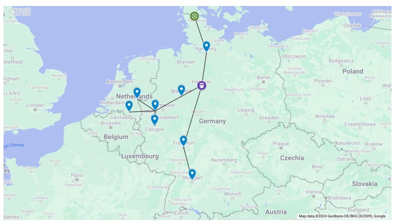
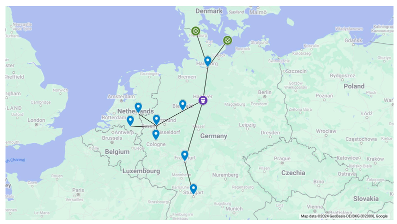
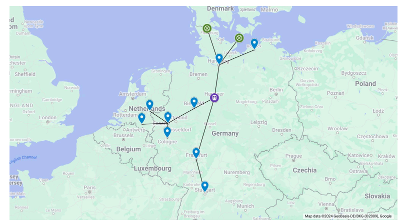
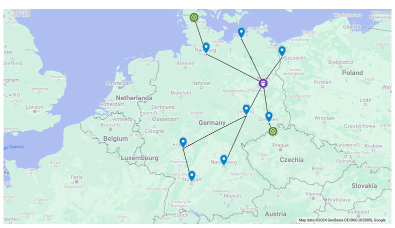
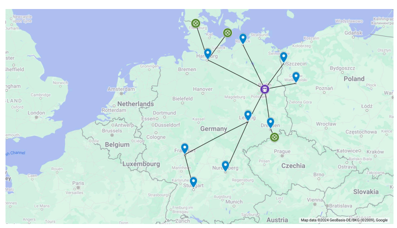
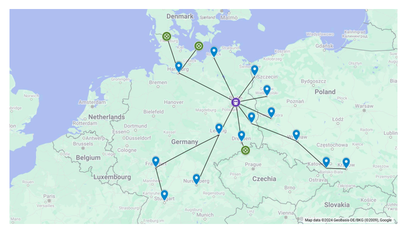
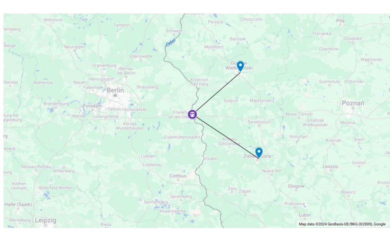
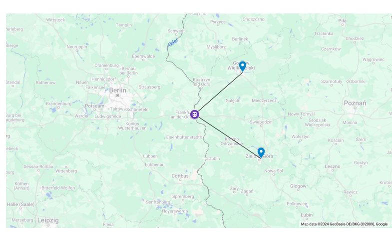
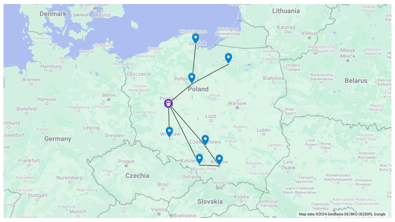
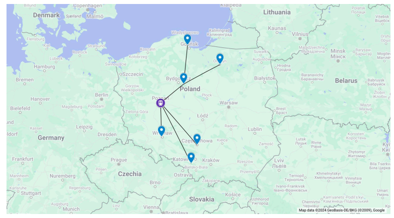
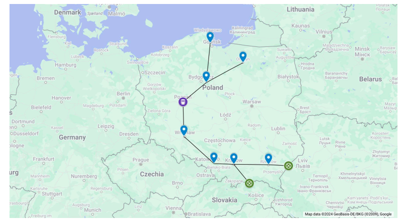
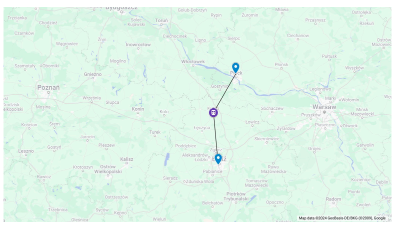
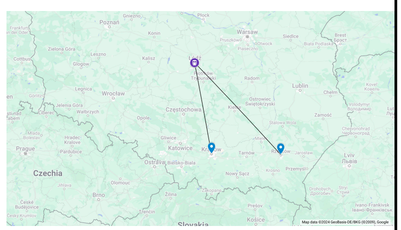
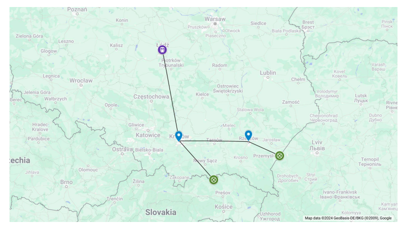
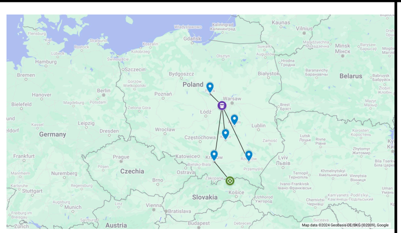
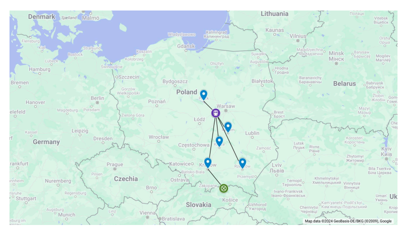
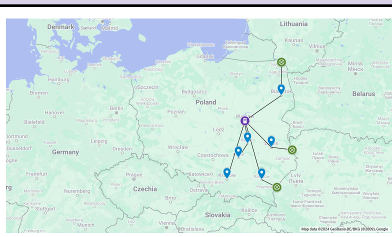
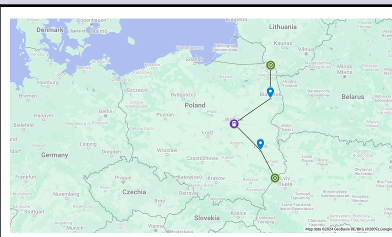
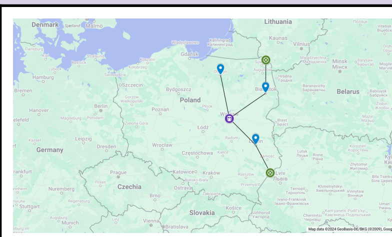
Osnabrück		
		
Areas: Cologne, Ruhr, Münster, Flensburg, Bremen, Hamburg Countries: Denmark	Areas: Cologne, Ruhr, Münster, Flensburg, Bremen, Hamburg Countries: Denmark	Areas: Cologne, Ruhr, Münster, Flensburg, Bremen, Hamburg Countries: Denmark
Hanover		
		
Areas: Hamburg, Arnhem-Nijmegen, Ruhr, Cologne, Bielefeld Countries: Denmark	Areas: Hamburg, Arnhem-Nijmegen, Ruhr, Cologne, Bielefeld Countries: Denmark	Areas: Rostock, Hamburg Arnhem-Nijmegen, Ruhr, Cologne, Bielefeld; Countries: Denmark
Berlin		
		
Areas: Hamburg, Rostock, Szczecin, Dresden, Leipzig, Countries: Denmark, Czechia	Areas: Hamburg, Rostock, Szczecin, Gorzów, Dresden, Leipzig Countries: Denmark, Czechia	Areas: Hamburg, Rostock, Szczecin, Gorzów, Zielona Góra, Cottbus, Wrocław, Katowice-Ostrava, Krakow, Dresden, Leipzig Countries: Denmark, Czechia
Frankfurt (Oder)		
		*stop not served in S3*
Areas: Gorzów, Zielona Góra	Areas: Gorzów, Zielona Góra	

Table D.3. Visualisations of the "attracting nodes" - Poznań, Kutno/Łódź, CPK (STH), Warsaw

Poznań		
		
Areas: Tricity, Olsztyn, Bydgoszcz-Toruń, Częstochowa, Kraków, Katowice-Ostrava, Wrocław	Areas: Tricity, Olsztyn, Bydgoszcz-Toruń, Częstochowa, Katowice-Ostrava, Wrocław	Areas: Tricity, Olsztyn, Bydgoszcz - Toruń, Kraków, Katowice-Ostrava, Wrocław; Countries: Slovakia, UA
Kutno/Łódź		
		
Areas (Kutno): Łódź, Płock	Areas (Łódź): Kraków, Rzeszów	Areas (Łódź): Kraków, Rzeszów Countries: Slovakia, Ukraine
CPK (Solidarity Transport Hub)		
stop not served in S1		
	Areas: Bydgoszcz-Toruń, Radom, Kielce, Rzeszów, Kraków; Countries: Slovakia	Areas: Bydgoszcz-Toruń, Radom, Kielce, Rzeszów, Kraków; Countries: Slovakia
Warsaw		
		
Areas: Białystok, Lublin,Rzeszów, Radom, Kielce, Krakow; Countries: Lithuania, Ukraine, Slovakia	Areas: Białystok, Lublin Countries: Lithuania, Ukraine	Areas: Olsztyn, Białystok, Lublin Countries: Lithuania, Ukraine

14.5. Appendix E: Assumptions behind travel time determination

Table E.1. Assumptions behind travel time determination for S1

Assumption	Explanation
Travel time between two stations remains the same if no stop is skipped	NSBE in S1 is to use the same train stock and infrastructure as ICB and BWE.
NSBE has planning priority	Due to limited time, this priority is assumed not to have to analyse the whole (inter)national train networks. This also means that the travel time result is possibly minimum travel time, and stop durations could potentially have to change.
Vectron MS with 9 wagons	*Explained in Section 2.3.*
Performance under 3 kV DC and 15 kV 16.7 Hz AC is equivalent to the average of performance under 1.5 kV DC and 25 kV 50 Hz DC	Only performance data for 1.5 kV DC and 25 kV AC was available for this stock. While performance of rolling stock is generally the worst under 1.5 kV DC and the best under 25 kV AC for the four voltages listed, it generally lies in between these for the other two. Therefore, for 15 kV AC and 3 kV DC the average between the travel time saving for 1.5 kV DC and the one for 25 kV AC was assumed.
Train performance of 90%	Train performance is the value that is assumed, so that in case of a delay the train can decrease its delay, increasing its speed closer to the max. speed allowed. In the Netherlands 93 to 94% is assumed, and from the calculations performed on the itinerary data for ICB in Germany, this number also turned out to be slightly above 90%. 90% was deemed as a safe choice, as it is only slightly below the generally assumed values, and introduces some margin to account for other assumptions that could decrease the travel time. For example, this implies that the NSBE would reach 144 km/h when the limit is 160 km/h according to the schedule.
Current stop durations for the stations	The stop durations were taken directly from timetables for ICB and BWE, except for Poznań Główny. The stop there is 11-min-long, as PKP IC lacks a sufficient number of multi - system locomotives and there the locomotive is changed. NSBE is to be dragged by the same locomotive on all its way, therefore the stop duration can be decreased to 4 minutes.
ERTMS on all sections	Although ERTMS will not be implemented on all the used infrastructure by 2025, it makes it significantly simpler for the simulation to be run in OpenTrack. This means that for the skipped stations that have currently no ERTMS, OpenTrack can somewhat underestimate the travel time needed. ProRail (de Pundert et al., 2010) made simulations for the comparison of ERTMS and ATB) for Utrecht - 's Hertogenbosch, and the difference in travel time was under 2.5% for intercity trains. So it is expected that this assumption will have a very limited effect on the travel time in S1.

Table E.2. Assumptions behind travel time determination for S2 and S3

Assumption	Explanation
Train performance of 90%	*Same as in Table E.1.*
NSBE has planning priority	*Same as in Table E.1.*
ETR 1000 rolling stock	*Explained in Section 2.3.*
Current stop duration	The duration of stops was assumed to be equivalent to ICB or BWE, except the stations that are currently not served or stations that changed their role, that is: - New stations assumed with 2 minutes duration as a default: Almere Centrum, Zwolle, CPK (STH) - Łódź Fabryczna was assigned 3 minutes, as it is expected to attract many passengers - Hengelo and Frankfurt (O) were assigned 3 minutes, as these are the closest to borders and can serve as a technical point.
Routing of new HSR if currently unknown	Not all routing of the new railway lines until 2050 is known yet. For S2 the only such line is Frankfurt (O) - Poznań HSL. For S3 multiple lines were assumed, as the authors of *the Metropolitan Network* only propose rough routings. All routings were assumed with approximating geometry needed for given speed parameters, while omitting lakes, cities, towns and other infrastructure. If the geometry of current tracks was suitable, the routing was assumed to overlap current tracks. These routings are not exact, as determining them is not the focus of this thesis. The assumed routings can be found in Appendix G.
Speed parameters on Polish HSR from CPK plans (350 km/h)	New CPK HSR infrastructure is planned with 350 km/h design speed, but the speed will be limited to 250 km/h upon opening. The opening of the *Y-line* is planned in 2030s, therefore it was deemed as realistic that the speed will already be raised to 350 km/h by 2050 . Moreover, it is currently discussed whether the 350 km/h upgrade should not be realised already during the Y-line's construction (Czubiński, 2024).
Speed parameter on Frankfurt (Oder) - Poznań HSL from TEN-T (300 km/h)	New HSLs as defined by Eurostat (2023) have to have a minimum speed of at least 250 km/h. As in general the assumption behind new Polish HSR network is for it to have a limit of 350 km/h in the future, 300 km/h limit for the Frankfurt (Oder) - Poznań HSL was deemed as a realistic assumption, as this line is to be finished by 2050 (contrary to the *Y-line*).
Speed parameters on HSLs that are currently unplanned (S3 only)	The authors of *the Metropolitan Network* (2023) assumed the design speed to be 300 km/h if it was unknown. Therefore this is also the assumption for this thesis.
Voltage change possible with no time loss	The change of voltages happens with no time loss (either on stations or can be done at maximum line speed).
Voltages for lines that are to be built and no information was known (S3 only)	The new lines that would need to be built for *the Metropolitan Network* (but not for national or European plans) are Almere - Zwolle - Hengelo HSL and Hengelo - Hannover HSL. The first one is assumed to have 25 kV 50 Hz AC voltage (voltage used on HSR in NL) and the second one to have 15 kV 16.7 Hz AC (voltage used on HSR in DE).

14.6. Appendix F: ETR 1000 operation data

Table F.1. Technical data used for adapting Figure F.1. and running OpenTrack (adapted from Canetta (2015) and Enes (2013))

ETR 1000 (Frecciarossa 1000)	
Length	202 m
Mass	~500 t
Voltages	1.5 kV DC 3 kV DC 15 kV 16.7 Hz AC 25 kV 50 Hz AC
Maximum tractive force	370 kN (all voltages)
Maximum power	3050 kW (1.5 kV DC); 6900 kW (3 kV DC & 15 kV 16.7 Hz AC); 9800 kW (25 kV 50 Hz AC)
Maximum speed	400 km/h
Operating speed	360 km/h
Maximum acceleration	0.7 m/s^2
Maximum deceleration	1.2 m/s^2
Deceleration used during regular decelerating	0.6 m/s^2

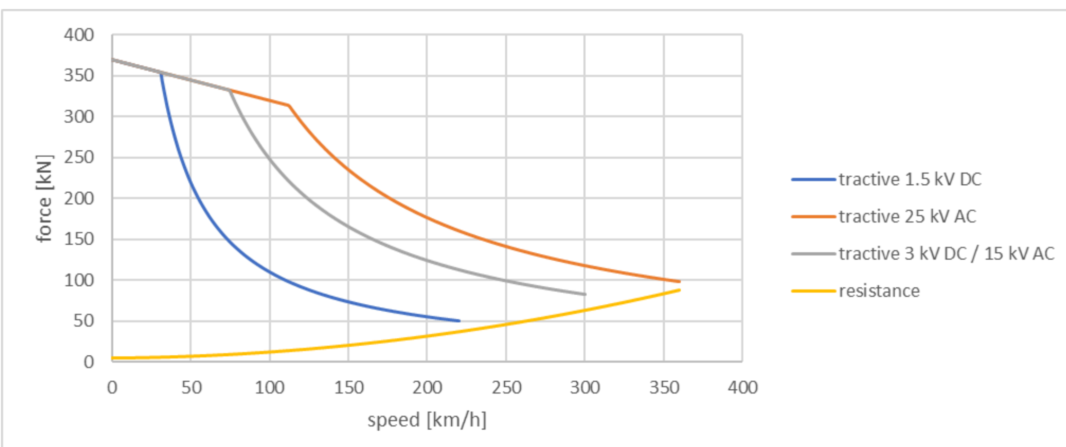


Figure F.1. Tractive and resistance forces for Frecciarossa 1000 (adapted from Canetta (2015))

14.7. Appendix G: Assumed routings for high-speed lines with unknown routings

On the figures below, black indicates a line that is currently a part of national or European plans (Frankfurt (Oder) - Poznań HSL only), purple a line from *the Metropolitan Network* that overlaps current lines only partially and turquoise/green-blue a line from *the Metropolitan Network* that could be built by modernising current lines to the standard of 300 km/h.

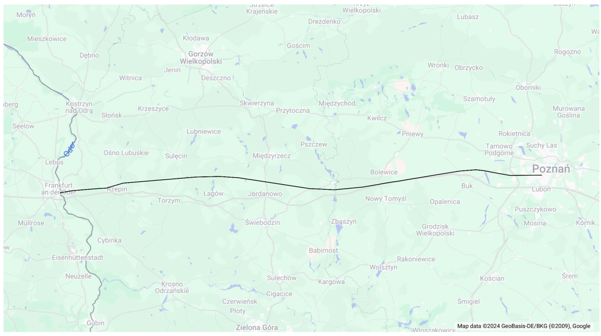


Figure G.1. Assumed routing for Frankfurt (Oder) - Poznań HSL

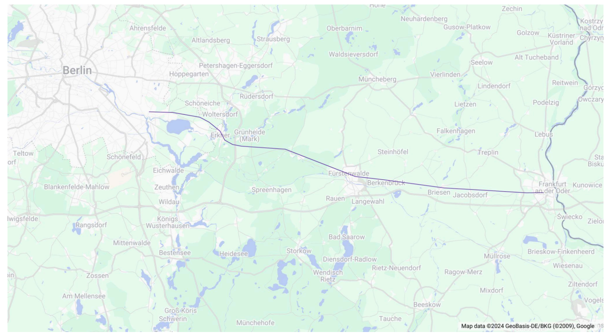


Figure G.2. Assumed routing for Berlin - Frankfurt (Oder) HSL (for S3 only)

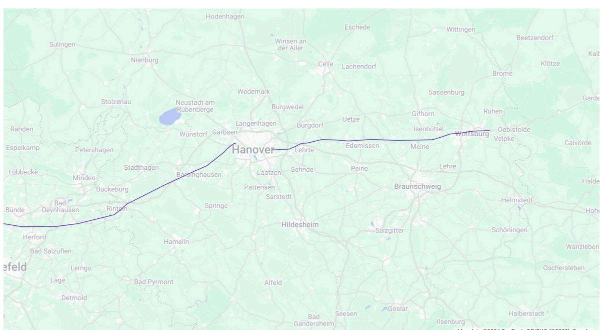


Figure G.3. Assumed routing for Wolfsburg - Hannover, and part of Hannover - Osnabrück HSLs (for S3 only)

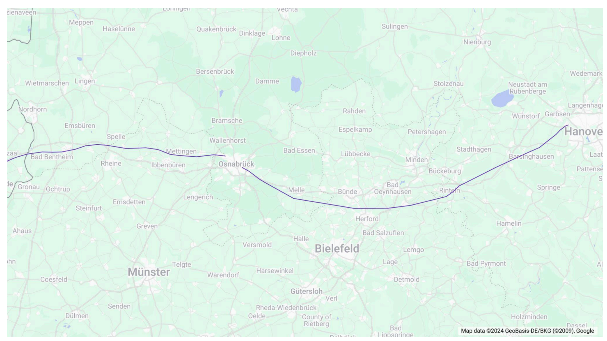


Figure G.4. Assumed routing for the second part of Hannover - Osnabrück HSLs (for S3 only)

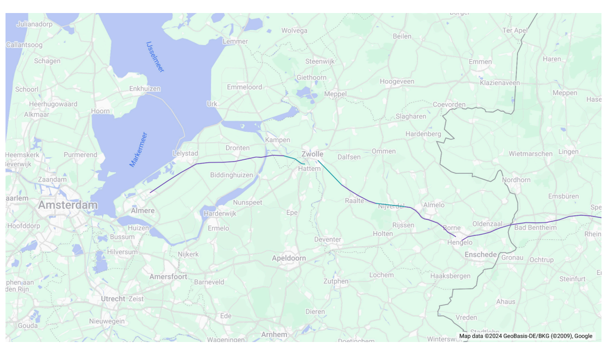


Figure G.5. Assumed routing for Dutch border - Hengelo and Hengelo - Zwolle - Almere HSL (for S3 only)

14.8. Appendix H: Cost calculations

Table H.1. Investment calculations for scenario 1

Investment costs: S1 (direct train on current infrastructure)					
Rolling stock	**Cost in mln €**	**Year of cost**	**Source**	**Cumulative price change** (Webster, n.d.)	**Cost in mln €2024**
Vectron MS	8	2019	Railway PRO (2019)	21.20%	9.7
New ÖBB Nightjet* composition (7 wagons)	40	2021	Railvolution (2021)	16.92%	46.8
*(two seat cars, two sleeping cars, three couchettes with mini-cabins; family rooms; sleeper cabs with shower facilities)					
OR					
Vectron MS	8	2019	Railway PRO (2019)	21.20%	9.7
9 new-concept PKP IC wagons***	58.9	2024	Madrjas (2024a)	0%	58.9
*** 1 1st class wagon (partially compartment and partially open) 1 2nd class compartment wagon 5 2nd class wagons (incl. 1 wagon with seats for persons with disabilities and 1 with places for bicycles) 1 restaurant wagon 1 day-night convertible wagon (compartments that can be easily converted from 6 seats to 4 couchettes)					

	Night composition (mln €2024)	**Day composition (mln €2024)**
Total	56.46	68.62
NL	9.87	8.12
DE	31.62	26.02
PL	27.14	22.33

Table H.2a. Operation costs calculations for scenario 1 (part A)

Operation costs: S1 (direct train on current infrastructure)					
Services costs (whole route)					
	Operating cost per train-km [€/train-km] (incl. stock maintenance)	**Based on country**	**Source**	**Year**	**Cumulative price increase**
	38	NL	Steer Davies Gleave (2015)	2012	30.09%
	16	DE			
	16	PL			
Total per year	22035729.15				

Table H.2b. Operation costs calculations for scenario 1 (part B)

	Route length [km]	**Route length daily per outbound-inbound connection** [km]	**Route length yearly per train** [km]	**Total operating cost** [mln €2024 per year]	
NL	174	348	127107	6.29	
DE	557.5	1115	407253.75	8.48	
PL	478.5	957	349544.25	7.28	
No new infrastructure -> no new railway line operating costs					

Table H.3a. Investment calculations for scenario 2 (part A)

Investment costs: S2 (national and European plans until 2050)										
Type of investment	**Country**	**Note**	**Length** [km]	**Cost** (in mln €/km if unit not given)	**Source**	**Year of value**	**Cumulative price increase**	**International share on the section**	**Current cost for international** [mln €]	
									min	*max*
UPGRADES										
Speed raises according to national plans										
Almere - Lelystad	NL	from 140 to 160 km/h	18.1	5.5	Upgrade between 120-159 to 160 km/h - Schade et al. (2018)	2015	27.77%	14.29%	18.18	18.18
Osnabrück - Löhne	DE	from 140 to 160 km/h	47	5.5				50%	165.14	165.14
Wolfsburg - Berlin (excl. Stendal bypass and Westhavelland Nature Park)	DE	from 250 to 300 km/h	125.2	5.4 +- 60% mln €/km	HSR upgrade - Attinà et al. (2018)			20%	69.11	276.42
Upgrade to double track - national plans										
Zwolle - Wierden	NL		37.8	500 - 1000 mln € (total)	Specific cost - Ministry of Infrastructure and Water Management (2021)	2021	16.92%	20%	116.92	233.84

Table H.3b. Investment calculations for scenario 2 (part B)

Type of investment	**Country**	**Note**	**Length** [km]	**Cost** (in mln €/km if unit not given)	**Source**	**Year of value**	**Cumulative price increase**	**International share on the section**	**Current cost for international [mln €]**	
									min	*max*
Speed raise - TEN-T (ERTMS included)										
Wierden - Almelo	NL	from 130 to 160 km/h	4.25	5.5	Upgrade between 120-159 to 160 km/h (Schade et al., 2018)	2015	27.77%	14.29%	4.27	4.27
Almelo - Hengelo	NL	from 130 to 160 km/h	12.1	5.5				14.29%	12.15	12.15
Hengelo - Oldenzaal	NL	from 125 to 160 km/h	9.77	5.5				100%	68.66	68.66
Oldenzaal - German border	DE	from 125 to 160 km/h	6.5	5.5				100%	45.68	45.68
German border - Rheine	DE	from 125/140 to 160 km/h	28.9	5.5				79.20%	160.85	160.85
Rheine - Osnabrück	DE	from 140 to 160 km/h	42.7	5.5				50%	150.03	150.03
ERTMS implementation (no speed raise)										
Löhne - Wolfsburg	DE		165.51	0.5 +- 60% mln €/km	Signalling (Attinà et al., 2018)	2015	27.77%	50%	8.63	34.51
New HSR										
Poznań - Kalisz HSR	PL	350 km/h	102	35.2 mln €2024/km (150 mln PLN2024/km) + partial upgrade 6.9 +- 60% mln €2024/km **	Upgrade - Attinà et al. (2018); Specific cost per km - LOS (2024)	2015 - Attinà et al. (2018); 2024 - LOS (2024)	0.00%	33.22%	4,073.54	4,887.37
Kalisz - Sieradz HSR	PL	350 km/h	42.5							
Sieradz - Łódź HSR	PL	350 km/h	50.4							
Łódź HSR tunnel (in construction)	PL	160 km/h	16.29							
Łódź - Warsaw HSR	PL	350 km/h	101							
Warsaw HSR tunnel	PL	200 km/h	13							
Frankfurt (O) - Poznań HSR	PL	300 km/h (assumption)	159	14.1 +- 16%	HSR construction - Attinà et al. (2018)	2015	27.77%	96.02%	2310.39	3190.54

***Y-line's cost per km is significantly higher than general cost of HSR per km in the EU, as it requires building two long under-city tunnels in Warsaw and Łódź; partial upgrade is included as the line will have 250 km/h upon opening, which is to be increased later*

Table H.3c. Investment calculations for scenario 2 (part C)

ROLLING STOCK	**Cost per train**	**Source**	**Cumulative price increase**	**Current cost** [mln €]
ETR 1000 (2)	30.8 mln €2010	Railway Gazette (2021)	36.97%	84.37352

Table H.4. Operation costs calculations for scenario 2

Operation costs: S2 (national and European plans until 2050)						
Services costs (whole route)						
	Operating cost per seat-km [€/seat-km]	**Maintenance cost per seat-km** [€/year/seat-km]	**Based on platform**	**Source**	**Year**	**Cumulative price increase**
	0.1212	0.01	ICE-3 Multi-system	Campos and de Rus (2009)	2002	60.66%
Total per year [€/year]	81,105,445.9	6,691,868.474				
Railway line costs (new infrastructure only)						
	Infrastructure maintenance cost per km [€/km]	**Based on country**	**Source**	**Year**	**Cumulative price increase**	**Percentage of international use**
HSR	31683	Belgium (due to data unavailability)	Campos and de Rus (2009)	2002	60.66%	54.23%
Total per year [€/year]	13,909,708.31					
Country	**Route length** [km]	**Percentage of route per country**	**Total operating cost** [mln €2024 per year]			
NL	190.97	15.31%	15.57			
DE	546.02	43.76%	44.51			
PL	510.69	40.93%	41.63			

Table H.5a. Investment calculations for scenario 3 (part A)

Investment costs: S3 *(the Metropolitan Network)*										
Type of investment	**Country**	**Note**	**Length** [km]	**Cost** (in mln €/km if unit not given)	**Source**	**Year of value**	**Cumulative price increase**	**International share on the section**	**Current cost for international** [mln €]	
									min	*max*
New HSR (new routing) - Metropolitan Network (routing assumed)										
Almere - Zwolle HSR	NL	300 km/h	46.6	14.1 +- 16%	HSR construction - Attinà et al. (2018)	2015	27.77%	33.33%	235.07	324.62
Raalte HSR bypass	NL	300 km/h	12.7					33.33%	64.06	88.47
Wierden - Hengelo HSR	NL	300 km/h (largely next to A35)	19.8					33.33%	99.88	137.93
Hengelo - German border HSR	NL	300 km/h	17.1					100.00 %	258.78	357.36
German border - Osnabrück HSR	DE	300 km/h	65.8					62%	617.37	852.56
Osnabrück - Hannover HSR	DE	300 km/h	117					30.06%	532.23	734.99
Hannover - Wolfsburg HSR	DE	300 km/h	72					25%	272.40	376.17
Briesen - Frankfurt (O) HSR	DE	300 km/h	18.3					50.00%	138.47	191.22
New HSR (upgrade of current lines) - Metropolitan Network (routing assumed)										
Part of Hanzelijn (west of Zwolle)	NL	300 km/h	7.52	5.4 +- 60%	HSR upgrade - Attinà et al. (2018)	2015	27.77%	33.33%	6.92	27.67
Sallandlijn (Zwolle - Heino)	NL	300 km/h	11					33.33%	10.12	40.48
Sallandlijn (around Nijverdal and Wierden)	NL	300 km/h	9.81					33.33%	9.02	36.10
Berlin Köpenick - Briesen HSR	DE	300 km/h	49.2					50.00%	67.89	271.57
Speed raises according to national plans										
Wolfsburg - Berlin (excl. Stendal bypass and Westhavelland Nature Park)	DE	from 250 to 300 km/h	125.2	5.4 +- 60%	HSR upgrade - Attinà et al. (2018)	2015	27.77%	20%	69.11	276.42

Table H.5b. Investment calculations for scenario 3 (part B)

Type of investment	**Country**	**Note**	**Length** [km]	**Cost** (in mln €/km if unit not given)	**Source**	**Year of value**	**Cumulative price increase**	**International share on the section**	**Current cost for international** [mln €]	
									min	*max*
New HSR - national plans (Y-line)										
Poznań - Kalisz HSR	PL	350 km/h	102	35.2 mln €2024/km (150 mln PLN2024/km) + upgrade after construction 6.9 +- 60% mln €2024/km	Upgrade - Attinà et al. (2018); Specific cost per km - LOS (2024)	2015 - Attinà et al. (2018); 2024 - LOS (2024)	0%	33.22%	4073.89	4887.80
Kalisz - Sieradz HSR	PL	350 km/h	42.5							
Sieradz - Łódź HSR	PL	350 km/h	50.4							
Łódź HSR tunnel (in construction)	PL	160 km/h	16.29							
Łódź - Warsaw HSR	PL	350 km/h	101							
Warsaw HSR tunnel	PL	200 km/h	13							
New HSR - TEN-T (routing assumed)										
Frankfurt (O) - Poznań HSR	PL	300 km/h (assumption)	159	14.1 +- 16%	HSR construction - Attinà et al. (2018)	2015	27.77%	96.02%	2310.39	3190.54

Rolling stock costs	**Cost per train**	**Source**	**Cumulative price increase**	**Current cost [mln €]**
ETR 1000 (2)	30.8 mln €2010	Railway Gazette (2021)	36.97%	84.37

Table H.6a. Operation costs calculations for scenario 3 (Part A)

Operation costs: S3 *(the Metropolitan Network)*						
Services costs (whole route)						
	Operating cost per seat-km [€/seat-km]	**Maintenance cost per seat-km** [€/year/seat-km]	**Based on platform**	**Source**	**Year**	**Cumulative price increase**
	0.1212	0.01	ICE-3 Multi-system	Campos and de Rus (2009)	2002	60.66%
Total per per year [€/year]	79,382,813.24	6,549,737.066				

Table H.6b. Operation costs calculations for scenario 3 (Part B)

Railway line costs (new infrastructure only)						
	Infrastructure maintenance cost per km [€/km]	**Based on country**	**Source**	**Year**	Cumulative price increase	**Percentage of international use**
HSR	31683	Belgium (due to data unavailability)	Campos and de Rus (2009)	2002	60.66%	48.13%
Total per year [€/year]	23,193,531.81					

Country	**Route length** [km]	**Percentage of route per country**	**Total operating cost** [mln €2024 per year]
NL	171.3	14.03%	18.84
DE	539.19	44.15%	59.29
PL	510.69	41.82%	56.16

14.9. Appendix I: Assumptions behind RHDHV model operation

Table I.1. An overview of assumptions made to operate the RHDHV model

Assumption	Explanation
Medium-distance travels not considered	This is an inherent assumption of the RHDHV model, as it is constructed for international long-distance trains. The travel times for these trains will mostly not benefit medium-distance travellers (e.g. Amsterdam - Hengelo), as these trains are usually not offered with sufficient frequency to do this.
2.10% yearly growth in passenger numbers	This assumption was decided on with an RHDHV expert on the model, who also judged this number to be very conservative and a minimum growth that should be assumed for international EU long-distance connections. As this number is a conservative assumption, it may mean that the time savings benefits arrived at are minimum benefits.
Omission of some stops in the calculation due to no data in the model (also see Appendix J)	Some of the stops the NSBE is to serve were not present in the model due to their small size (Bad Bentheim, Zwolle and Frankfurt (O)) or a lack of data for a big project that is to be realised (CPK (STH) stop).
No in-city travel	Travels solely inside metropolitan areas (e.g. Amsterdam Zuid - Almere Centrum) are not allowed. This also goes in accordance with the intercity stopping policies in Germany and Poland.
List of cities (third cities) from/to which the NSBE travellers may transfer from/to	This list can be seen in Appendix D. These included the biggest metropolitan areas that are to possibly be well-connected to the NSBE (therefore the NSBE would serve not only the areas it stops in). For each scenario (as the infrastructure for the cities changes as well) there were rough estimations of travel times from/to these cities from/to the connecting stop (see Appendix D). For EU countries besides NL, DE and PL only Brussels, Antwerp, Prague and Ostrava were considered, due to their favourable geographical alignment in relation to the NSBE.
No complex international travel	If there were two transfers to be made to travel between a given OD pair, and one of these transfer connections would be extensive, the given OD pair was not considered (this mainly applies to travels between third cities in PL and third cities in DE).

14.10. Appendix J: Metropolitan areas considered in used model

Table J.1. Stops of the NSBE and the metropolitan areas assigned for them in RHDHV model

Stops of the NSBE					
Stop area	**Scenario**	**Metropolitan area assigned**	**Stop area**	**Scenario**	**Metropolitan area assigned**
Amsterdam (incl. Almere)	all	Amsterdam	Frankfurt (Oder)	S1&2	NA (nearby Zielona Góra and Gorzów also NA)
Zwolle	S2&3	NA	Poznań	all	Poznań
Hengelo (Enschede)	all	Enschede (Twente)	Kutno	S1	Łódź (Kutno to serve Łódź)
Bad Bentheim	S1	NA	Łódź	S2&3	Łódź
Osnabrück	all	Osnabrück	CPK	S2&3	NA
Hannover	all	Hannover	Warsaw	all	Warsaw
Berlin	all	Berlin			

Table J.2. Metropolitan areas to be well-connected to the NSBE

Considered areas	Included in the model?	Considered areas	Included in the model?
Brussels	✓	Leipzig	✓
Antwerpen	✓	Frankfurt (O) (S3)	NA
The Hague - Rotterdam	✓	Prague	✓
Utrecht	✓	Szczecin	NA
Eindhoven	✓	Gorzów Wlkp.i	NA
Apeldoorn	NA	Zielona Góra	NA
Leeuwarden	NA	Wroclaw	✓
Groningen	✓	Gdansk	✓
Arnhem-Nijmegen	✓	Bydgoszcz - Toruń	NA
Zwolle (S1 only)	NA	Olsztyn	NA
Cologne	✓	Częstochowa	NA
Ruhr agglomeration	✓	Kielce	NA
Münster	NA	Radom	NA
Bielefeld	NA	Płock	NA
Bremen	✓	Katowice-Ostrava	as Katowice & Ostrava (Bielsko-B. NA)
Flensburg	NA	Krakow	✓
Hamburg	✓	Bialystok	NA
Rostock (S3 only)	NA	Rzeszów	✓
Dresden	✓	Lublin	✓

Table J.3. Assumed travel times between the connected city and the transfer city

	Connected metropolitan area and assumed travel time to the transfer stop					
Transfer stop	**S1** (2025; current infrastructure)		**S2** (2050; TEN-T+national plans)		**S3** (2050; *the Metropolitan Network*)	
Amsterdam	Brussels	02:01	Brussels	02:01	Brussels	02:01
	Antwerpen	01:23	Antwerpen	01:23	Antwerpen	01:23
	Rotterdam	00:41	Rotterdam	00:41	Rotterdam	00:41
	Utrecht	00:26	Utrecht	00:20	Utrecht	00:10
			Groningen	01:30	Groningen	00:40
Hengelo	Groningen	01:54	Eindhoven	02:00	Eindhoven	02:00
	Eindhoven	02:17	Arnhem	00:50	Arnhem	00:50
	Arnhem	01:03				
Osnabrück	Duisburg	01:22	Bremen	00:30	Bremen	00:30
	Bremen	00:51			Duisburg	01:00
					Cologne	01:50
Hannover	Cologne	03:08	Duisburg	01:00		
			Cologne	01:50		
Berlin	Hamburg	02:30	Hamburg	02:30	Hamburg	02:30
	Dresden	01:49	Dresden	00:50	Dresden	00:50
	Leipzig	01:15	Leipzig	01:15	Leipzig	01:15
	Prague	04:15	Prague	01:30	Prague	01:30
					Wrocław	01:30
					Krakow	02:50
					Katowice	02:30
					Ostrava	02:50
Poznań	Wrocław	01:30	Wrocław	00:50	Gdańsk	01:20
	Gdańsk	02:55	Gdańsk	01:30		
	Katowice	04:00				
	Ostrava	05:50				
Łódź			Rzeszów	02:30	Rzeszów	02:50
			Krakow	01:50		
			Katowice	01:10		
			Ostrava	01:40		
Warsaw	Krakow	02:15	Lublin	01:30	Lublin	00:50
	Lublin	01:54				
	Rzeszów	04:00				

14.11. Appendix K: VTTS values

Table K.1. Values of travel time savings on railways/public transport for the Netherlands, Germany and Poland

	Values of travel time savings [€2024/h]		
distance [km]	**Netherlands** (Kouwenhoven et al., 2023)	**Germany** (Axhausen et al., 2015)	**Poland** (estimate)
<10	10.16	4.93	3.44
10-20		5.23	3.64
20-30		7.03	4.89
30-40		8.09	5.62
40-50		9.02	6.27
50-60		9.62	6.70
60-70		10.16	7.07
70-80		10.59	7.37
80-90		11.03	7.67
90-100		11.31	7.87
100-125		11.83	8.23
125-150		12.42	8.64
150-175		13.15	9.15
175-200		13.61	9.47
200-225		13.94	9.70
225-250		14.23	9.90
250-300		14.67	10.21
300-350		15.27	10.62
350-400		15.69	10.91
400-450		16.07	11.18
450-500		16.47	11.46
>500		17.34	12.06

14.12. Appendix L: Modal splits and modal shifts

In the tables below WAR is the metropolitan area of Warsaw, ŁÓD - Łódź, POZ - Poznań, BER - Berlin, HAN - Hannover, OSN - Osnabrück, Twente - Hengelo/Enschede, AMS - Amsterdam.

Table L.1. Modal split on the corridor of the NSBE (result of the RHDHV model)

Modal split: train																	
Current	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS		S1	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS
AMS	0%	1%	2%	25%	41%	35%				AMS	2%	10%	18%	30%	47%	54%		
TWE	4%	14%	23%	72%	61%					TWE	17%	46%	62%	73%	62%			
OSN	7%	23%	0%	78%				50%		OSN	26%	60%	0%	79%				54%
HAN	3%	13%	0%				59%	41%		HAN	24%	55%	0%				62%	47%
BER	29%	55%				62%	59%	25%		BER	34%	61%				79%	73%	30%
POZ	51%	64%			0%	0%	18%	2%		POZ	52%	65%			0%	0%	62%	18%
ŁÓD			64%	55%	13%	18%	12%	1%		ŁÓD			65%	61%	55%	60%	46%	10%
WAR			51%	29%	3%	6%	4%	0%		WAR			52%	34%	24%	26%	17%	2%
S2	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS		S3	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS
AMS	14%	36%	49%	47%	57%	62%				AMS	31%	61%	74%	70%	75%	73%		
TWE	47%	75%	82%	81%	67%					TWE	64%	86%	90%	89%	76%			
OSN	58%	82%	0%	83%				62%		OSN	70%	88%	0%	88%				73%
HAN	63%	81%	0%				67%	57%		HAN	70%	85%	0%				76%	75%
BER	68%	80%				83%	81%	47%		BER	72%	83%				88%	89%	70%
POZ	67%	70%			0%	0%	82%	49%		POZ	67%	70%			0%	0%	90%	74%
ŁÓD			70%	80%	81%	82%	75%	36%		ŁÓD			70%	83%	85%	88%	86%	61%
WAR			67%	68%	63%	58%	47%	14%		WAR			67%	72%	70%	70%	64%	31%

Table L.2a. Change in modal share of railways on the NSBE corridor (part A)

Change in modal share of railways																	
S1	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS	S2	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS
AMS	+2%	+9%	+16%	+5%	+6%	+19%			AMS	+14%	+35%	+47%	+22%	+16%	+27%		
TWE	+13%	+32%	+39%	+1%	+1%				TWE	+43%	+61%	+59%	+9%	+6%			
OSN	+19%	+37%	+0%	+1%				+4%	OSN	+51%	+59%	+0%	+5%				+12%
HAN	+21%	+42%	+0%				+3%	+6%	HAN	+60%	+68%	+0%				+8%	+16%
BER	+5%	+6%				+17%	+14%	+5%	BER	+39%	+25%				+21%	+22%	+22%
POZ	+1%	+1%			+0%	+0%	+44%	+16%	POZ	+16%	+6%			+0%	+0%	+64%	+47%
ŁÓD			+1%	+6%	+42%	+42%	+34%	+9%	ŁÓD			+6%	+25%	+68%	+64%	+63%	+35%
WAR			+1%	+5%	+21%	+20%	+13%	+2%	WAR			+16%	+39%	+60%	+52%	+43%	+14%

Table L.2b. Change in modal share of railways on the corridor of the NSBE (result from RHDHV model; part B)

Change in modal split of railways								
S3	**WAR**	**ŁÓD**	**POZ**	**BER**	**HAN**	**OSN**	**TWE**	**AMS**
AMS	+31%	+60%	+72%	+45%	+34%	+38%		
TWE	+60%	+72%	+67%	+17%	+15%			
OSN	+63%	+65%	+0%	+10%				+23%
HAN	+67%	+72%	+0%				+17%	+34%
BER	+43%	+28%				+26%	+30%	+45%
POZ	+16%	+6%			+0%	+0%	+72%	+72%
ŁÓD			+6%	+28%	+72%	+70%	+74%	+60%
WAR			+16%	+43%	+67%	+64%	+60%	+31%

Table L.3. Change in modal share of road transport on the corridor of the NSBE (result from RHDHV model)

Change in modal split of road transport																	
S1	**WAR**	**ŁÓD**	**POZ**	**BER**	**HAN**	**OSN**	**TWE**	**AMS**	**S2**	**WAR**	**ŁÓD**	**POZ**	**BER**	**HAN**	**OSN**	**TWE**	**AMS**
AMS	-1%	-3%	-7%	-1%	-4%	-23%			**AMS**	-1%	-3%	-7%	-1%	-4%	-23%		
TWE	0%	-1%	-5%	-1%	-1%				**TWE**	0%	-1%	-5%	-1%	-1%			
OSN	0%	-2%	-24%	-1%				-3%	**OSN**	0%	-2%	-24%	-1%				-3%
HAN	-9%	-23%	-30%				0%	-4%	**HAN**	-9%	-23%	-30%				0%	-4%
BER	-2%	-4%				+9%	+3%	-1%	**BER**	-2%	-4%				+9%	+3%	-1%
POZ	-1%	-1%			-30%	+12%	0%	-7%	**POZ**	-1%	-1%			-30%	+12%	0%	-7%
ŁÓD			-1%	-4%	-23%	0%	0%	-3%	**ŁÓD**			-1%	-4%	-23%	0%	0%	-3%
WAR			-1%	-2%	-9%	0%	0%	-1%	**WAR**			-1%	-2%	-9%	0%	0%	-1%

S3	**WAR**	**ŁÓD**	**POZ**	**BER**	**HAN**	**OSN**	**TWE**	**AMS**
AMS	-2%	-6%	-14%	-5%	-11%	-30%		
TWE	0%	-2%	-7%	-3%	-6%			
OSN	-1%	-3%	-31%	-4%				-10%
HAN	-20%	-39%	-47%				-5%	-11%
BER	-15%	-18%				+6%	0%	-5%
POZ	-12%	-6%			-47%	+4%	-2%	-14%
ŁÓD			-6%	-18%	-39%	0%	-1%	-6%
WAR			-12%	-15%	-20%	0%	0%	-2%

Table L.4. Change in modal share of aviation on the corridor of the NSBE (result from RHDHV model)

Change in modal split of aviation																	
S1	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS	S2	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS
AMS	-1%	-5%	-9%	-4%	-2%	+4%			AMS	-12%	-29%	-33%	-16%	-5%	+3%		
TWE	-13%	-31%	-33%	-1%	0%				TWE	-43%	-59%	-52%	-6%	0%			
OSN	-19%	-36%	0%	0%				-1%	OSN	-51%	-57%	0%	-2%				-1%
HAN	-12%	-18%	0%				-3%	-2%	HAN	-41%	-29%	0%				-3%	-5%
BER	-3%	-2%				-26%	-18%	-4%	BER	-24%	-6%				-28%	-23%	-16%
POZ	0%				0%	-56%	-43%	-9%	POZ	-4%				0%	-56%	-62%	-33%
ŁÓD				-2%	-18%	-43%	-34%	-5%	ŁÓD				-6%	-29%	-64%	-62%	-29%
WAR			0%	-3%	-12%	-20%	-13%	-1%	WAR			-4%	-24%	-41%	-52%	-43%	-12%
S3	WAR	ŁÓD	POZ	BER	HAN	OSN	TWE	AMS									
AMS	-28%	-54%	-55%	-35%	-11%	+2%											
TWE	-60%	-70%	-60%	-11%	0%												
OSN	-62%	-63%	0%	-3%				-3%									
HAN	-46%	-30%	0%				-4%	-11%									
BER	-27%	-7%				-29%	-28%	-35%									
POZ	-4%				0%	-56%	-70%	-55%									
ŁÓD				-7%	-30%	-70%	-73%	-54%									
WAR			-4%	-27%	-46%	-63%	-60%	-28%									

14.13. Appendix M. Benefit-cost ratios

Table M.1. Benefit-cost ratio for the scenarios (costs and benefits not fully estimated)

Benefit-cost ratio (discount rate 3.25%)			
	S1	**S2**	**S3**
Netherlands	0.130 - 0.277	0.017 - 0.583	0.188 - 0.639
Germany	0.255 - 0.492	0.203 - 0.587	0.179 - 0.541
Poland	0.169 - 0.320	0.046 - 0.108	0.049 - 0.119
All	**0.192 - 0.389**	**0.083 - 0.256**	**0.099 - 0.307**