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Further Development of the European High Speed Rail Network

System Economic Evaluation of Development Options

Summary Report

Study commissioned by Alstom and SNCF

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Executive Summary

European policymakers are committed to expansion of the European high speed rail network in order to improve mobility and connectivity. Exactly **how** the European rail network is to be expanded remains unclear. Potential options include (i) new very high speed rail lines (VHS) with design speeds at or above 300 km/h, (ii) new medium high speed rail lines (MHS) with design speeds at 250 - 280 km/h, or (iii) upgrades of conventional lines (CUP) typically at 200 - 220 km/h. This document uses a high-level system economic analysis to assess the options and identify patterns where each option is preferable.

This full system economic analysis includes railway system costs as well as commercial and wider socioeconomic benefits. System costs consist of infrastructure costs, which are typically dominant, and train operators' costs. System benefits consist of commercial revenues, user benefits through travel time gains and wider socioeconomic benefits.

The benefits generated in this analysis are fundamentally driven by passenger demand. The passenger volume observed on existing European rail corridors ranges significantly from as little as 3 million to as many as 39 million passengers per year. A larger passenger market size at the origin, destination and key intermediate stops permits an attractive frequency of train services and is a prerequisite to justify the construction of expensive infrastructure. For all potential investment options, these markets must have a large and dense enough population and economic base to boost travel demand.

The widespread belief that train operators' costs for higher speed options are higher is inaccurate. In fact, on corridors suitable for very high speed travel, operations costs of modern and purpose-built trainsets are lowest at design speeds between 250 km/h and 300 km/h and only gradually increase at speeds beyond 300 km/h. This is primarily a result of the higher train mileage covered by faster trains in the same amount of time. As a result, labour costs and rolling stock capital costs decrease with higher speeds. These costs are then counterbalanced by the cost of increasing energy consumption at very high speeds.

The design speed of lines is only one of many parameters that impacts infrastructure costs. Infrastructure, which includes track, civil structures, signalling/train control, electrification and all other related assets, typically represents the dominant cost component of all new rail systems, regardless of whether the system is very high speed or lower. Important infrastructure cost drivers are (i) the degree of required civil structures along the line, (ii) where applicable, the additional cost needed to accommodate a mix of both high speed trains and slower, heavier trains such as freight trains and (iii) massive surcharges to build or refurbish any new line in a densely populated urban area. As a consequence, infrastructure costs, whether for new or upgraded lines, depend strongly on the specific corridor characteristics and the operational strategy of the railway. Therefore, in all options, infrastructure costs can vary substantially. The cost ranges overlap and are not only a function of speed.

Commercial revenues are generally a direct function of passenger demand. Studies measuring the demand elasticity of higher speed rail systems show that the competitiveness of high speed rail compared against other modes is highest at distances between 300 km and 800 km, which in other words is where the highest elasticities of demand are observed. At shorter distances, effective travel time gains are perceived as less relevant by the passenger. At longer distances, air travel tends to maintain its competitive advantage. The driver for travel time gains is effective speed, not design speed. The ratio of effective speed to design speed ("speed yield") differs widely for existing European corridors. The investment for very high speed is only justified if high speed yields can be achieved.

In corridors with high travel time elasticity, the business case for higher and very high speed options can be made, because the increased demand from markets with sizeable passenger volumes translates into higher revenues. Additionally, the potential to charge a price premium for higher speed services (and ideally high quality branded products such as the AVE, Eurostar, ICE, TGV, Thalys and others) can be used to increase revenues further.

User benefits, specifically passenger travel time savings, are a major non-commercial but socioeconomic benefit. Effective travel time savings and passenger volumes translate directly into user benefits. In effect, user benefits are broadly proportional to demand and speed gains when compared to competing modes.

External costs (emissions, land use, safety risks) of all transport modes are significant. Differences between external costs of competing modes can be considered as relative external benefits. Rail has external cost advantages over air and still more so over road transportation. The external cost differences between the options are relatively small, however, compared to commercial revenues and user benefits. Still, a shift from road and air to rail reduces overall external costs for the corridor and thus generates external benefits. In many cases, however, higher speed rail not only shifts traffic but induces new demand which comes with higher external cost to the rail mode.

The choice of developing a corridor with very high speed rail, medium high speed rail or a conventional upgrade depends on a complex array of operational, infrastructural and market parameters. In healthy demand and elasticity scenarios, very high speed is often the superior option while in other scenarios a conventional upgrade may have a better benefit-cost ratio. In favourable scenarios, e.g. those with high demand and elasticity, benefit-cost ratios can be as high as 2,0 to 3,0. In more modest demand and elasticity scenarios, very high speed and conventional upgrade benefit-cost ratios tend to be similar but with proportionally lower absolute values. The medium high speed option, in contrast, often has a lower benefit-cost ratio since infrastructure costs are approximately the same as for very high speed while the demand is lower. Because of the complex array of parameters, each potential rail corridor must be analysed individually to assess which option is optimal.

As already mentioned, favourable conditions for very high speed exist in scenarios with healthy passenger demand, high speed yield and strong demand elasticity. Such corridors are particularly suitable for very high speed when longer stretches of uninterrupted travel at consistent speeds (i.e. high speed yield) can be assured. Very high speed can then make up for potentially higher infrastructure costs through substantially higher user benefits and commercial revenues. Very high speed is preferable over conventional upgrades when the gap between very high speed and conventional upgrade infrastructure costs is relatively low. Finally, if capacity constraints are an issue, very high speed has the best ability to help alleviate future congestion. Increased effective speed and shortened cycle time of trains result in increased network capacity. On congested networks, the construction of a new corridor also frees up conventional lines for other uses.

Construction of a medium high speed system with design speeds of 250 - 280 km/h is often not an optimal choice from a benefit-cost perspective. In a few exceptional cases where specific alignment constraints could make very high speed infrastructure more expensive than medium high speed infrastructure, this option may be preferable. In networks with foreseeable and sustained growth rates, very high speed systems offer higher capacity reserves for the future than lower speed options can. These factors can make a very high speed option the better long-term choice even if lower speed options would be sufficient to accommodate the traffic in the short to medium term.

Upgrading conventional lines to speeds of 200 - 220 km/h makes sense in a variety of scenarios. One of the most attractive reasons for upgrading is the potentially relatively low additional cost of infrastructure required compared to the construction of a new line. However, in practice, upgrading expenditures can sometimes exceed normal levels by far, nearing costs of higher speed options. This can happen when upgrading takes place in densely populated urban areas or when more fundamental changes in the alignment and equipment of a corridor are required. In terms of benefits, time savings and additional revenues can be generated in cases where the upgrading already represents a substantial leap forward compared to the previous railway offering. A conventional upgrade has less potential to achieve demand that higher speed rail could generate. However, in situations where very or medium high speed rail designs cannot deliver superior speed yields, conventional upgrades are fit for purpose and capable of achieving better benefit-cost ratios.

European policymakers have prioritised a number of corridors for further development of the European high speed rail network. Within a subset of this portfolio, a number of corridors have the necessary characteristics that make them candidates for very high speed rail. The candidate corridors within this subset selected for additional analysis are:

- ***Amsterdam – Berlin – Warsaw***
- ***Riga – Warsaw***

For both corridors, the benefit-cost ratio is comparatively high for the conventional upgrade and very high speed rail. Between these two options, the ratio is slightly higher for the conventional upgrade, yet in terms of the absolute surplus benefit, very high speed rail is the better choice for both corridors and is particularly large compared to an upgrade on the *Amsterdam - Warsaw* corridor.

This report represents a strategic analysis to examine the benefits and costs of very high speed rail, medium high speed rail, and conventional upgrades. Further corridor-specific assessment by the member states and railway administrations is needed to study benefits and costs more thoroughly before making a final decision on the optimal speed option for an actual corridor. As the process of integrating Europe through higher speed rail moves forward and decisions about speed options need to be made, this document can be used to help guide corridor-specific analyses.

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1. Introduction

European policymakers are committed to expansion of the European high speed rail network in order to improve mobility and connectivity. Exactly **how** the European rail network is to be expanded remains unclear. Potential options include (i) new very high speed rail lines (VHS) with design speeds at or above 300 km/h, (ii) new medium high speed rail lines (MHS) with design speeds at 250 - 280 km/h, or (iii) upgrades of conventional lines (CUP) typically at 200 - 220 km/h. This document uses a high-level system economic analysis to assess the options and identify patterns where each option is preferable.

This full system economic analysis includes railway system costs as well as commercial and wider socioeconomic benefits. System costs consist of infrastructure costs, which are typically dominant, and train operators' costs. System benefits consist of commercial revenues, user benefits through travel time gains and wider socioeconomic benefits.

Chapter 2 sets the framework by describing the European policy context and the stated intent of the European Commission to further develop the high-speed rail network over the next one or two decades.

Chapter 3 describes the three pillars for the analysis. The first pillar of the analysis includes the foundation and characteristics of the model. The second pillar includes the modelling of a variety of "real life" scenarios under typical European rail circumstances. The third pillar applies the analytical framework to assess potential future corridors.

Chapter 3 describes the system economic analysis and is the heart of the scenario analysis. Within this chapter, the report provides a profile of key characteristics for the three principal rail development options and describes the overall logic of the system economic model. It will also include the model components and specifications. The system economic analysis is conducted to model a variety of "real life" scenarios under typical European rail circumstances. A systematic sensitivity analysis of such scenarios is performed to provide detailed comparisons of how the benefits and costs behave under each circumstance, and how the inputs affect the overall results. All input data to the modelling are based on empirical research for existing conventional and high speed railway systems in Europe. Standard input data are used as a starting point to gauge the model; sensitivity analysis is then undertaken to model and understand the impact of varying input parameters within realistic European ranges.

The model itself is capable of handling a range of given configurations and respective system parameters. It is generic enough to be used in future studies to carry out high level assessments of corridors under discussion.

Based on this systematic scenario analysis, the results and sensitivity analysis provides strategic conclusions on the economic justification of investments in higher speed options and shows how choosing between rail development options is situation-dependent.

Chapter 4 of this document applies the model to assess potential future higher speed corridors. It applies the options of very high speed rail, high speed rail, and conventional upgrade to proposed high speed rail corridors in Europe that have been discussed as candidate corridors or could be eligible for investment. From a large sample of candidate corridors, two are chosen and analysed using the model analysis framework, then interpreted and proposed for further consideration.

Finally, Chapter 5 provides a summary and conclusions related to analysis findings. Detailed background information is available regarding the topics highlighted in this report.

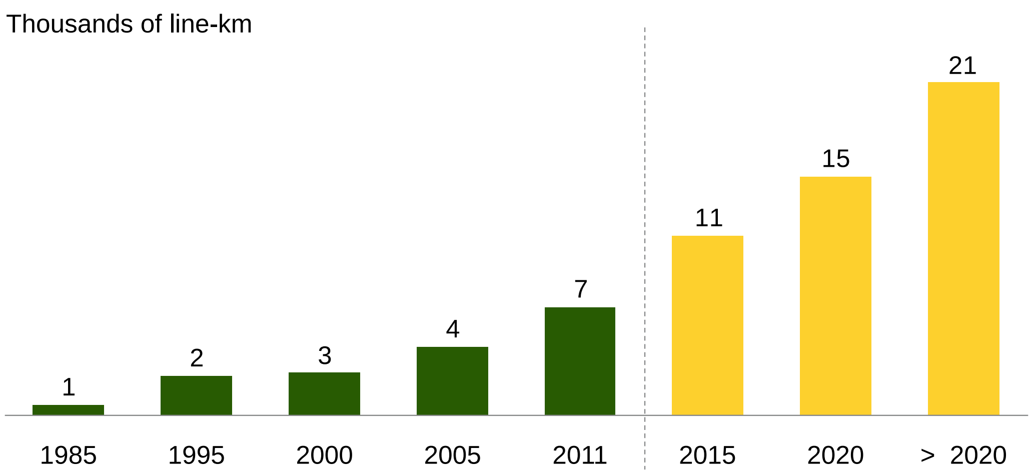
2. European High Speed Rail Context

The European Commission (EC) has far-reaching ambitions for the development of the European high speed rail network. As stated in its 2011 White Paper, the European Commission envisages a tripling of the line-kilometers in the current system by 2030 and a completion of a coherent high speed rail network by 2050. The vision of a coherent network includes links and accessibility between all major cities and core network airports.

The policy for a European-wide high speed rail network calls for the majority of all medium-distance intercity passenger traffic to move by rail as compared to other modes such as on road or by air. Additionally, the policy calls for 50 % of all freight to shift over to non-road corridors by 2050 in Europe, which has network capacity implications. A shift to rail for passenger and freight traffic is intended to support the transportation sector in achieving a reduction in greenhouse gas emissions of 60 % between 1990 and 2050.

A few determined governments started on the development of European high speed rail corridors starting in the 1990s, with the movement gaining momentum since. However, in order to develop a complete and coherent rail network, significant gaps will need to be filled.

Since 1990, the total length of high speed lines (those with speeds above 200 km/h) has increased seven-fold to an order of 10.000 kilometres. Between 2006 and 2011, approximately 320 kilometres of lines were built annually in Europe.



Source: For datapoints 1985 – 2011, EU transport in figures – statistical pocketbook 2012. For datapoints 2015 and up, European Commission, "High Speed Rail – An Easy Way to Connect", 2009.

Figure 1: Planned European High Speed Rail Network by 2020, Design Speeds ≥ 250 km/h

In order to meet current plans (15.000 kilometres by 2020 and 21.000 kilometres beyond 2020), approximately 800 to 1000 kilometres of lines with design speeds of 250 km/h or higher would need to be constructed annually.

France, Italy and Spain already have trunk rail networks in place that connect most major cities with 300 km/h services. In France, for example, the Mobility 21 Commission concluded that the focus of future investment here should be on maintenance and improvement of the existing network given the extensiveness of the current rail network. The commission determined that the problem in France is not gaps in rail service – it is financial losses, a weak rail freight system and a lack of focus on problems confronting primary network nodes, among others.

In the rest of Western Europe, however, there are still many high speed gaps that exist. In Central, Eastern and South Eastern Europe, the majority of lines are designed for operations at relatively low speeds. Given their travel speeds, a number of these rail corridors are comparatively unattractive compared to other modes.

Given the ambitious expansion plans for the European network, the completion of the network would require an estimated investment of 300 - 500 billion Euros at current prices.

While these plans are ambitious in terms of scope and funding volume, they would also require a three-fold increase in the pace of construction, which makes achievement of the plan within the envisaged timeframe rather unlikely.

Some funding, and in particular co-funding, is available through various European facilities (Cohesion Fund, Structural and Investment Fund, European Investment Bank, CEF/TEN-T funding). However, total available funds from these sources for rail transport are relatively minor when compared to the full cost of constructing the envisaged system.

The decision-making for rail-corridor development mainly rests with the European member states, which have to make careful choices about where scarce funds should be invested. European stakeholders have been ambivalent when weighing the options in terms of economic benefits of railway infrastructure investments. Recently, high speed plans have faced criticism because of doubts about the value of higher speed from an economic perspective. Some countries have redirected their policy towards "modest high speed" and have instead emphasised connectivity at interchanges.

While some rail configurations indeed may not benefit enough from higher-speed, in other cases arguments against higher speed are based on assumptions and opinions rather than analysis.

In the face of policy ambitions on the one hand and funding restrictions on the other, decisions regarding new rail investments require strong economic foundations and careful analysis of choices. Ideally, throughout Europe these decisions should be based on a coherent analytical framework that gives policy-makers a common platform to set priorities under the same measures. The aim of this study is to show under what circumstances the development of new VHS, MHS and CUP lines is appropriate and provides an analysis framework to select the optimal design speed on a corridor-specific level.

High benefit-to-cost ratios are a prerequisite in the consideration of investments. However, when benefit-to-cost ratios are similar across different options, decision makers may select the option with the higher absolute surplus benefit (i.e. total benefit minus total cost). Additionally, decision-makers should emphasise routes that help to close gaps and complete networks. The European high speed rail experience has shown that closing network gaps can give an extra boost to network demand.

3. General System Economic Analysis

3.1 Overview

This chapter describes the system economics analysis of potential high speed rail development options and assesses a set of scenarios. It includes the three pillars of the analysis where the first pillar of the analysis includes the foundation and characteristics of the model. The second pillar includes the modelling of a variety of "real life" scenarios under typical European rail circumstances. The third pillar applies the analytical framework to assess potential future corridors.

Section 3.2 provides a brief description of the technical options to develop a corridor towards higher speed. This includes options such as upgrading conventional lines as well as developing new lines with speeds above and beyond 300 km/h. Section 3.3 describes the overall philosophy and logic on the wider (i.e. socioeconomic) system analysis is described. Section 3.4 details and explains the modelling approach, the input parameters and mechanisms and interdependencies for and between all constituents of the analysis. Section 3.5 provides an overview of quantitative results, describes the logic of scenarios studied, the ranges of configurations that are covered by the sensitivity analysis, and the interpretation of results. Section 3.6 then concludes this chapter with the strategic implications regarding the choice of higher speed rail infrastructure development options.

3.2 Higher Speed Options

Rail corridors most appropriate for speed enhancements include conventional "legacy" rail lines with current design speeds of 120 - 160 km/h in Western Europe, and rail lines with significantly lower speeds in Central and Eastern Europe. There are three primary options that can be implemented to improve travel times and connectivity on a conventional (long distance) rail line. The three primary enhancement options are:

- **The construction of a new very high speed line.** Built and equipped for design speeds of 300 km/h and higher and denoted in this report as Very High Speed or "**VHS**", 300 - 350 km/h, these lines are typically built as dedicated lines for high speed trainsets only.
- **The construction of a new medium high speed line** built and equipped for design speeds of 250 - 280 km/h. In this report, this option is denoted as

Medium High Speed or "**MHS**", 250 - 280 km/h. These lines are sometimes also built to handle both freight and passenger traffic. Topographical alignment, safety standards and train control/safety technology of MHS lines must have distinctly higher standards than CUP lines. The infrastructure standards are in fact similar to very high speed infrastructure.

- **An upgrade and modernisation of the existing infrastructure** to facilitate the line for speeds at or slightly above 200 km/h. These upgrades maintain the same topographical alignment and with similar technological equipment as the existing line. These lines are typically purpose built for mixed passenger and freight traffic. Throughout the report this option is denoted as Conventional Upgrade or "**CUP**", 200 - 220 km/h.

All of these configurations exist in some form in Europe. Switzerland, for instance, has decided to upgrade the majority of its network to handle speeds of 200 km/h, while other countries such as France and Spain have determinedly focused on a VHS-level system implementation. The relatively short travel distance between most station stops in Switzerland is one important reason behind this philosophy. Germany, on the other hand, has taken a mixed approach. Some lines, such as *Frankfurt – Cologne*, have design speed sections of 300 km/h, but the majority of the long-distance network operates at speeds between 150 km/h and 250 km/h and accommodates mixed traffic.

A key purpose of this rail development option study is to determine how these technical enhancement options compare under different operational and market conditions from a benefit and cost perspective. The fundamentals of the economic approach are described in the following section.

3.3 Full System Economic Account

Determining whether an infrastructure investment generates value from a policy perspective - or which choice among a set of options is preferable - should be based on a socioeconomic system account.

A full system economic account would incorporate all direct system costs plus external costs on one hand, and all commercial revenues plus societal benefits on the other. This would require giving a full account of total cost beyond what is reported at face value in a profit and loss statement, which means including reported costs plus the external (i.e. non-commercial) costs for emissions, noise, safety risk, land use and other societal impacts. Many times, a railway undertaking incurs costs for track access charges that typically cover marginal cost of infrastructure only, not taking into account the societal costs. In addition, in the context of European railways, governments are often providing substantial funds (especially for infrastructure finance) "off-balance sheet". For a full system account, however, total costs of infrastructure need to be adopted for the analysis, be they “on-balance sheet” or “off-balance sheet” for the infrastructure provider.

For a full system economic account of benefits, beyond commercial revenues, there is broad consensus to measure user (i.e. passenger) benefits though travel-time gains and a monetised value of time saved per type of passenger. To be fully comprehensive, regional economic impacts gained from improved travel connections can also be considered, although they are difficult to measure.

In comparing different transport modes (rail, road, air), societal costs can either be calculated directly or as relative benefits considering differences in external costs. Most studies agree that the rail mode has lower external costs as compared to other modes such as road or air. In this analysis, the external cost advantage is described as a relative or comparative benefit rather than an absolute one.

In Europe, there is no standardised approach developed for measuring the economic benefits and costs for railway infrastructure investment. Based on a review of studies, a case-by-case approach still prevails.

The European Commission advocates a comprehensive ("Full System Account") approach and has taken steps to help standardise investment appraisal. TEN-T audits and EU co-funding policy analyses have revealed that there is no agreement on a consistent methodology to assess socioeconomic benefits and award criteria for the selection of projects on the basis of their costs and benefits. In separate studies, the UIC and the EU "HEATCO" project (i.e. Harmonised European Approaches for Transport Costing and Project Assessment) found significant differences in how transport projects were appraised.

For the purpose of this study a full account is used for the costs of infrastructure and train operations. Likewise, a full system economic account of benefits is used, which are defined as the total of commercial revenues, external benefits (i.e. external cost advantages) and monetised user benefits stemming from total travel time savings.

A sample result for a full system economic account, shown as a cost-benefit ratio, is illustrated in Figure 2.

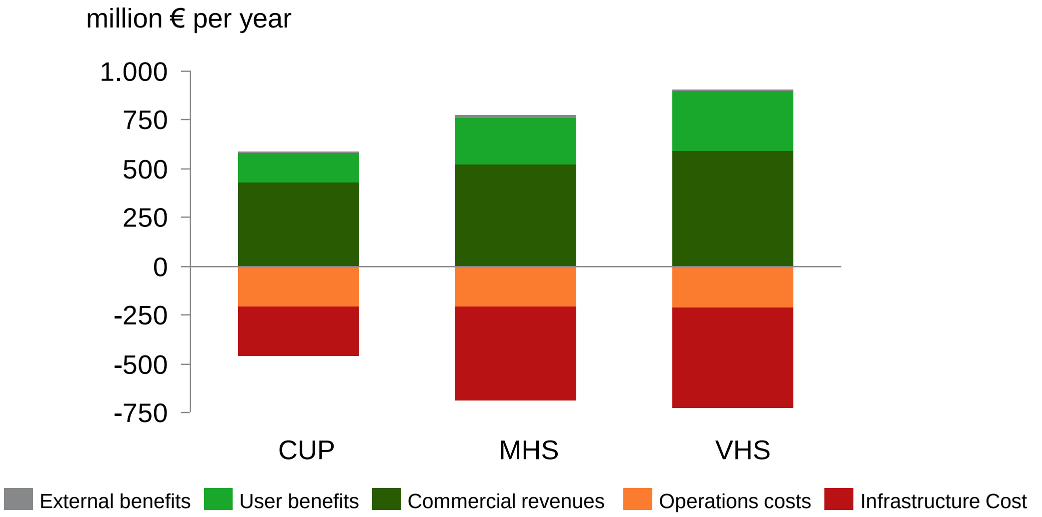


Figure 2: Sample Benefit-Cost Analysis Output

The following paragraphs provide detailed descriptions of all relevant constituents of the economic appraisal model.

3.4 Principal Benefit and Cost Constituents

Overview

The benefit-cost ratio of a railway infrastructure investment depends entirely on operational/technical corridor characteristics and on the relevant market size along such a corridor. Infrastructure layout (topography, type of traffic) and the choice of the development options determine infrastructure costs to a large degree. Train operations on the infrastructure need to reflect the speed choice of the infrastructure and match with demand in order to provide adequate frequency of services. Demand is strongly driven by passenger rail market size along the line, but is also a function of the competitiveness of rail services on the route as compared to road and air.

The travel time advantage over competing modes is a strong driver of demand ("travel time demand elasticity") as is the relative tariff level for different travel modes ("price demand elasticity"). Both factors affect the modal share in a given corridor. Railway management has an opportunity to actively manage yield with pricing policies either towards higher unit revenues at lower fleet utilisation or vice versa.

Figure 3 gives an overview of the main constituents of benefits and costs analysed in this study, and show the major interdependencies between them.

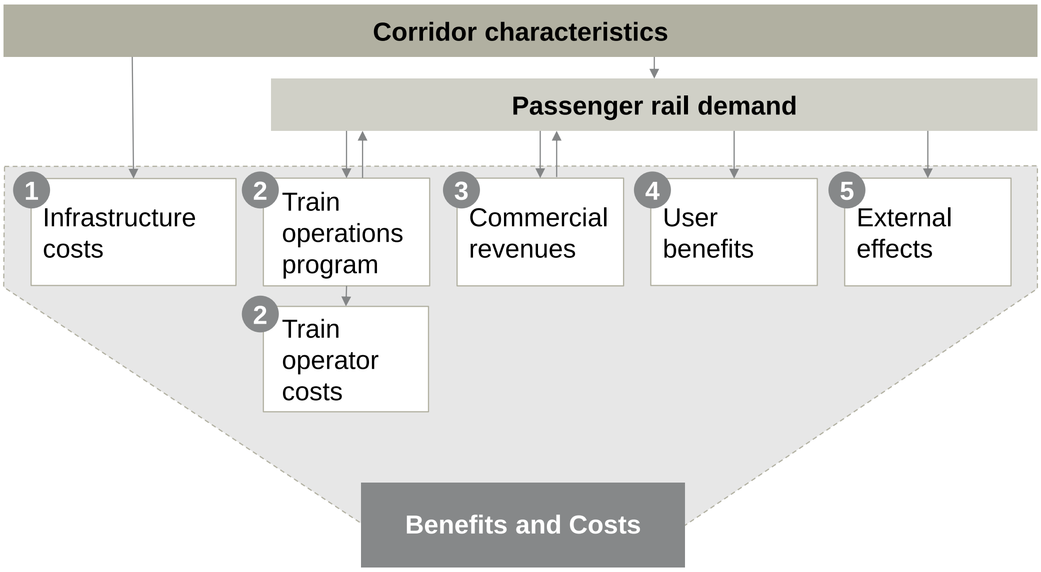


Figure 3: Key Model Constituents

Each of these constituents is now described with its key characteristics.

Corridor characteristics

Corridor characteristics that underlie the economic model include both market demand and operational/technical features. Key market demand is driven by the size of the market (population in catchment areas), the population average income, the service offering and relative attractiveness of competing modes, the pricing strategy, the effective travel speed and the typical distance travelled.

Important operational/technical features include the chosen design speed with the corresponding requirements for alignment and technical equipment, the topography (with a key factor whether there is the need for costly civil structures) and the system decision between dedicated or mixed traffic purpose.

These market demand and operational/technical corridor characteristics set the stage and form the basic input to the system analysis.

Passenger Rail Demand

A strong market for rail travel is critical to justify the construction of expensive infrastructure and the offering of convenient services frequent enough to attract passengers from other modes. Figure 4 gives an overview of passenger demand on a sample of high speed rail corridors in Europe.

Corridor name	Corridor length	Passengers per year million
Paris – Lyon (2008)	409 km	39
Valence – Marseille, LGV Med (2004)	250 km	20
Lyon – Valence, LGV Rhône-Alpes (2006)	115 km	19
Frankfurt – Cologne (2012)	180 km	12
Paris – Nord de la France (2002)	333 km	6
Madrid – Sevilla (2011)	472 km	3
Madrid – Valencia (2011)	391 km	2

Figure 4: Passengers Per Year on Notable High Speed Rail Lines

The range of ridership on the sample corridors is wide with some corridors far below 10 million travellers per year, others far above.

When a corridor is tied into a larger network, additional passenger demand may be created through **network effects** (see Laird, Nellthorp and Mackie). One example is the ICE line in Germany between Frankfurt and Cologne. If these two markets were the only ones served by high speed rail, passenger demand would be lower than it currently is. But because the line is also used to serve customers in the Ruhr Region, Munich, Stuttgart and elsewhere, network effects drastically increase demand.

Passenger demand for rail is strongly dependent on **travel time** and **price elasticity of demand**. Elasticity values measure how sensitive potential passengers are to changes in travel time and price[1]. For example, a high speed elasticity of demand would indicate that passengers are relatively willing to switch to rail when travel time is improved. Low price elasticity of demand would indicate, on the other hand, that customers are not sensitive to potential increases in ticket prices, which could be a revenue-generating opportunity for the railway. Many factors, including income in the catchment area, transit connectivity to the railway station and the competitiveness of other modes influ-

[1] A reduction of travel time by 1% leading to a 2% increase in demand indicates a travel time elasticity of -2.0.

ence these elasticities. For example, if airline competition with rail is intense, travel time elasticities need to be relatively high to draw passengers to higher speed rail. Various European studies observe that travel time elasticities typically range between -0,8 and -2,0 for longer-distance rail traffic (see Breimeier, LeBoeuf), but can deviate further from this range.

Commercial revenues are generally a direct function of passenger demand. Studies measuring the demand elasticity of higher speed rail systems show that the competitiveness of high speed rail compared against other modes is highest at distances between 300 km and 800 km, which is where the highest elasticities of demand are observed. At distances shorter than 300 km, effective travel time gains are perceived as less relevant by the passenger. At distances above 800 km, air travel tends to maintain its competitive advantage. Figure 5 highlights key ranges where higher speed rail competes well with other modes.

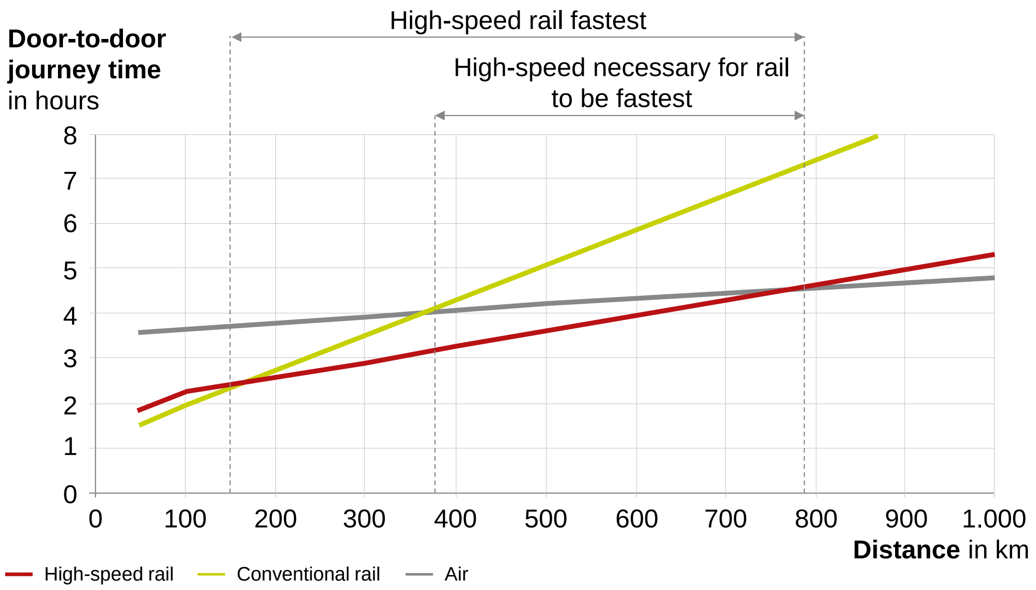


Figure 5: Competitiveness of Rail with Respect to Distance

One critical operational parameter for a high speed corridor is the **speed yield**. The term speed yield refers to the ratio of the effective travel speed to the design speed of a line. Speed yields can decrease, for example, when the corridor is densely populated with many stops. Additionally, if only parts of the rail corridor are designed for VHS speeds, the full potential of the line will not be realised. Higher speed yields also result in improved use of the infrastructure and rolling stock. The French high speed system is one of the best European examples of speed yield maximisation for VHS corridors. Figure 6 shows average speeds, maximum speeds and percentage of tracks where maximum speeds can be reached on several key European VHS corridors.

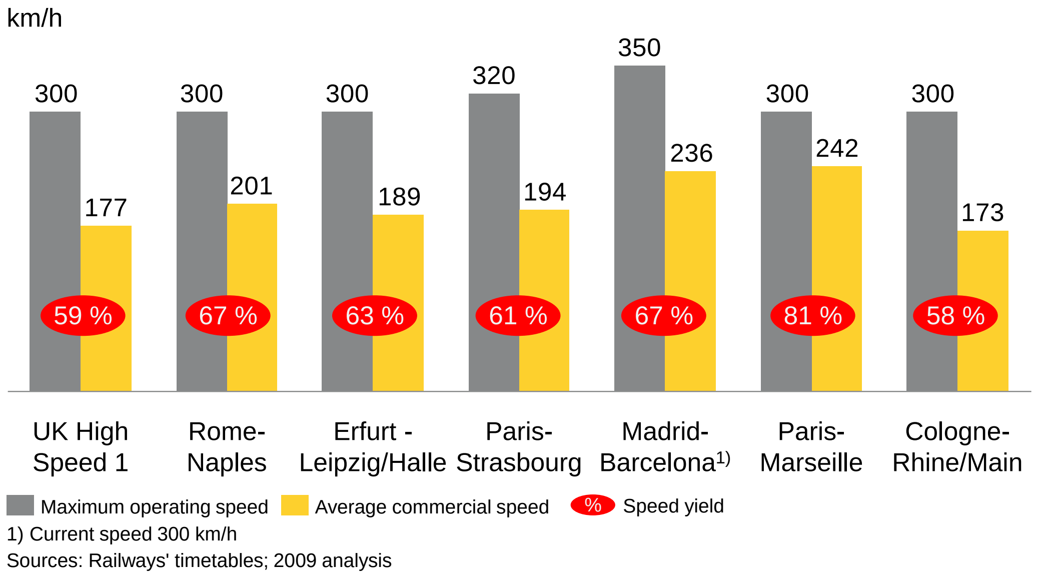


Figure 6: Effective Speed Yields on European Corridors

In summary, the higher the base demand, travel time elasticity and speed yield, the more benefits will be derived through development of higher speed rail. In some special cases a low price elasticity of demand creates opportunities to charge premium ticket prices without a significant reduction in passenger demand.

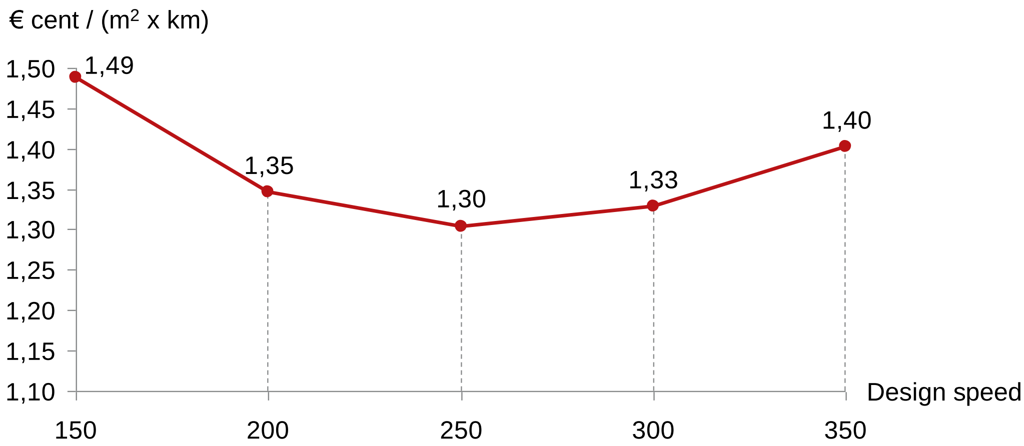
Train Operations Program and Train Operator Costs

The train operations program is defined as the service frequency and capacity on the route to meet demand. The train operations program consists of key input parameters including daily hours of operation, train departures in peak/off-peak periods and turnaround times. These parameters, in addition to reserve factors (e.g. reserve fleet to support train maintenance issues), are used to determine the key resources required, i.e. the number of drivers and total fleet size.

Utilisation of capacity is a prime performance measure for commercially efficient rail service. Research for this study shows that some VHS providers operate with a seat utilisation of 70 % and higher, while others run at approximately 50 % seat utilisation. A pivotal route-specific operations decision is the frequency of train departures during the peak travel period, as this has a significant direct impact on the total rolling stock required to handle total peak and off-peak demand.

Train operator costs, which include the capital and operational cost of rolling stock, train operator personnel costs, energy consumption and others, are a direct result of the implemented train operations program. A common misconception is that train operator costs are much higher at higher speeds. In fact, on corridors suitable for very high speed travel (see Figure 7), operations costs of modern and purpose-built trainsets are typically lowest at design speeds between 250 km/h and 300 km/h and only gradually increase at speeds beyond 300 km/h (see Breimeier; Garcia). Additionally, UIC studies have verified that labour costs and rolling stock capital costs decrease with increasing speeds. This is primarily a result of the increased annual train mileage for higher speed trains and their potential for additional trip cycles per day. These costs are then counterbalanced by the cost of increasing energy consumption at very high speeds (particularly at speeds above 300 km/h).

High speed trainsets are typically more expensive than conventional trains, but the price per train also varies based on the total quantity ordered, total capacity and train-specific features, among other factors. The analysis is constructed to model individual situations more precisely. Energy costs are also heavily dependent on country and railway-specific energy cost agreements.



Source: Dr. Rudolf Breimeier, Transrapid oder Eisenbahn

Figure 7: Sample Train Operating Costs of an ICE III

Infrastructure Costs

The largest cost component when constructing or upgrading rail lines is usually the **cost of infrastructure**. Infrastructure includes tracks, civil structures (tunnels, bridges and power supply), signalling/train control, electrification and all other related assets. This system analysis covers total cost of infrastructure, i.e. annualised capital costs (depreciation and interest), and maintenance and network operations/traffic control. Major infrastructure cost drivers are (i) the degree of required civil structures along the line, (ii) where applicable, the additional cost needed to accommodate a mix of both high speed trains and slower, heavier trains such as freight trains and (iii) massive surcharges to build or refurbish new lines (or upgrades) in densely populated urban areas. Civil structures add significant costs to projects. Mountainous topography, mixed lines and construction in urban areas will usually require more investment in major tunnels or bridges, which results in substantial cost increases.

Usually, although it provides less additional traffic capacity, CUP has lower infrastructure costs, while the construction of a new line (MHS/VHS) may be significantly more expensive. The fact that infrastructure costs are often lower for the CUP option makes this option competitive with the VHS option in the total benefit-cost ratio. For all options, a large degree of variability, primarily due to the construction environment, exists with regards to the cost per line-km.

Commercial Revenues

Commercial revenues are a direct function of passenger demand, the railway pricing structure and consumer willingness to accept ticket price premia for higher speeds. Railway operators have different strategies with regard to the implementation of price premia for higher speeds. In cases of high travel time elasticity, substantial demand increases can translate into higher revenues and drive the business case for MHS and VHS options. The absolute revenue increase is more pronounced in markets with sizeable passenger volumes. Additionally, the potential to charge a price premium for higher speed services (and ideally high quality branded products such as the AVE, Eurostar, ICE, TGV, Thalys and others), can be used to increase revenues further. The system analysis is based on **modest pricing levels** in the European context and then allows for variations and sensitivity analyses.

User Benefits

User benefits, defined as passenger travel time savings for this analysis, are a major non-commercial but socioeconomic driver of benefits. These benefits accrue from total passenger travel time savings in comparison to a “no build” option. For example, if a new VHS route reduces travel time from Point A to Point B, all passengers will experience time savings which can be monetised. Additionally, automobile drivers and air travellers on the same corridor that switch to rail may also see travel time savings. Given the potential of higher speeds to reduce travel times significantly for millions of passengers, a shift to a higher speed alternative would be a key benefit for passengers and the economy in general.

External Effects

Finally, one of the most commonly cited benefits of rail is that it is generally a more environmentally-friendly transportation option than road or air options if seat utilisation is high enough. As a result, a new rail project may result in **external benefits**. Total external costs of all modes on a corridor (total external costs include not only greenhouse gases and air pollution, but also urban effects, impacts on nature/landscape, noise, accidents and other impacts) are generally high on major European corridors. UIC studies conclude that rail as a mode, at 2,5 Eurocents per passenger-km, has only half the external costs of air travel and a third of the external costs compared to automobile travel per passenger-km. Hence, developing high speed rail can reduce overall external costs in a corridor, to the extent it shifts users from road and air. In cases where passengers shift significantly from air and road to rail, external benefits of higher speed rail become increasingly relevant. However, high speed rail often also induces new demand along the corridor. If much of the new rail traffic is induced, total corridor-specific external cost balances may be negligible or potentially even negative.

Qualitative Benefits

A variety of other qualitative benefits can be attributed to higher speed rail.

One is the **economic development** of regions. The OECD states that "*it is extremely difficult to measure the exact relationship between transport infrastructure investment and regional development.*" Hence economic development impacts are not always included in the quantitative component of benefit-cost analyses.

Three examples of cities that have benefitted economically from VHS are Lille, France, the Yongsan district in South Korea, and the area around St. Pancras station in London.

Safety is another benefit of all higher speed rail options. Fatalities per billion airline, bus and coach passenger-km are both 0.4. For passenger cars, the value is 5.9 while for high speed rail it is close to zero (see Palmer and James). All rail options have high safety standards and rail is the safest long distance transport mode.

Added rail network capacity is one important collateral benefit of higher speed rail. While the construction of a high speed line is relatively expensive, this frees up capacity on the old lines and helps mitigate potential future congestion concerns. Upgrading a line, by contrast, might not add significant capacity to accommodate growing passenger demand. This is important in regions where passenger and freight rail is expected to increase in the future.

Also, freed airport capacity is a potential benefit as many EU airports are already heavily congested. Studies suggest that in 2035, 12 % of air travel demand will not be accommodated in 2035. Almost two million flights a year would have nowhere to land or take off (see Eurocontrol). As a result, higher speed rail options (particularly VHS, given that it is more likely to be competitive with air travel on medium distance routes) can mitigate the congestion problem at airports.

That EU citizens have become more mobile and connected through high speed is a major benefit in its own right. With the European network development to date, travel times have already been reduced to a large extent.

3.5 Results and Sensitivity Analysis

Overview

As evident from the previous description of the various constituents of the analysis, a whole array of parameters needs to be set to calculate a scenario. The full economic system account established with the model for this study comprises a set of more than 150 input and output parameters. In order to gauge the model and put it on a "real-life" footing that reflects typical European operating conditions, a large amount of empirical data was compiled. These data provide a realistic assessment of normal conditions (a "demonstrator case") and the typical ranges of key parameters as they can occur in specific European circumstances.

Important parameters that are all "reality-checked" in this way are (i) passenger rail demand, (ii) travel time elasticities, (iii) train service frequencies, (iv) unit revenues/tariffs, (v) effective speed yields and (vi) the quantity of expensive civil structures on a typical line.

Because large variations exist in practice, the demonstrator case was chosen as a starting point for subsequent sensitivity analyses to reflect modest assumptions, for instance a base-case passenger demand of 6 million passengers per year and unit revenues of 11 Eurocents per passenger kilometre.

The demonstrator case, which is for illustration purposes only, will be shown and interpreted in the following paragraph. Then the logic and the key parameter variations used for the sensitivity analysis will be explained. Finally, quantitative results for a relevant sample of scenarios are given and interpreted.

Demonstrator Case Results

Corridor-specific analysis should incorporate inputs that are particular to the individual circumstances, whether it is base demand and elasticities, or infrastructure costs to name just a few. This demonstrator case serves as an illustration only for a standard-case comparison between the underlying development options CUP, MHS and VHS. Figure 8 shows the benefit and cost results by categories as described in section 3.2.

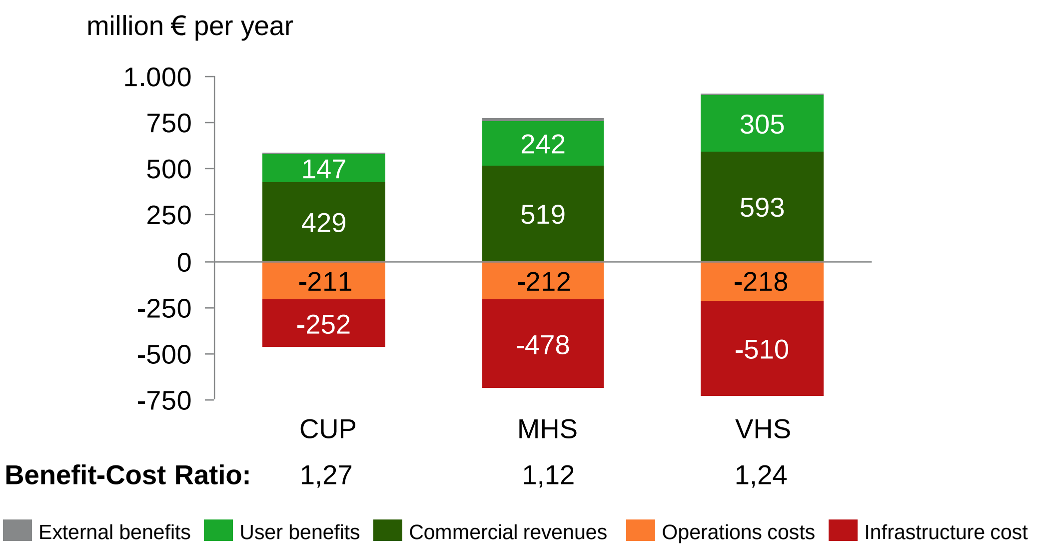


Figure 8: Demonstrator Case: Full System Benefit-Cost Perspective

In this demonstrator case with modest demand assumptions, the benefit-cost ratios of CUP and VHS are comparable. The MHS result is somewhat lower and only slightly above 1,0. Train operations cost are similar in all three options, but CUP stands out with lower infrastructure costs that compensate for the lower revenues and user benefit. In all of these scenarios subsidies would be required since commercial revenues do not cover total costs.

VHS has the highest infrastructure costs but also the highest revenues and twice the user benefits as compared with CUP. The relative disadvantage of

MHS lies in high infrastructure costs, close to VHS, but with lower revenues and user benefits.

For the CUP option, normal infrastructure costs are assumed. If CUP was constructed in difficult urban areas or very major changes to the existing line were necessary, the respective infrastructure cost for the CUP option would go up significantly.

Finally, the external benefits in the demonstrator case are minor compared to the other cost and benefit constituents.

The total external costs for this corridor in the VHS option are nearly € 700 million and fairly significant as such. However, the differentials between the options are minimal, because a strong induced (additional) demand compensates the external cost gains arising from the modal shift towards rail.

Sensitivity Analysis Logic

The sensitivity analysis serves two main purposes. One is to identify the prominent levers among the large set of input parameters that have the most pronounced impact on benefit and cost results. The second purpose is to build on this information to determine a whole range of scenarios that cover favorable and not so favorable circumstances for all three development options. This is to distinguish these options regarding their suitability and of course to find out whether and when benefit-cost ratios are strong enough to justify investments.

Based on results from the sensitivity analysis, five prominent levers have the most significant impact on benefits and costs under practically relevant circumstances. These levers are:

- **Market size and base travel demand in and along the corridor**
- **Demand versus travel time elasticity**
- **Effective speed yield**
- **Infrastructure cost in combination with complexity**
- **Situation-specific costs of conventional infrastructure upgrades**

Beyond these levers, it is somewhat arbitrary to consider further parameters and the model is open to handle this. However it would lead to great complexity and make it far more difficult to detect patterns with regard to the discrimination of the development options.

One parameter beyond the selected five parameters that qualifies most for additional incorporation into the scenario analysis is the pricing of passenger traffic. As indicated before, this study has opted to use modest price levels (i.e. unit revenues per passenger-kilometre) as a precaution to not overestimate revenue gains from speed-induced demand increases. Also, the effect of negative price demand elasticity, which reduces passenger volumes at higher price levels, has a counterbalancing effect that limits the actual effect on absolute revenues. It is nevertheless a promising territory for railway undertakings to yield-optimise pricing strategies under their specific market conditions.

The prominent levers identified for this analysis include:

- **Market size and base demand**

  Market size and base demand is the fundamental and strongest system economic driver. It governs commercial revenues as much as it governs user benefits. Healthy demand also provides the opportunity to achieve appropriate capacity utilisation of both trains and infrastructure. The range of actual passenger volumes in existing European high speed corridors is so varied (from 3 to 39 million passengers per year) that the effect on system economics is evident.

- **Travel time elasticity in combination with effective speed yield**

  Travel time elasticity in combination with the effective speed-yield is decisive in the comparison of the three development options. High speed yields reflect the capability of a line to deliver effective speeds that are close to the design speed, which a corridor is built and equipped for. Travel time gains depend on the effective speed only. In cases with high travel time elasticity, customers are more willing to switch to rail when higher speed services are offered. Hence the high speed and particularly the very high speed options in such a scenario generate superior commercial revenues and user benefits, favouring higher speed versus lower speed options. In low travel time elasticity scenarios (i.e. for instance at very long distances where air travel is preferable, or at short distances and frequent stops) however, the three options are similar on the revenue and benefit side. In these cases, lower infrastructure costs tilt the balance towards the CUP option.

  Economically, "the worst of all worlds" is a configuration in which a line is built and equipped for VHS, trainsets are VHS purpose-built and yet the speed yield is so low (e.g. with short stop distances) that superior demand does not materialise. In such a scenario, expensive infrastructure and expensive trains do not provide added value.

- **Infrastructure costs in combination with complexity**

  On some European corridors, the total length of tunnels or bridges can comprise 50 % of the total line length. This contributes significantly to the overall infrastructure costs. The complexity of the topography increases the requirements for such civil structures; for example in flat, open countryside usually less than 10 % of the line-km requires civil structures. Requirements for MHS and VHS in general are structurally higher because gradients and curve radii make the corridor alignment less flexible. Because the cost of infrastructure is already a strong driver of overall costs, the effect of infrastructure complexity also effects overall benefit-cost ratios significantly.

- **Situation specific cost of CUP infrastructure**

  Under "normal" conditions, the refurbishment cost of conventional infrastructure is significantly lower than for newly built lines, which gives the CUP option an advantage over MHS and VHS. However, in practice, there are situations where the cost of an upgrade actually comes close to building a new line, such as in densely populated urban areas. In these cases, the cost advantages of CUP are diminished or disappear.

Because of the relevance of these five prominent levers, the scenario-analysis was built on a whole set of variations for all of these parameters.

Scenarios were defined systematically to span the entire space of parameters between making a reasonably good case for VHS and making a difficult case where VHS is unlikely to show sufficient benefit-cost ratios. The choice and variations of the core parameters in those cases is illustrated in Figure 9.

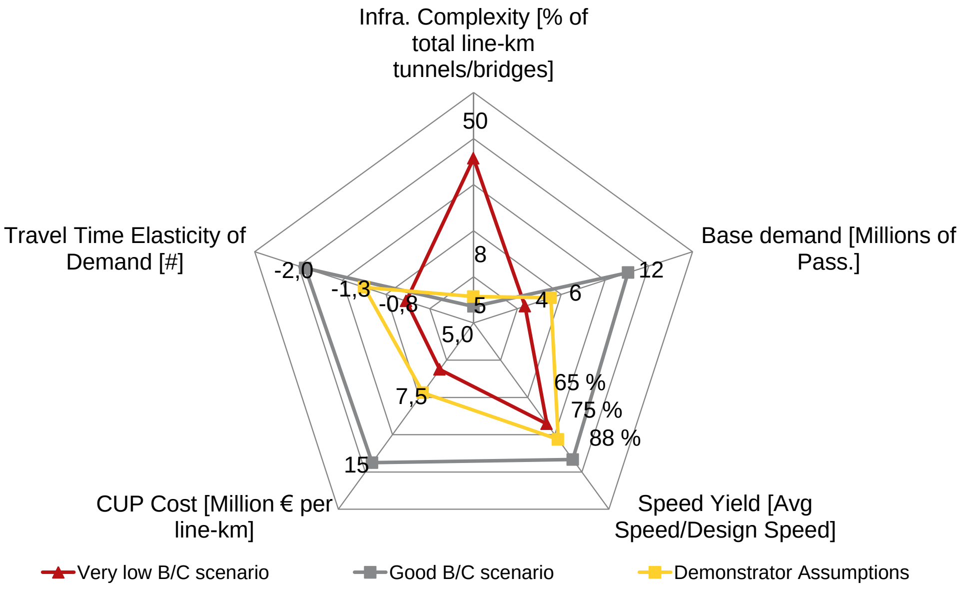


Figure 9: Values for Five Key Parameters in Sensitivity Analysis

Benefit and cost results for these "reasonably good" and "difficult" cases are calculated. In a next step, starting from the good scenario (note: this is not a "best case" but a "reasonably good" case) a set of moderate scenarios was generated by altering one parameter at a time to the "difficult" position. This systematic analysis provides insights on how each individual parameter affects benefit-cost results.

Subsequently, combinations of two parameters were set to the "difficult" position which drives benefit-cost ratios further down and brings some of the scenarios to down "break-even" or below 1.0 benefit-cost ratios.

The table of scenarios generated by this logic is presented in Figure 10.

Note: Green indicates a potentially positive parameter change for the VHS B/C ratio, while red indicates a potentially negative parameter change for the VHS B/C ratio. A white field indicates that the same values as in the demonstrator model were used.

Figure 10: Adjustment of Key Benefit-Cost Drivers by Scenario

All scenario results are available from the study. For the sake of better interpretation, three characteristic scenarios are selected and described in the following paragraph. The respective parameter sets for these scenarios are illustrated in Figure 11.

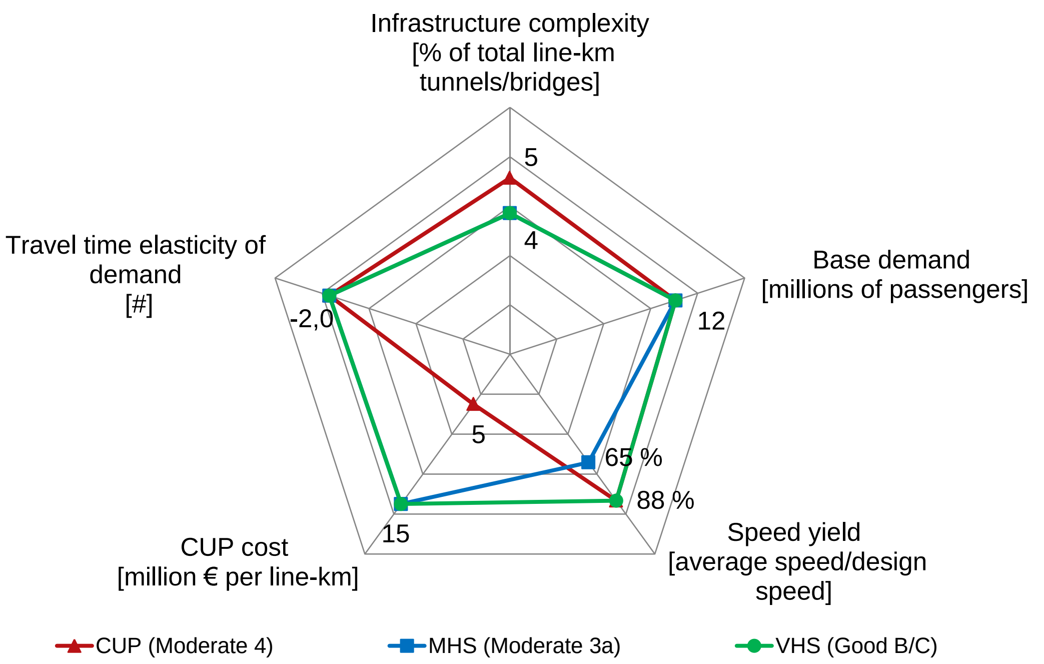


Figure 11: Values of Adjusted Parameters for Three Characteristic Scenarios

Following the above logic, the reasonable good VHS case results are described first.

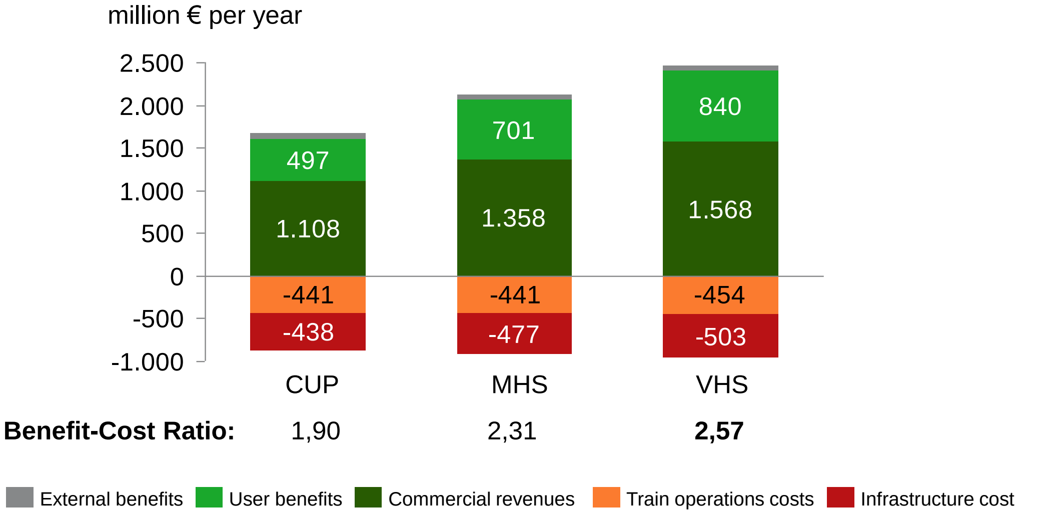


Figure 12: Benefit-Cost Analysis Results: Reasonably Good Case for Very High Speed

In this scenario, the benefit-cost ratio of VHS with a value of around 2,5 is higher than for MHS and CUP, mainly due to higher demand capture and high user benefits. Since a difficult CUP refurbishment was assumed, the infrastructure cost of CUP is only slightly below that of for MHS and VHS. However, even if CUP infrastructure costs were assumed lower, the net benefit surplus of VHS (€ 1,5 billion) outweighs the net benefit surplus of CUP (€ 0,7 billion) by a big margin.

The moderate scenario 3a differs from the previous one by a significantly diminished speed-yield for the VHS option. (Note that MHS and CUP differ from the ideal version because different train operating assumptions were made).

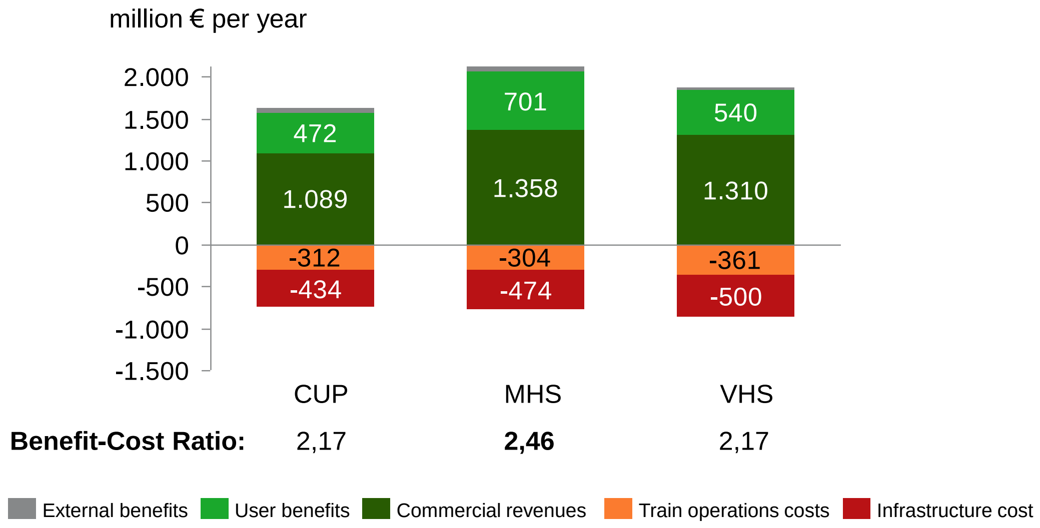


Figure 13: Benefit-Cost Analysis Results: Modest Scenario 3a

The effect of a lower speed yield becomes immediately clear. The VHS benefit-cost ratio goes down to just under 2,2 and the net benefit surplus shrinks to € 1,0 billion.

As a summary overview of all scenarios modelled, Figure 14 gives all benefit-cost ratios per scenario for all three rail development options (CUP, MHS, VHS). The option with the highest benefit-cost ratio is listed in the bubble above each scenario. To reference how each of the scenarios was modified from the demonstrator case, see Figure 10.

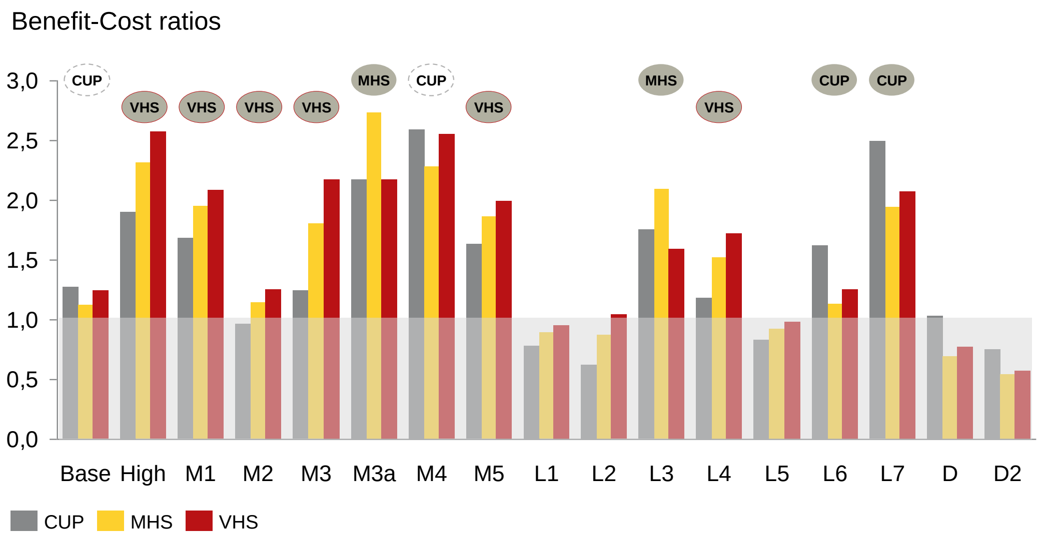
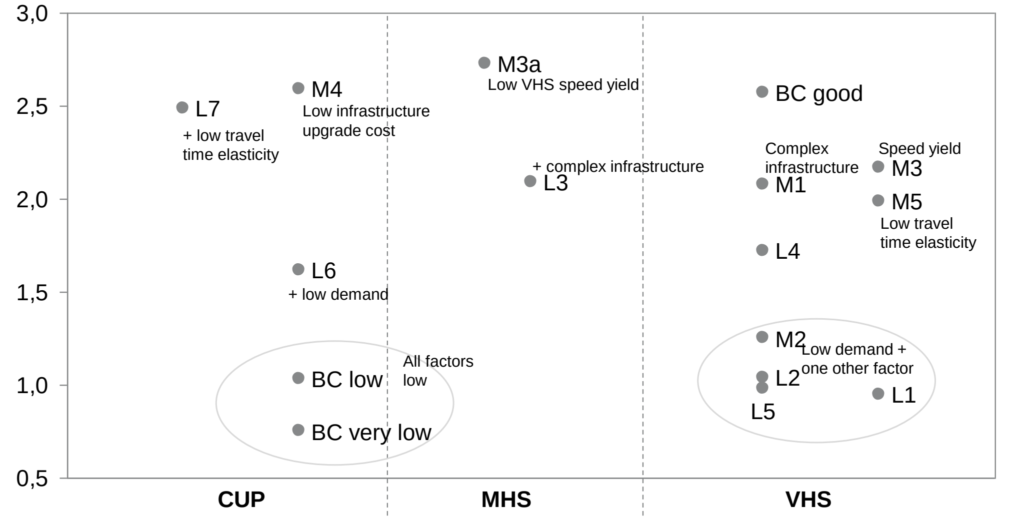


Figure 14: Sensitivity Analysis Results

For the scenarios that have a benefit-cost ratio above 1,0 VHS is the preferable option in about half of all cases. CUP qualifies clearly in two cases and narrowly in two more cases. In the latter two, the absolute benefits (in million Euros) of VHS are significantly higher so that the actual choice between CUP and VHS is not as straightforward. MHS finally qualifies as being preferable in two other cases.

Figure 15 gives another visualisation where those options are shown that represent the preferable solution in any of the given scenarios.



Note: The chart shows only the option with the highest benefit-cost ratio for each scenario.

Figure 15: Visualisation of Sensitivity Analysis Results

Certain CUP scenarios have good benefit-cost ratios and are preferable over high speed options when demand and travel time elasticity are weak. MHS can be preferable to VHS in situations where VHS cannot deliver high speed yields. And conversely, VHS options are clearly superior under scenarios of healthy demand, high speed-yields and strong elasticity characteristics.

3.6 Results and Sensitivity Analysis

The results of this system economic analysis demonstrate that the best option is dependent on a number of factors and a case can be made for CUP, MHS and VHS. The scenario analysis makes it possible to draw key conclusions about when each of the options is preferable. It also makes clear that it is always necessary to review each corridor individually from a full system economic perspective to understand the key drivers for the results.

Favourable conditions for **VHS** exist in scenarios with healthy passenger demand, high speed yield and demand elasticity. Such corridors are particularly suitable for VHS when longer stretches of uninterrupted travel at consistent speeds (i.e. high speed yield) can be assured. This allows VHS to compensate for potentially higher infrastructure costs through substantially higher user benefits and commercial revenues. VHS is a preferable option over conventional upgrades when the gap between very high speed and conventional upgrade infrastructure costs is relatively low. Finally, if capacity constraints are an issue, VHS has the best ability to help alleviate future congestion. Increased effective speed and shortened cycle time of trains result in increased capacity. On congested networks, the construction of a new corridor also frees up conventional lines for other uses.

Construction of a **MHS** system with design speeds of 250 - 280 km/h is often not an optimal choice from a benefit-cost perspective. In a few exceptional cases where specific alignment constraints could make VHS infrastructure more expensive than MHS infrastructure, this option may be preferable. A MHS line may also be sufficient when construction of a VHS line is limited with respect to its speed yield. In networks with consistent foreseeable growth rates, VHS systems offer higher capacity reserves for the future than MHS can. This can make a VHS option the better long-term choice even if lower speed options would be sufficient to accommodate the traffic in the short to medium term.

Upgrading conventional lines to speeds of 200 - 220 km/h with the CUP option makes sense in a variety of scenarios. One of the most attractive reasons for upgrading is the potentially relatively low additional cost of infrastructure required compared to the construction of a new line. However, in practice, upgrading expenditures can sometimes significantly exceed a normal cost level (assumed in the demonstrator model), nearing costs for construction of high speed. This can happen when upgrading takes place in densely populated urban areas or when more fundamental changes in the alignment and equipment of a corridor are required. In terms of benefits, time savings and additional revenues can be generated in cases where the upgrading already represents a leap forward compared to the previous railway offering. CUP solutions could not achieve the level of passenger demand that MHS/VHS could generate, however, in situations where MHS/VHS rail designs cannot deliver superior speed yields, CUPs are fit for purpose and capable of achieving better benefit-cost ratios.

4. Future Higher Speed Corridors in Europe

4.1 Broad Assessment of Candidate Corridors

A variety of corridors are often discussed as potential candidates for high speed development. Several promising corridors were selected from the TEN-T network and further data was collected to determine whether they qualify for future consideration. Corridors considered were those where (i) catchment areas are high, resulting in potentially high demand, (ii) topography is flat or only partially hilly, potentially reducing the high cost of infrastructure, and (iii) the majority of the route is not yet at higher speed levels. A broad range of European corridors could benefit from an upgrade. After a careful review of catchment areas, market demand, topography data, current plans for higher speeds and other criteria, the corridors shown in Figure 16 were selected for further analysis.[2]

Corridor

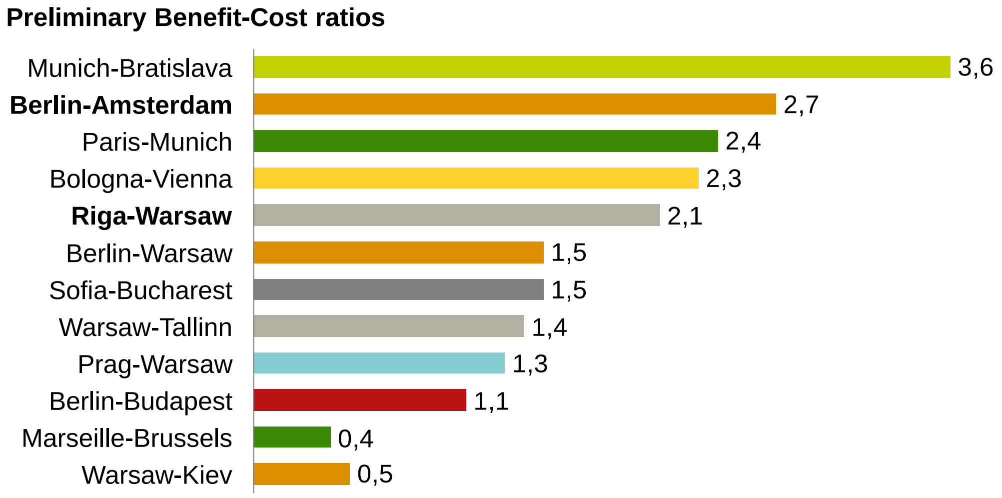
- Munich – Linz – Vienna – Bratislava
- Amsterdam – Osnabrück – Hannover – Berlin – Poznan – Lodz – Warsaw – Lublin – Kiev
- Bologna – Paadova – Ljubljana – Maribor – Salzburg – Vienna
- Tallinn – Riga – Kaunas – Warsaw
- Sofia – Veliko Tarnovo – Bucharest
- Prague – Wroclaw – Lodz – Warsaw
- Berlin – Dresden – Prague – Brno – Vienna – Budapest

Source: TEN-T, civity research

Figure 16: Potential European High Speed Corridors Selected for Further Analysis

For each of these corridors, a simplified benefit-cost ratio (excluding train operator costs) was calculated in a first step to rank the options under a VHS scenario. This is shown in Figure 17. The analysis took income per capita growth estimates into account for valid longer-term projections and benefits, while also roughly approximating infrastructure costs based on general topography.

[22] Please note that other corridors and other markets exist for potential higher speed rail in Europe. The first selection was made primarily based on qualitative data – actual benefits and/or costs may not be optimal for higher speed rail implementation.



1) Commercial revenues per passenger were adjusted based on the income per capita data in relation to France (impacts benefits in eastern Europe negatively, Luxembourg positively). Construction costs estimated equal for all, assuming world market prices.

Figure 17: Simplified Benefit-Cost Ratio Calculation for VHS for Potential EU Higher Speed Corridors (Excluding Train Operator Costs)

Additionally, Figure 17 shows that the rail corridors in a majority of Eastern European countries generally have lower benefit-cost ratios than those in Western Europe. This is primarily due to the lower spending power in these countries, requiring railways in most Eastern European countries to lower prices significantly compared to the price levels in Western Europe in order to attract similar passenger levels in markets of similar size. However, an OECD study predicts that Eastern European countries will close a significant portion of the gap to Western Europe by 2060 in terms of GDP per capita, which will support building the case for high speed infrastructure in the long-term (see Johansson et al.).

4.2 System Economic Model Application – Top Sample

Amsterdam – Warsaw via Berlin and *Riga – Warsaw* would both see a significant benefit from increased speeds compared to current travel times. These corridors meet many of the criteria mentioned and they have high potential benefit-cost ratios for VHS. Additionally, this selection allows for analysis of one corridor from Eastern Europe and one from Western Europe.

Amsterdam – Warsaw

This route would be a major east-west connector and would better link The Netherlands, Belgium and northwest Germany with the cities of Warsaw and Berlin. Currently, the route between Berlin and Warsaw is served by conventional rail. A higher speed stretch exists between Berlin and Hannover, but the remainder of the stretch between Hannover and Amsterdam is not at a high speed level. High speed railways would compete effectively with air travel in the corridors *Amsterdam-Berlin*, *Berlin-Warsaw*, *Amsterdam-Hannover* and potentially also between *Amsterdam-Warsaw*.

Currently, the corridor is mostly operating below high speed. In Germany, a longer section between Hannover and Berlin is operating at speeds of 250 km/h, while in The Netherlands the majority of the current line operates at speeds between 125 - 139 km/h. In Poland, wide variations in speed exist between 60 - 160 km/h.

km of line by current max. operating speed

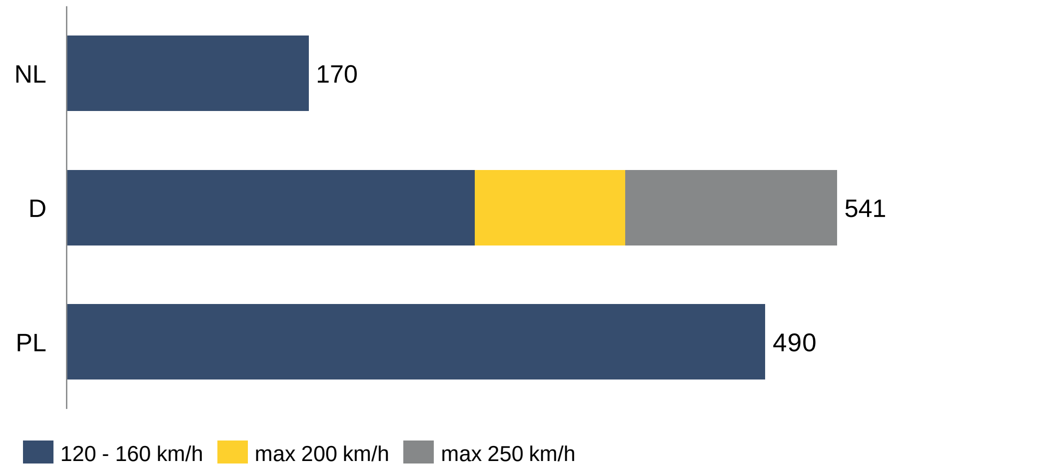


Figure 18: Line-km Categorised by Maximum Operating Speed, *Amsterdam – Warsaw*

Total corridor costs and benefits were calculated using the model described in Chapter 3. New travel times were assumed as a result of implementation of each of the three options. Corridor-specific factors, such as travel time, value of time, estimated revenues and others were incorporated into the model to calculate a specific benefit-cost ratio for each of the options (VHS, MHS, CUP).

The results of the analysis, as shown in Figure 19, indicate that CUP has the highest benefit-cost ratio. VHS, however, has the highest absolute benefit surplus of all the options at € 2,0 billion (total benefits – total costs), which is approximately 30 % higher than CUP. Additionally, from a net financial benefit (commercial revenues – costs) CUP and VHS are nearly equal.

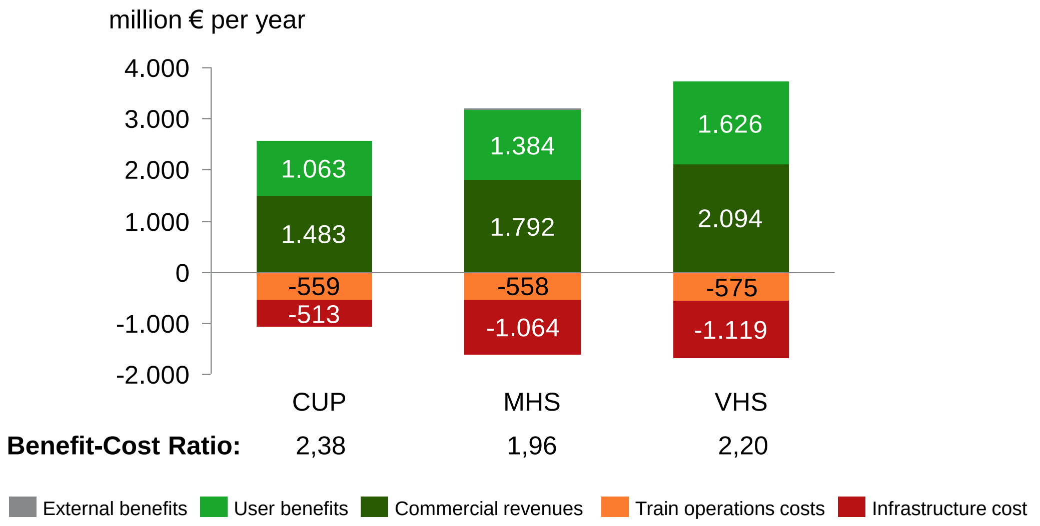


Figure 19: Benefit-Cost Analysis Results: *Amsterdam – Warsaw* Corridor

Riga – Warsaw

Current travel times between these Eastern European capitals are extremely high, at 27 hours for less than 700 km of distance. Plans to incrementally upgrade this corridor to higher conventional rail speeds are currently being implemented. This is a part of the Priority Project 27 for the EU which further connects with Tallinn and Helsinki to the north and is referred to as “Rail Baltica”.

As a result of implementation of CUP, MHS or VHS on the entire corridor, travel times would be reduced to 3:44, 3:05 and 2:39 (h:mm) respectively. As a result of the vast improvement over current travel times, a high level of benefits would be generated for all options. Figure 20 shows the benefits and costs as a result of these options.

The user benefits arising from higher speed rail are very high for this corridor because the rail share of the market and travel speed is low today. Commercial revenues and user benefits are lower than in Western European countries because of the lower GDP per capita. Construction cost, however, would be close to Western Europe prices, assuming that the cost of infrastructure, construction and rolling stock will be at world market prices. The cost of the infrastructure for CUP is expected to be higher than in other areas, because of the low current standard of the line.

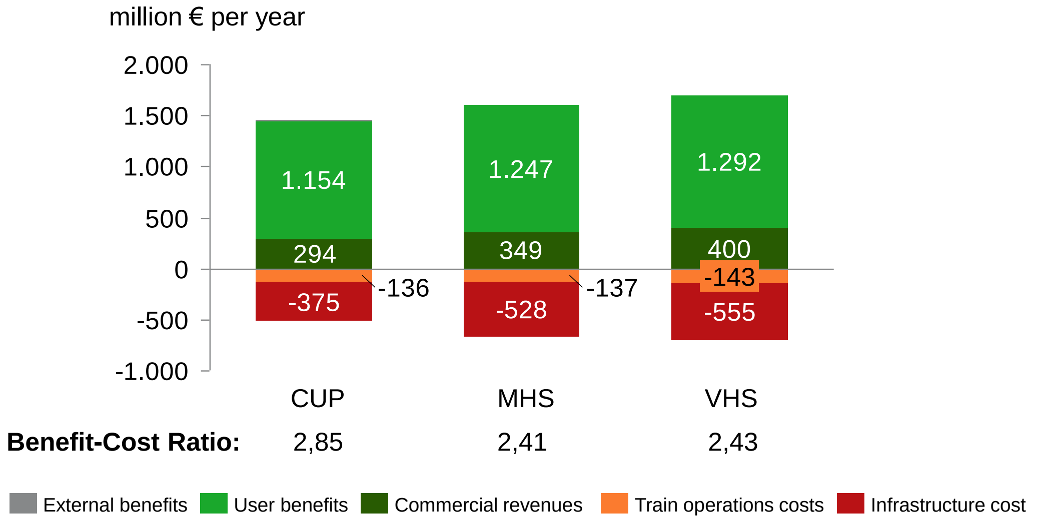


Figure 20: Benefit-Cost Analysis Results: *Riga – Warsaw* Corridor

In this case, similar to the *Amsterdam - Warsaw* corridor, the VHS benefit-cost ratio may be lower than that of CUP, but the absolute surplus benefits for VHS are higher than for CUP by 6 %. This absolute surplus benefit difference to CUP is lower than for the *Amsterdam – Warsaw* corridor, which makes the case for VHS more difficult on this corridor. However, when excluding user and external benefits from the analysis, the CUP and VHS benefit-cost ratios are about equal. From a financial perspective, all three options would require government subsidisation.

The analysis shows that while VHS results in higher absolute surplus benefits than the other options, the benefit-cost ratios tend to favour the CUP option. The results of this high-level analysis do not signify that any of the options on existing corridors are particularly suited for one option over another. As stated previously, an in-depth analysis comparing speed options needs to be conducted for all potential corridors to further differentiate between the benefits and costs of speed options from a full system cost perspective.

5. Summary and Conclusions

The EU has ambitious plans for furthering the development of higher speed rail in Europe. However, given tight budgets for infrastructure investment, a solid economic case needs to be made to warrant investment. Full system economic analysis can support policymakers make this decision. Such an analysis should integrate corridor characteristics and corridor-specific demand, as well as an assessment of major direct and socioeconomic costs and benefits that result from the project.

The choice to develop a corridor either through VHS, MHS or a CUP depends on a complex array of operational, infrastructural and market parameters. Base demand and elasticity of demand are key contributors to determining a preferred alternative, as are infrastructure costs and corridor characteristics. In healthy demand and elasticity scenarios, VHS is often the superior option while in other scenarios CUP may have a better benefit-cost ratio. In favourable cases, benefit-cost ratios for all options are as high as 2,0 to 3,0. In more modest demand and elasticity scenarios, VHS and CUP benefit-cost ratios tend to be similar but with proportionally lower values. Because of the complex array of parameters, each potential rail corridor must be analysed individually to assess which option is optimal.

Favourable conditions for VHS exist in scenarios with healthy passenger demand, long stretches of uninterrupted travel (high speed yield) and high travel time elasticity of demand. If capacity constraints are an issue, both VHS and MHS can help alleviate future congestion. On congested networks, the construction of a new corridor also frees up conventional lines for other uses. Construction of a MHS system with design speeds of 250 - 280 km/h is often not an optimal choice from a benefit-cost perspective. It often has a lower benefit-cost ratio since infrastructure costs are approximately the same as VHS while demand is lower. In a few exceptional cases where a high speed yield cannot be achieved (as a result of specific alignment constraints, short distances between stops) this option may be preferable. Upgrading conventional lines to speeds of 200 - 220 km/h makes sense in a variety of scenarios, primarily because of the potentially relatively low additional cost of infrastructure. However, in practice, upgrading expenditures can sometimes significantly exceed a normal cost level (assumed in the demonstrator model), nearing costs for construction of MHS/VHS. This can happen when upgrading takes place in densely populated urban areas or when more fundamental changes in the alignment and equipment of a corridor are required. Absolute benefits generated by CUP will not usually be at the levels of VHS or MHS. However, in situations where high speed rail designs cannot deliver superior speed yields, catchment areas are modest and no additional capacity is required, CUP is fit for purpose and capable of achieving better benefit-cost ratios.

Finally, two corridors *Amsterdam – Warsaw* and *Riga – Warsaw* were analysed with regard to VHS, MHS and CUP suitability. In both cases, the CUP option shows the highest benefit-cost ratio, while VHS had the highest absolute surplus benefit (total benefits – total costs). These corridors would generate significant user benefits as a result of travel time savings. These benefits are complemented by higher commercial revenues as a result of increased demand on the routes.

In summary, the full system economic account from this study comparing the three higher speed options VHS, MHS and CUP reveals that scenarios exist where each option is the optimal one. The future decisions facing policymakers and railways with respect to financing higher speed rail investment projects will require such analyses to select the optimal design speed on a corridor-specific level. Certain corridors may be ideal for VHS while for some corridors a conventional upgrade will suffice. When looking beyond the benefit-cost perspective, other factors, including capacity concerns, citizen mobility and environmental impacts also help make the case for each of the options. For the pressing issue of freight and passenger rail network saturation specifically, it may be a wise decision to allocate capacity to higher speeds on the European network.

Glossary

Very High Speed Rail (VHS): Passenger rail lines built and equipped for design speeds of 300 km/h and higher.

Medium High Speed Rail (MHS): Passenger rail lines built and equipped for design speeds of 250 - 280 km/h.

Conventional Upgrade (CUP): Upgrade and modernisation of the existing infrastructure to enable speeds on the line at or slightly above 200 km/h.

Travel time elasticity of demand: The travel time elasticity of demand is defined as the percentage change in total passenger demand for rail trips divided by the percentage change in price of rail trips.

Price elasticity of demand: The price elasticity of demand is defined as the percentage change in total passenger demand for rail trips divided by the percentage change in total travel time of rail trips.

Catchment areas: The area and population from which a service (in this case rail service) attracts customers.

Speed yield: The ratio of the effective travel speed to the design speed of a line.

Absolute surplus benefit: The total benefits minus the total costs.

System economic analysis: Holistic approach to measuring potential benefits and costs of a system. For the train system, this involves costs such as total infrastructure costs and operations costs. Benefits include commercial revenues from the train service itself as well as monetised travel time savings that users realise and monetised externalities.

Benefit-cost ratio: Summation of total benefits (in the system economic analysis external benefits, user benefits and commercial revenues) divided by total costs (train operator costs and infrastructure costs).

Dedicated lines: Tracks that are meant to serve only passenger rail traffic.

Mixed traffic: Tracks that support both freight and passenger rail traffic.

Train operations program: The service frequency and capacity on the route to meet demand.

Turnaround times: The length of time that a train spends at its terminating station after a trip before leaving the terminating station for another trip.

Commercial revenue: Revenue from ticket sales

Reserve factors: Total number of train and staff that the railway has in order to support additional capacity needs for unscheduled events including but not limited to major emergencies, train malfunctions, strikes etc.

Civil structures: Defined as tunnels and bridges for the purposes of this study

External benefits: External benefits as defined in this study are the additional monetised societal benefits that a higher speed rail option brings in the areas of climate change impacts, air pollution impacts, urban effects, impacts on nature/landscape, noise, accidents and others.

Design speed: The speed at which trains were designed to operate on a given route or track segment.

Effective travel speed: The measured speed between two cities when taking into account all planned stops and slower speed sections of a particular route. For example, while the majority of track between city X and Y may support train operations at 300 km/h, planned stops as well as acceleration and deceleration lower the effective speed below 300 km/h.

References

Bickel, P., Friedrich, R., Burgess, A., Fagiani, P., Hunt, A., De Jong, G., Laird, J., Lieb, C., Lindberg, G., Mackie, P., Navrud, S., Odgaard, T., Ricci, A., Shires, J., Tavasszyet, L. (2006). Developing Harmonised European Approaches for Transport Costing and Project Assessment.

Breimeier, R. (2002). Transrapid oder Eisenbahn: Ein technisch-wirtschaftlicher Vergleich, Luzern.

Deutsche Bahn. (2010). Deutsche Bahn: 2012 Annual Report, downloaded from the DB website.

Eurocontrol. (2013). Challenges of Growth 2013, Summary Report.

European Commission (1). (2011). White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system.

European Commission (2). (2012). EU transport in figures – statistical pocketbook 2012.

European Commission (3), Directorate General Regional Policy. (2008). Guide to Benefit-Cost Analysis of Investment Projects.

European Commission (4), Directorate General Regional Policy. (2010). High-speed Europe: A sustainable link between citizens.

Garcia, A. (2010). Relationship between rail service operating direct costs and speed, prepared for the International Union of Railways (UIC).

Johansson, A. et al for the OECD (2012). Looking to 2060: Long-term growth prospects for the world.

Laird J., Nellthorp J., Mackie P. (2005). Network effects and total economic impact in transport appraisal, Transport Policy 12, pp.537-544.

LeBoeuf, M. and Paix, J.F. (2012). Analyse économique de a vite se sur les LGV, La Revue Générale des Chemins de Fer.

MVV Consulting and Tractebel Engineering. (2009). High Speed Rail – An Easy Way to Connect, prepared for the European Commission – DG TREN.

Nash, C. (2010). Enhancing the Cost Benefit Analysis of High Speed Rail, Center for Environmental Public Policy, UC Berkeley.

Palmer, Derek and James, Ceri. (2011). High Speed Rail and Sustainability, prepared for the UIC.

Schade, W., Senger, F., Rothengatter, W., Meyer-Rühle, O., Brouwer, IS. (2013). TEN-T Large Projects: Investments and Costs, requested by the European Parliament's Committee on Transport and Tourism.

Steer Davies Gleave, Commission for Integrated Transport. (2004). High-speed rails: international comparisons, London.

UIC Pamphlet. (2012). High Speed Rail: Fast track to sustainable mobility, prepared by the International Union of Railways (UIC).