The Swiss singularity in the European high-speed rail network

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Abstract

In a scenario where the high-speed rail is constantly expanding and getting popular worldwide, the present project focuses on its current situation and its future development in the European network:

In the first part, some case studies are considered being representative for the existing high-speed rail within the continent. Different usages are reported for this new infrastructure amongst the analysed countries, thus, implying different efficiency levels for the correspondent investments. That being a highly disputed issue, this document studies the existing network characteristics and the observed impacts in every case; some key issues have been identified affecting demand volumes in the high-speed lines. Therefore, by using the learned lessons, further development can be assessed elsewhere.

According to the performed analysis in part one, the second part of this project focuses on the particularities for the Swiss scenario. Despite some factors favouring high-speed implementation, Switzerland has opted for alternative railway development so far. Thus, by applying the planning guidance suggested in part one, the possibility for a new high-speed line has been assessed in the country. During this process, reasons leading to its current rejection have been identified. Nonetheless, an adapted design has proved some kind of high-speed to be potentially beneficial regarding the current transportation scenario.

Hence, accounting for the Swiss singularities, the present project proposes a feasible alternative for further railway development, introducing the benefits of the high-speed in the Helvetic country.
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0 Introduction

Since the early days of the industrial era, mobility has enormously increased. Successive industrial revolutions have brought new, faster, and relatively less expensive opportunities for both passengers and goods [1]. It has been during the second half of the 60’s in the XX century, with the rapid expansion of the economy in the main European countries, that passenger transportation demand volumes started to grow considerably in between major population nucleus [2].

Many studies have referred to this correlation between mobility and economic growth. Schäfer and Victor (2000) showed how passenger traffic and GDP per capita were directly linked one with another all over the world (Figure 1).

![Figure 1. Evolution of the total mobility according to the averaged GDP per capita. (Data 1960-1990; Trends 1960-2050). Source: Schäfer and Victor (2000)](image)

Hence, in this context of increasing mobility, it is interesting to focus on how do people move so that transport efficiency can be improved.

It has to be highlighted that despite rising mobility, travel time budgets have remained the same for everyone. According to that, the coupling distance/GDP is strongly related to the coupling speed/GDP [3], and that suggests how the development of high-speed modes has played a major role over the last years. In the graph below (Figure 2) Doomernik shows this tendency of increasing demand for fast modes:
In this line, the air sector started a huge expansion during 1960-70 with the development of jet planes. Air traffic for passengers brought along the possibility of travelling long distances in lesser timings, at the same time that it provided his clients with good safety standards. It has been, undoubtedly, a big leap in people’s mobility.

Nonetheless, as it was getting popular, problems start arising relating to airport congestion – due to capacity limitations – and pollution – regarding energy consume and CO₂ emissions. Thus, air traffic succeeded in the long-trip market, but there was still the willing to look for more efficient modes.

It is this reasoning, and the experimented drops in their market share, that led the railway sector to strive for its boosting and to come up with a new travelling concept: thereby, the high-speed railway (HSR) was introduced as a fast, safe, high-capacity and environmentally-friendly mode. Moreover, and contrary to the plane, the possibility of linking the origin and destination to many other intermediate nodes promoted the attractiveness of this mode to a broader extent of the population. Hence, the HSR was foreseen as the potential mode for medium and relatively long-distance trips.

0.1. Existing problematic

After 1964, with the Shinkansen success in Japan, and since the inauguration of the popular Paris-Lyon connexion in 1981, many European countries opted for building their own HSR national network, so that the presence of this transportation mode has considerably increased throughout the continent. At present, there are 29,792 track kilometres of high speed in the world (UIC, April 2015), from which 7,400 km are located in Europe (López Pita, 2014).

Whilst countries such as France, Spain, Germany or Italy connect now their territory through a relatively extensive HSR network, the scenario presents different in other regions. HSR has been one of the most innovative elements affecting transport over the last years. However, despite its advantages, those kind of infrastructures are expensive, they require significant investment and, at the same time, their economical and social
effects are difficult to predict [4]. There are cases where high-speed lines (HSL) have been built not matching with their expected demand. That introduces an efficiency problem for those lines which is still being a highly disputed issue, and which has led other countries to adopt transportation policies disregarding the high-speed train.

That is the case of Switzerland, where the HSR network has been discarded many years ago. Instead, they opted for improving their conventional train network by upgrading some infrastructure sections and rescheduling their trains.

That said, what is the most cost-effective solution for rail development? In order to prove socio-economical profitability for these new infrastructures, the current situation manifests an urgent need for a careful assessment of the costs and benefits for each particular case. It is therefore important to be aware of existing research in the impact that new HSL have had on the economy, transport patterns and general society.

0.2 Project goals

According to the presented problem, this project is aimed to analyse the current situation of the European high-speed network:

In the first part, the most relevant networks in Europe are going to be reviewed. By taking some case scenarios, the main goal would be to identify the most significant factors influencing demand volumes. That would lead to pinpoint the main causes affecting observed efficiency and profitability of the concerned infrastructures, so that afterwards, the identified factors could serve to assess future railway development elsewhere.

In the second part, the project is going to focus on the Swiss case. As mentioned above, Switzerland does not account with a HSR network. Thus, by analysing the present scenario and taking into account the learned lessons in the first part, the main goal would be to perform a HSR project appraisal in the country. Would it be profitable to construct a new HSR line in Switzerland? What is the best solution?

In the end, the ultimate goal of this study is to identify and discuss which are the Swiss singularities that led the country to adopt different policies within the European high-speed rail network. According to them, future railway development is going to be assessed.
1 The high-speed rail

Before starting with the project analysis, a brief introduction of the high-speed rail is presented in this first section.

1.1 General definitions of high-speed

High-speed rail is a combination of all the elements which constitute the railway system, namely the infrastructure, the rolling stock and the operation conditions. Consequently, due to many different possibilities in their performance, it becomes difficult to find a single standard definition for a HSL.

Even though high speed usually means at least 250 km/h, the definition is not unique. Criterion for lines to be claimed HSL usually differ according to the country, so that it gets complicated to compare the situation in between them.

Nonetheless, in order to standardize the situation, the European Union gave a definition which encompasses a large number of systems under the banner of high speed. When it comes to the infrastructure [5]:


1.2 Evolution of maximum speed on rails

Throughout rail history, consecutive tests have been performed in order to beat new speed records. As aforementioned, the high-speed threshold is fixed around 250 km/h, but
since it was reached, due to new technologies and knowledge improvement, the operational speed has already reached 320 km/h so far (UIC, April 2015, maximum speed in revenue operation).

Figure 3 shows the speed evolution both in tests and in train operation:

![Figure 3. Evolution of maximum speed on rails. Source: UIC High Speed (June 2009).](image)

### 1.3 Advantages

When talking about high-speed, the main advantage that comes to our head is time savings. However, the introduction of this new transportation mode implied the introduction of further advantages comparing to other fast modes:

**Time of travel**

Not only HSR allows travelling with a high level of speed, but it also benefits from a better travel time door to door for a certain range of distances (Figure 4). Door to door time is the key variable in determining the travellers modal choice.

![Figure 4. HSR travel time benefits door-to-door. Source: López Pita, 2014 [2].](image)
Whilst short distances do not allow the effects of speed to be noticed - due to performance in acceleration/deceleration - and convenience of the car is hard to beat, when trips become too large, higher speeds of planes - around 900 km/h for an Airbus A320 - lead air travel to gain the upper hand.

Nevertheless, there is a range in between 150-800 km [7] where HSRs are preferred over the other modes. Some literature talk about the “three-hours travel time threshold”, which states that trips taking less than 3 hours are rather preferred by train than by plane. Some of the reasons explaining this behaviour lie on:

- Strategic positioning of HSR stations, usually located not far to the city centres, unlike airports.
- Accessibility, avoiding check-in times.

Apart from a shift in transportation market shares, such an appealing characteristic has also brought some induced demand; HSR allows one-day trips back and forth, and that has increased mobility rates within a country, mainly amongst businessmen.

**High capacity**

High-speed branches provide higher passenger capacities than air traffic. When it comes to medium-distance trips, where HSR compete with air, planes do offer capacities around 110 seats, reaching a maximum of 200 seats. Meanwhile, high-speed trains present minimum capacities around 350 seats, and a maximum of 500 for the two-stages branches. Moreover, the possibility of coupling two different branches still leaves room for the total rail capacity to be doubled [2].

Also, higher capacities in high-speed branches lead to less probability of congestion. For a same demand, wider time margins can be planned in rail operation so that it becomes easier to absorb potential delays. Hence, HSR can be stated to be a more reliable mode than planes when it comes to punctuality.

**Environmental respect**

Since the mobility expansion started, due to the great increment in road and air traffic, petrol consume has also augmented over the last years. Petrol is an expensive and limited natural resource whose consumption should be regulated.

Rail transport has been proved to be a more energy efficient mode. Specifically, whilst HSR consumes less than 20 gep/PKm (equivalent grams of petrol per passenger kilometre), cars need something around 30 gep/PKm and planes more than 40 gep/PKm [2].

Moreover, during their operation, the concerned transportation modes emit CO₂ gases, which are prejudicial for the environment, boosting the so-called Global Warming. It has been proved that journeys by HSR produce much lesser emissions per passenger than those performed by car or plane [10].
It should be added that landscape integration is also better for rail than it is for road or air traffic. Motorways and airports construction require a greater land occupation, representing not only a space fragmentation and a huge visual impact, but also affecting biodiversity and damaging a greater part of natural habitats (even though it has to be taken into account that one airport flies to many destinations, whereas HSR travels between a limited number of stations) [11].

**High safety**

High-speed rail has proved to be the safest mass transport mode in the world. Up to today, no accidents with injured passengers are reported in rail at more than 200 km/h. [UIC, June 2015].

**1.4. HSR network in the world**

In the world, HSR network extends to 29.792 km of lines in operation (UIC, April 2015) according to the criteria defined by the European Union.
By considering only those lines where speeds reach 250 km/h (with exceptions for Germany), this value reduces to 22,954 km (UIC, 2014) [6], from which 7,400 km are located in Europe (López Pita, 2014). Figure 7 shows the evolution and the expected trends for HSR infrastructure in the world.

Focusing on Europe, HSL are projected to triplicate the current network length. Nowadays, 2,929 km of HSL are being constructed in Europe, and 10,815 km of new infrastructure are also planned for long-term (UIC, 2014) [6].

In this context, it is interesting to focus on the development of HSR in the European continent in order to assess future expansion.
PART 1: CASE STUDIES
2 The European high-speed rail network

2.1 Previous considerations

1) In order to study the HSR development in Europe, this project is only going to focus on some representative country case studies. France, Spain Germany and Italy are the selected ones, since the HSR network in these four countries alone account for the 93% of the total network within the whole continent (\(v > 250\) km/h, with exceptions for Germany, UIC 2014) [6].

![Figure 8. The European high-speed rail network. Source: UIC, 2013](image)

2) HSR performance and efficiency of usage are only going to be assessed for passengers’ transportation, disregarding effects on freight.

3) Even though the recent effort from the European Commission to build an international HSR network (Ten-T project) [7] and despite the existence of some links in between countries, for the moment, international passenger volumes in rail transport for the selected case studies are considered to be irrelevant. Figure 9 plots the averaged rail travelled distance per inhabitant in each country, both nationally and internationally.

It has to be highlighted that this values stand for the total rail mobility - HSR plus conventional train -, so that HSR international percentages might be higher than the showed values. Still, the possible difference is assumed not to be significant enough, so that national mobility keeps representing the vast majority of high-speed rail trips. Hence, only national mobility is going to be analysed throughout the case studies.
2.2 Mobility patterns

A first glance into mobility patterns would be the first step for its own optimisation in a country. It is important to understand transportation trends in order to consider different solutions and new infrastructure needs that could lead to real efficiency improvement.

For the selected countries, national mobility patterns show as:

Figure 10 does only show national mobility patterns for inland modes, since domestic air transport statistics for passengers were not available in the consulted sources. Note also that HSR statistics were not always specified in national terms, so data has been adapted by following the observed trends (annex A.1).

According to the observed patterns, road traffic – both public and private - represents by far the greatest part of national mobility within a country. There are many factors intervening in each individual's modal choice, but large volumes in road traffic can be roughly explained by its extended existing infrastructure (Figure 12), as well as by the comfort and the flexibility it provides for the numerous amount of performed short trips. However, when it comes to long distance trips, traveling times do significantly increase by...
road, thus reducing its attractiveness. It is generally in these cases where rail alternatives do also play a role.

Looking at the exact values for mobility (normalised values in p-km/inhabitant, Figure 11), it is possible to easily identify different behaviours in between countries. Some remarks are:

- France has larger inland domestic mobility than the other regarded countries, whilst Spain is situated at the bottom of the queue. Mobility in Spain represents only the 58% of that in France, expressed in averaged travelled distances per inhabitant (p-km/inhab).

- Also rail mobility has the largest ratios in France, with the 10.5% of total travelled distances performed either by conventional or HS trains. These distances represent a 7.5% in the case of Germany, and only around 5% for Spain and Italy.

- When it comes to HSR, the French population travel 53% of the total rail distances by high-speed. However, in the other analysed countries, this percentage turns out to be in between 26-28%.

Hence, in averaged travelled distances (p-km/inhab), total HSR mobility relatively to France stands for only the 15% in Spain, 32.5% in Germany, and 23% in Italy.

It looks like HSR transportation has been a complete success amongst the French. However, in order to check its efficiency, it is necessary to analyse the existing infrastructure supporting this mobility.

### 2.3 Existing infrastructure

In order to give service to the observed demand, the existing infrastructure in each country follows the following patterns (Figure 12):
Focusing on rail infrastructure (Figure 13):

In all cases, according to observed mobility patterns, an extensive road network gives service to the high demand travelling by car, whilst rail stands on a second stage. However, it can be noticed that the relation “infrastructure length – demand” is not proportional for the different modes and in between countries.

Table 1 compares infrastructure and mobility values in each studied case, taking France as a reference:
Looking at the presented values, the situation should be highlighted for the high-speed rail, where differences in the infrastructure usage turn out to be particularly high. The most extreme deviations come from comparing the French to the Spanish scenario: in Spain, a network which is a 8% more extensive carries only the 15% of the averaged HSR traffic in France. Thus, it evidences huge differences in the existing HSR network usages.

### 2.4 Efficiency of the network usage

According to the presented data, no correlation between infrastructure length and demand can be observed, so that it would result difficult to predict future infrastructure usage.

However, looking at historical statistics for each country, a similar trend can be generally proved for both factors over the years; an increase in demand is observed as far as infrastructure network is expanded (Figure 15).
The Swiss singularity in the European high-speed rail network

**Figure 15.** Infrastructure (km) – traffic (p-km/inhab) evolution. Source: collected data from various sources (annex A-1).

Focusing again on HSR:

**Figure 16.** Infrastructure – traffic evolution in HSR. Source: collected data from various sources (annex A.1).
Figure 16 plots together the growth in HSR infrastructure and its respective demand evolution in the regarded countries. All of them show an increasing tendency, but still different efficiency levels are clearly distinguished for each case study.

Definitely, it can be stated that France has succeeded in attracting travellers to its new HSR network, whose usage turn out to be the highest amongst the analysed cases in Europe. But which are the reasons that led to the different scenarios in the other countries? Which factors do influence this non-proportional infrastructure-demand growth?

Summing up, a relevant efficiency difference has been identified for certain HSR investments in Europe. It is not only the network dimension that attracts demand to new infrastructure, but some other factors seem to play a role. Therefore, in order to improve future investments, it would be convenient to be aware of the factors explaining such different mobility patterns. In this aim, the next section is going to analyse different characteristics diverging throughout the selected countries and whose influence is likely to affect HSR demand rates.
3 Key factors in HSR demand

In the last section, a relevant efficiency difference has been identified for HSR networks in Europe. Different demand patterns have been observed throughout the analysed countries, leading to low usage rates in some cases.

To better understand the reasons that led to such a situation, this section characterises the HSR network in each country. Factors that are likely to affect demand have been identified and they are going to be described and compared in between the selected case studies.

Below, the following subsections are going to present those key factors: they have been distinguished between country characteristics, existing HSR network characteristics and those regarding other existing transportation alternatives within the nation.

3.1 Country characteristics

3.1.1 Urban structure

Urban structure relates to the existing population and its distribution throughout the country. When it comes to HSR lines, it becomes essential to connect the most populous and important cities in the territory to justify investments and achieve satisfactory socio-economic returns. Thus, referring to urban structure is a first step to understand HSL designs and its performance.

As a first approach, it seems logical to state that the more people living in a country, the more potential demand an infrastructure would have. However, this has proved not to be a direct relation, so that many other demographic factors do also play a role (note that the exposed mobility values in former sections have already been normalised by the number of inhabitants in each country – expressed in passengers’ kilometres per inhabitant-).

Therefore, the demographic factors affecting the observed mobility behaviours relate basically to how all this population distribute over the territory. In order to get an idea of that, population density and urban agglomerations location can be referred.

Population density

When it comes to potential demand for HSR, higher densities in urban areas will allow a larger part of their population having easy access to the train station. Conversely, sparse distribution would imply higher efforts – either time or monetary costs – for population to take the HS train, thus reducing its potential benefits and its attractiveness.

Regarding the selected case studies, France and Spain are countries with relatively low densities – 118 hab/km² and 92 hab/km² respectively -, compared to the 233 hab/km² in Germany, or 202 hab/km² in Italy. However, as mentioned above, it is population in urban agglomerations, where train stations are located, that is going to affect potential traffic to a greater extent.
Figure 17. Population density in the 10 major urban agglomerations and in the country. Source: own production from collected data (annex A2). Agglomeration densities according to “Demographia” [13].

Figure 17 plots the ratio between population density in the ten major urban areas versus the country density. High ratios indicate high presence of human densified nucleuses. Hence, countries such as Spain or France are more likely to get higher HSR potential demand than countries where people live in lightly populated suburbs.

To illustrate this factor, in France, it is routes serving Paris that get the higher demand, leaving second-rank cities such as Lille, Lyon or Nantes with little potential traffic in between them [3]. The main reasoning for such situation is the huge potential attraction of the French capital, with a population of 10,858,000 citizens and a density standing around 21,000 hab/km² in the very city centre, doubling that of the second larger and most densified agglomeration, Lyon, with 1,583,000 inhabitants and a density of 9,900 hab/km².

Therefore, it seems reasonable to state that population density is a good indicator to identify major agglomerations with high potential demand for HSR services.

Urban agglomerations location

Since HSLs are aimed to connect major urban agglomerations, once these potential areas have been identified, another relevant factor would be the location of the two points – origin (O) and destination (D) – over the territory.

Passengers demand will increase in a line if there is the possibility to serve not only O and D, but also other potential intermediate areas along the trajectory. The same will happen if the infrastructure improves accessibility to further urban nucleuses. The main idea is to design a line able to give service to a wider area, so that a larger part of population can benefit from it.

However, this possibility of widening service does mainly depend on how “friendly” the urban distribution is to HSR: a HSL is likely to be stronger if population is located in corridors that can be served in a single line.

Italy, for instance, exemplifies this mentioned corridor scenario; with its long and thin nature, its HSR services link main cities from north to south in a single line, namely Naples,
Rome, Florence, Bologna Milan and Turin. Consequently, the haul Rome- Florence is of benefit for a large number of different cities, and not just these two.

Another example would be France, with its “Paris-Lyon” model. When it was inaugurated, the first HSL in Europe connected the two main agglomerations within the French territory, which basically explains the huge success of this line. Nevertheless, the new link also benefited accessibility from the capital to further cities such as Marseille, the 3rd most populated urban agglomeration within the country. Such scenario allowed increasing the efficiency ratio for the infrastructure investment. Still, after the arrival of the HSR to Marseille with the LGV Mediterrané, the French distribution kept allowing significant timesavings for other important cities located on the Mediterranean coast: conventional branches improve access also to Nice, Toulon, or even Toulouse.

Therefore, both in France, and mainly in Italy, the existing population distribution has enabled maximum use to be made of HSR [3].

In Spain, however, even though potential demand benefits from large urban agglomerations, the distribution of these nucleuses over the territory does not show the same advantages. The HSR network connects the capital city, Madrid, with the other large cities following a radial-shaped network. Hence, as most of these large cities are located on the coast, the existing distribution does not allow HSL to benefit further areas. Moreover, intermediate medium-cities are not seen to provide relevant potential demand.

To finish with, German population has been seen to distribute more sparsely around the country. Unlike France or Spain, it lacks a mono-centric focus, and cities are often medium-sized, not far from one another. As a result, high-speed lines do connect small centres all along their trajectories, so that demand in intermediate stops becomes relevant comparing to that in origin and terminus.
### 3.1.2 Distances between population centres

As seen in section 1.3, HSR offers timing advantage for journeys over medium-distances, but little over long or very short hauls. Hence, HSL investments would only make sense in between stations located at a certain distance. The optimum range is proved to be generally around 150-800km [7] in order to provide faster services than road or air (Figure 18).

![Figure 18. Door-to-door journey time v. distance for rail and air transport](image)

It is again urban agglomerations location that is going to determine suitability for HSR alternatives. HSR stations are usually placed in the largest cities, and therefore, it is the distance in between them what matters.

Both in France and Spain, the situation presents ideal to fulfil such a distance requirement. In the first one, the majority of the journeys from Paris are more than 400 km away and, except Nice, not further than 800 km [3] (journey distances by HSR, not straight distances). Hence, links connecting main cities fall within the optimal range. Also in Spain, with Madrid located in the centre, other major cities are found on the coast, 400-600 km away by HSR.

Conversely, urban agglomerations in Germany and Italy are sufficiently close together so that HSR offers little advantage. In Italy, the country structure leads HSR to connect a sequence of medium and large urban areas no further than 100-250 km from one another, thus falling in a range where competition with road is high.

(1) It should not be linear.
In order to get an idea of how “friendly” is the country when it comes to distances, Table 2 presents an averaged value of connexion distances between the 10 main urban areas. Note that this is just a rough approach to assess the country’ scenario, so that straight distances instead of infrastructure lengths have been measured for the most likely consecutive connexions (see annex A.2).

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<tr>
<td></td>
<td>276 km</td>
<td>310 km</td>
<td>196 km</td>
<td>147 km</td>
</tr>
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</table>

*Table 2. Distances between main cities. Source: own production (annex A.2).*

### 3.1.3 GDP and economic distribution

As presented in the introduction, population’s mobility increases with GDP (Figure 1). Thus, countries with higher GDP per capita are expected to exhibit higher mobility demand ratios.

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</thead>
<tbody>
<tr>
<td>GDP per capita [eur/inhab]</td>
<td>33.361</td>
<td>22.415</td>
<td>35.866</td>
<td>26.519</td>
</tr>
<tr>
<td>Inland national mobility [p-km/inhab]</td>
<td>15.322</td>
<td>8.924</td>
<td>12.731</td>
<td>14.244</td>
</tr>
</tbody>
</table>

*Table 3. GDP per capita v. national mobility. Source: World Bank (2015) and various sources for mobility, 2010 (annex A.1).*

However, according to figures in Table 3, the expected relation is not fulfilled. Therefore, it would be proper to account not only for the GDP by itself, but also for the economic distribution over the territory.

France, as a centralised country, gathers its economical activity mainly in the capital city. Therefore, French citizens might have a greater need to travel from and to Paris. On the contrary, a more homogeneous distribution might lead Germany to show a fewer amount of trips in between its cities. This reasoning might help to explain the no direct correlation between GDP and mobility.

Hence, in order to account for the two factors together – GDP and economic distribution -, a good indicator could be the “mobility habitude”, simply reflected on the total national mobility statistics. Taking France as a reference, mobility habitude shows (Table 4):

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<tr>
<td></td>
<td>1</td>
<td>0,58</td>
<td>0,83</td>
<td>0,93</td>
</tr>
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</table>

*Table 4. Inland national mobility comparison: Mobility habitude. Source: collected data from various sources, 2010 (annex A.1).*

France shows the highest passenger traffic, and figures are not far from those in Italy. In Germany, although having a more even economic distribution of urban areas, the observed values do not drop that much. Nonetheless, passenger mobility in Spain drops almost to
half of that in France. Therefore, even having a similar distribution, radial-shaped and with the capital city as the main focus, stronger economic nodes might exist in Spain, leading people to less mobility habitudes. Also some cultural aspects could be a cause for the observed behaviour.

Up to here, key characteristics have been analysed regarding the own limitation for mobility demand in each country. Consequently, it is imperative to assess the "country potential" for HSR as a first step before starting to plan a future national network.

### 3.2 HSR network characteristics

#### 3.2.1 Construction motivations: network design and functionality

There are many reasons that can lead a country to opt for a new HSL construction. Usually, and contrary to what can be thought, it is not that much about speed, but capacity reasons that make HSR an attractive alternative.

Capacity has been the main justification for constructing the first HSLs, like Paris-Lyon, and it has continued being the main reason for other connexions, such as Rome-Naples, in Italy, where the gain in speed was relatively small [12]. In saturated connexions, HSR becomes a good solution; on the one hand, it allows getting rid of congestion, and on the other, the infrastructure efficiency is assured, since potential demand does already exist in the congested line.

Nonetheless, time reductions have also been a reason promoting HSR investment in those segments where the existing rail geometry limited train speeds.

Whilst France has designed its whole HSR network focusing on solving capacity problems for passengers, Spain has opted for equity and cohesion motivations, striving to improve accessibility of the regions to the capital city. In Italy, investments were made to provide a more efficient alternative mode, overcoming both capacity and slow sections limitations in the already existing rail lines. Hence, all these cases led to a HSL design that allowed passenger trains to circulate more efficiently according to the pursued goal.

In Germany, however, different targets led their national high-speed network to a particular scenario. First new lines in Germany were aimed to connect economical and big industrial areas; thus, both passenger and freight traffic were allowed through the new infrastructure. Mixed traffic models imply some restrictions in the track design – requirements in slope and radius size -, an increase in cost of maintenance, and limitations in passenger trains capacity, whose frequencies can be affected. Hence, those are not recommended for relations with high passengers traffic. Moreover, speed targets where not that important according to the German goals, and consequently, maximum speeds were fixed at a lower level than in the other analysed countries.

Definitely, the German model would not have worked for a saturated line as Paris-Lyon, but it suited the country goals instead. Hence, that manifests the importance of analysing each particular scenario and understanding the main motivations behind any infrastructure before evaluating it. Having a clear idea of the main goal will lead to adapt the railway design and to select the best exploitation mode for the lines to achieve efficiency.
3.2.2 Maximum and commercial speed: intermediate stops

Maximum speed is defined as the maximum travelling speed that a high-speed train can reach at some point during its journey. However, track limitations, intermediate stops or acceleration and braking performance can change the speed efficiency for the rolling stock, thus leading to an increase of the total journey time. In order to measure all these factors, it is proper to rather refer to the concept of commercial speed.

Commercial speed for a certain relation is computed as the distance divided by the total time needed to get from O to D. As it is door-to-door time what matters to passengers, it is usually commercial speed, and not the maximum one, that becomes a better indicator in explaining demand patterns.

Table 5 shows the design speed values and the averaged commercial speeds for the HSR network in each case study. In order to compute commercial speed, some representative lines have been considered in each country (see annex A.3).

<table>
<thead>
<tr>
<th>Av. maximum speed in the HSR network [km/h]</th>
<th>Av. Commercial speed [km/h]</th>
<th>Ratio com/max speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>198</td>
<td>0,65</td>
</tr>
<tr>
<td>20%</td>
<td>=307</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>=291</td>
<td>0,73</td>
</tr>
<tr>
<td>60%</td>
<td>=264</td>
<td>0,58</td>
</tr>
<tr>
<td>80%</td>
<td>=250</td>
<td>0,61</td>
</tr>
<tr>
<td>100%</td>
<td>=284</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Averaged maximum and commercial speed in national HSR networks. Source: Maximum speed according to UIC [6] and own production from various sources (annex A.3).

According to their characteristics and motivations, the German scenario can be highlighted having a slower network. Besides, infrastructure in France stands out to have the fastest tracks. Nonetheless, maximum speeds do not match with averaged commercial speeds.

Variations in the commercial/maximum speed ratio depend on track limitations - which can be linked to topography difficulties or urban agglomerations - and on the number of intermediate stops. Being the latter the main intervening factor, it is interesting to focus on intermediate stop policies in the regarded countries.

Intermediate stops

Intermediate stops in HSR routes are one of the key factors privileging rail modes against national air traffic when it comes to potential demand. New stops along an O-D connexion do increase the served population, thus leading to more people using the concerned infrastructure.

However, intermediate stops do also carry an important trade-off between attracting new markets and loosing share in the major potential O-D connexion through a loss in speed. When related to important potential demands and supported by good access, intermediate stations are more likely to promote traffic gains. Thus, they need to be carefully planed.
Reviewing the European scenarios, different strategies have been adopted throughout the continent:

In France, for example, they opted for new lines over long distances, adopting a door-to-door logic between major centres of population. Generally, when a line passes close to a medium-size city, it avoids it; there are few intermediate stations. However, where considered necessary, a special station outside town has been built providing access to the HSR system; this way, time losses are minimised avoiding penetration into urban dense areas. Frequencies to these stops are linked to the size of the conurbation [3]. Similar urban characteristics led to an analogous model in Spain, where also gauge reasons required of new lines in order to develop HSR.

Nevertheless, other forms of development have been seen in Germany, where high population densities require a great number of intermediate stops. In there, old tracks have been upgraded allowing HSR arriving to all the historical stations. Thus, people’s access is improved, but on the flip side, the numerous intermediate stops, plus the fact that they are located in dense areas and close to each other, explain the low speeds in the country.

To get an order an order of magnitude, a value for the number of intermediate stops and distances between them has been computed in each case (Table 6). Again, such figures have been averaged by taking the regarded representative HSLs and according to the stopping frequencies in each station (see annex A.3).

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<tr>
<td>Av. number of intermediate stops in HSL</td>
<td>1,03</td>
<td>0,99</td>
<td>1,58</td>
<td>2,11</td>
</tr>
<tr>
<td>Av. intermediate distance in HSL [km]</td>
<td>261</td>
<td>239</td>
<td>113</td>
<td>121</td>
</tr>
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</table>

*Table 6. Intermediate stops policies and characteristics in HSR. Source: own production from various sources (annex A.3).*

With a similar average for intermediate distances, a higher ratio of intermediate stops in France could help to explain the observed difference in the commercial/maximum speed ratio between Spain and France. However, this reasoning seems not to be enough, so that the other mentioned factors (topography, human settlements, etc.) might also play a role in this case.

In Italy, the high ratio of intermediate stops is explained due to the layout of its national network, consisting of a single line including some of the bigger urban areas, but also due to the existence of extra stations in the outskirts of the main cities. However, comparing to the German case, commercial speeds are not heavily penalised. Other network and country characteristics are suspected to explain the difference (longer distances in between stops, less population density along the trajectory, new entire lines, etc.).

### 3.2.3 Frequency

Higher circulation frequencies are linked to better flexibilities for passengers, and better flexibilities do generally imply waiting time reductions. Thus, higher circulations would allow better timing perceptions and more willingness to take the concerned mode.
Frequencies turn out to be especially sensible for those trips implying some change, since waiting time would be unavoidable and completely dependent on the planned schedules.

As aforementioned, operation models can affect the train circulation capacity. Hence, according to the German model (section 3.2.1), lower frequencies can be expected due to freight circulation limiting passenger trains’ capacity. Figure 19 evidences this reality:

![Figure 19. Trains per direction per day on HSLs. Source: [12]](image)

So as to get averaged data for the selected countries, frequencies have been measured in the representative connexions (annex A.3). However, and contrary to data in Figure 19, the obtained results show no big differences for the average country services.

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<tr>
<td></td>
<td>18,8</td>
<td>20,2</td>
<td>19,6</td>
<td>21,3</td>
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*Table 7. Averaged number of trains per day and direction in the main HSR relations. Source: own production from various sources (annex A.3).*

On the one hand, it has to be considered that computed data represents just the number of high-speed services connecting a certain relation, and that differs from the total number of trains running through that specific stretch on a daily basis.

Furthermore, only main city relations have been checked. Hence, it makes sense to have similar frequencies for all the links, since even having less circulation capacity, time schedules would probably be planned so that major connexions are not affected.

### 3.2.4 Intermodality and infrastructure integration

Typically, greater traffic volumes will be obtained where there is possibility of the HSR route being integrated with the rest of the network [9]. Accessibility has already been mentioned as one of the key factors in determining demand. Therefore, apart from planning lines running through the main urban agglomerations, accessibility can also be improved for further areas by ensuring the infrastructure integration within the current network.
In order to expand its benefits to further areas, it is possible to talk about the intermodality and the integration of a HSR network:

**Intermodality**

When there is the willing to attract demand through an intermediate stop, a good practise is to guarantee good accessibility to the regarded station by using the already existing transportation network.

In France, contrary to Germany or Italy, they did not look for connexions HSR-conventional lines along the planned high-speed trajectories. Some intermediate stations have been planned far from city centres, isolated. Even it is true that the main reasoning behind it was to avoid sinuosity and speed loss by going into the cities, a lack of intermodality has led the private car to be the only way to get in there. Hence, the French HSR network presents with few intermediate stops and with limited service in those [14].

Le Creusot and Mâcon, in the Paris-Lyon HSL, are some examples for these peripheral stations in France. The main idea in both cases was to create an activity zone around those stops. However, its success was closely linked to accessibility and relationship to the nearest urban area. Whilst in the first case the lack of conventional train or even a good highway access resulted in little interest for the region development, in the second, improved connexions by highway led to a more successful scenario. Yet, as none of the mentioned stations was planned for intermodal connexions, they are still suffering from this status. Hence, HSR proves not being self-sufficient to develop attractiveness by itself.

In Spain, the scenario presents similar. Intermediate stops within the Spanish network show generally poor developed surroundings. Activity zones have not been properly planned in the area, and a lack of multimodal access is also affecting HSR demand volumes [15].

Nonetheless, the country characteristics and the adopted network models in the German and the Italian cases let their HSR infrastructures to take more profit of intermediate stops. On the one hand, population distribution along the line allows higher potential demand in intermediate stations (section 3.1.1), and on the other, high-speed services arriving at the historical stations allows a high level of intermodality, thus extending its benefits to a broader area thanks to a good accessibility.

Consequently, in light of all the above, the principle of multimodal connexion has been adopted as a crucial factor for attractiveness.

**Integration**

It is not only intermodality in stations, but also the network integration, that can boost demand increase by means of serving a broader part of society. By network integration it is here referred the possibility to operate conventional and HSR lines together.

The French TGV, for example, is allowed to run on conventional electrified lines, and that brings over 200 stations being directly benefited from high-speed services [3]. Such a possibility, however, stems from the continuous efforts of the French in keeping their conventional network in good state. Thanks to that, HSR services are nowadays quite competitive throughout these lines (Figure 20).
Also the German model, due to its fully mixed system, allows entire integration for the HSR. Moreover, since the HSR network in the country was thought as an upgrade of the conventional one, not only high-speed trains can run on conventional lines, but also the other way around.

The Italian network is also planned considering integration of the HSR with the conventional rail.

In Spain, however, high-speed trains do usually run only on specially designed lines. The main reason is the broader gauge used in conventional lines, which differs from the UIC one used in HSLs. Nonetheless, since the introduction of the adaptable Talgo rolling stock, some HSR journeys can also continue over the conventional line. Yet, given the low quality of the old tracks, significant speed reductions lead those journeys to loss competitiveness.

Table 8 provides an indicator for this integration factor in the studied countries. In order to compute it, some relations have been checked in between main cities, where the origin has been chosen to be the capital city and the destination has been selected amongst the largest ten cities not disposing of direct HSL connexions with the capital (see annex A.4). By doing that, the commercial speed in mixed connexions has been averaged and compare to this of fully HSR connexions.

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<tbody>
<tr>
<td>Ratio commercial speed mixed/HSR</td>
<td>0,78</td>
<td>0,45</td>
<td>0,78</td>
<td>0,62</td>
</tr>
</tbody>
</table>

*Table 8. Integration indicator for the HSR with the conventional rail network. Source: own production from various sources (annex A.4).*

The resulting values do reflect the mentioned characteristics for integration in each case.
3.2.5 Pricing

Due to its improved service, travelling by high-speed modes does usually imply an increment of the ticket price compared to conventional modes. Therefore, for rail modes, the development of HSR entailed an increment of its averaged monetary cost.

Depending on adopted pricing policies, the ratio HS/conventional is seen to differ from country to country. For those cases where it turns out to be smaller, there is theoretically a less negative impact on demand, since people is already used to pay similar prices for worst rail services, so a small difference will pay off.

Moreover, when it comes to people’s perceptions, another factor to consider is society’s wealth, so the GDP will also be a relevant data. Generally speaking, wealthier societies will be less sensible to ticket prices increments.

Although it is difficult to determine the averaged costs, because of HSR fares being typically fixed according to yield management, some values have been computed by checking current prices in some representative links for every country (annex A.5). Therefore, even not accurate, presented figures can give a rough idea of the fare scenario in each case.

Table 9 shows the obtained order of magnitudes for price kilometre, as well as the price perception according to de national GDP and the comparison with conventional train tickets (see also annex A.5):

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<tbody>
<tr>
<td>Av. HSR fares</td>
<td>0,148</td>
<td>0,145</td>
<td>0,244</td>
<td>0,128</td>
</tr>
<tr>
<td>[eur/km]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSR fare/GDP per capita [eur/km/Meur]</td>
<td>4,4</td>
<td>6,5</td>
<td>6,8</td>
<td>4,8</td>
</tr>
<tr>
<td>Ratio HSR/CT fares</td>
<td>1,1</td>
<td>1,38</td>
<td>1,32</td>
<td>1,79</td>
</tr>
</tbody>
</table>

Table 9. HSR fares analysis and country perception. Source: own production from various sources (annex A.5).

Results suggest especially high fares for the rail in Spain and Germany, and a huge increase for HSR fares in Italy comparing to the conventional services. In France, however, adopted pricing policies in HSR can be stated to be one of the key factors explaining its success; low differences in costs are perceived for usual travellers, so that provided benefits by high-speed result even more attractive.
3.3 Competitiveness of other transport modes

Amongst all the existing possibilities to move from one point to another, it is well known that people will choose the transportation mode that best fits their necessities or their preferences. Thus, it is utility of each alternative mode to each particular traveller that is going to determine the modal choice.

Utility for one mode can be defined through many factors, which are very variable according not only each individual’s perception (wealth, personal preferences, etc.), but also to each single trip (total duration, purposes, etc.). Usually, in order to keep it simple, utility is expressed by just including the most relevant factors:

$$ Utility = f(time, fares) $$

Other factors like comfort, regularity and safety could also be introduced in the function. However, those are expected to have less influence in general terms.

Consequently, when planning a transport infrastructure in a certain relation, it becomes crucial to analyse the existing alternative modes. So that to ensure competitive market shares, the main goal would be to strive for maximizing general utilities in the new mode.

According to that, competition for HSR needs to be analysed for the selected case studies, since it also represents a key factor explaining observed demand volumes. Thus, road and air performances are going to be assessed in each country for those routes where they are competing with the existing high-speed infrastructure (2). Note that competition with conventional rail is not considered, since HSR is usually a substitute for it.

As mentioned above, the main factors determining utility are time and fares. Hence, the analysis is going to focus on those terms, and results are going to be compared in between modes.

---

(2) Note that obtained performances by road and rail are not going to be representative for their entire network within the country, since it is only routes covered by HSR that are going to be assessed.
3.3.1 Road traffic

As aforementioned, road trips loose attractiveness when it comes to long distances (sections 1.3 and 3.1.2); higher speeds in alternative modes make trips significantly shorter, thus favouring their utility. For the present study, concerning HSR routes, considered distances are likely to be out of the scope for competitive road timings. Nonetheless, fares still need to be analysed so that they can be balanced against obtained timings.

In order to get time and monetary costs, road data has been estimated for the selected routes by checking “Via Michelin” (see the procedure and results in annex A.6). Table 10 shows the comparative ratios between road and HSR according to the averaged values in each country.

<table>
<thead>
<tr>
<th></th>
<th>Fares</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Av. road fares [eur/car/km]</td>
<td>Ratio road/HSR</td>
</tr>
<tr>
<td>FR</td>
<td>0</td>
<td>0,97</td>
</tr>
<tr>
<td>ES</td>
<td>0,084</td>
<td>0,58</td>
</tr>
<tr>
<td>DE</td>
<td>0,068</td>
<td>0,28</td>
</tr>
<tr>
<td>IT</td>
<td>0,17</td>
<td>1,32</td>
</tr>
</tbody>
</table>

*Table 10. Road – HSR utility comparison. Source: own production from complied data (annex A.6).*

Whilst averaged timings do increase considerably in all cases, representing at least double time by car, different pricing policies put the road traffic in a different position in every country. Relating to the latter, road fares have been averaged per car; nevertheless, as it is not always individual trips, it would be wise to reduce them by considering an averaged occupancy rate. Thus, Table 11 shows the new fare ratios computed by taking an averaged occupancy rate of two people per car.

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio road/HSR fares (2pax/car)</td>
<td>0,49</td>
<td>0,29</td>
<td>0,13</td>
<td>0,66</td>
</tr>
</tbody>
</table>

*Table 11. Road – HSR fares travelling 2 people per car. Source: own production from complied data (annex A.6).*

In this line, current initiatives should be mentioned trying to promote higher occupancy rates in cars. The so-called “car-pooling”, for example, allows people traveling the same route to agree in order to fill cars and split costs, and it is a practice which is getting quite popular amongst the studied countries. Thus averaged road prices can be expected to reduce even more in the early future.

By analysing the obtained values, the following can be stated:

- Comparing to the other European scenarios, extremely high prices are observed for the road transport in Italy. If travelling alone, costs by car can get higher than those by taking the high-speed. Moreover, driving times are reported being more than doubled.
Thus, the situation turns clearly favourable for the HSR in the country, helping it to gain market shares in the concerned relations.

- Road tolls in France are similar to those in Italy, turning car trips into a quite expensive option as well. Hence, even to a lesser extent, adopted pricing policies do also favour traffic volumes in the HSR.

- In Germany, the absence of tolls in their road network places this mode in a very good position regarding demand attraction. HSR fares have been seen to be the highest amongst the studied cases, whilst road fares are seen to be the cheapest now. Furthermore, even if driving times are doubled, distances have been seen to be generally shorter, so that road mobility can be stated to be in high competition with the HSR in the country. Consequently, German rail infrastructures require of a good strategy and planning in order to capture demand.

Up to here, the most relevant factors in people’s utility have been analysed in general terms at a country level. However, other intervening factors should not be forgotten when planning a new infrastructure. Regarding road competitiveness, frequency and comfort do also play a role in modal choice.

Averaged values in Table 10 were meant to get a general picture of the country competitiveness between road and HSR. Nonetheless, Figure 22 shows the existing variability for each particular relation in the selected sample. Therefore, in order to assess a specific HSR line, route variability evidences the necessity of analysing performance in each single corridor by itself, and not in a country level.

### 3.3.2 Air traffic

Contrary to what happens with short distances by road, when trips become too long, it is air traffic that comes into play. Although significant times spent in going to the airport - usually located far away on the city outskirts - and times required to pass the security controls, higher speeds of planes can lead to shorter travel times when it comes to long distances, thus tipping the scale towards better air utilities.

Nonetheless, there are still fares to be analysed, so it is both factors that might be balanced in order to get an idea of the final utility values.

By following the same procedure as in the former section, average performance of plane is going to be compared against HSR in the regarded relations for each country. This time, plane data has been estimated from “skyscanner.com”, and only direct flights have been considered (see procedure in Annex a.6).

However, regarding air traffic, it has been seen that not all the selected HSR routes are served by plane. Therefore, in order to get an idea of the air competitiveness presence, Table 12 shows the averaged frequency values for the whole sample:

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. air frequencies [flights/day]</td>
<td>8</td>
<td>6,3</td>
<td>0,6</td>
<td>10,6</td>
</tr>
<tr>
<td>Ratio air/HSR frequencies</td>
<td>0,42</td>
<td>0,34</td>
<td>0,02</td>
<td>0,39</td>
</tr>
</tbody>
</table>

*Table 12. Air competitiveness presence in potential HSR relations. Source: own production from complied data (annex A.6).*
According to that, it can be highlighted how the German rail network privileges from a low air traffic competitiveness. That stems from the particular country's initial goals for HSR, whose main target was to build high-speed connecting relatively nearby cities by improving their conventional network. Consequently, involved short distances do not become competitive for the air mode.

Thus, in order to keep with the utility assessment, a new air average is going to be computed by just considering the air-connected relations within the initial sample (annex A.6). Results show in Table 13:

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio air/HSR fares (where existing)</td>
<td>2,1</td>
<td>1,7</td>
<td>2,7</td>
<td>2</td>
</tr>
<tr>
<td>Ratio air/HSR times (where existing)</td>
<td>0,48</td>
<td>0,49</td>
<td>0,6</td>
<td>0,55</td>
</tr>
<tr>
<td>Ratio air +1h30/HSR times (where existing)</td>
<td>1,15</td>
<td>1,15</td>
<td>1,95</td>
<td>1,44</td>
</tr>
</tbody>
</table>

Table 13. Air – HSR utility comparison. Source: own production from complied data (annex A.6).

Regarding the obtained results, some important considerations are:

- Air fares are summed to great uncertainty due to their strong yield managing pricing policies (see air price variability in annex A.6).

- Obtained values show great dependability on the taken sample. Whilst in France or Spain the air averages have been finally computed by considering several relations, in Germany, only one air connexion existed within the initial sample. Therefore, it will be not accurate to refer to the country level by just analysing these results.

Nonetheless, sticking to the defined criteria, the following can be stated:

- Due to higher speeds, planes are able to perform the regarded trips in less time than HSR. Nonetheless, it is door-to-door time what matters; thus, the situation reverses when adding access time to the airport (assuming 1h30). According to obtained data, the scenario presents especially favourable for the HSR in Germany, since as aforementioned, high-speed rail in the country is generally meant to serve in between nearby cities.

- Generally speaking, air tickets are more expensive that those for HSR. The lowest rations are suggested in Spain, where air competition has been actually stated to be higher than in the other studied countries (both for fare and timing reasons) [16].

Based on the countries assessment, the situation seems generally favourable for the HSR against air traffic. However, it should be reminded the existence of a greater amount of factors taking part on each particular choice, and also their strong variability in each specific relation.

Thus, as stated for road competitiveness, existing route variability in air performance manifests the necessity of analysing every specific relation by its own instead of in a country level (Figure 22).
Figure 22. Variability in road and air competitiveness according to the particular route (road fares per car). Source: own production from collected data (annex A.6).

Figure 23 below presents a basic relationship between timing and HSR - air market share. The existing scattering comes from the remaining influencing factors in each mode’s utility. [3]. Note how values can highly differ for the HSR depending on the route characteristics in a same country.
As an example, Route characteristics in the lines between Paris-Lyon and Madrid-Sevilla have led them to be the most quoted changes in modal shares within the European high-speed network, with the 91% and 84% of the total traffic respectively [4].
4 The HSR investment: profitability

Traffic volumes in a certain transport infrastructure determine its efficiency of usage. Talking about profitability, efficiency of usage becomes imperative for any investment as far as the larger the demand is, the higher the obtained benefits are.

A profitable investment is characterised by showing resulting benefits high enough to balance the total costs:

$$\text{Profits} = \text{Benefits} - \text{Costs}$$

In HSR, infrastructures are quite expensive, so that they require of great benefits in order to become profitable. Profits can be measured in economical or in social terms, depending on the considered benefits. For the present case:

$$\text{Economic benefits} = (\text{ticket price}) \cdot (\text{demand})$$
$$\text{Social benefits} = (\text{time savings} + \text{comfort} + \text{environment} + \ldots) \cdot (\text{demand})$$

Note how in any case, benefits in HSR do directly depend on the number of passengers using the line. Thus, it manifests the importance of a good demand forecast to ensure profitability before implementation.

In the precedent section, the difficulty of predicting social and economical effects have been illustrated by showing the existing efficiency differences in the European high-speed rail network. Nonetheless, in order to check profitability, it is not only about demand, but the total obtained benefits are to be balanced against costs in each particular case. According to the profitability definition, not by having less demand it does mean the infrastructure is more deficient, other factors do also play a major role, and it becomes imperative to take them into account when planning a new HSR line.

It has to be born in mind that the final purpose for any infrastructure investment is to become profitable, either economically or in social terms. Hence, apart from the total demand, the following factors need to be analysed:

- **Infrastructure costs**: Including the initial investment as well as the maintenance and operation costs on an annual basis.

- **Revenues**: The economic benefit is going to be determined by the pricing policies adopted for using the concerned infrastructure.

- **Individual social benefits**: If those are high, the infrastructure will be more likely to produce higher social benefits for the entire population, when multiplying per the demand.

In this section, costs and social benefits are going to be reviewed for the studied cases. About economical benefits, revenues would depend on every country’s pricing policies, already analysed in section 3.2.5.
4.1 Costs

Topography can be determined as one of the key factors affecting construction costs. Flat countries allow HSL construction to a less cost than those where there is an abrupt terrain. To get an order of magnitude, lines in tunnel cost approximately twice than those that run in open air [2].

In Europe, construction of 1 km of new high-speed line costs, in average, 12-30M euros [10], and more specifically, for some relations in the analysed countries:

<table>
<thead>
<tr>
<th>HSL</th>
<th>Construction cost [M€/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR</td>
<td></td>
</tr>
<tr>
<td>Paris-Lyon</td>
<td>4,6</td>
</tr>
<tr>
<td>TGV Mediterranée</td>
<td>12,6</td>
</tr>
<tr>
<td>ES</td>
<td></td>
</tr>
<tr>
<td>Madrid-Barcelona</td>
<td>11,6</td>
</tr>
<tr>
<td>Madrid-Valladolid</td>
<td>23,2</td>
</tr>
<tr>
<td>DE</td>
<td></td>
</tr>
<tr>
<td>Hannover-Wurzburg</td>
<td>15,4</td>
</tr>
<tr>
<td>Manheim-Stuttgart</td>
<td>15,3</td>
</tr>
<tr>
<td>IT</td>
<td></td>
</tr>
<tr>
<td>Turin-Milan</td>
<td>53,8</td>
</tr>
<tr>
<td>Rome-Naples</td>
<td>24</td>
</tr>
</tbody>
</table>

*Table 14. HSL construction costs. Source: Alabate and Bel, 2010, UB [8].*

Variations in costs depend on the specific trajectory followed by each line. In France, whilst the relation Paris-Lyon was exhaustively designed avoiding tunnel construction [2], the Lyon-Marseille, running along the Massif Central and the Alps, required a larger budget.

In Spain, the high cost for the line Madrid-Valladolid is explained by the construction of the Guadarrama tunnels, with 28 km, being the largest tunnels in Spain and sixth in Europe [33]. Also the new German lines have been more expensive than the French ones due to more difficult terrain, which led the network to a higher portion of line in tunnel [9]. Nonetheless, the higher costs are observed in Italy, and they are also attributable to a mountainous terrain and high seismic risk [8]. Thus, the relation cost-terrain becomes evident.

However, there are also other reasons explaining costs increments:

- Dense urbanisation structures make it difficult to design straight, open-air lines, since land is already occupied by human settlements, which cannot be moved nor divided.

- Some HSR purposes can imply further limitations in the design. For example, the multi-purpose use of the German HSLs, both for passenger and freight trains, have brought some restrictions to the track radius and slope, which has increased the cost for some segments.

- Last, it is also possible to include the concept of GDP to justify infrastructure costs. Generally, wealthier countries would require higher budgets in order to cover material prices and worker salaries.
4.2 Time savings

Many factors determine the social benefits provided the HSR: time savings, comfort, noise, environmental issues, etc. However, as many of those are difficult to measure, the present section is just going to focus on one of the most relevant issues, the time savings.

In order to be attractive and socially profitable, HSL investments must ensure competitive timings. Table 15 shows the averaged time reduction in railway transport allowed by HSR introduction:

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>43%</td>
<td>58%</td>
<td>33%</td>
<td>31%</td>
</tr>
</tbody>
</table>

*Table 15. Time reduction HSR comparing to former conventional rail services. Source: own production from various sources (annex A.3).*

Note that in Germany, according to their non-speed related goals and due to short distances between stops, time savings have been more modest. Also in Italy short distances can also explain the lower gain (averaged distances between intermediate stops in HSL, Table 6).

Nevertheless, it is not necessarily the highest percentages in time savings that lead to the highest individual benefits. Instead, it is the total amount of minutes gained what determines social benefits and the potential contribution in capturing demand as well. Thus, looking at the absolute values (Figure 25):

![Figure 25. Absolute time savings comparison. Source: own production from various sources (annex A.3).](image)

The amount of minutes gained turns out to be very dependent on both the country characteristics and the former existing service. Still, a proper planning becomes crucial to maximise the total amount of time benefits in society.
5 Summary table

Below, the most relevant reviewed issues are presented in a comparative table for the analysed countries (Table 16):
### COUNTRY CHARACTERISTICS

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (1) [Mhab]</th>
<th>ρ country [hab/km²]</th>
<th>ρ major agglomerations ρ country</th>
<th>City distances [km]</th>
<th>Corridor</th>
<th>Topography</th>
<th>GDP per capita [€/hab]</th>
<th>National mobility [p-km/hab]</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR</td>
<td>62.8</td>
<td>118</td>
<td>56</td>
<td>276</td>
<td>Some</td>
<td>Easy</td>
<td>33.361</td>
<td>15,322</td>
</tr>
<tr>
<td>ES</td>
<td>46.5</td>
<td>92</td>
<td>50</td>
<td>310</td>
<td>No</td>
<td>Difficult</td>
<td>22.415</td>
<td>8,924</td>
</tr>
<tr>
<td>DE</td>
<td>81.8</td>
<td>233</td>
<td>10</td>
<td>196</td>
<td>Yes</td>
<td>Difficult</td>
<td>35.866</td>
<td>12,731</td>
</tr>
<tr>
<td>IT</td>
<td>59.2</td>
<td>202</td>
<td>20</td>
<td>147</td>
<td>Yes</td>
<td>Very diffic.</td>
<td>26.519</td>
<td>14,244</td>
</tr>
</tbody>
</table>

### HSR NETWORK CHARACTERISTICS

<table>
<thead>
<tr>
<th>Country</th>
<th>HSL [km]</th>
<th>Av. maximum speed [km/h]</th>
<th>Av. commercial speed [km/h]</th>
<th>Av. # intern. stops</th>
<th>Av. intern. distances [km]</th>
<th>Av. frequency [trains/day]</th>
<th>Intermodality degree</th>
<th>Integration indicator</th>
<th>HSR fare GDP per cap.</th>
<th>HSR fare CT fare</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR</td>
<td>2.036</td>
<td>307</td>
<td>198</td>
<td>1.03</td>
<td>261</td>
<td>18.8</td>
<td>Low</td>
<td>0.78</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>ES</td>
<td>2.515</td>
<td>291</td>
<td>211</td>
<td>0.99</td>
<td>239</td>
<td>20.2</td>
<td>Low</td>
<td>0.45</td>
<td>1.48</td>
<td>1.38</td>
</tr>
<tr>
<td>DE</td>
<td>1.300</td>
<td>264</td>
<td>153</td>
<td>1.58</td>
<td>113</td>
<td>19.7</td>
<td>Medium</td>
<td>0.78</td>
<td>1.55</td>
<td>1.32</td>
</tr>
<tr>
<td>IT</td>
<td>923</td>
<td>284</td>
<td>173</td>
<td>2.11</td>
<td>121</td>
<td>21.3</td>
<td>Medium</td>
<td>0.62</td>
<td>1.09</td>
<td>1.79</td>
</tr>
</tbody>
</table>

### HSR COMPETITIVENESS (5)

<table>
<thead>
<tr>
<th>Country</th>
<th>Road fare (6) HSR fare</th>
<th>Road time HSR time</th>
<th>Air freq HSR freq</th>
<th>Air fare HSR fare</th>
<th>Air time HSR time</th>
<th>Travelled dist [p-km/hab]</th>
<th>Line occupancy [p-km/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR</td>
<td>0.97</td>
<td>2.1</td>
<td>0.42</td>
<td>2</td>
<td>0.48</td>
<td>841</td>
<td>25.9</td>
</tr>
<tr>
<td>ES</td>
<td>0.58</td>
<td>2.56</td>
<td>0.34</td>
<td>1.7</td>
<td>0.49</td>
<td>126</td>
<td>2.3</td>
</tr>
<tr>
<td>DE</td>
<td>0.28</td>
<td>2.02</td>
<td>0.02</td>
<td>2.7</td>
<td>0.6</td>
<td>273</td>
<td>17.2</td>
</tr>
<tr>
<td>IT</td>
<td>1.32</td>
<td>2.41</td>
<td>0.39</td>
<td>2.00</td>
<td>0.55</td>
<td>192</td>
<td>12.3</td>
</tr>
</tbody>
</table>

(2): According to operation (intern. stops policies).  
(3): Based on [65], which includes Switzerland (high).  
(4): Taking France as a reference.  
(5): Bear in mind route variability.  
(6): Fare per vehicle, not per passenger.
6 Learned lessons

In the precedent sections, HSR networks have been characterised in every country, so that it has been possible to identify key factors affecting demand volumes in those new lines. Still, many of the intervening factors are seen to vary depending on the specific line, rather than in a country level.

Therefore, the first thing to be noticed is that there are no general rules for HSR development; many factors do affect potential demand in a HSL, and their effects need to be analysed for each particular case.

Identified the major variables, it would be interesting to look for the correlation between them all, so that a demand model could be built. Defining a specific model could help in predicting traffic volumes for future HSR development. Nonetheless, as key factors do depend on every specific relation, complexity and lack of data prevents from a proper calibration. Furthermore, a qualitative analysis allows taking into account all possible forms of social issues, which even not included before, might also be relevant explaining particular transportation patterns (i.e., political issues).

Thus, by reviewing the analysed case studies, some qualitative recommendation is presented below regarding identified key factors:

0) So as to start thinking about a new HSL, it is necessary to identify the reasons giving purpose to the required investment (capacity problems, speed goals, etc.). By keeping clear targets, the best design could be reached according to them. It is important to bear in mind that HSR does not have one single meaning, so that every line has to be analysed consistent with its defined objectives.

1) In order to get a profitable investment - both in economic and social terms – the total demand in the line needs to be maximised. Thus, lines should be implemented in those relations where higher traffics exist. Generally, higher mobility is seen in between large dense population nucleus, so that building links between them is usually the most efficient way to ensure potential demand.

Moreover, the line trajectory should be designed accounting not only for the selected origin and destination, but also for the possibility of serving wider areas. Thus, so as to obtain higher benefits from HSR, intermediate stops can be included along the line. Also, the possibility of serving further areas with the designed line can turn interesting for demand purposes.

2) Distances in between stations need to be suitable for the HSR mode. Hence, in order to show good performances, consecutive stops need to be planned ensuring competitive timings. Regarding intermediate stops, included agglomerations need to be assessed proving enough attraction to justify the induced loss in the time savings (check population, economical activity, tourism, etc.). Be aware of alternative modes’ performances.

3) The designed trajectory must consider the existing topography and other track limitations, so that the cheaper alternative can be selected.

4) HSR stations need to be properly connected to the whole transportation network. This way, time benefits brought by the high-speed are going to be expanded and
better perceived for people travelling elsewhere. Otherwise, the line advantages get lost for a great part of the population and captured demand volumes will also suffer from that.

5) Operation policies need to be set according to the characteristics of the existing demand. On the one hand, population’s willingness to pay needs to be evaluated; too high fares would have a negative impact on demand volumes. On the other, frequencies have to be planned absorbing all the traffic and providing travelling flexibility. The influence of alternative modes in the concerned link is an important issue to consider when setting HSR operation policies.

The above recommendations have been listed in the purpose of being considered for future HSR development. Those are based on the learned lessons from the already implemented lines in Europe. Thus, the main goal is to bring out the major mistakes so that they can be avoided in future designs.

By taking the presented issues as a design guide, resulting lines are expected to come up with the most suitable HSR alternatives in each specific implementation scenario. Still, the performance of a final cost-benefit analysis will be imperative to determine the final profitability for the proposed infrastructure.
PART 2: THE SWISS CASE
7 The rail network in Switzerland: Current scenario

Regarding railway development, Swiss transportation policies are seen to diverge from those adopted in other European countries. Even their strategic location, positioned at the very centre of the continent, and being one of the largest national rail mobility worldwide, the Helvetic Confederation has decided not to introduce high-speed lines within their territory.

It is therefore interesting to approach the reasons that led the country to the current scenario, and to assess mobility trends in order to think of future development for the railway sector in Switzerland.

7.1 Antecedents: Project Rail 2000. Rejection to the HSR

Swiss citizen’s mobility has always been characterised to be one of the largest mobilities in the world. Moreover, railway’s success in the country dates back from early ages since its implementation, so that this mode has always constituted a key role in the national transportation.

Nonetheless, in the seventies, due to the car-boom and the rapid expansion of the road network, a loose of rail competitiveness was verified against road for the first time; rail market share decreased from 51 to 20%. Even though the number of railway users kept high in comparison with the European standards, it represented a relevant change in the country mobility scenario. Thus, facing such a situation, and once the new road infrastructure was already planned and decided, it was time for the rail to rethink about new strategies in order to keep with its former competitiveness levels.

There were many reasons that led the country to strive for the railway boosting again. Basically, it was the willing to provide the population with a good transportation offer that motivated the Swiss. As aforementioned, the Helvetic country has always showed strong mobility demands, so that promoting public transport became crucial in order to better deal with large capacities. Also environmental concerns played a role in such decisions; road traffic brought along increasing pollution, and therefore, better rail performance would help towards a more sustainable scenario.

Thereby, as an attempt to cope with these challenges, the Confederation created a commission responsible for drafting the Conception Globale Suisse des Transports (CGST). As a first proposal, the CGST presented, in 1973, the possibility of introducing new high-speed line connections between Geneva and Lake Constance, and from Basel to Chiasso. The HSL idea had already been introduced by Oskar Baumann in 1969; however, it was just formulated as something very abstract, since the engineer himself doubted about its suitability for the country. Effectively, when presented to the population some years later, it resulted as Baumann expected: the high-speed rail approach was rapidly rejected. The reasons leading to this rejection relate basically to the demography configuration in the country, but also to the political scenario should be regarded.

Switzerland is a federal republic consisting of 26 cantons and governed by a direct democracy system, which means that Swiss citizens do vote policy initiatives in a direct way. Moreover, the country is characterised by its regional balance; people do live fairly distributed all over the territory, so that every canton is equally important. In this context,
the idea of building a new high-speed line connecting just two nodes led to the possibility of inequitable development amongst cities, leaving a vast majority of the population with no benefits from such an infrastructure. Thus, according to their political system, the HSR project was immediately rejected by the great non-benefited majority.

Given this scenario, the CGST was forced to look for a new system to revitalize the rail market while meeting the expectations of regional balance that the situation required. For that purpose, the project Rail 2000 was finally approved in 1987:

Rail 2000 consisted on a project aiming to provide Switzerland with a highly meshed rail network extending through all the most populated areas, and targeted to improve door-to-door services through its correspondences with the metropolitan transport. In other words, after the rejection of the HSR, the main goal of Rail 2000 was to ensure good territory coverage on the entire country more than strongly reducing certain travel times. Rescheduling and upgrading were the key tools leading to the Rail 2000 success. On the one hand, correspondences were grounded in a clock-face scheduling, with a new symmetrical regular-time interval timetable which organised the exploitation. On the other, infrastructure upgrading and rolling stock modernisation were also crucial factors allowing timings to reduce as much as necessary according to the new timetable. Thereby, passenger’s demand was supplied in between many links and reaching a high level of performance.

Promoted with the slogan “pas aussi vite que possible, mais aussi rapidement que nécessaire" (not as fast as possible, but just as fast as needed), Rail 2000 was presented in referendum the year 1987 as a mode “Plus rapide, plus fréquent, plus direct et plus confortable” (faster, more frequent, more direct and more comfortable).

1) **Speed**: New infrastructure sections and new tilting rolling stock allowed a gain of time of 17% over 20 cities and of 8% on the total rail network.

2) **Frequency**: New timetables planned better rail frequencies.

3) **Direct**: New nodes and planned correspondences allowed more direct connexions within the rail network.
4) **Comfort**: New rolling material and renewed stations turned rail trips into more comfortable journeys.

The project became rapidly popular, and it has succeeded in changing mobility patterns in favour of rail.

Also a second stage called project ZEB, a third stage called RAIL 2030 and a forth stage called RAIL 2050 were proposed regarding future further development.

### 7.2 Mobility patterns and existing infrastructure

As mentioned when analysing the European transportation scenario, a first glance into mobility patterns becomes of paramount importance in order to understand the existing trends over the country. That is undoubtedly the starting point to identify existing transportation needs and how to approach efficiency improvements. Going back to the seventies, mobility patterns helped policy makers to be aware of road increase over rail and to realise about the urgency for Rail 2000. Thus, it is nowadays interesting to focus again on the observed trends in order to verify the current transportation network.

As defined in Part 1, due to the non-relevance of the international traffic, the scope of this project limits to the national passengers traffic (section 2.1). Comparing the Swiss case with the other analysed scenarios in Europe (Figure 27):

![Figure 27. National mobility patterns in transportation, Switzerland comparison. Modal split in p-km. Source: collected data from various sources, 2010 (annex A.1).](image)

Complied data shows the vast majority of the mobility being performed by means of road in every case, including Switzerland. As suggested when analysing the case studies, those large volumes in road traffic can be somehow explained by its extended infrastructure (Figure 30) and the comfort and flexibility provided by the car when it comes to the numerous amount of performed short trips. Nonetheless, large rail traffic volumes must be highlighted for the Swiss case; with a 16% of its total national passengers mobility, Switzerland tops de ranking in rail mobility amongst the other studied cases.
Taking a look at the exact values (normalised: p-km/inhabitant) (Figure 28):

![Graph showing national mobility traffic volumes normalised per inhabitant.](image)

**Figure 28.** National mobility traffic volumes normalised per inhabitant. Switzerland comparison, in p-km/inhab. Source: collected data from various sources, 2010 (annex A.1).

Even being a small country, in terms of total mobility, the Swiss population is seen to travel a lot within their territory. Total domestic figures do reach, in average, the 14,237 kilometres travelled yearly per inhabitant (data from 2010). Such mobility, being similar to the one in Italy, corresponds to the 93% of that observed in France, and 160% of that in Spain.

Focusing on rail mobility, figures amount to 2,333 averaged kilometres per inhabitant, which is 46% higher than that in France, occupying now the second rank after Switzerland.

However, so as to highlight the huge difference in country size – Switzerland being considerably smaller compared to the other case studies -, Figure 29 shows the rail mobility values normalised not only per inhabitant, but also according to the country area in kilometres square.

![Graph showing national rail traffic volumes normalised per inhabitant and country area.](image)

**Figure 29.** National rail traffic volumes normalised per inhabitant and country area. Switzerland comparison, in p-km/hab/km². Source: collected data from various sources, 2010 (annex A.1).
Such a difference in size is considered to be relevant as far as it indicates shorter trips in Switzerland, thus leading to a much higher ratio when it comes to the averaged number of performed trips in absolute values.

The showed values evidence how rail modes do play a strong role within the Swiss transportation network. Yet, and contrary to the other analysed cases, no HSR modes do exist in the country; all rail traffic volumes take place on conventional lines.

As a next step to check the network efficiency, the existing infrastructure supporting the observed mobility is going to be analysed in each case.

**Existing infrastructure**

Figure 30 plots the scenario for the infrastructure supplying existing demand over the countries:

![Existing infrastructure graph]

*Figure 30. Existing infrastructure in transportation. Switzerland comparison. Source: collected data from various sources, 2010 (annex A.1).*

As expected, and according to observed mobility patterns, road network represents the vast majority of the national transportation network over the five European countries. Focusing again on the railway infrastructure (Figure 31):
At a first glance, given its great traffic volumes, it strikes how small the Swiss rail network is in comparison to those in the other European countries. Nonetheless, we should refer back to the country size.

Normalising the infrastructure length by the country area, Figure 32 shows the current values for infrastructure density:

Thereby, in accordance with its large traffics, Switzerland counts with a dense railway network to serve its population mobility demands.

**Infrastructure use**

Even accounting with the densest network, the observed ratios concerning both demand and supply put in evidence the high occupancy rates existing in the Swiss transportation infrastructure.
As far as railway mobility is concerned in this project, an indicator for the “rail line use” is going to be computed (Table 17). So as to show how loaded the network is, the averaged number of passengers transported on a yearly basis can be calculated per railway kilometre for each studied case. This value will give an idea of how used the national rail system is (note that, in case of existing, the indicator considers both conventional and HSR network).

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<tbody>
<tr>
<td>2.98</td>
<td>1.45</td>
<td>2.33</td>
<td>2.36</td>
<td>3.54</td>
</tr>
</tbody>
</table>

*Table 17. Rail line use in millions p-km per infrastructure unit length. Source: own production from collected data (annex A.1).*

Comparing these results with the total population in each country (Figure 33):

![Figure 33. Rail line use v. country population. Source: own production from collected data (annex A.1).](image)

Despite being the smallest population, results prove the Swiss railway network being the most used amongst the other European analysed scenarios.

**Rail 2000 impacts**

Generally, current mobility patterns in a country are the direct result of former transportation policies adopted at some point. In Switzerland, for instance, even though rail mobility has always been especially high, the project Rail 2000 can be said to be one of the reasons explaining the great relevance of this mode nowadays.
Contrary to what could have been expected after the car-boom period, Rail 2000 represented a turning point for the Swiss transport and entailed a spectacular growth in railway demand, achieving even better results than forecasted (see the demand evolution in Figure 34 above).

Paul Blumenthal, member of the manager’s office at CFF (Chemins de Fer Fédéraux suisses – Swiss Federal Railways) and head of passenger’s section, stated during the transport forum 2006: “The introduction of Rail 2000 shows perfectly that an improvement in the supply induces an extension of the market” [40].

Nonetheless, such an induced extension of the railway market implies nowadays reaching almost full capacity at some sections in the planned infrastructure (Figure 35).
Capacity problems are especially noted around large cities. The situation presents difficult mainly in Zurich and throughout the Lemanic arch, being the two main economical areas in Switzerland.

According to Mr. Weidmann in [40], the ETH’s professor attributes the current congestion not only to the development of Rail 2000, but to the following five main aspects:

1) The supply improvement by the densification of the schedule and the correspondences, which has induced a demand increase, accompanied by a change in mobility patterns (Rail 2000).

2) The Swiss population increase by 17% over the past 20 years, largely because it is an increase of economically active population that makes a greater amount of trips per day.

3) The change in land uses and zoning, with a centralization of jobs

4) The maintenance of the general price of travelcards and the introduction from 1987 of the Half-Fare Travelcares. Both are tickets that reward the heavy use of the service to get the maximum return of them.

5) The fact that the project Rail 2000 is just the first part of a series of projects planned to take place in the following years. Thus, the first stage was dimensioned taking account of an immediate second stage, which nowadays has not still been done (project ZEB).

**Future demand expectations**

Mobility demand is expected to keep increasing during the following years (Figure 36). If the increasing tendency continues, the scenario would result alarming for transportation in a near future.

![Figure 36. Prospect of railway passenger’s traffic increase from 2005 to 2030. Source: ARE](image-url)
In order to deal with the already existing problems, some measures have already been taken in an attempt to optimise the current capacity (part of ZEB project): Densification of the trains frequency, suppression of some intermediate stops so that to improve acceleration performance or the use of double-deck rolling stock are some of the actions taken against congestion [41]. However, those are quite light actions whose efficiency can be discussed when facing the future expected scenario. Thus, it would be reasonable to think of stronger measures to cope with that.

7.3 International scenario: strategic location

Due to its privileged location in the centre of Europe, and being surrounded by some of the most influencing countries in the continent, Switzerland results very attractive when it comes to building connexions in between the European states.

Recently, a new initiative has been manifested from the European Commission, willing to connect Europe. As of January 2014, the European Union has a new transport infrastructure policy that connects the continent between East and West, North and South. The so-called TEN-T project comprises hundreds of projects whose ultimate purpose is to ensure cohesion, interconnection and interoperability of the trans-European transport network. Those projects include all modes of transport: road, rail, maritime, inland waterways, air, etc. and they have been classified into priorities [43].

From the 30 regarded priority axis, the Priority Project 24 (PP24) -comprised within the Rhine-Alpine corridor-, represents a freight and passenger railway axis including conventional and high speed traffic for passengers. It involves five Member States (the Netherlands, Belgium, Germany, France and Italy) and transits through Switzerland (Figure 37).

Figure 37. Priority project 24 of TEN-T. Source: INEA, TEN-T project. European Commission.
According to that, it is mainly the North-South corridor that seems to be relevant for international connexions in Switzerland. For this purpose, both the Lötschberg Tunnel and the Gotthard Tunnel have been planned to absorb and improve rail traffic (60% freight and 40 % passengers traffic). Nonetheless, the TEN-T idea manifests a general willing to keep improving international corridors all over the territory, and thus, any other form of infrastructure development would result interesting from this point of view.
8 Future railway development: a new HSR line?

Looking at the current mobility scenario in Switzerland, some issues have been identified requiring new strategies for future development in the national railway sector:

- On the one hand, a lack of capacity is threatening the railway system. The number of users in the network is expected to keep growing during the following years, and the current service is not enough to absorb such an increase in demand. Due to that, urgent measures should be implemented.

- Also, new transportation policies seem to focus in establishing better European connexions, and there, Switzerland plays a key role. Thus, further railway development in the country is thought to be interesting on this line.

Given the statements above, and considering a European context where HSR is getting every time more popular, the idea of building a new high-speed line is put forward in the present study. About that, further in-depth assessment is going to be carried out in the following sections, but at a first glance, the new line can be expected to bring some benefits along:

1) Regarding capacity problems, a new line would allow to decongest the existing infrastructure, which is nowadays supporting mixed traffic, both passengers and freight. By diverting circulations, regional trains and freight would keep running on the former conventional network, whilst the intercity would be reconverted to high-speed in the new infrastructure. In this way, general train performance would be improved, not only in terms of capacity, but also in terms of speed.

2) When it comes to the international scenario, a new high-speed line crossing the Swiss country would benefit the on-going international transportation projects. Thus, not only would it represent some time savings for national travellers, but also international traffic (even small) would get benefits from a potential line connecting with the already exiting HS European rail network.

3) Comparing to other modes, the HSR is considered to entail safety and environmental benefits as well (see section 1.3). Regarding the latter, it seems that the Swiss are quite concerned about it; environmental issues partly boosted the development of the Rail 2000 project during the car-boom period, and they have also been decisive part for approving the Alp Transit project, comprising both the Lötschberg and the Gotthard Tunnel in the N-S corridor.

On the flip side, it is also important to keep in mind recent experiences from other European countries, which have shown that not always HSR results into the best solution. In this line, the first part of this document has manifested some of the main factors affecting the HSR success. Thereby, it would be interesting to review the analysed case studies in order to evaluate the HSR potential in Switzerland.

Moreover, it cannot be forgotten the fact that such a project has already been rejected once. Hence, by following both the extracted “learned lessons” in Part 1 (section 6), and by considering the country particularities when it comes to the “regional balance”, a new HSL design is going to be assessed suiting the Swiss scenario. The goal in this section is then to identify the possible potential corridors within the country, whose social and financial profitability is going to be deeply analysed later on.
To start with, the country potential for HS is going to be evaluated according to the identified factors in Part 1; thus, Section 8.1 below is going to deal with the country characteristics in order to assess potential demand. Afterwards, according to the observed country features, potential corridors will be presented in Section 8.2; amongst them, the better solution is going to be picked. Finally, the suitability for selected line is going to be verified in Section 8.3 making sure that the learned lessons have been applied and that the regional balance criterion is also fulfilled.

8.1 Country characteristics

By following the same procedure as in Part 1 when identifying the key factors affecting demand, the present section is aimed to assess the country potential for a possible HSR network in Switzerland. Thus, the following aspects are to be analysed:

- Urban structure
- Distances between population centres
- GDP and economic distribution

However, in order to better understand the urban structure of the country, it would be proper to refer first to the singular topography of the country.

8.1.1 Topography

Switzerland is composed of a varied landscape, differentiated in three major areas: the Alps (60%), the Plateau (30%) and the Jura (10%) [40], according to its topography (Figure 38):

Figure 38. The Swiss topography. Source: Wikipedia.
The Plateau is the area where the economic life concentrates; there are two-thirds of the total population living in this zone. Geographically, it extends from Geneva to Constance’s Lake, close to St.Gallen. On its northwest side, it lies The Jura, composed by a more mountainous territory. However, it is in the Alps where the topography turns out to be especially difficult; occupying all the southern side of the country, this is the less densely inhabited area.

Note that the topography by itself does not directly affect the demand volumes in transportation, and thus, it was not included as an affecting factor when analysing the case studies. Yet, in Switzerland, with 2/3 of its population concentrated in the 30% of the territory, topographic constraints are a key issue in order to understand human settlements and urban structure, which is presented in the following section (8.1.2).

### 8.1.2 Urban structure

Urban structure deals with the existing population and its distribution. Switzerland is characterised for being a small country with much lesser population than the other European studied cases (Table 18). Moreover, its particular topography is seen to strongly affect human settlements over the territory, concentrating the great majority of its citizens in an even smaller area.

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<th>ES</th>
<th>DE</th>
<th>IT</th>
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<tbody>
<tr>
<td>Population [Mhab]</td>
<td>62.8</td>
<td>46.5</td>
<td>81.8</td>
<td>59.2</td>
<td>7.8</td>
</tr>
<tr>
<td>Country area [km2]</td>
<td>543.965</td>
<td>505.940</td>
<td>348.540</td>
<td>301.340</td>
<td>41.277</td>
</tr>
</tbody>
</table>

*Table 18. Population and country area comparison. Source: collected data from various sources, 2010 (annex A.1).*

Despite the mentioned small population - representing only a 10% of that in Germany and or 18% of that in Spain -, it has been proved that the number of people living in a country does not directly match with the observed traffic rates for a specific infrastructure (note mobility patterns have already been analysed normalising per inhabitant). On the contrary, how these people distribute seems to be more determining. Therefore, other major demographic factors have been identified affecting demand values: population density and urban agglomeration location have been suggested as key factors.

As HSLs are meant to serve as much population as possible (so as to maximise benefits), it is highlighted the importance of establishing connexions in between the most populated and important cities in the territory. Hence, as a starting point, the ten major urban agglomerations are going to be identified in Switzerland (Table 19, Figure 39):
Table 19. Main urban agglomerations in Switzerland and city density. Source: population according to OFS and density to Wikipedia, data 2014.

<table>
<thead>
<tr>
<th>Urban area</th>
<th>Population [Mhab]</th>
<th>City density [hab/km²]</th>
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<tbody>
<tr>
<td>Zurich</td>
<td>1,32</td>
<td>4.453</td>
</tr>
<tr>
<td>Geneva</td>
<td>0,57</td>
<td>12.216</td>
</tr>
<tr>
<td>Basel</td>
<td>0,54</td>
<td>7.051</td>
</tr>
<tr>
<td>Bern</td>
<td>0,41</td>
<td>2.500</td>
</tr>
<tr>
<td>Lausanne</td>
<td>0,4</td>
<td>3.236</td>
</tr>
<tr>
<td>Luzern</td>
<td>0,21</td>
<td>2.167</td>
</tr>
<tr>
<td>St. Gallen</td>
<td>0,16</td>
<td>1.912</td>
</tr>
<tr>
<td>Lugano</td>
<td>0,15</td>
<td>1.990</td>
</tr>
<tr>
<td>Fribourg</td>
<td>0,1</td>
<td>2.956</td>
</tr>
<tr>
<td>Thun</td>
<td>0,05</td>
<td>4.261</td>
</tr>
</tbody>
</table>

Figure 39. Location of the main urban agglomerations in Switzerland. Source: own production.

Population density

By comparing the averaged density in those ten major areas with the total country density, the human agglomeration level is going to be displayed (Figure 40). As aforementioned in Part 1, densified nucleuses do usually involve higher potential demand for HSR, since in
case of placing a train station in there, human concentration will improve the infrastructure access for a larger part of the population.

At a first glance, the situation in Switzerland could be fairly compared with that in Italy; density values turn out to be very similar in both cases. Nonetheless, it is here where topography constraints should be considered:

Due to the presence of the Alps, occupying the 60% of the country area, population has been seen to concentrate in the remaining 40% part. Thereby, in order to better reflect the actual dynamics in the territory, it would be proper to compare the major agglomerations’ density with that of the more inhabited area, leaving the mountainous area apart. In this case, the lower bar in Figure 40 would considerably increase in size, modifying the density ratio and approaching it to a the values found for the German case.

Therefore, it can be concluded from all the above that, when thinking of a new possible HSL, the scenario has to be regarded as it is in Germany; Swiss population is quite evenly distributed all over the more inhabited area, lacking a mono-centric focus. In terms of the HSR design, that also requires a similar model than the Germans: a relevant number of intermediate stops would have to be regarded in order to provide service all along the line, as no representative population would be served by just linking one single O-D pair. Such a characteristic can be said to reflect the aforementioned “regional balance” existing in the Helvetic country.

**Urban agglomerations location**

Again, due to the presence of the Alps in the southern area of the country, the population distributes mainly along an East-West corridor, as showed in Figure 39. Given the even population distribution in the area, requiring a significant number of intermediate stops, such a corridor-shape turns up to be ideal in order to cover the main intermediate areas in a single line.

Also, in order to cover Lugano, a North-South corridor can be drawn including some of the most populated areas in the national territory. Thus, it can be said that, despite its small/medium-sized cities, the urban distribution in Switzerland results to be quite
“friendly” to HSR: it is possible to serve the vast majority of the Swiss population by just drawing two different lines.

Therefore, if well located, population distribution would enable maximum use to be made of the new suggested HSR network.

### 8.1.3 Distances between population centres

Up to now, it seems that the country characteristics in Switzerland do favour the implementation of a new HSR network connecting the territory. However, it is this section that presents one of the most relevant constraints: the distance in between cities (Figure 41).

![Figure 41. Straight distances between main cities in Switzerland: selected relations. Source: own production.](image)

Contrary to the other European cases, and due to its small dimensions, distances in between main cities turn out to be significantly smaller in the Helvetic country. Table 20 displays the computed average for the regarded scenarios; averaged distances in Switzerland are seen to be around 64 km, less than 50% of those in Italy, where they were already seen to be the shortest among the case studies.

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<tr>
<td></td>
<td>276 km</td>
<td>310 km</td>
<td>196 km</td>
<td>147 km</td>
<td>64 km</td>
</tr>
</tbody>
</table>

*Table 20. Distances between main cities. Source: own production (annex A.2).*

Such short distances difficult an optimal performance for HSR, since it has been showed how this mode does offer timing advantages for journeys in a range of 150-800 km (section 3.1.2).

Therefore, that poses a question for intermediate stops; would it be become more efficient to neglect intermediate stations so as to gain in speed benefits? The trade-off demand-speed is manifested. Nonetheless, political reasons have proved to be determining in the past, so the “regional balance” constraint should not be forgotten.
8.1.4 GDP and economic distribution

According to the stated relation GDP-mobility (Figure 1), the high figures of the Swiss GDP per capita manifest the high existing mobility rates in the country. Nonetheless, it has been suggested in Part 1 that it is not the GDP alone, but also how the economy distributes over the territory, what better determines the observed traffic. Therefore, it is the total national mobility that has been taken as an indicator for the "mobility habitue" in each country (section 3.1.3). In Switzerland (Table 21):

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<tbody>
<tr>
<td>GDP per capita [€/hab]</td>
<td>33.361</td>
<td>22.415</td>
<td>35.866</td>
<td>26.519</td>
<td>72.705</td>
</tr>
</tbody>
</table>

*Table 21. GDP per capita v. national mobility (mobility habitue). Source: World Bank (2015) and various sources for mobility, 2010 (annex A.1).*

Again, as aforementioned when analysing the current mobility in Section 7.2, the particularly short distances in Switzerland should be stand out, implying an even greater number of trips than in the other exemplified cases. Table 22 below compares both the averaged distance travelled yearly per inhabitant, and the same value but normalised per country area. Taking France as a reference:

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</tr>
</thead>
<tbody>
<tr>
<td>Mobility [p-km/inhab]</td>
<td>1</td>
<td>0,58</td>
<td>0,83</td>
<td>0,93</td>
<td>0,93</td>
</tr>
<tr>
<td>Mobility [p-km/inhab/a]</td>
<td>1</td>
<td>0,63</td>
<td>1,3</td>
<td>1,68</td>
<td>12,25</td>
</tr>
</tbody>
</table>

*Table 22. Inland national mobility comparison (mobility habitue). Values in traffic per inhabitant and traffic per inhabitant normalised per country area. Source: collected data from various sources, 2010 (annex A.1).*

Thus, it evidences the relevant number of trips performed in Switzerland, where, being a small country, those are expected to be everywhere, dispersed all around the territory.

As a matter of fact, economic distribution is quite homogeneous in Switzerland. The financial centres are located in six major urban areas: Zurich, Basel, Geneva, Lausanne, Lugano and Bern, and they are responsible for the 84% of the country’s economic output [40]. Consequently, it appears that both demographically and economically, Switzerland is a country with a strong regional balance, and that tips the balance in favour of intermediate stops, rather than speed benefits.

8.2 Identified corridors

After analysing the country characteristics in Switzerland, two major corridors have been identified inducing potential demand. In the former sections it has been seen how, just by drawing two different lines, the whole of the ten major cities would be covered by the new transportation network (Figure 42). That would represent almost the 50% the total Swiss population being served, plus improved access to the remaining minor agglomerations.
Figure 42. Potential demand corridors in Switzerland. Source: own production.

Moreover, not only are these the most favourable corridors in terms of potential demand, but it also turns out that they are ideally placed so as to fulfil the specified requirements when it comes to future railway strategy in the country:

- Since these are the most populated axis, the aforementioned capacity problems do focus in these two corridors, especially in the E-W one (Figure 36). Hence, new infrastructure in these links would effectively help to decongest the system.

- The N-S axis comprises part of the international Priority Project 24 within the frame of the TEN-T (Figure 37). Thus, further infrastructure development in the corridor would also help in this purpose.

That said, interest has been manifested for the two alternatives. However, in the scope of this project, only one line is going to be considered. Thereupon, both solutions are going to be weighted up in order to pick the investment entailing the higher benefits.

8.2.1 The East-West corridor

Figure 43. The E-W corridor. Location: demography and topography. Source: own production and Wikipedia.
The East-West corridor runs all along the Plateau, where topography conditions turn out to be the optimal in the country concerning construction difficulties. Moreover, Swiss population has been seen to gather mainly in that part; comprised cities in the E-W corridor account for the 36% of the total population. Hence, such features turn out to be ideal for HSR when it comes to potential benefits. On the one hand, high demand maximises both financial revenues and the total amount of minutes saved, and on the other, the easier terrain would make the initial investment less costly:

\[ \text{Higher demand + Lower costs } \rightarrow \text{Higher financial benefits} \]

\[ \text{Higher demand \cdot Timesavings } \rightarrow \text{Higher social benefits} \]

Regarding social benefits, it is also interesting to refer to the potential time savings that the new line can bring along. As aforementioned, due to the regional balance particularities in Switzerland, intermediate stops cannot generally be neglected, thus, making in-between city distances quite short. In this context, time savings per journey cannot be expected to be comparable in absolute value to those in other European countries. Yet, potential time savings can still represent a significant percentage reduction of the current service, so they are to be analysed more in-depth.

### 8.2.2 The North-South corridor

Unlike the former alternative, the North-South corridor runs throughout the Swiss Alps, what implies much more difficult topographic conditions when building the suggested line. Regarding demand, the present alternative provides direct access to the 11% of the total country population (24% in case of running the line through Zurich instead of Luzern). Note that in this case the covered population is lower than for the E-W corridor; however, it is the only way to improve access to Lugano (151.000 inhabitants, 2014), located at the very south of Switzerland.

Considering the whole situation, extra benefits in the N-S corridor, compared to the ones in the E-W, do not seem to compensate for the higher construction costs it implies to run a new line under the Alps.

Nonetheless, checking the current scenario, one realises about the possibility of taking profit of the already exiting infrastructure in order to reduce costs.

---

(3) Urban areas: Geneva, Lausanne, Fribourg, Bern, Zurich, St.Gallen.
(4) Urban areas: Basel, Luzern, Lugano.
Nowadays, there already exist some railway tunnels crossing the Helvetic country from north to south; both the Lötschberg (2007) and the Gotthard Tunnel (2016) have been constructed so as to improve traffic in the N-S corridor (Figure 45). In fact, the Gotthard tunnel has been planned for speeds reaching the 250 km/h, which according to the European standards, could be classified as a high-speed rail section. Therefore, for the present purpose, connecting the proposed corridor to the Gotthard Tunnel would imply significant reductions in the infrastructure costs.

![Figure 45. Gotthard base tunnel: trajectory. Source: Wikipedia.](image)

Being the longest rail tunnel in the world, with 57 km, The Gotthard base tunnel has been recently opened to traffic (June 2016). For the moment, passenger trains are going to run at a speed of 200 km/h, but in the future, top speeds are possible up to 250 km/h. That enables to bring passengers from Zurich to Milan in 2h50, which already means a reduction of 1h with respect to the former performance [44].

Therefore, even if it is true that such connection would diminish construction costs, it should also be born in mind that the already improved service in the tunnel section also reduces the potential time savings provided by the possible new corridor. Moreover, potential demand in the N-S axis keeps being the same; Figure 46 illustrates the significant difference in current demand between the N-S and the E-W corridors.

Summing up:

\[
\text{Lower demand} + \text{Lower costs} \rightarrow \text{Financial benefits} \\
\text{Lower demand} \cdot \text{Lower timesavings} \rightarrow \text{Lower social benefits}
\]

Costs and demand should be analysed more in-depth to weight them up and assess financial benefits in both corridor options. Yet, social benefits are expected to be low in the N-S alternative.

Most importantly, mention that with the opening of the Gotthard tunnel, existing infrastructure in the N-S corridor will already solve major capacity problems in that axis. Hence, the main targets for the new HSR network turn out to be nonsense anymore.

Based on all the above, it is concluded that the best way to proceed would be to leave the N-S corridor as it has been planned, served with the Gotthard tunnel, and rather focus on
the development for the E-W axis. This way, higher benefits are expected to be obtained from the proposed investment, turning it into a more profitable option.

Figure 46. Route and rail passenger traffic flux in Switzerland, 2010. Source: OFS, ARE.
8.3 Proposed HSR line

Given its characteristics, the E-W corridor has been selected as the wiser option where to implement the new passengers HSL. According to the observed homogeneity in the country, the suggested line would include all the major cities on the axis.

Figure 47 shows the proposed design:

Note how population values do not strongly differ from one to another along the corridor, making it difficult to discard any city. However, even though it has been remarked the non-possibility of skipping any stop, questions about the involved efficiency losses have also been introduced. Following this reasoning, another feasible alternative has been proposed entailing better speed performances:

Based on its population, Fribourg's potential demand can be expected to be the lowest amongst the concerned cities, and moreover, it turns out to be located quite close to Bern, so that associated time benefits by HSR are likely to be less noticeable (refer to section 9.1 for fixed distances justification). Hence, in order to give assessment on the trade-off between demand and individual time savings, both presented scenarios are going to be analysed. Whether or not to include Fribourg would be decided later on, according to the obtained socio-economic results.

8.3.1 Verification

In any case, bear in mind that the two proposed designs have been selected by fulfilling suitability criteria; on the one hand, the line has been assessed pursuing specific goals (capacity problems and service improvement) and on the other, the location has been cautiously chosen so as to maximise potential demand. Regarding the learned lessons concluding the European analysis in Part 1, those would already verify the first two points (0, 1) in section 6. Then, when it comes to the remaining points:
0. **Define a goal:** To solve capacity problems in the existing rail network and to improve the current service by decreasing travel timings and by bringing a safest and more environmental-friendly mode.

1. **Maximise potential demand:** By connecting identified major cities in a single corridor where moreover, strong demand patterns have already been observed.

2. **Maximise speed performance:** Short distances and a strong regional balance have been seen as country particularities. Optimal speeds are going to be determined; yet, there is no much option in neglecting intermediate stops. An alternative without stopping in Fribourg is going to be analysed.

3. **Select easier topography:** The E-W corridor is ideally located in the area where topography presents less problematic for the new line construction.

4. **Maximise intermodality and integration:** Due to the high quality of connexions in the current railway network - with the symmetrical regular-time interval timetable organising the exploitation - HSR services could be fitted in the same way. Thus, good intermodality and good integration could be ensured, maintaining the same level of service as nowadays.

5. **Set proper operation policies:** Ticket prices are to be fixed making sure competitive fares are offered; a certain level of revenues has to be obtained without inducing lower demand values. Also frequencies have to be planned ensuring a high quality of service, and in any case the new mode should worsen the current offer, since that could also lead demand reductions.

Consequently, the designed HSR in Switzerland seems to have strong potential to become a successful infrastructure. Thus, given the favourable conditions, the next step is to go more in-depth with the feasibility analysis. In order to make a profitable investment, further evaluation needs to prove the benefits outweighing the costs. Thereupon, Section 9 is going to better determine which are the new line characteristics so that expected benefits can be quantified.
9 HSR network characteristics

The proposed designs for the new HSR line in Switzerland have been presented in the former section. Nonetheless, in order to better determine which are the associated socio-economic benefits, characteristics about their exploitation are still to be decided in each case. Thus, the present section is going to deal with the following operating issues:

- Running speed
- Fares
- Frequency of trains

Those will determine the level of service of the line, inducing a certain demand in the infrastructure. At the same time, however, the level of service needs to be fixed according to the number of users, which turns the problem into a complex bidirectional relationship. In order to deal with it, the situation requires of some hypothesis to work on a demand forecast before implementation.

Once the exploitation is defined and the expected number of users is determined, both financial revenues and social benefits would be determined.

9.1 Trajectory

The designed trajectories would determine the HSR network size in each case. However, in the scope of this project, routes are not going to be thoroughly analysed. Instead, some simple assumptions have been made:

- All the stops in the HSL are going to be located in the historical centres, making use of the already existing stations, which would probably have to be amplified. This way, HSR would ensure easy access to the city, and also connectivity with the other modes would be kept at the current level.

- As terrain information is not available, a straight line has been considered connecting intermediate cities, and distances have been majored by an extra 10% in order to account for possible curves and forced deviations. By doing that, the values presented in Figure 47 and Figure 48 have been obtained. Note that to prove sense, those have been compared to the current conventional distances (Table 23).

<table>
<thead>
<tr>
<th></th>
<th>Conventional rail distance [km]</th>
<th>HSR dist variation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A1</td>
</tr>
<tr>
<td>Geneva-Lausanne</td>
<td>60,26</td>
<td>-7,4</td>
</tr>
<tr>
<td>Lausanne-Fribourg</td>
<td>65,99</td>
<td>-15,4</td>
</tr>
<tr>
<td>Fribourg-Bern</td>
<td>31,19</td>
<td>-5</td>
</tr>
<tr>
<td>Bern-Zurich</td>
<td>106,14</td>
<td>-0,5</td>
</tr>
<tr>
<td>Zurich-St.Gallen</td>
<td>84,07</td>
<td>-21,3</td>
</tr>
</tbody>
</table>

Table 23. HSR v. conventional distances in the Swiss railway network. Source: Réseau ferré Suisse. Atlas technique et historique, SBB [46].
To minimise timings, HSR lines are thought to run as straight as possible. Hence, shorter distances in the new line make sense, and provided that differences are not big, the presented values are assumed to be realistic. The largest difference encountered in the section Zurich-St.Gallen (21.3%) can be explained by the new trajectory avoiding its pass through Winterthur.

9.2 Optimal speed and travel times

Being the trajectory fixed, train performances can already be assessed. For that, it is important to bear in mind the existing constraints due to intermediate distances; because of acceleration and braking performances of the rolling stock, to increase speed does not imply to decrease travel time linearly, especially in short journeys. That would be an important issue when fixing the maximum running speeds.

9.2.1 Sensitivity analysis

Acceleration and braking performances are seen to diverge depending on the characteristics of the used rolling stock (annex B.1). Thus, in order to evaluate the present scenario, two different types of train have been selected so that a sensitivity analysis can be carried out between them:

- **TGV-POS**: Alstom’s model being currently used in the high-speed international relations arriving to Switzerland (TGV Lyria).
- **AGV-10C**: Alstom’s newest high-speed rolling stock, whose recent technology allows some benefits with respect to their former TGV-POS:
  - AGV has new technology, with a permanent magnet motor and smaller (so, lighter). Traction is not only in the engine but all along the train instead.
  - Wider doors, allowing reduced dwelling times for passengers exchange.
  - Better adhesion, which is important in Switzerland due to usual wet rails because of the ice and the snow.

Then, the optimal running speed has to be assessed. In this purpose, travel times are going to be simulated by fixing the maximum speed at:

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>160</th>
<th>200</th>
<th>250</th>
<th>300</th>
</tr>
</thead>
</table>

Being 160 km/h the current maximum speed for conventional trains in Switzerland, and 250 km/h the high-speed threshold for new lines according to the European standards.

Obtained timings are also expected to vary depending on the topographic characteristics along the line; the inclination of the track does affect on speed efficiencies, entailing longer timings for uphill grades [45]. However, performed simulations are going to assume a 0% inclination all along the line; corrections for this hypothesis are going to be considered later on.

See all the simulation results for the sensitivity analysis in annex B.1.
9.2.2 Optimal speed

According to the obtained results in the sensitivity analysis (annex B.1), it is concluded:

- Not relevant differences are perceived in timing performance between the selected rolling stock models. Hence, considering its benefits, the AGV-10C is going to be used.

- Due to different stretch characteristics along the line, maximum speeds are going to be fixed independently in each section.

The optimal speed value is going to be assessed by following logical arguments about the amount of minutes saved and considering the correspondent costs of increasing speed. The main factors to be regarded are listed below:

Time savings

Due to acceleration and braking performances, relative time savings become lower as maximum speed increases, especially in the shortest sections (Figure 49). Therefore, extra savings start being nonsense at a certain point, making it not worth to upgrade the line for higher speeds.

![Figure 49. Obtained timing results in the sensitivity analysis for Alternative 1 with AGV-10C. Source: own production from results in annex B.1.](image)

Energy consumption

The amount of energy required for running a train increases exponentially with speed; Figure 50 illustrates this relationship. Hence, energy representing a relevant part within the operations budget, its cost would not compensate the obtained benefits up to a certain speed.

\[ E \propto V^2 \] [45]

With:

- \( E \): consumed energy
- \( V \): running speed
The Swiss singularity in the European high-speed rail network

Infrastructures construction costs

Higher speeds do involve higher constraints for the railway infrastructure. For instance, in order to fulfill forces dynamics and security standards, the minimum radius required on the current Swiss railways tracks corresponds to the following expression:

$$ R = 0.042 \cdot V^2 \quad [47] $$

With:

- $R$: radius [m]
- $V$: running speed [km/h]

Being the radius proportional to the square of the speed means construction difficulties getting also exponentially higher. Moreover, special restrictions are fixed for speeds as of 250 km/h, threshold for high-speed according to the European standards.

In light of all the above, the following speeds have been taken as optimal for each stretch in the designed scenarios (Figure 51 and Figure 52):

Alternative 1:

<table>
<thead>
<tr>
<th>Location</th>
<th>Speed</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geneva</td>
<td>200 km/h</td>
<td>570.200 km</td>
</tr>
<tr>
<td>Lausanne</td>
<td>200 km/h</td>
<td>402.900 km</td>
</tr>
<tr>
<td>Fribourg</td>
<td>160 km/h</td>
<td>96.000 km</td>
</tr>
<tr>
<td>Bern</td>
<td>250 km/h</td>
<td>406.900 km</td>
</tr>
<tr>
<td>Zurich</td>
<td>200 km/h</td>
<td>1,315.700 km</td>
</tr>
<tr>
<td>St.Gallen</td>
<td>200 km/h</td>
<td>160.000 km</td>
</tr>
</tbody>
</table>

Figure 50. Energy consumption increase with speed. Source: Ibañez Porcar, S [45].

Figure 51. Selected speeds for the Swiss HSR proposed design. Alternative 1. Source: own production.
Alternative 2:

![Diagram of selected speeds for the Swiss HSR proposed design. Alternative 1. Source: own production.](image)

**Figure 52. Selected speeds for the Swiss HSR proposed design. Alternative 1. Source: own production.**

Regarding this choice, some considerations must be highlighted:

- This is just an expert appraisal, which means that implied costs have not been thoroughly evaluated for increasing speeds. Even though they have been taken into consideration, within the scope of this project the final selection has been mainly based on the observed timings. Further research should be done in order to verify the optimal solution.

- The target of this section is to get design objectives. Nonetheless, when drawing the specific trajectory, some unexpected difficulties can be encountered on the terrain. In this case, suggested speeds can always be lowered along the problematic section.

- Note that the maximum speed has been fixed at 250 km/h. By keeping it at that value, design speed can always be lowered to 249 km/h in case it is necessary to avoid imposed trajectory restrictions for the high-speed according to the European standards.

### 9.2.3 Travel timings

Annex B.1 contains the obtained timings for the simulated scenarios. Note that those figures correspond to the “practical journey time”, already accounting for possible delays in operation (see the annex B.1 for further explanation).

However, for the present study, some extra time should still be added in order to fix the final timetables:

- As trajectories in the proposed HSR alternatives are mentioned to pass through the historical centres, speed reductions are going to be required when entering the cities. Thus, an extra minute has been added for every train approaching or leaving the existing rail stations.

- Some dwelling time is needed in order to allow passengers getting in and out of trains at every stop. For this purpose, three minutes are assumed to be enough.

- Final timings are finally majored by another 10% in order to account for the full lack of real geometrical characteristics in the trajectory; speed reductions might be required due to uphill grades, downhill grades, curves, etc. which have been previously simplified.

Therefore, according to the choice in optimal speeds, the final schedules are presented below (Table 24 and Table 25). Note that OD matrixes are symmetric in both cases.
Alternative 1:

<table>
<thead>
<tr>
<th></th>
<th>Geneva</th>
<th>Lausanne</th>
<th>Fribourg</th>
<th>Bern</th>
<th>Zurich</th>
<th>St.Gallen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geneva</td>
<td>-</td>
<td>24,2</td>
<td>51,7</td>
<td>71,7</td>
<td>109,7</td>
<td>141,5</td>
</tr>
<tr>
<td>Lausanne</td>
<td>-</td>
<td>24,5</td>
<td>44,5</td>
<td>85,5</td>
<td>114,4</td>
<td></td>
</tr>
<tr>
<td>Fribourg</td>
<td></td>
<td>17</td>
<td>55</td>
<td></td>
<td>86,8</td>
<td></td>
</tr>
<tr>
<td>Bern</td>
<td>-</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td>66,8</td>
</tr>
<tr>
<td>Zurich</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td>28,8</td>
</tr>
</tbody>
</table>

*Table 24. Journey times in the designed HSR line, alternative 1. Source: own computations.*

Alternative 2:

<table>
<thead>
<tr>
<th></th>
<th>Geneva</th>
<th>Lausanne</th>
<th>Bern</th>
<th>Zurich</th>
<th>St.Gallen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geneva</td>
<td>-</td>
<td>24,2</td>
<td>56,5</td>
<td>94,5</td>
<td>126,4</td>
</tr>
<tr>
<td>Lausanne</td>
<td>-</td>
<td>29,4</td>
<td>67,4</td>
<td>99,2</td>
<td></td>
</tr>
<tr>
<td>Bern</td>
<td>-</td>
<td>-</td>
<td>35</td>
<td></td>
<td>66,8</td>
</tr>
<tr>
<td>Zurich</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>28,8</td>
</tr>
<tr>
<td>St.Gallen</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 25. Journey times in the designed HSR line, alternative 1. Source: own computations.*

That represents approximately time savings in the line around the 37% in alternative 1 and 45% in alternative 2, with respect to the conventional rail services.

### 9.3 Demand forecast

As aforementioned, it is the HSL characteristics that are going to define the offered service to the population, and according to its quality, a certain level of demand is going to be observed for the planned infrastructure. Regarding the present study, fares and frequencies are still to be fixed, so that the expected demand would also depend on these two variables. In order to deal with the situation, the procedure will be the following:

- Future demand is going to be forecasted taking into account price sensibility. Hence, different pricing scenarios are going to be assessed making sure both social and economic benefits do fall within acceptable ranges.

- Minimum HSR frequencies are going to be fixed at the same level as the current conventional service; this way, no losses in demand can be triggered from a service reduction. Once forecasted, larger future demands may lead to higher frequencies in order to absorb all users, but their effect on demand attraction is not going to be considered on its own.

Therefore, it is the demand analysis itself that is going to end up showing the best way to deal with fares and frequencies, but most importantly, this forecast will determine the profitability of the inversion later on in Section 10.
To start with, the current demand has to be analysed (Section 9.3.1). From that, future growth will be assessed later on (Section 9.3.2).

### 9.3.1 Current demand

From all the possible origin-destination pairs in the designed line, data has only been found regarding the total number of railway passengers passing by the Lémanic Arch. That is to say, passengers running from Geneva to Lausanne or the other way around, but whose origin or whose last destination is not necessarily one of these two:

- The CFF estimated rail traffic in the Lémanic Arch to be of 50,000 passengers per day in 2010. [48]

However, the concerned railway section is compounded by several tracks, some of them serving either regional trains or InterCitys coming from departure stations different from the ones within the E-W axis. According to that, only a part of the total Lémanic traffic is going to be captured by the designed HSL:

- The 80% of the total Lémanic traffic is considered to be travelling in between main cities along the E-W corridor.

By using this data, a model needs to be calibrated being able to predict traffic in the entire line. To do so, the well-known Gravity Model is going to be applied.

**Model calibration**

Usually, the Gravity Model is expressed as follows:

\[
D_{(\alpha)} = \alpha \cdot \frac{O \cdot D}{t^2}
\]

With:
- \(D\): demand from a certain origin to a certain destination.
- \(\alpha\): model constant (to be calibrated).
- \(O\): city population in the origin.
- \(D\): city population in the destination.
- \(t\): travel time from the regarded origin to the regarded destination.

Alpha accounts for all the remaining factors which can intervene in determining demand; country characteristics, such mobility habitude or existing modal competence in transportation are included in this constant value. Thus, alpha can be calibrated for the existing data and considered the same for the remaining relations in Switzerland.

Note that sometimes, depending on the specific case and the demand composition, an alternative model can better suit observed patterns by changing the time elasticity. Then the model is expressed as:

\[
D_{(\beta)} = \beta \cdot \frac{O \cdot D}{t}
\]

Being all the variables the same as before, except for the constant \((\beta)\), which is going to take a different value after calibration.

According to that, both models have been applied so as to choose the one that better fits the particular behaviour in present scenario. Figure 53 show the obtained results.
As aforementioned, no more traffic data is available to verify the obtained values. Nonetheless, in order to have some reference, the existing train capacity has been checked. Train frequencies are expected to be higher for those relations where high demand exists. Then, accounting for the maximum capacity during the peak hours in each case (5), Figure 54 compares it with the obtained calibrated results:

Four main lines are seen to diverge between the two models:

(5) Frequency of trains checked in the SBB website for every particular relation. Each train is assumed to have a capacity for 1500 passengers and 10% of the total traffic is expected during the peak hours (see Section 9.4 for justification).
On the one hand, common sense suggests results in the time square model (demand alpha) to be more reasonable; despite their large populations, long trips between Geneva and Lausanne to Zurich are less likely to be performed daily by the great number of commuters using the line. Moreover, existing capacity shows no need for higher frequencies in those two relations. Instead, capacity increase in Geneva-Lausanne and Fribourg-Bern can be taken as a confirmation for the first model better fitting the Swiss scenario.

In light of the above, the time square model (demand alpha) is going to be used for demand forecasting in the present study. Anyway, note that differences are not seen to diverge that much between obtained results, so that no relevant mistakes are expected to be triggered because of the accuracy in the model choice.

**Demand in 2010**

The final OD matrixes for 2010 are presented in annex B.2. Note that total demand is increased about a 23% in Alternative 1, since population is also served in Fribourg (Table 26):

<table>
<thead>
<tr>
<th></th>
<th>Total rail demand in 2010 [pax/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>109,654</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>89,330</td>
</tr>
</tbody>
</table>


**9.3.2 Future demand**

Once the model has been calibrated, the next step would be to extrapolate demand values from 2010 to future years. Accounting for its implementation in 2030, the HSR investment would be assessed for the demand at that time.

For the present case, demand variations will be differentiated in two triggering factors:

- Current trends do already suggest a constant growth of the railway traffic in the Swiss network [49]. Such a variation in demand can be explained by the expected evolution of the socio-economic variables in the country, including population growth, GDP increase, further industrial development, etc.

- Due to the HSR implementation, a better service will be offered at 2030. Thus, a more competitive railway line is expected to induce new users and to capture some formerly using other modes.

Table 27 classifies the commented factors in exogenous and endogenous factors respectively:
The Swiss singularity in the European high-speed rail network

Table 27. Taxonomy of the impacts on HSR demand. Source: HSR demand: empirical and modelling evidences from Italy [22].

9.3.2.1 Endogenous factors

According to the Swiss Federal Statistical Office (OFS) [28], total rail traffic has increased from 19,177 passengers-kilometres in 2010 to 20,010 passengers-kilometres in 2014, what represents a 1,07% of annual growth rate.

Regarding future demand, LITRA estimates the public transport to increase from 23,200 to 27,9000 passengers-kilometres in 20 years, from 2010 to 2030. That would represent a 0.93% annual rate [49].

Looking at historical trends (Figure 55), railway demand seems to show higher increases than the general public transport as a whole. Therefore, considering constant tendencies for the regarded mode, a 1,1% annual growth is thought to be a good approach in order to forecast demand for 2030.
Future demand = Past demand \cdot \left(1 + \frac{r}{100}\right)^n

With:
- \(r\): annual growth rate [%]
- \(n\): number of years

Hence, a 1.1% annual growth rate implies an almost 25% railway demand increase in 20 years (24.5%), when the designed HSR line is supposed to start its service. Total demands have increased up to (Table 28):

<table>
<thead>
<tr>
<th>Total rail demand in 2030 (before HSR) [pax/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
</tr>
<tr>
<td>Alternative 2</td>
</tr>
</tbody>
</table>


9.3.2.2 Exogenous factors

Apart from the already expected demand increase in the current network, HSR will bring along further induced and diverted traffic. In comparison with the conventional service, changes in demand for the new line have been considered not to be relevant relating connectivity and frequency factors (see hypothesis in sections 9.1 and 9.3). Instead, it is basically time savings and fares that are going to make a difference. However, in order to proceed, the latter do still need to be fixed.

The utility concept: HSR fares

The concept of “utility” has been often used to explain observed behaviours in transport choices (section 3.3). Brief, people choose the model that brings them higher utilities; that is to say, higher benefits. Utility is measured according to each individual’s perceptions, and it usually comprises timings and fares as key variables.

By using the concept of “value of time”, utility can be expressed in monetary terms as:

\[ U = \alpha - GC = \alpha - VoT \cdot T - P \]

With:
- \(U\): utility [€]
- \(\alpha\): constant
- \(GC\): generalised costs
- \(VoT\): value of time [€/h]
- \(T\): travel time [h]
- \(P\): ticket price [€]

Alpha represents an average of the remaining factors intervening in each individual’s choice (comfort, personal preferences, etc.) and it is particular for every specific scenario and every specific transport mode.

Then, since the new line is thought to improve all rail users’ conditions, its corresponding utility shall be higher than the current one:

\[ \frac{U_{HSR}}{U_{CT}} > 1 \]
As both utilities are dealing with rail modes, alpha can be considered the same. Thus:

\[ GC_{HSR} < GC_{CT} \rightarrow VoT \cdot T_{HSR} + P_{HSR} < VoT \cdot T_{CT} + P_{CT} \]

Knowing the value of time, the current fares and the timing performances, an upper limit can be fixed for the HSR fare not to produce demand loosess amongst the current users.

In Switzerland, the averaged VoT is taken as 17.56 €/h (annex B.2), and conventional rail fares, accounting for the existing reductions tickets, are averaged to 0.152 €/km (0.169 CHF/km according to the SBB revenues, 2015)[50]. Hence, accounting for the computed times by HSR (section 9.2.3) and checking current times by conventional train (web SBB, shortest timings), the allowed increase is obtained for every possible OD relation (see annex B.2).

Based on the results, the upper limit can be fixed around a 30% increase; higher fares would imply a loss of service competitiveness for users in some specific relations. Therefore, in order to conduct a sensitivity analysis, the following pricing scenarios are going to be considered, maintaining or increasing HSR utilities for rail users:

<table>
<thead>
<tr>
<th>+0%</th>
<th>+10%</th>
<th>+20%</th>
<th>+30%</th>
</tr>
</thead>
</table>

Once the prices have been fixed making sure that the entire conventional demand is captured, the amount of new users should also be assessed. Regarding diverted demand, it would also be useful to check the correspondent utility values. New demand would come from those whose perceptions fulfil:

\[ \frac{U_{CT}}{U_{alternative}} < 1 , \text{but} \quad \frac{U_{HSR}}{U_{alternative}} > 1 \]

By knowing those values, it would be possible to proceed with a Logit model to estimate the future modal share. Nevertheless, missing data for the alternative modes requires the situation to be approached in a different way.

The elasticity concept: Captured demand

A measure frequently used to summarise the responsiveness of demand to changes in its determining factors is elasticity. The elasticity of demand can be defined as [51]:

\[ e_{x_i} = \frac{\text{The proportional change in demand}}{\text{The proportional change in the explanatory variable}} = \left( \frac{dD}{D} \cdot \frac{dx_i}{x_i} \right) \]

Where:

- \(dD\): differential change in demand (D)
- \(dx_i\): differential change in the explanatory variable (x_i)

Elasticities are usually calculated at one or two explanatory variables; for the present case, the main ones have been seen to be time and fares. Thus, future demand in the new line would be forecasted as:

\[ D = \theta \cdot T^\beta \cdot P^\gamma \]
with $\theta$ a constant to be calibrated, and both $\beta$ and $\gamma$ being the time and the fare elasticities measuring the impact of the HSR introduction.

According to available data for conventional rail demand in 2030 (section 9.3.2.1):

$$\frac{D_{\text{HSR}(2030)}}{D_{\text{CT}(2030)}} = \frac{\theta}{\theta} \cdot \frac{T_{\text{HSR}}^\beta \cdot P_{\text{HSR}}^\gamma}{T_{\text{CT}}^\beta \cdot P_{\text{CT}}^\gamma}$$

In order to obtain elasticities, literature shows some values computed for similar projects, so that it would be wise to focus on them. However, a great variance is observed amongst the consulted sources.

Table 29 below gathers some time and fare elasticity values for HSR projects in other countries. Some of them are based on empirical evidence after implementation whilst others result from cross-section surveys and performed studies:

<table>
<thead>
<tr>
<th>Source</th>
<th>Time elasticity HSR</th>
<th>Fare elasticity HSR</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atkins (2003)</td>
<td>-0.9/-1.3 Business</td>
<td>-</td>
<td>Cross-section RP/SP data.UK HSR corridors.</td>
</tr>
<tr>
<td></td>
<td>-0.8/-0.9 Private</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bok et al. (2010)</td>
<td>-0.6 Business</td>
<td>-</td>
<td>Average distance elasticity. Portugal. Cross-section RP data.</td>
</tr>
<tr>
<td></td>
<td>-0.5 Commuters</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.3 Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rohr (2010)</td>
<td>-0.9 Business</td>
<td>-0.5</td>
<td>Average distance elasticity. UK. Cross-section RP data.</td>
</tr>
<tr>
<td></td>
<td>-0.4 Private</td>
<td>-0.9 Commute</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.9 Others</td>
<td></td>
</tr>
<tr>
<td>Spain (Sanchez-Borras)</td>
<td>-1.3 Mad-Bcn</td>
<td>-0.5</td>
<td>HSR line 2008</td>
</tr>
<tr>
<td></td>
<td>-1.2 Mad-Sevilla</td>
<td></td>
<td>HSR line 1992</td>
</tr>
<tr>
<td>TGV Paris-Lyon</td>
<td>-1.6 (phase 1)</td>
<td>-</td>
<td>HSR lines 1981-1983</td>
</tr>
<tr>
<td></td>
<td>-1.1 (phase 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ben-Akiva</td>
<td>-</td>
<td>-0.41/-0.49 1st class</td>
<td>Naples-Rome HSR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.34/-0.38 2nd class</td>
<td></td>
</tr>
</tbody>
</table>

Table 29. Time and fare elasticities in literature. Sources: [22], [52] and [53].

Such a variance in elasticities can be explained by the fact that, somehow, those values are implicitly including other socio-economic variables. Some examples are:

- Factors such as the GDP and the averaged value of time in the country can make a difference in both time and fare variations perception.

- Averaged intermediate distances can also intervene in determining elasticities, since these are suggested to change according to the total journey timing; extra minutes are perceived differently in short than in long trips.
- Existing competitiveness can also play a role in observed elasticities. Given a scenario where alternative modes beat the former rail service, some improvement would easily attract this high potential demand.

Consequently, it seems that elasticities can be strongly associated to the country characteristics, so in this context, it becomes difficult to make a good guess for Switzerland.

**HSR demand scenarios**

Even though some elasticity values are more likely to fit in the Swiss case than others, uncertainty will always be present. Thus, as a way to deal with it, three different scenarios are going to be considered (Table 30):

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>-1,1</td>
<td>-0,9</td>
<td>-0,6</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>-0,5</td>
<td>-0,5</td>
<td>-0,5</td>
</tr>
</tbody>
</table>

*Table 30. Considered elasticities: HSR demand scenarios to be analysed.*

Since it has been used in many occasions applying to similar projects, fare elasticity has been fixed at $\gamma = -0,5$ [45] [52]. Regarding time elasticities, the chosen scenarios comprise a wide range of variability, from being quite optimistic considering $\beta = -1,1$ to being more pessimistic by taking one of the lowest reported values, $\beta = -0,6$.

Therefore, those three scenarios, added to the pricing sensitivity analysis, consider twelve different possibilities for the future HSR implementation. Moreover, weather to include Fribourg or not is still to be discussed.

The suggested growths due to HSR are presented below, as well as the total resulting demand for the line in each case (Table 31 and Table 32). Note that even presenting higher attraction, total demand keeps always higher in Alternative 1. This would be the main reason leading to its final selection (see section 10.1.3 for further details).

**Alternative 1:**

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\frac{D_{\text{HSR}(2030)}}{D_{\text{CT}(2030)}}$</td>
<td>Demand [pax/day]</td>
<td>$\frac{D_{\text{HSR}(2030)}}{D_{\text{CT}(2030)}}$</td>
</tr>
<tr>
<td>0%</td>
<td>1,64</td>
<td>223.540</td>
<td>1,5</td>
</tr>
<tr>
<td>10%</td>
<td>1,56</td>
<td>213.137</td>
<td>1,43</td>
</tr>
<tr>
<td>20%</td>
<td>1,5</td>
<td>204.063</td>
<td>1,36</td>
</tr>
<tr>
<td>30%</td>
<td>1,44</td>
<td>196.057</td>
<td>1,31</td>
</tr>
</tbody>
</table>


**Alternative 2:**
By comparing these values to historical results, the third scenario could be considered to be the most realistic one.

On the one hand, the ICE implantation in Germany reported only a 12% of travellers shifted from other modes (Cheng, 2010) [52]. Cheng suggests that the high price of the train service explains the low shift, and another explanation is that HSR compete less with air travel because it is more focused on regional travel. Note that HSR price in Germany represents a 30% increase comparing to the conventional train, which has also been considered for Switzerland. Moreover, it is important to highlight that air competition does not exist neither for the Swiss HSR in a national level. Thus, the given similitudes suggest a moderate value for captured demand.

Also, it has to be stand out the fact that both in France and Spain, where time elasticities are reported the highest, it has been observed that most of the additional trips were substituted air trips (COST318, 1998) [52]. Again, given the non-existing air competitiveness in Switzerland, that reinforces the idea of moderate captured demand.

Still, so as to follow with a sensitivity analysis, and since different scenarios can absorb possible variability in analysis hypothesis made so far, the three of the considered time elasticities are going to be assessed in the final Cost-Benefit Analysis.

Table 32. Demand scenarios in rail transport after HSR implementation in 2030. Alternative 2. 
Source: own computations.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th></th>
<th>Scenario 2</th>
<th></th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\frac{D_{\text{HSR}(2030)}}{D_{\text{CT}(2030)}})</td>
<td>Demand [pax/day]</td>
<td>(\frac{D_{\text{HSR}(2030)}}{D_{\text{CT}(2030)}})</td>
<td>Demand [pax/day]</td>
<td>(\frac{D_{\text{HSR}(2030)}}{D_{\text{CT}(2030)}})</td>
</tr>
<tr>
<td>0%</td>
<td>1,8</td>
<td>199,987</td>
<td>1,61</td>
<td>179,401</td>
<td>1,37</td>
</tr>
<tr>
<td>10%</td>
<td>1,7</td>
<td>190,680</td>
<td>1,54</td>
<td>171,052</td>
<td>1,31</td>
</tr>
<tr>
<td>20%</td>
<td>1,64</td>
<td>182,562</td>
<td>1,47</td>
<td>163,770</td>
<td>1,25</td>
</tr>
<tr>
<td>30%</td>
<td>1,58</td>
<td>175,400</td>
<td>1,42</td>
<td>157,345</td>
<td>1,2</td>
</tr>
</tbody>
</table>

Figure 56. Demand evolution with HSR according to the scenario. Alternative 1. Source: own production. (Note evolution is not linear, it is only values at 2010 and 2030 what matter).
9.4 Frequencies

Minimum HSR frequencies have been assumed at the current level not to induce demand losses from service reductions (section 9.3). Possible increases are considered in case future demand would require it. Furthermore, the symmetrical timetable in conventional lines is going to be maintained. This way HSR services could be fitted in the existing schedules, ensuring good intermodality and integration for the new mode (section 8.3).

In order to start planning future services, the final forecasted demand has to be considered (Table 31, alternative 1, see justification in section 10.1.3). The number of trains would be augmented when reaching capacity, so that passengers’ traffic can be absorbed at every time.

To start with, it is imperative to know first about the traffic distribution throughout the day.

![Traffic distribution](image)

*Figure 57. Railway demand distribution throughout the day during the weekdays. Source: Les CFF: faits et chiffres, 2015 [50].*

The national rail company reports passengers in Switzerland to be distributed as illustrated above, in Figure 57 (SBB, 2015). From that, a maximum of 10% the daily demand can be assumed to concentrate during the most crowded hours.

This pattern is going to be considered constant in time, so that it will not change by 2030. Moreover, in order to account for direction, a 50% of the total traffic in each relation is going to be assumed travelling from west to east, and the remaining 50%, from east to west.

Current conventional frequencies

By checking conventional frequencies (SBB website), two services per hour are seen covering the E-W axis nowadays (6). This frequency extends not only to the peak hours, but also during standard hours, what means 14h per day. During the low hours (5h), only one train operates in the corridor every hour (6). Therefore, future services will have to ensure those minimums.

---

(6) Regarding current frequencies, it important to distinguish services in the E-W axis from services in between consecutive sops, which are probably higher due to other lines also running on that stretch.
Future HSR frequencies

Following the same exploitation schema that nowadays, HSR services are going to organise in two blocs:

- Standard hours: 14h/day, fulfilling peak capacity (from 6h to 20h).
- Low hours: 5h/day, reducing standard services at 50% (from 5h-6h and 20h-24h).

In order to fulfil future peak capacity, the number of passengers traveling in each section is computed at those times (10% total demand, according to Figure 57). Figure 58 and Figure 59 show the results for the highest and the lowest forecasted demands respectively. Note that plotted volumes correspond to the traffic in one direction (50%).

![Figure 58. Peak hour HSR demand in 2030, traffic in each section per direction. Scenario 1, fares +0%. Source: own production.](image1)

![Figure 59. Peak hour HSR demand in 2030, traffic in each section per direction. Scenario 3, fares +30%. Source: own production.](image2)

Based on conventional trains, HSR trains are assumed to have a capacity for 1200 passengers (double-deck), since nowadays, conventional train do allow 1500 passengers
inside (also double-deck) [54]. Hence, considering some comfort improvement in the new rolling stock, future HSR capacity can be expected to be around 1200 passengers per train.

Note that not all the sections are equally loaded: Bern-Zurich and Geneva-Lausanne turn out to be the most critical ones. In order to deal with them, extra trains could be planned running only on those sections. However, that would require deeper operation analysis to check the best option. For the present case, just a simple model is going to be regarded assuming the each train running the whole line, always from Geneva to St. Gallen and the other way around. Therefore, results suggest a necessary increase of one or two trains per hour, depending on the considered demand scenario.

Within the scope of this project, it has been decided to go only for the most critical scenario; four trains per hour are going to be assumed during the standard operation hours. Even if the final growth shows lower, that would already allow some margin for future increase, and moreover, it represents a better HSR offer.

Hence, the final HSR operation will consist on:

- 4 trains/hour during the standard hours (14h).
- 2 trains/hour during the low hours (5h).

All of them scheduled in a symmetrical timetable (Figure 60):

Once the number of daily circulations is fixed, the correspondent operation costs can already be determined. Both the number of rolling stock units and the required energy consumption are approached in annex B.3. Those values would be used to compute costs later on in the cost-benefit analysis (section 10.2).
10 Cost benefit analysis

In order to make a profitable investment, costs and benefits need to be quantified for the present HSR project.

On the one hand, a financial analysis would verify if economical benefits could be expected to outweigh costs for the new infrastructure; that would indicate profitability for the rail operator. Also, the introduction of the HSR does bring other type of benefits along, both for the infrastructure users and for the general society; thus, time savings, environmental benefits, safety and other social issues should also be taken into account.

However, so as to provide an accurate social balance, data regarding alternative modes should be available. As this is not the case, the present analysis is just going to focus on the expected time savings to assess social benefits.

\[
\text{Financial profitability} = \text{Economical benefits} - \text{Costs} \\
\text{Social benefits} = \text{Time benefits}
\]

By expressing all benefits in monetary terms, it would be possible to weigh them up against costs.

The project profitability is going to be analysed for its first year of service, in 2030. Whilst demand has already been forecasted for that time, all monetary units would still have to be updated. However, as we have no economic data to forecast the price evolution in 2030, all costs and benefits are going to be referenced at 2015. Possible variations on the future results are assumed not to be so significant.

10.1 Benefits

In this section economical and social benefits are going to be quantified. Benefits are strongly dependent on the amount of users in the infrastructure; note that whilst economical benefits do come from ticket revenues, the social ones result from adding the time savings for all performed trips:

\[
\text{Economical benefits} = \text{Demand} \cdot \text{Ticket price} \\
\text{Social benefits} = \text{Demand} \cdot \text{Trip time savings}
\]

That evidences the great impact of the demand forecast on the final profitability for the inversion. Hence, considering all the regarded scenarios, twelve different possibilities are going to be analysed for each HSR alternative.

10.1.1 Economical benefits

Economical benefits are obtained from multiplying each demand value in the forecasted OD matrix per the correspondent ticket price according to the specific line relation.

Figure 61 shows the obtained results in millions of euros per day for the four pricing scenarios and the three time elasticities. Moreover, alternative 1 (including Fribourg) is compared to alternative 2 (without Fribourg).
10.1.2 Social benefits

Social benefits are obtained from multiplying each demand value in the forecasted OD matrix per the correspondent time savings expressed according to the specific line relation.

Figure 61. Economical benefits and served demand with HSR. Source: own production.
In order to have all benefits in the same units, time savings can be expressed in monetary terms by multiplying them per the value of time. In Switzerland, a VoT=17.56 €/h has been considered (annex B.2).

Figure 62 shows the obtained results in millions of euros per day for the four pricing scenarios and the three time elasticities. Moreover, alternative 1 (including Fribourg) is compared to alternative 2 (without Fribourg).

*Figure 62. Social benefits and served demand with HSR. Source: own production*
Note that time savings have been computed by subtracting the new HSR timings to the former ones by conventional rail. Nevertheless, part of the future demand is either captured from other modes or newly generated, so those values are going to differ for them. Yet, due to lack of accurate data, time savings have been assumed the same for everyone.

**10.1.3 Selection of the HSR alternative**

According to the results, it is observed how in all cases the alternative with Fribourg implies a higher amount of population being served. Given the demographic scenario and the political constraints in Switzerland, demand would be the main priority for the HSR design, so there is little discussion about the final alternative. Moreover, higher operator's revenues reported in the economic analysis would also support the choice of alternative 1 for the HSR design.

On the flip side, obtained timesavings turn out to be higher in alternative 2. That is to say that by neglecting Fribourg, people travelling in between the remaining stops would be better served, and that leads to the service itself producing higher social benefits.

Therefore, despite the clear Swiss priorities, the trade-off between demand and speed is presented again. In this case, however, a high potential demand in Fribourg and higher economical revenues seem to partly justify the final election.

**10.2 Costs**

Given the scope of this analysis it is not be possible to give an accurate value for the total cost of the proposed infrastructure. Nonetheless, by checking similar projects and price values in the literature, an order of magnitude can be approached so that costs can be balanced against the obtained benefits.

Below, there are listed all the considered costs that would need to be assumed for operating the HSR line. Presented figures have already been updated to 2015. Detail and justification regarding the assumed values can be checked in annex B.4.

**Initial investment**

- Infrastructure cost: 14.306 M€ (45 M€/km).
  That includes previous studies, land rights, double track, structures, fixed equipment for electric traction, signalling, railway stations amplification, human work, etc.
  Depreciation: 60 years.

- Rolling stock: 1.000 M€ (40 M€/train).
  25 double-deck trains.
  Depreciation: 30 years.

**Maintenance**

- Infrastructure maintenance: 286 M€/year.
  Yearly percentage of the investment: 2 %

- Rolling stock maintenance: 70 M€/year.
  Yearly percentage of the investment: 7 %
- Track renewal: 223 M€ (0.7 M€/km). The track should be changed after 30 years.

Operation costs
- Energy: 24.6 M€/year.
- Salaries: 128 M€/year.

Regarding operation, costs have been computed assuming complete service during the weekdays (265 days per year) but a 40% reduction has been supposed during the holidays and weekends (100 days per year), accounting for lower traffics.

Therefore, the total annual costs to operate the designed line has been approximated to (Figure 63):

788 M€/year

Figure 63. Annual cost distribution for the proposed HSR design. Source: own production.

10.3 Balance

In order to balance benefits against costs, the first ones need to be expressed on a yearly basis. Note that the demand forecast has been assessed on a usual weekday, and that computed costs have already accounted for different traffic dynamics during the holidays and weekends. Hence, traffic is going to be assumed reduced at a 50% during those days (100 days per year); that would directly imply its correspondent reduction both in financial and social benefits.

All values obtained, financial and social analysis have been performed (Figure 64):

Financial profitability = Economical benefits − Costs

Socio – economic profitability = Economical benefits + Social benefits − Costs
The balance shows profitability in all cases for the proposed HSR investment. Therefore, even if a more accurate analysis should be done so as to verify the final values regarding costs and demand, the performed sensitivity analysis suggests the new HSR line to be a potentially profitable investment.

Below, the obtained internal rates of return (IRRs) are presented in every case (Table 33):

<table>
<thead>
<tr>
<th>IRR (T=60 years)</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>2.8%</td>
<td>2%</td>
<td>0.7%</td>
</tr>
<tr>
<td>10%</td>
<td>3.3%</td>
<td>2.4%</td>
<td>1.1%</td>
</tr>
<tr>
<td>20%</td>
<td>3.7%</td>
<td>2.8%</td>
<td>1.5%</td>
</tr>
<tr>
<td>30%</td>
<td>4%</td>
<td>3.2%</td>
<td>1.9%</td>
</tr>
</tbody>
</table>

Note that computed IRRs have assumed a constant cash flow during the whole economic life of the infrastructure (60 years), maintaining the profitability levels for 2030. However, since demand volumes are expected to increase in time, it should be remarked that presented values are likely to be higher (see annex B.4 for further explanation).
11 Conclusions

According to the final balance, the proposed line has been proved to be a potentially profitable investment. Thus, its construction would succeed in solving capacity problems at the same time that it would provide better transportation services in Switzerland.

Nonetheless, it should be born in mind the fact that, across this document, all the aspects regarding the infrastructure design have been adapted to the Swiss scenario in order to come up with the best solution. Therefore, due to adapted speeds, the final proposal would not be classified as a complete high-speed rail line according to the European standards (section 1.1).

In this context, it is interesting to account for the extra costs and extra benefits resulting from increasing speeds in the line; would it be worth it to adapt a HSR according to the fixed standards? Again, a cost-benefit analysis is going to be performed for the proposed line, but this time, profitability is going to be assessed at 250 km/h and 300 km/h on the entire corridor.

11.1 UIC HSR: design at 250 km/h and 300 km/h

The present section is going to analyse extra benefits provided by increasing speeds, and associated costs are also going to be quantified. Thus, profitability can be presented and compared in between the different speed scenarios.

Extra benefits

Extra benefits would come basically from reduced timings. On the one hand, social benefits would increase for those already using the line. On the other, faster trips are supposed to attract more demand. However, given the scenario in the concerned corridor, new demand is going to be neglected:

- Small potential time savings are assumed not to produce relevant changes in the number of users, and moreover, different demand scenarios do already account for possible variations.

Thus, benefits for the new HSR would be computed as:

\[
\text{Economical benefits} = \text{Demand} \cdot \text{Ticket price}
\]

\[
\text{Social benefits} = \text{Demand} \cdot \text{New trip time savings}
\]

Extra costs

Extra costs would come from:

- Stricter constraints for the infrastructure to circulate at higher speeds (section 9.2.2).
- Consumed energy showing quadratic growth with increasing speed (section 9.2.2).
- Salaries representing the 50% of the total operator cost, which turns higher for increasing speeds (maintained hypothesis, see annex B.4).

Note that extra costs have not been accounted for the rolling stock, since the same AGV model can reach speeds up to 360 km/h. Also trains’ maintenance and track renewal have been considered constant.

Even though it is suspected that rolling stock would require higher maintenance budgets due to the rolling parts being submitted to higher wears, given the full lack of detail, no relevant differences are going to be assumed for these costs. A similar reasoning applies for the track renewal hypothesis.

Figure 65 shows the resulting cost increase with speed. See annex B.4 for further detail in costs.

![Figure 65. Implied costs growth in the Swiss HSR with increasing speeds. Source: own production (annex B.4).](image)

**Balance**

With respect to the proposed design, to increase the speed in the HSR line supposes to increase costs and benefits in the following way (Table 34):

<table>
<thead>
<tr>
<th>Speed [km/h]</th>
<th>250 km/h</th>
<th>300 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits</td>
<td>+ 16%</td>
<td>+ 29%</td>
</tr>
<tr>
<td>Costs</td>
<td>+ 40%</td>
<td>+ 90%</td>
</tr>
</tbody>
</table>

*Table 34. Costs and benefits variations with increasing speeds in the Swiss HSR. Source: own computations.*

Moreover, not only do costs increase much more than the obtained benefits, but it is also seen how those speed scenarios do not get to reach good financial results; only small financial profits are observed in the most positive demand scenario.

Figures below show obtained profitability for the line at 250 km/h and at 300 km/h (Figure 66 and Figure 67):

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Even though a positive balance remains for the social benefits at 250 km/h and some economic revenues are showed for the most optimistic scenario, all results by increasing speeds are much less favourable than in the proposed line. Therefore, by analysing the country characteristics and the infrastructure impacts in there, it is finally concluded that the high speed rail, as understood in European standards, is not worth it in Switzerland.
11.2 International scenario

In section 7, two main issues have been identified requiring further railway development in Switzerland: capacity problems and international transportation policies. In the end, the chosen E-W line has been seen to efficiently deal with capacity, but international connexions have not been considered in its design.

- Generally speaking, international passenger volumes in rail transport have been seen to be not relevant in Europe (section 2.1). Moreover, neither in Switzerland, the great number of national trips does not turn international design into a priority (Figure 68).

- International traffic in Switzerland has been seen concerning mainly the N-S corridor, where the Gotthard base tunnel has already been constructed in that purpose. Therefore, only a small part of the non-domestic traffic would go through the designed E-W axis.

Therefore, the international influence proves to be irrelevant in the regarded corridor. Moreover, due to the high competitiveness of the airplane in these domains, possible time improvements in train are not expected to raise the observed values in a significant way.

Thus, the presented scenario manifests the priority of focusing on the design for domestic traffic, since international benefits would never get to compensate the required costs by themselves.

Still, the planned HSL can be stated to improve international timings as well, and in any case, supposing a change in the demand patterns, the line could always be operated with some non-stop circulations, if required.
11.3 Alternative inversions

Contrary to the proposed design, higher speeds have been proved not to be a good solution for the future rail development in Switzerland. Thus, the presented infrastructure turns out to be the best option regarding the construction of a new line.

Nonetheless, in order to prove it the best solution amongst all, other alternative projects should also be assessed concerning different measures. So as to improve capacity, the following actions can be taken:

1. **To increase passengers capacity in the trains:**
   
   By changing rolling stock to larger trains, more passengers could fit in every circulation. That would reduce the necessity of increasing the total frequency so as to absorb the entire demand. However, this measure has already been applied in the regarded line by using double-deck rolling stock, and still, its effects are seen not to be enough.

2. **To improve signalling:**

   Implementing the new ERMTS (European Rail Traffic Management System) levels in the Swiss network would allow a reduction of the trains’ headway – time in between consecutive running trains -. That would help in solving capacity problems allowing a higher number of circulations on the same line. However, its effects are expected to be much lower than those of a new line.

3. **To build new infrastructure:**

   It looks like adding extra tracks is the best way to improve capacity in rail transportation. However, apart from the already assessed HSR, other alternative infrastructure could also be explored. Building a new track by widening the existing line would imply the same capacity advantages than the proposed HSR, whilst costs would probably diminish in a significant way. Still, an exhaustive CBA analysis should be performed to check the opportunity cost in each case, since even if costs are reduced by using the same line, speed would remain the same, so no time benefits would be observed from that.

Therefore, the presented alternative measures should also be assessed and compared to prove if some of them can deal with future demand in a more efficient way. Nonetheless, note that the new HSR is the only option able to significantly improve social benefits.

Last, mention the possibility of studying the proposed line implementation but just for those sections where the situation presents more critical. Total benefits would reduce, but, at the same time, costs would be significantly cut as well; a new balance has to be performed.
12 The Swiss singularities

Surrounded by some of the greatest European powers and due to its strategic location in the international transportation network, infrastructure development in Switzerland turns interesting boosting further connections within the continent.

Moreover, regarding its status as the highest rail mobility in the world, existing capacity problems do also require for new solutions improving the current transportation scenario in the country.

These reasons open the debate for future high-speed rail development in the Helvetic country. However, weather they are going to justify the investment or not is to be determined by exploring the Swiss characteristics.

- The small size of the country does not favour competitive distances for HSR. Existing short distances in between the main cities forces the line to be thought neglecting intermediate stops in order to obtain good speed performances.

- However, population distributing in scattered small agglomerations, plus the economical regional balance characterising the country, imply low benefit from a direct HSR service.

- Thus, despite the lack of air competition (again, due to short distances), national traffic volumes captured by HSR are likely to be small if no intermediate stops are included.

- Low international traffic does not justify a design disregarding national benefits.

- Moreover, the political system in Switzerland would never allow infrastructure development favouring certain nodes and leaving out the great part of the total population.

According to the stated factors, the proposal for a new HSR line in Switzerland lies imperatively in including intermediate stops along its trajectory:

- In order to maximise served demand in intermediate stations, population distributed in corridors allows including all the main cities by just drawing two different lines on the territory.

- Thus, not only because of the particularly short implied distances – inducing poor speed performances in acceleration – but also due to an already good conventional rail service, low potential time savings are expected from the HSR.

- The good quality of the existing transportation network would contribute to a good connectivity for the HSR line. Time benefits would be expanded to further locations, thus favouring the demand attraction to the new infrastructure.

- The high GDP in the country could justify high fares leading to high revenues in HSR. Nonetheless, due to the significant road competitiveness in such short distances, fares have to be limited according to road performance. Better utilities have to be ensured by HSR not to loose market share.
Therefore, even the low time savings, if good utilities are achieved in the HSR design, high potential demand is expected for the new infrastructure. Yet, obtained benefits need to be high enough to balance the required investment.

- Given its topography, **construction costs** in Switzerland turn out to be especially high for railway infrastructure.

Summing up, the Swiss singularities in the European high-speed rail network are:

<table>
<thead>
<tr>
<th>Favouring HSR</th>
<th>Disfavouring HSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic location</td>
<td>Short distances</td>
</tr>
<tr>
<td>High rail mobility</td>
<td>Scattered small agglomerations</td>
</tr>
<tr>
<td>Lack of air competition</td>
<td>Regional balance</td>
</tr>
<tr>
<td>Corridors</td>
<td>Low international traffic</td>
</tr>
<tr>
<td>Good connectivity</td>
<td>Political system</td>
</tr>
<tr>
<td>High GDP</td>
<td>Good conventional rail service</td>
</tr>
<tr>
<td>High construction costs</td>
<td></td>
</tr>
</tbody>
</table>

By estimating both expected benefits and expected costs, the present project has proved a negative balance for the HSR as it is understood according to the European standards. Even though high usages are obtained for the infrastructure, **high investments per minute saved** are the main reason leading to discard the idea of the HSR in Switzerland.

Still, due to observed capacity reasons, action should be taken in the Swiss railway network. Thus, future development requires alternative solutions lowering the mentioned ratio.

\[ \text{investment} \text{minute saved} \]

In this project, a new line has been proposed showing profitability. Design speeds have been reduced, but due to the country characteristics, that results in a higher reduction in costs than the one in benefits.

\[ \text{Benefits} \downarrow \quad \text{Costs} \downarrow \downarrow \downarrow \]

Therefore, even not fulfilling the European definitions, high-speed development could be considered in Switzerland with implementation in some sections and including some speed exceptions.
13 Further research

Results in this project suggest profitability for the proposed HSR design in Switzerland. Nonetheless, that is just a first step encouraging future rail development to further enquire about the presented alternative.

On the one hand, since used values have been roughly approximated for the given scenario, further research should be done analysing the designed line characteristics and its social impacts in a more detailed way. On the other, assessment for the mentioned alternative projects in section 11.3 is also recommended, especially the one regarding the HSR implementation by sections.

Therefore, by performing a more in-depth analysis for all suggested options, the best solution could be finally determined defining the best strategy for the Swiss railway sector.

Concerning the selection of the HSR alternative (section 10.1.3), whether to include Fribourg or not has been finally determined regarding the existing social and political constraints in the country; in this case, the trade-off between demand and speed has showed to tip the balance in favour of demand. Nonetheless, the total timesavings have not been optimised by the chosen alternative.

In this regard, a pre-study has been carried out before starting the present project in order to understand the mentioned trade-off. Annex C shows the started model; its aim was to determine criteria for intermediate stops planning, so that total timesavings could be ensured higher by the chosen design (stops vs. direct connexion). However, within the scope of the pre-study, the attached code includes many simplifications that can still be improved by doing further development.

Therefore, it would result interesting to continue working on that model so that it could serve as a helping tool for future HSR infrastructure planning. Yet, as seen for the Swiss case, the influence of other social issues cannot often be neglected, so that it is important to bear in mind that the proposed tool would just deal with the issue in a theoretical way.
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