The Swiss singularity in the European high-speed rail network

ANNEXES

Meritxell Salas Pérez
Annex A

A.1 Mobility and infrastructure

Table 1. National mobility and existing infrastructure. Data 2010.

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FR</td>
<td>62.8</td>
<td>543.965</td>
<td>1.038.725</td>
<td>13.724</td>
<td>31.712</td>
<td>757</td>
<td>1.896</td>
<td>841</td>
</tr>
<tr>
<td>ES</td>
<td>46.5</td>
<td>505.940</td>
<td>683.175</td>
<td>8.444</td>
<td>13.261</td>
<td>353</td>
<td>2.056</td>
<td>126</td>
</tr>
<tr>
<td>DE</td>
<td>81.8</td>
<td>348.540</td>
<td>643.702</td>
<td>11.771</td>
<td>32.423</td>
<td>687</td>
<td>1.285</td>
<td>273</td>
</tr>
<tr>
<td>IT</td>
<td>59.2</td>
<td>301.340</td>
<td>491.124</td>
<td>13.526</td>
<td>17.088</td>
<td>525</td>
<td>923</td>
<td>192</td>
</tr>
<tr>
<td>CH</td>
<td>7.8</td>
<td>41.277</td>
<td>71.452</td>
<td>11.905</td>
<td>5.124</td>
<td>2.333</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Data for the mobility and the infrastructure evolution has been gathered from various sources:

- Regarding the infrastructure length, data has been taken from Eurostat [23], the World Bank data [24], the European Commission pocketbook [25], the European Union Road Federation (ERF) [26], from some national statistic institutes (INE, OFS) [27] [28] and from the International Union of Railways (UIC) [5].

- Mobility data has been obtained basically from the correspondent national statistic institutes (INSEE, INE, DESTATIS) [29] [27] [30], Eurostat [23], the OECD statistics [31] and from the Swiss public transports office, LITRA [32].

Adapted data: International rail mobility

Not in all cases was data available distinguishing between national and international rail mobility. However, information about international rail transport was found for the years 2012, 2013 and 2014 in several countries (Figure 1).

Therefore, even though they are likely to reduce in former years, due to lack of data, these values have been assumed constant for the whole analysed period.

It has to be mentioned that within rail transport, it is more likely to have international traffic in the HSR lines than in the conventional ones. Hence, the observed percentages have been calibrated by using data from France, the only country that provided it in a more detailed way. According to the French values, international percentages can be majored by 1,2 in high-speed and minored by 0,8 in conventional rail.

Consequently, the presented values for mobility cannot be taken as precise data, but still, for the project purposes, they turn out to give valuable information regarding the order of magnitude for traffic in each case.
A.2 Country characteristics

The ten major urban agglomerations have been identified in each country. It is important to note the difference between urban agglomerations and cities, the former including the suburb areas.

However, in order to get a better idea of population concentration, densities have been reported in the city.

Table 2. 10 major urban agglomerations. Population 2015.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris</td>
<td>10,9</td>
<td>20.980</td>
<td>Madrid</td>
<td>6,2</td>
<td>5.185</td>
<td>Berlin</td>
<td>4,1</td>
<td>3.758</td>
</tr>
<tr>
<td>Lyon</td>
<td>1,6</td>
<td>9.922</td>
<td>Barcelona</td>
<td>4,7</td>
<td>16.373</td>
<td>Cologne</td>
<td>2,1</td>
<td>1.468</td>
</tr>
<tr>
<td>Marseille</td>
<td>1,4</td>
<td>3.538</td>
<td>Valencia</td>
<td>1,56</td>
<td>5.824</td>
<td>Hamburg</td>
<td>2,09</td>
<td>2.126</td>
</tr>
<tr>
<td>Lille</td>
<td>1,01</td>
<td>5.859</td>
<td>Sevilla</td>
<td>1,1</td>
<td>4.921</td>
<td>Munich</td>
<td>2</td>
<td>2.678</td>
</tr>
<tr>
<td>Nice</td>
<td>0,98</td>
<td>4.795</td>
<td>Bilbao</td>
<td>0,95</td>
<td>8.526</td>
<td>Frankfurt</td>
<td>1,9</td>
<td>2.143</td>
</tr>
<tr>
<td>Toulouse</td>
<td>0,92</td>
<td>3.716</td>
<td>Oviedo</td>
<td>0,85</td>
<td>1.199</td>
<td>Stuttgart</td>
<td>1,4</td>
<td>2.883</td>
</tr>
<tr>
<td>Bordeaux</td>
<td>0,88</td>
<td>4.845</td>
<td>Zaragoza</td>
<td>0,72</td>
<td>626</td>
<td>Dresden</td>
<td>0,73</td>
<td>1.597</td>
</tr>
<tr>
<td>Nantes</td>
<td>0,62</td>
<td>4.371</td>
<td>Malaga</td>
<td>0,70</td>
<td>1.435</td>
<td>Hannover</td>
<td>0,71</td>
<td>2.519</td>
</tr>
<tr>
<td>Toulon</td>
<td>0,59</td>
<td>3.841</td>
<td>Murcia</td>
<td>0,50</td>
<td>499</td>
<td>Nuremberg</td>
<td>0,67</td>
<td>2.656</td>
</tr>
<tr>
<td>Strasbourg</td>
<td>0,5</td>
<td>3.473</td>
<td>Alicante</td>
<td>0,44</td>
<td>1.650</td>
<td>Bremen</td>
<td>0,66</td>
<td>1.678</td>
</tr>
</tbody>
</table>

Source: Demographia [13] and Wikipedia for densities [33].
Distances in between major urban agglomerations

Straight distances considered in between consecutive cities to get an order of magnitude of distances in every country:

Figure 2. Considered straight distances between cities.

Table 3. Averaged distances

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>276 km</td>
<td>310 km</td>
<td>196 km</td>
<td>147 km</td>
</tr>
</tbody>
</table>

A.3 HSR network

Corridor selection: methodology

In order to show the HSR network characteristics and to assess its performance, its level of service is going to be evaluated in between main urban areas. Therefore, amongst all the possible existing relations where HSR operates, a sample of city connexions is going to be
taken so that it can be considered to be representative for the whole national network service. To do that, links covering the whole network are going to be selected according to some criteria:

- As potential demand concentrates in between larger urban areas, the first criterion for the selected sample has been to focus only on those existing high-speed links connecting some of the ten larger urban areas in every country (Table 4).

- However, an exception has been made for those particular lines where the terminus locates in smaller cities, in case they don't have HSR continuity to further to larger centres (i.e. Madrid-Valladolid, in Spain, being the latter a second-order city).

- On the other hand, for those lines finishing at smaller cities, but where the same train can continue on upgraded tracks until a main agglomeration, the entire trajectory has been included, even lower speeds are allowed in those stretches (i.e. the HSR Paris-Le Mans, upgraded until Nantes).

- Selected relations should not take more than 3h30 from origin to destination. For those timings, potential demand by HSR is considered to low due to increasing competition with air modes.

Table 4. Selected representative relations in the HSR network.

<table>
<thead>
<tr>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris-Lyon</td>
<td>Madrid-Sevilla</td>
<td>Hannover-Nuremberg *</td>
<td>Naples-Rome</td>
</tr>
<tr>
<td>Lyon-Marseille</td>
<td>Madrid-Barcelona</td>
<td>Mannheim-Stuttgart</td>
<td>Rome-Milan</td>
</tr>
<tr>
<td>Paris-Marseille</td>
<td>Madrid-Zaragoza</td>
<td>Hannover-Berlin *</td>
<td>Milan-Turin</td>
</tr>
<tr>
<td>Paris-Nantes *</td>
<td>Zaragoza-Barcelona</td>
<td>Koln-Frankfurt</td>
<td></td>
</tr>
<tr>
<td>Paris-Strasbourg</td>
<td>Madrid-Valencia</td>
<td>Hamburg-Berlin *</td>
<td></td>
</tr>
<tr>
<td>Paris-Lille</td>
<td>Madrid-Valladolid</td>
<td>Nuremberg-Munich *</td>
<td></td>
</tr>
</tbody>
</table>

* Mixed connections, including upgraded sections

In the Italian network, as one single line includes all stops from north to south, the network has been covered by considering the main potential relations, which link the four major urban areas in the country.

Note that this is just been a rough approach to consider the most potential demanded links along the network. The reliability of the sample could be improved if mobility data were available for every specific relation. However, such information has not been found in the consulted sources. Therefore, born in mind that the obtained results in the analysis would be subjected to possible variations depending on the selection accuracy representing the offered services in the entire country.
Figure 3. Selected representative corridors.
HSR characteristics and performance

Data for each line has been obtained relating to its characteristics and operation policies. By averaging the whole selection in each country, values have been computed for commercial speed, intermediate distances, time reductions comparing to the conventional service and frequency policies.

Example for gathered data for the Spanish HSR network:

Table 5. Characteristics and operation performance for the Spanish HSR

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Mad-Sev 471</td>
<td>0</td>
<td>471</td>
<td>140</td>
<td>202</td>
<td>220</td>
<td>61</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>236</td>
<td>150</td>
<td>188</td>
<td>210</td>
<td>58</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>118</td>
<td>160</td>
<td>177</td>
<td>200</td>
<td>56</td>
<td>5</td>
</tr>
<tr>
<td>Mad-Bcn 620</td>
<td>0</td>
<td>620</td>
<td>150</td>
<td>248</td>
<td>240</td>
<td>62</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>310</td>
<td>165</td>
<td>225</td>
<td>225</td>
<td>58</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>207</td>
<td>170</td>
<td>219</td>
<td>220</td>
<td>56</td>
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<td></td>
<td>4</td>
<td>124</td>
<td>190</td>
<td>196</td>
<td>200</td>
<td>51</td>
<td>5</td>
</tr>
<tr>
<td>Mad-Zgz 307</td>
<td>0</td>
<td>307</td>
<td>75</td>
<td>246</td>
<td>100</td>
<td>57</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>154</td>
<td>81</td>
<td>227</td>
<td>94</td>
<td>54</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>102</td>
<td>88</td>
<td>209</td>
<td>87</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>Zgz-Bcn 313</td>
<td>0</td>
<td>313</td>
<td>83</td>
<td>226</td>
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<td>157</td>
<td>95</td>
<td>198</td>
<td>220</td>
<td>70</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>104</td>
<td>100</td>
<td>188</td>
<td>215</td>
<td>68</td>
<td>12</td>
</tr>
<tr>
<td>Mad-Val 391</td>
<td>0</td>
<td>391</td>
<td>100</td>
<td>235</td>
<td>105</td>
<td>51</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>196</td>
<td>105</td>
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<td>49</td>
<td>3</td>
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<td>2</td>
<td>130</td>
<td>110</td>
<td>213</td>
<td>95</td>
<td>46</td>
<td>3</td>
</tr>
<tr>
<td>Mad-Vallad 184</td>
<td>0</td>
<td>184</td>
<td>55</td>
<td>201</td>
<td>88</td>
<td>62</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>92</td>
<td>65</td>
<td>170</td>
<td>100</td>
<td>61</td>
<td>7</td>
</tr>
</tbody>
</table>

Consulted sources:
Specific distances have been defined according to the UIC [6]. Information regarding operation has been obtained from the rail operators' websites (RENFE, DB) [34] [35] and from captaintrain.com [36]. Former timings for the conventional train have been taken from LITRA [37].

Only direct train connections have been considered, disregarding changes.

Note that resulting averages in each country have been computed according to the total number of circulations (pondering by train frequencies).

A.4 Integration indicator: HSR - conventional network

Table 6. Characteristics and operation performance in mixed relations HSR-CT.

<table>
<thead>
<tr>
<th>FR</th>
<th>Distance [km]</th>
<th>Commercial speed [km/h]</th>
<th>Av. com. speed (mixed) [km/h]</th>
<th>Av. commercial speed (HS) [km/h]</th>
<th>Ratio mixed/HS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris-Nice</td>
<td>860</td>
<td>143</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paris-Bordeaux</td>
<td>560</td>
<td>160</td>
<td>154</td>
<td>198</td>
<td>0.78</td>
</tr>
<tr>
<td>Paris-Nantes</td>
<td>386</td>
<td>160</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ES</th>
<th>Distance [km]</th>
<th>Commercial speed [km/h]</th>
<th>Av. com. speed (mixed) [km/h]</th>
<th>Av. commercial speed (HS) [km/h]</th>
<th>Ratio mixed/HS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madrid-Bilbao</td>
<td>440</td>
<td>86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madrid-Oviedo</td>
<td>430</td>
<td>92</td>
<td>94</td>
<td>211</td>
<td>0.45</td>
</tr>
<tr>
<td>Madrid-Murcia</td>
<td>450</td>
<td>104</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DE</th>
<th>Distance [km]</th>
<th>Commercial speed [km/h]</th>
<th>Av. com. speed (mixed) [km/h]</th>
<th>Av. commercial speed (HS) [km/h]</th>
<th>Ratio mixed/HS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berlin-Frankfurt</td>
<td>510</td>
<td>128</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berlin-Bremen</td>
<td>360</td>
<td>123</td>
<td>120</td>
<td>153</td>
<td>0.78</td>
</tr>
<tr>
<td>Berlin-Nuremberg</td>
<td>650</td>
<td>108</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IT</th>
<th>Distance [km]</th>
<th>Commercial speed [km/h]</th>
<th>Av. com. speed (mixed) [km/h]</th>
<th>Av. commercial speed (HS) [km/h]</th>
<th>Ratio mixed/HS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rome-Venice</td>
<td>470</td>
<td>138</td>
<td>107</td>
<td>173</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Consulted sources:

Distances for the mixed railway relations have been approximated by using the measuring tool in Google maps. Times have been obtained from the website captaintrain.com [36] and from RENFE in Spain [34]; presented values have been averaged according to all the possible daily connections, including changes.

Note that in some cases various trajectories were possible for a single relation. Thus, values have been averaged between the existent alternatives, and consequently, they should not be regarded accurately.

Nonetheless, the resulting ratio between mixed commercial speed and the obtained HS commercial in section A.3 gives an idea of how well the new railway network is integrated to the former one.
A.5 HSR fares

In order to obtain the cost of travelling by HSR in every country, fares have been checked for some of the selected representative relations (Table 7):

Table 7. Route sample for HSR fares.

<table>
<thead>
<tr>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris-Marseille</td>
<td>Madrid-Barcelona</td>
<td>Hamburg-Berlin *</td>
<td>Milan-Turin</td>
</tr>
<tr>
<td>Paris-Lille</td>
<td>Madrid-Sevilla</td>
<td>Koln-Frankfurt</td>
<td>Rome-Milan</td>
</tr>
<tr>
<td>Paris-Strasbourg</td>
<td>Madrid-Valencia</td>
<td>Nuremberg-Munich *</td>
<td>Naples-Rome</td>
</tr>
</tbody>
</table>

* Mixed connections, including upgraded sections

HSR fares do vary not only according to the distance and the traveling class, but also due to the adopted yield management in pricing. The yield management principle determines ticket prices according to the specific destination, the day, the time of travel and how close the departure is to the moment when the ticket is purchased.

However, in order to get some significant values, the following hypothesis have been made:

- 50 % of the demand is buying the train ticket one month in advanced.
- The remaining 50% is going to purchase it one week before the departure.

The cost for each regarded relation results from averaging the existing ticket prices in 2nd class for a whole working day, where no holidays or special event are taking place. The same probability has been considered for all the scheduled trips (which is not accurate since peak hours will show higher demands). Also, only trains with direct relations have been considered, so no changes are included.

Conventional rail fares

To compare HSR fares with the ones that people was used to pay in conventional train, some conventional relations have been considered and the current price per kilometre has been averaged in those links.

Relatively long routes have been selected not to confuse mix long haul with commuting services. Ranges: ES [110-245km], FR [115-320km], DE [120-170km], IT [150-440km]). Random routes have been chosen in between medium cities trying to cover the whole territory.

The same procedure as in HSR has been followed to obtain the averaged conventional fares. In this case, route distances have been roughly computed by using the measuring tool in Google maps.
A.6 Competitiveness

Road competitiveness

Time and fares by road have been obtained by checking *Via Michelin* [38] in all the HSR selected routes. The petrol price has been adapted according to the current market and assuming all circulations with diesel vehicles.

Table 8. Averaged railway fares.

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. HSR fares [eur/km]</td>
<td>0,148</td>
<td>0,145</td>
<td>0,244</td>
<td>0,128</td>
</tr>
<tr>
<td>Av. CT fares [eur/km]</td>
<td>0,134</td>
<td>0,105</td>
<td>0,184</td>
<td>0,072</td>
</tr>
</tbody>
</table>

*Source: own computations from collected data [34] [35] [36].*

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. HSR fares [eur/car/km]</td>
<td>0,144</td>
<td>0,084</td>
<td>0,068</td>
<td>0,17</td>
</tr>
<tr>
<td>Av. road time [h]</td>
<td>4,6</td>
<td>4,6</td>
<td>3</td>
<td>3,7</td>
</tr>
</tbody>
</table>

*Source: Via Michelin.*

Air competitiveness

To get an idea of the air the competitiveness presence in each country, flight frequencies have been averaged taking the whole routes in the HSR sample.

The number of daily services has been checked for all weekdays, assuming that:

- 25% of the demand would travel in 3 weeks.
- 25% of the demand would travel in 4 weeks.
- 25% of the demand would travel in 6 weeks.
- 25% of the demand would travel in 8 weeks.

Table 9. Price diesel, April 2016 [eur/L].

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price diesel, April 2016 [eur/L]</td>
<td>1,08</td>
<td>0,98</td>
<td>1,05</td>
<td>1,27</td>
</tr>
</tbody>
</table>

*Source: http://www.dieselogasolina.com*

Costs by car do include both petrol costs and road tolls in case of existing.

Table 10. Averaged fares and timings by road.

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. road fares [eur/car/km]</td>
<td>0,144</td>
<td>0,084</td>
<td>0,068</td>
<td>0,17</td>
</tr>
<tr>
<td>Av. road time [h]</td>
<td>4,6</td>
<td>4,6</td>
<td>3</td>
<td>3,7</td>
</tr>
</tbody>
</table>

*Source: Via Michelin.*
Data has been obtained from skyscanner.com [39], considering only direct flights (checked dates around April-May 2016).

Table 11. Averaged air frequencies in the selected HSR routes.

<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>
</tbody>
</table>

*Source: own production from skyscanner.com data.*

Nevertheless, note that the selected representative routes in HSR have already ruled out very long haul relations, precisely for air competitiveness reasons. Thus, presented averages do show the competitiveness level for the “potential HSR relations”, and those are likely to increase when comparing the whole country scenario.

From the selected sample, those are the routes being served also by the air mode:

Table 12. Selected routes served by air.

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris-Lyon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lyon-Marseille</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paris-Marseille</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paris-Nantes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madrid-Sevilla</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madrid-Barcelona</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madrid-Valencia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuremberg-Munich *</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naples-Rome</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rome-Milan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Mixed connections, including upgraded sections

Times and fares have been averaged for those relations above. Data has also been obtained from skyscanner.com and by considering the same hypothesis as mentioned before when checking frequencies.

Table 13. Averaged fares and timings by road.

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>ES</th>
<th>DE</th>
<th>IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. air fares [euro/km]</td>
<td>0,31</td>
<td>0,24</td>
<td>0,66</td>
<td>0,26</td>
</tr>
<tr>
<td>Av. air time [h]</td>
<td>1,1</td>
<td>1,1</td>
<td>0,67</td>
<td>1</td>
</tr>
</tbody>
</table>

*Source: skyscanner.com*

Regarding air timings, extra time should be added accounting for the access to the airport (usually located far from the city centres) plus the time spent in checking in or in the security checks. Thus, air times should be considered +1h30.

When it comes to airfares, the uncertainty in the presented values should be stood out. Due to strong yield managing in pricing policies, great variability has been noticed in fares. Figures below show the variability in transport modes fares over the analysed countries:
Figure 4. Fare variability in France

Figure 5. Fare variability in Spain

Figure 6. Fare variability in Germany
Figure 7. Fare variability in Italy

Source: own production from skyscanner.com data.

<table>
<thead>
<tr>
<th>Table 14. Maximum variability observed in selected routes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FR</strong></td>
</tr>
<tr>
<td>Air fares variability</td>
</tr>
<tr>
<td>HSR fares variability</td>
</tr>
<tr>
<td>Road fares variability</td>
</tr>
</tbody>
</table>

Source: own computations from skyscanner.com data
ANNEX B
Annex B

B.1. Speed performance

Rolling stock running dynamics

Acceleration and deceleration values are not constant in train performance, and those have to be properly accounted for in order to obtain real timings for a certain trajectory.

Figure 1. Rolling stock dynamics, simplified schema.

\[
\begin{align*}
\text{N} & \quad \text{v} \\
\text{R} & \quad \text{a} \\
\text{F}_T & \\
\text{m} \cdot g \\
\end{align*}
\]

*Source: own production.*

The traction force (\(F_T\)) for the rolling stock depends on its technical characteristics, as well as on the electrification of the lines where it runs through.

- In Switzerland the electrification of the rail lines is 15kV, whilst Spain, for example, has 25kV in order to reach higher speeds with better performances. For the present analysis, 15kV has been maintained, since current electrification is still expected to stay for a lot of time.

However, the effective traction (\(F_T^*\)) needs to account for movement resistances (R). Resistances do also depend on the type of rolling stock, since its shape would affect the aerodynamics. The slope of the track would also influence on the existing movement resistance.

- In the present analysis 0% inclination has been assumed.

The figure below (Figure 2) shows the tractive effort for a specific train model (AGV-11 with 6 traction units) and the mentioned variations according to the slope and the track electrification power.
The effective acceleration would considerably reduce as the rolling stock increases in speed. Consequently, it takes every time longer to get higher speeds.

The figures in the next page show the tractive effort-speed curve for the two selected rolling stock models in the sensitivity analysis (Figure 3).
Figure 3. Tractive effort-speed curve for the TGV-POS and AGV-10C
Sensitivity analysis: simulation results

Table 1. Time results in Alternative 1.

<table>
<thead>
<tr>
<th>Source: Railnet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Travel time [min]</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Gva-Laus</td>
</tr>
<tr>
<td>Laus-Frib</td>
</tr>
<tr>
<td>Frib-Bern</td>
</tr>
<tr>
<td>Bern-Zch</td>
</tr>
<tr>
<td>Zch-St.G</td>
</tr>
</tbody>
</table>

Source: Railnet

Table 2. Time results in Alternative 2.

<table>
<thead>
<tr>
<th>Source: Railnet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Travel time [min]</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Gva-Laus</td>
</tr>
<tr>
<td>Laus-Bern</td>
</tr>
<tr>
<td>Bern-Zch</td>
</tr>
<tr>
<td>Zch-St.G</td>
</tr>
</tbody>
</table>

Source: Railnet

Figure 4. Plotted time results AGV-10C in Alternative 1.
In the next page, speed performances for the AGV at 300 km/h are plotted all along the designed line (Figure 6):

- The first drawing corresponds to Alternative 2, neglecting the stop in Fribourg.
- The second plotting shows the detail between Lausanne and Bern for Alternative 1, when stopping in Fribourg.

Note how the effect of the high-speed cannot be perceived in short distances; speed does not even reach the 300 km/h in the section between Fribourg and Bern (Figure 7).

**Timings**

Presented timings correspond to the so-called "practical journey time":

- **Technical journey time**: Time accounting for a maximum performance during the whole travelled section. However, this has low probability to happen; it would only be reached in case of being able to automatize the train. Hence, some margin time should be added so that a realistic performance can be approached.

- **Practical journey time**: Time used to plan train schedules in each section; it already accounts for possible delays due to performance variations. In Switzerland, an extra 7% is added to the technical journey time. This way, it can be ensured the 98% of the trains reaching the next station in time.
Figure 6. Trajectory diagram for the AGV-10C at 300 km/h.
Figure 7. Trajectory diagram for the AGV-10C at 300km/h. Detail stop Fribourg.
B.2. Demand analysis

Modelled demand: OD matrix in 2010


<table>
<thead>
<tr>
<th></th>
<th>OD railway traffic [pax/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geneva</td>
</tr>
<tr>
<td>Geneva</td>
<td>-</td>
</tr>
<tr>
<td>Lausanne</td>
<td>-</td>
</tr>
<tr>
<td>Fribourg</td>
<td>-</td>
</tr>
<tr>
<td>Bern</td>
<td>-</td>
</tr>
<tr>
<td>Zurich</td>
<td>-</td>
</tr>
<tr>
<td>St.Gallen</td>
<td>-</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th></th>
<th>OD railway traffic [pax/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geneva</td>
</tr>
<tr>
<td>Geneva</td>
<td>-</td>
</tr>
<tr>
<td>Lausanne</td>
<td>-</td>
</tr>
<tr>
<td>Bern</td>
<td>-</td>
</tr>
<tr>
<td>Zurich</td>
<td>-</td>
</tr>
<tr>
<td>St.Gallen</td>
<td>-</td>
</tr>
</tbody>
</table>

Note that 50% of the demand is assumed travelling in each direction.

Value of time in Switzerland

According to the Swiss statistics, 75% of passengers in rail commute every day, whilst the remaining 25% travels for leisure purposes (Figure 8):

Figure 8. Passengers transport in Switzerland, 2010.
The VoT for the Swiss population are estimated according to the trip purpose as [57]:

- Leisure trips: 11.9 CHF/h
- Business trips: 25.18 CHF/h
- Commuters (no business): 18.93 CHF/h

Transforming monetary values to euros: 1 CHF = 0.9 EUR (April 2016)

In order to get the averaged VoT, the mentioned 75% of commuters in Switzerland has been split assuming 50% business and 50% no business.

Thus, the final averaged result is computed as VoT = **17,56€/h** in Switzerland.

**HSR fares increase**

In order to maintain the same utilities in HSR than in CT, the maximum allowed fares in each relation within the line are (Table 5 and Table 6):

<table>
<thead>
<tr>
<th>HSR/CT fare ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geneva</td>
</tr>
<tr>
<td>Geneva</td>
</tr>
<tr>
<td>Lausanne</td>
</tr>
<tr>
<td>Fribourg</td>
</tr>
<tr>
<td>Bern</td>
</tr>
<tr>
<td>Zurich</td>
</tr>
<tr>
<td>St.Gallen</td>
</tr>
</tbody>
</table>

Thus, maximum allowed increase to ensure same or higher utilities for all the users is +30%. By increasing it a 40%, rail passengers in some relations would be disfavoured by the new HSR service, namely:

- Geneva-Lausanne and Bern-Zurich in Alternative 2.
B.3. Frequency operation

Number of rolling stock

The total fleet should be determined according to the peak hour operation. To operate at the fixed frequency of 4 trains/hour, the required number of rolling stock is:

Rotation time

- Geneva – St.Gallen: 2 hours 22 minutes.
- Cleaning time: 23 minutes.

![Figure 9. Rotation time. Scheduled departures during standard hours.](source: own production.

Then, the rotation time for a train is 5 hours 30 minutes until it gets to the same point where it started. The required number of rolling stock is 22 trains.

Accounting for possible technical problems, it is advisable to account with some extra trains. Therefore, the number of available trains to operate the designed line has been fixed at 25 rolling stock units.

Distance travelled

According to the fixed frequencies, the total travelled distance by the entire train fleet is:

- 4 trains/hour during 14h per day in each direction.
- 2 trains/hour during 5h per day in each direction.

Being 317.9 km the distance from Geneva to St.Gallen, it results in **41.963 km** per day in both directions.
B.4. Cost benefit analysis

Note that different investments are made in different moments in time. However, due to lack of future economical data, all cash fluxes (both benefits and costs) have been assumed for the year 2015.

Costs in former years are going to be actualised according to the observed evolution for the consumer price index (CPI) in Switzerland [28].

Costs: Initial investment

The initial investment would include the infrastructure costs and the purchase of the required rolling stock fleet.

Infrastructure costs

In these costs it is included all previous studies, land rights, the required double track, structures (tunnels, bridges, etc.), fixed equipment for electric traction, signalling, the required amplification in the concerned historical stations, human work, etc.

Baumgartner [59] suggests these costs amounting to 50 M€/km (price 2001) in case of difficult topographies for the regarded speed range, between 100-300km/h. Actualising to 2015, that would represent a cost of 52,6 M€/km.

Ibañez Porcar, S. [45] estimates the cost for a railway line Geneva-Lausanne operating at 250km/h to be of 46,3 M€/km (price 2013). Actualising to 2015, that would represent a cost of 45,4 M€/km.

However, reviewing the already performed projects in Switzerland (Table 7):

<table>
<thead>
<tr>
<th>Vmax [km/h]</th>
<th>Longitude [km]</th>
<th>Year</th>
<th>Cost [M€]</th>
<th>Cost per km [M€/km]</th>
<th>Cost 2015 [M€/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basel-Olten</td>
<td>160</td>
<td>7</td>
<td>92-2000</td>
<td>348</td>
<td>49,8</td>
</tr>
<tr>
<td>Bern-Lausanne</td>
<td>140</td>
<td>2</td>
<td>98-2001</td>
<td>76</td>
<td>37,8</td>
</tr>
<tr>
<td>Biel-Lausanne</td>
<td>160</td>
<td>11</td>
<td>93-2001</td>
<td>320</td>
<td>29,0</td>
</tr>
<tr>
<td>Olten-Biel</td>
<td>200</td>
<td>11</td>
<td>1996-2003</td>
<td>96</td>
<td>8,8</td>
</tr>
<tr>
<td>Zurich-Thalwil</td>
<td>160</td>
<td>9</td>
<td>2002-2003</td>
<td>851</td>
<td>94,5</td>
</tr>
<tr>
<td>Bern-Olten</td>
<td>200</td>
<td>52</td>
<td>96-2004</td>
<td>1511</td>
<td>29,1</td>
</tr>
<tr>
<td>Lausanne-Visp</td>
<td>160</td>
<td>7</td>
<td>98-2004</td>
<td>243</td>
<td>34,7</td>
</tr>
<tr>
<td>Geneva-Lausanne</td>
<td>140</td>
<td>14</td>
<td>94-2004</td>
<td>238</td>
<td>17,0</td>
</tr>
<tr>
<td>Lötschberg base tunnel</td>
<td>250</td>
<td>35</td>
<td>1995-2007</td>
<td>3872</td>
<td>110,6</td>
</tr>
<tr>
<td>Gotthard base tunnel</td>
<td>250</td>
<td>57</td>
<td>1996-2016</td>
<td>10530</td>
<td>184,7</td>
</tr>
</tbody>
</table>

Source: Sanz Modrego, R. UPC [60]. 1CHF=0,9 € (April 2016).

Great variability is observed in railway infrastructure costs in Switzerland. The final price is seen to strongly depend on the particular project, its location and its requirements.
Given this scenario, the following costs have been assumed in the present project basing on the observed historical ranges:

- **45 M€/km** have been assumed for the proposed line.
- **70 M€/km** have been assumed for the proposed line operating at 250km/h along the entire trajectory.
- **100 M€/km** have been assumed for the proposed line operating at 300km/h along the entire trajectory.

Note that the reported increase comes from increasing limitations in the railway geometry. Operating the suggested line at 300km/h would require a great percentage of the trajectory to be run in tunnel.

The economic life for the infrastructure is estimated at 60 years (reasonable value for railway). Apart from that, annual maintenance would be required, as well as the track renewal after 30 years.

**Rolling stock**

25 double-deck trains need to be purchased. The cost per train has to be estimated:

- The first AGV trains were sold to operate the high-speed line connecting Milan with Naples, inaugurated in 2011. In this case, the agreement fixed 25 trains for 650 M€ (in a deal worth 1,5€ billion, including the maintenance contracts) [61]. That represents a cost of 26 M€ per train (price 2011). Actualising to 2015, that would represent a cost of 25,5 M€/train.

  Nonetheless, the required trains in Switzerland have been defined as double-deck trains. Therefore, the 50% is going to be added to the final price. That results in cost of 38,2M€ per train.

- Disregarding particular deals, other sources report the price per seat in high-speed rail to approximately of 33.000 €/seat (price 1997) [62]. That would represent an actualised cost of 35.900 €/seat, which multiplied for the required capacity of 1200 pax/train would result in a cost of 43 M€ per train.

Given the stated order of magnitudes, the cost for each rolling stock unit has been estimated at **40 M€/train** in this project.

The economic life for the rolling stock is estimated at 30 years. After this time, the whole fleet would need to be renewed. Moreover, annual maintenance costs do also have to be assumed.

**Costs: Maintenance**

Infrastructure maintenance can be considered at a 2% of the total initial investment, whilst rolling stock’s can be estimated at 7% of the purchasing price [62].

The cost for the track renewal 30 years later can be assumed at 0,7 M€/km, according to Baumgartner. This price accounts for 0,5 M€/km intended for the new track and 0,2 M€/km for dismantling and removing the existing one [59].
Costs: Operation

Energy costs

Baumgartner [59] estimates the averaged unit cost of electricity at 0,1 €/kWh (price 2001). Actualising to 2015, it represents 0,105 €/kWh. Regarding the energy consumption, this can be fixed at 40 Wh/TKBC \(^{(1)}\) for the proposed design.

\[^{(1)}\text{TKBC} = \text{total gross tonne-kilometre}\]

For the used rolling stock, a weight of 430 tonnes has been assumed, corresponding to the former TGV. Even though the considered rolling stock in this project concern double-deck trains, which are expected to be heavier, new technologies for the AGV can reduce the total tonnage.

\[
\text{Energy cost} = 0,105 \cdot \frac{€}{kWh} \cdot 40 \cdot \frac{Wh}{TKBC} \cdot 430 \text{ t} \cdot \text{travelled distance}
\]

The travelled distance has been computed as 41.963 km per day (section B.3). This result corresponds to a normal weekday. Thus, in order to obtain the total energy cost for an entire operation year, services have been assumed reduced at the 60\% in the weekends and holidays (100 days per year). Note that traffic is also considered reduced during these days.

\[
\text{Travelled distance (1 year)} = 41.963 \frac{km}{day} \cdot (265 \text{ days} + 0,6 \cdot 100 \text{ days}) = 13,64 \text{ Mkm}
\]

Therefore, the total cost for the consumed energy in the line results in 24,63 M€ per operation year.

For increasing speeds, energy costs are assumed to increase proportionally with the velocity as (section 9.2.2 in the report):

\[
E \propto V^2
\]

Then,

- Energy costs when running the line at 250 km/h: 38,5 M€/year.
- Energy costs when running the line at 300 km/h: 55,4 M€/year.

Salaries

According to a study of the costs faced by the train operator companies in Europe [63], the typical major cost categories do usually distribute as (Figure 10):
Figure 10. Distribution of typical major costs categories for train operator companies.

Where:

- Rolling stock CAPEX corresponds to the rolling stock depreciation (15%).
- Rolling stock OPEX corresponds to its maintenance costs (25%).
- Energy corresponds to the costs for the required traction power (10%).
- The remaining costs correspond all to salaries (48%).

It should be noted that the mentioned study includes performance for regional and long distance passenger trains, disregarding high-speed. Nevertheless, in order to get an order of magnitude, the cost distribution has been assumed similar for the proposed line.

Hence, salaries in the present project are assumed to represent the 50% of the total operator cost (disregarding infrastructure depreciation), amounting to **128 M€/year** for the designed line.

This hypothesis is going to be maintained when increasing speeds, so that higher operating costs would induce higher salary costs.

Figure 11. Operational costs distribution in the designed line and increasing speed.

*Source: Civity 2012 [63].*
**Internal rate of return (IRR)**

The Internal Rate of Return measures the profitability of potential investments. IRR is a discount rate that makes the Net Present Value (NPV) of all cash flows from a particular project zero [64]:

\[ NPV = \sum_{t=1}^{T} \frac{C_t}{(1 + r)^t} - I_o \]

\[ NPV = 0 = \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} - I_o \]

where:

- \( C_t \) = net cash flow during the period \( t \)
- \( I_o \) = initial investment cost
- \( r \) = discount rate
- \( T \) = total period

In order to obtain the IRRs for the presented alternatives regarding the designed line, the following has been considered:

- \( I_o \) concerns the initial investments in infrastructure and rolling stock
- The project is assessed for its economical life, \( T \)=60 years.
- \( C_t \) includes the annual benefits (depending on the demand scenario) minus the annual costs for maintenance (infrastructure and rolling stock), energy and salaries.

However, according to the defined life spans, new rolling stock and track renewal would have to be funded after 30 years. Thus, \( C_{30} \) does include the corresponding extra costs.

Regarding cash flows, note also that annual benefits are expected to change over the years according to the demand evolution. Nonetheless, levels for 2030 are assumed constant in the computations.

<table>
<thead>
<tr>
<th>Table 8. Investment profitability for the considered scenarios: IRR.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRG (T=60 years)</td>
</tr>
<tr>
<td>0%</td>
</tr>
<tr>
<td>10%</td>
</tr>
<tr>
<td>20%</td>
</tr>
<tr>
<td>30%</td>
</tr>
</tbody>
</table>
Annex C

C.1. Intermediate stops - Matlab code:

close all
clear all

% ANALYSIS
% This analysis considers only an scenario with N intermediate stops
% within an OD line (no branches). It will therefore compare the HS performance %
% between no stop or N stops.

% Moreover, for the moment, further hypothesis are:
% Equidistant distances between intermediate stops
% Fixed demand in each node:
  % Do: Demand in the origin (terminus)
  % Dd: Demand in the destination (terminus)
  % DN: Demand in the intermediate stops
% Do=Dd (to be fixed), DN=cte=Do -> alpha percentage (result we look for)
% D=population (fixed and equal everywhere)
% Alternative transportation modes: HS/conventional train
% Computations regard only time within the transportation mode, no waiting
% nor access times considered.

%Results: find percentage DN=Do=Dd so that time savings stops/no stops =0
% Variables: line length, N -> Graph relationship
  % Only lines with sufficient length to reach the maximum speed between stops
% have been considered in this model.

% This script computes the necessary percentages of population in the
% intermediate stations comparing to the terminus in order to make them worth
% stopping (alpha). It computes percentage values according to different line
% longitudes (from 100km to 1000km), and by changing manually the value of N
% (number of stops) we can obtain different relations alpha-L.
% Hence: alpha=f(L,N)
% We can also modify values regarding train performance, such as the train speed,
% the acceleration, or the time in each stop: alpha=f(L,N,V,a,t_stop).

%**************************** PROBLEM DATA *****************************

% Prelocate problem variables
theta=[0.01:0.0001:1]; % Vector with different theta % to calibrate alpha
  % Theta = percentage of demand in one stop travelling to intermediate
  % stops instead of to some terminys (criteria for the defined OD matrix)
  % Find theta which makes Balance=0 and check the correspondent value
  % for alpha
  % Alpha will be the result for the fixed L and N

alpha=zeros(1,length(theta));
L=[120:10:1000]; % tested line lengths [km]
Balance=zeros(length(L),length(theta));
N=[1:1:8]; % tested number of intermediate stops
Alpha_results_allN=zeros(length(L),length(N));

for w=1:length(N);
    for l=1:length(L);
        for k=1:length(theta);

            % Problem unknown:
            % Relation between populations in O-D and in N (alpha=Pop_N/Pop_o),
            alpha(k)=(theta(k)*(2+(N(w)-1)*theta(k)))/(N(w)*theta(k)+1); %RESULT

            % Define line characteristics:
            %L: Line length – tested vector
            %N: #intermediate stops – tested vector
            %L_int=L(l)/(N(w)+1); [%km] - Intermediate distances (equidistant!)
            Pop_o=500000; % # habitants in the origin
            Pop_d=Pop_o; % # habitants in the destination. HYP: same as origin (approx)
            Pop_N=alpha(k)*Pop_o; % # habitants in intermediate stops. HYP: same in all N, percentage of Pop_O

            %Distances matrix:
            Dist_vector=zeros(1,N(w)+2);
            Dist_vector(1)=0;
            for i=2:N(w)+2
                Dist_vector(i)=(i-1)*(L_int);
            end
            Dist_matrix=zeros(N(w)+2,N(w)+2);
            for i=1:N(w)+2 % origin (i) from O to D
                for j=1:N(w)+2 % destination (j) from 0 to D
                    Dist_matrix(i,j)=abs(Dist_vector(j)-Dist_vector(i));
                end
            end

%*************** DEMAND MODELLING ***********************

% Demand is considered to be a percentage of the population at each stop
Trav=0.1; % Fixed percentage of the population who travels. HYP: same everywhere
D_o=Pop_o*Trav; % Demand in the origin
D_d=Pop_d*Trav; % Demand in the destination
D_N=Pop_N*Trav; % Demand in each intermediate stop

% fraction of travelers from O to D (terminus to terminus)
D_term=D_o/(1+N(w)*theta(k));

OD_matrix=zeros(N(w)+2,N(w)+2); % Origin i, destination j

for i=1:N(w)+2
for j=1:N(w)+2
    OD_matrix(i,j)=theta(k)^2*D_term;

    if i==j
        OD_matrix(i,j)=0;
    elseif i==N(w)+2 && j==1
        OD_matrix(i,j)=D_term;
    elseif i==1 && j==N(w)+2
        OD_matrix(i,j)=D_term;
    elseif j>=2 && j<=N(w)+1
        if i==1
            OD_matrix(i,j)=theta(k)*D_term;
        elseif i==N(w)+2
            OD_matrix(i,j)=theta(k)*D_term;
        end
    elseif i>=2 && i<=N(w)+1
        if j==1
            OD_matrix(i,j)=theta(k)*D_term;
        elseif j==N+2
            OD_matrix(i,j)=theta(k)*D_term;
        end
    end
end
end

%**************************************** TRANSPORTATION MODES ****************************************

% HS train
V_HS=300; [%km/h] to be fixed
a_HS=6480; [%km/h^2] to be fixed (0.5m/s^2)
d_HS=10368; [%km/h^2] to be fixed (0.8m/s^2)
l_acc_HS=(V_HS^2)/(2*a_HS); [%km] Distance required to accelerate the HS train
l_brak_HS=((V_HS^2)/d_HS) R ((V_HS^2)/(2*d_HS)); [%km] Distance required to brake the HS train
t_acc_HS=(V_HS/a_HS); [%h] Time required to accelerate the HS train
t_brak_HS=(V_HS/d_HS); [%h] Time required to brake the HS train
t_stop=3/60; [%h] Waiting time at each stop

% NOTE that formulae for train performance have been simplified to the standard cinematic formulae, without accounting for the real rolling stock characteristics.

% Conventional train
V_CT=110; [%km/h averaged (includes acc/brak and stops) – commercial speed

%**************************************** TIME COMPUTATIONS ****************************************

% NO stops
% Travellers from O to D are going to use the HS train
T_OD_direct=((L(l) R l_acc_HS R l_brak_HS)/V_HS)+t_acc_HS+t_brak_HS;
% Travellers in N are going to use the conventional train
T_CT=Dist_matrix./V_CT;
% Stops
% Travellers both from O to D and in N are going to use the HS train
trip_time_HS=zeros(1,N(w)+2); %Vectors of time in HS from Ni to Ni,Ni+1, Ni+2...Ni+n
trip_time_HS(1)=0;
for i=2:N(w)+2
    trip_time_HS(i)=((Dist_vector(i)-(i-1)*(l_acc_HS+l_brak_HS))/V_HS)+((i-1)*(t_acc_HS+t_brk_HS)+(i-2)*t_stop);
end
T_HS_stops=zeros(N(w)+2,N(w)+2);
for i=1:N(w)+2
    for j=1:N(w)+2
        m=abs(i-j);
        T_HS_stops(i,j)=trip_time_HS(abs(1+m));
    end
end

%************************ GAINS/LOSSES ************************

% When establishing N intermediate stops...

% LOSSES
% Losses for people from O to D
% Compare time from O to D in direct connection with the time after
% extra stops. Multiply per demand to obtain the total time lost.
% time_loss=T_HS_stops(1,N(w)+2)-T_OD_direct; % For 1 individual
% Losses=(OD_matrix(1,N(w)+2)+OD_matrix(N(w)+2,1))*time_loss; %h For the whole mobility

% GAINS
% Gains for people in N
% Compare times in connections including N when performed with HS or
% CT. Multiply per the corresponding demand to obtain the total time gain.
% time_gain=T_CT_T_HS_stops; % Matrix with gains dor 1 individual. NOT consider
% OD/DO!! LOSS FOR THEM
% time_gain(1,N(w)+2)=0;
% time_gain(N(w)+2,1)=0;
% Gains_matrix=OD_matrix.*time_gain; %For the whole mobility in each relation
% including N
% Gains=sum(sum(Gains_matrix)); %h For the whole system

% BALANCE
% Gains-Losses: it should be + in order to be worth stopping
% Balance(l,k)=Gains-Losses; %h

end

%************************ THETA CALIBRATION ************************

figure (1)
plot(theta,Balance(l,:));
title('Calibration theta','fontsize',16);
xlabel(’theta’);
ylabel(’Balance’);
axis([theta(1) theta(end) Balance(l,1) Balance(l,end)])
hold on
plot(theta,zeros(1,length(Balance(l,:))),'--');
hold off

for s=1:length(Balance(l,:))
    if abs(Balance(l,s))==min(abs(Balance(l,:)));
        element=s;
        fix_Balance=Balance(l,s);
        fix_theta=theta(s); % It gives only 4 decimal values
        fix_alpha=alpha(s); %RESULT
    end
end

Alpha_results(l)=fix_alpha;
Alpha_results_allN(l,w)=Alpha_results(l);

end

%******************************************************************************** RESULTS ********************************************************************************

% PLOT ALONG LENGTH

N1=Alpha_results_allN(:,1);
N2=Alpha_results_allN(:,2);
N3=Alpha_results_allN(:,3);
N4=Alpha_results_allN(:,4);
N5=Alpha_results_allN(:,5);
N6=Alpha_results_allN(:,6);
N7=Alpha_results_allN(:,7);
N8=Alpha_results_allN(:,8);

figure (2)
plot(L,N1,'b');
hold on
plot(L,N2,'r--');
hold on
plot(L,N3,'c');
hold on
plot(L,N4,'g--');
hold on
plot(L,N5,'k');
hold on
plot(L,N6,'y');
hold on
plot(L,N7,'m');
hold on
plot(L,N8,'b--');
hold off
title(’Population % in Ni’,’fontsize’,16);
xlabel(’Line longitude’);
C.2. Intermediate stops – Results code:

For example, according to this simplified model, a line of 300km that wants to be planned with 4 equidistant intermediate stops:

\[ \alpha(L = 300\text{km}, N = 4\text{stops}) = 0,1327 = 13,27\% \]

Thus, the line would require intermediate cities to have a population at least of the 13,27% of that in the terminus in order to make it worth it to stop. Only in this case would total time benefits improve by implementing intermediate stations rather than establishing a direct connection.