

IMPACT ANALYSIS OF A HIGH-SPEED RAIL LINE PHASED IMPLEMENTATION IN THE LISBOA-PORTO CORRIDOR

– CASE STUDY OF PORTO-AVEIRO SECTION –

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Abstract

Today, the Portuguese high-speed railway is a cancelled project. However, investments in Portuguese railway network are a requirement to allow the railway transportation to become more efficient and competitive. The current work presents the hypothesis of incremental investments for the implementation of the high-speed rail network in Portugal. It is analysed the construction of the High-Speed Rail Line in one of the busiest sections of Northern Line, the Porto-Aveiro section. The analysis of this hypothesis is studied with the OpenTrack computer simulation tool by evaluating travel times, commercial speeds and line capacity.

Key-words: High-speed rail; incremental investment; capacity analysis; simulation; Lisboa-Porto Line.

1. INTRODUCTION

Portugal is crossing an economic and financial conjuncture that forced several changes in the high added-value projects of infrastructure. In order to viable economically a phased construction of (already designed) sections of high-speed rail line, those would have to be executed and connected with today congested sections of the conventional rail network. This study aims to evaluate the benefits of constructing the Porto-Aveiro section in a way to improve the level of service in the old line and at the same time, start with the execution of the new national high-speed rail network, which will be constructed with the international track gauge to allow a direct connection to the European high-speed network in the future.

This work is organized in three development chapters: notions of railway infrastructure and investments; modelling and simulation of railway operations; analysis of the case study.

2. RAILWAY INFRASTRUCTURE AND INVESTMENTS PLANNING

The main elements of a simple railway track are: the rails, which support and guide the rolling stock; the sleepers, where rails are fixed and maintained in their position; the ballast, which contains the last element in place and helps with the drainage. The rails, fastening system, and sleepers form together the track grid. The distance between rails in the track grid is denominated track gauge and is measured from the inner faces of the rail heads. The common track gauge used in Portugal is 1668 mm (Iberian gauge) while the current track gauge used in the European high-speed rail lines is 1435 mm (international gauge).

Nowadays, railway operation is conducted with the help of automatic signalling systems which provides a maximum utilization of the infrastructure in a safely manner by enabling trains to travel in a more efficient way and by automatically actuate in case of a human operation error.

An important factor for capturing railway traffic is the travel time required to execute an itinerary, in other words, the commercial speed. For this reason, line projects for improving the maximum running speed have been executed in older lines. This improvement is essentially done by rectifying the track layout, which consequently enables an upgrade of the maximum running speeds intervals from 120~150 km/h to 160~200 km/h [1]. High-speed rail lines resulted as an outcome of the lack of capacity on those lines which justified the construction of new lines with better track layout characteristics.

The Northern Line is inserted in a high-priority railway axis not only for Portugal but for Europe as well, as it goes along the littoral of Iberian Peninsula and links major cities of Portugal, including the biggest two, Lisboa and Porto. According to the company that manages the railway operation in Portugal, Northern Line is responsible for 75% of overall services which totally or partially uses that line [2]. In order to mitigate the effects of saturation in that line, it was initiated in 1996 works of modernization which would also allow vehicles to reach 220 km/h of maximum speed [2]. However the project went through several redesigns as works quickly went over budget because the great amount of work needed to correct the track layout to able trains for reaching those speeds. This was avoidable if the planning was more modest and took into consideration the future construction of a high-speed rail line in the same axis as planned in 1988. In the other hand, due to the undergoing economic and financial conjuncture Portugal is crossing plus the detected unconformities in concession contracts, the project for implementation of the high-speed rail network in Portugal was abandoned in 2012 [3].

Due to today's circumstances, it is important to do and have good interpretations of studies related to high added-value projects of infrastructure. According to studies, the corridor Lisboa-Porto of the Portuguese high-speed rail network is economically viable [4] [5]. The hypothesis analysed in this work is a phased investment of the High-Speed Rail Line by starting the execution with the Porto-Aveiro section, actually congested in Northern Line.

3. RAILWAY OPERATION MODELLING OF A CONVENTIONAL LINE WITH MIXED TRAFFIC CASE STUDY: NORTHERN LINE

Simulation has been an important asset used in numerous areas of engineering. In the case of railway engineering, the first application of simulation tools resulted from the necessity of computational assist to design timetables, since it presents itself as an extremely long and thorough process. Nowadays, simulation tools also assists in others tasks as detection of conflicts in real time, presenting possible solutions and consequences in rail network resulted from the applications of operational decisions. In short, real time simulation tools improve operation quality and can predict railway traffic with great precision.

Simulation tools are able to execute different models of simulation accordingly to the objectives to be achieved. Deterministic simulations are based in defined and determined data, and are mainly used for assisting in the design of new infrastructures and planning timetables. Stochastic simulations differ from deterministic simulations for considering the possibility of random events with a probability of occurrence previously established, and are mostly employed to analyse the robustness of timetables. Additionally, there are two basic strategies of simulation, the asynchronous and the synchronous. The asynchronous simulations execute train simulations by their order of priority classes, solving eventual conflicts by postponing the train of lower priority. In the synchronous simulations, the operations are simulated in a single line of events, simulating the train movements and conflict resolutions in real time.

Accordingly to the different scenarios software users want to simulate, there are different simulation tools available in the market, some examples are: RailSys, HERMES, DaVinci, Viriato; OpenTrack; railML (an interchangeable data project). The analysis of the case study presented in this work was made using the simulation tool OpenTrack (version 1.5) [6]. This tool functions by modules that can be summarized accordingly to Figure 1 which follows.

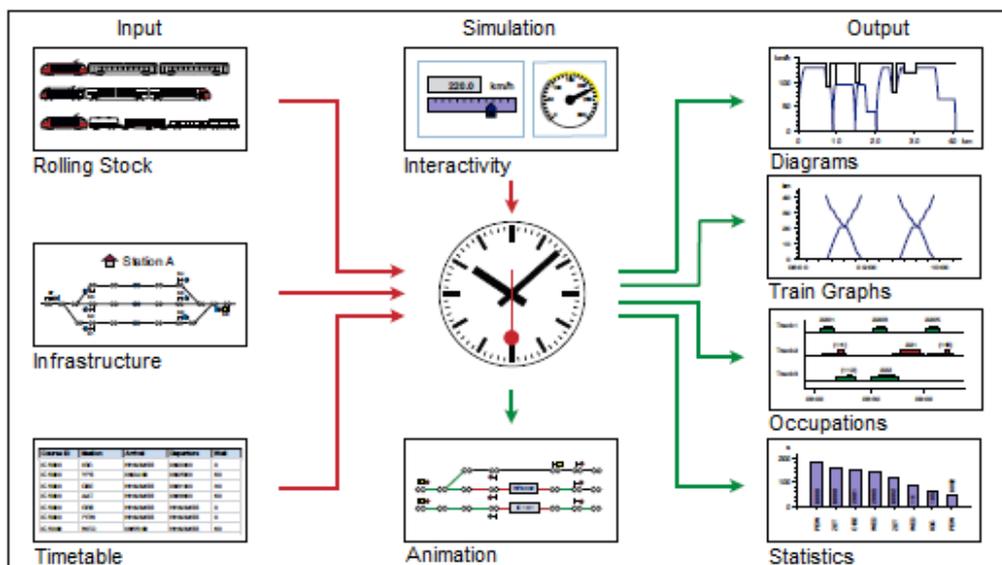


Figure 1 – Illustration of principal modules of OpenTrack. Adapted from Hürerlimann & Nash [7]

As shown in Figure 1, OpenTrack functions with the input of three data modules: Rolling Stock; Infrastructure; Timetable. To execute a valid simulation it is required to define those input modules. Simulation runs in OpenTrack through a mixed procedure of discrete and continuous simulation. The motion of trains is modelled by the solution of the differential motion equation in a continuous process, while signal information is modelled in a discrete method [7]. During simulation, OpenTrack can produce several files of output. Some of the output files can only be analysed within the tool itself, but the most are ASCII coded, meaning those can be evaluated and edited with word processing or spreadsheet software.

For a better comprehension of the method used to execute the modelling of Northern Line in OpenTrack, is exhibited a flowchart in Figure 2. The steps shown will be after explained.

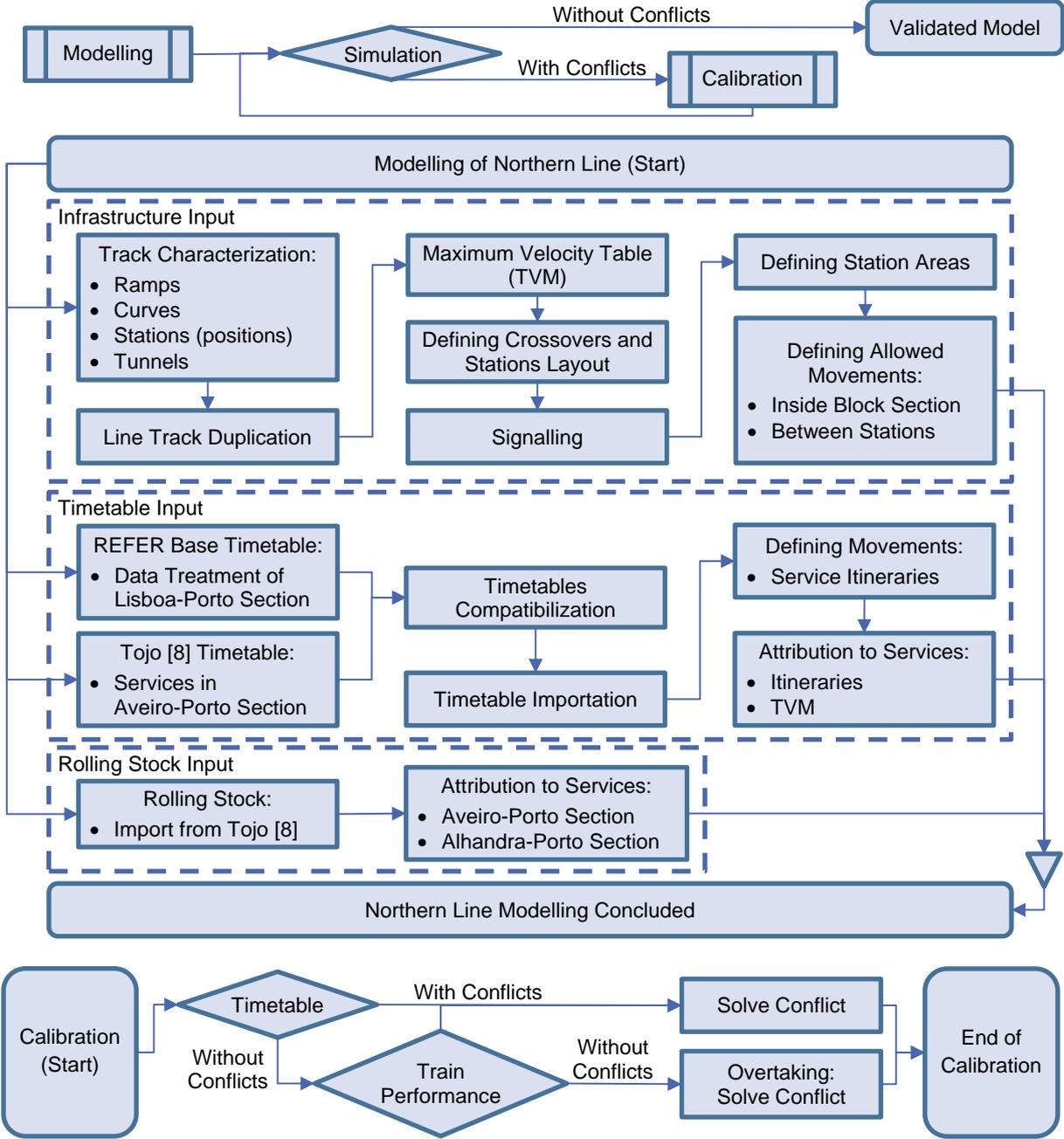


Figure 2 – Flowchart of the process carried for modelling Northern Line in OpenTrack.

In this case study was modelled 310 km of 336 km (about 92%) of the total extent of the Northern Line, which connects by railway Lisboa-Porto¹. The initial 26 km, between stations of Lisboa (Santa Apolónia) and Alhandra, was not taken into consideration because this section represents itself as one problematic section worthy of a particular case study. The modelling was made taking into consideration a 24h period of operation, on a Friday. The Northern Line modelling started with the input of the infrastructure, followed by the input of the timetable and finally concluded with the input of the rolling stock.

The input of the Northern Line infrastructure began with the characterization of the track layout. For every change in the track layout is defined a point with the respective kilometre point. These points are designated in OpenTrack as vertexes and when connected generates an edge, which represents a section that can be characterized accordingly. Edge radius, ramp gradient, tunnel factor, were then defined with the inspector tool. It was also with the inspector that vertexes were defined as stations vertexes, which represents station positions. After a single line track was modelled, and since Northern Line is double track, the modelled track was copied and inserted laterally to the first track. This process was only possible because of the symmetry between tracks characteristics until then defined. Since TVM is not symmetrical in both tracks, TVM was only defined on edges after completion of the track duplication. Afterwards were defined the remaining line details, mainly the stations layouts, the crossovers and finally the signalling components. Posteriorly was defined the stations areas, this was done by introducing an element which represents a specific station and grouping it with the corresponding station vertexes and tracks between the home signals at the station entrances. The final step of the infrastructure input was the definition of allowed movements which are organized in three levels. The first level is a route which consists in the link between two consecutive signals. Second level is a path and is formed by a set of routes accordingly to a determined logic. In this modelling paths were defined to group the following movements: crossing a station; between stations; in stations, in a way to start or finish a service. Last level is the itinerary itself and consists in a set of paths.

The input of the timetable was made through two sources: main timetable provided by REFER (Portuguese infrastructure manager); a timetable from a previous modelling made by Tojo [8] (only in Porto-Aveiro section). Both timetables were worked into one, which was then imported to OpenTrack. In the end, 522 services were modelled. Only afterwards the acknowledgement of the services was possible to attribute itineraries and TVM to services.

For the input of the rolling stock of Northern Line it was used the data modelled by Tojo [8].

To validate the modelling of the Northern Line a series of simulations were executed. When a conflict in the timetable was detected it was due to anomalies in the timetable itself, train performance or overtaking. When all conflicts were solved, the model was validated. In the end, all modelled services respect the timetable with a mean deviation of only 4 seconds.

¹ The section between Porto (Campanhã) and Aveiro stations (63 km) was modelled by Tojo [8].

4. IMPACT ANALYSIS OF A PHASED CONSTRUCTION OF A HIGH-SPEED RAIL LINE CASE STUDY: PORTO-AVEIRO SECTION

The Porto-Aveiro railway section is nowadays only served by the Northern Line, one of the busiest railway lines (and sections) exploited in Portugal. Furthermore, since the case study refers to a construction of a high-speed railway section in the same axis, it is relevant to have the knowledge of the development of the Northern Line in the Lisboa-Porto axis.

Northern Line had from start a troubled process of construction, having been signed several contracts due to lack of compliance of implementation deadlines. Lisboa-Carregado, a 36.5 km section in Northern Line, was effectively the first railway section built and exploited in Portugal, having been inaugurated in 1856. In the end, the Northern Line was finally concluded in 1877 when the bridge over Douro River was built, completing the link between Lisboa and Porto with a 336 km single-track. Since then, the Northern Line went through works of electrification, which were concluded in late 1966, and works of track duplication, concluded in all line extent in 1991.

In late 1995, works for modernization of Northern Line infrastructure was started and are still currently ongoing. Similarly to the line construction, so has the modernization works gone through several complications and the project quickly went over budget. The modernization of Northern Line is a project that was redesign more than once, being the current planned works only for the rehabilitation of the infrastructure. This means that rectifications to track layout are not planned and therefore, limits of TVM will not change.

Due to the limitations of the Northern Line, the future of Lisboa-Porto railway axis can be the construction of a new line with a better track layout which will allow trains to circulate at higher speeds. In fact, the High-Speed Rail Line project in the Lisboa-Porto axis already exists and the track layout design for the Porto-Aveiro section has already obtained a favourable Ambient Impact Declaration (DIA). In order to solve the complications due to lack of capacity in Porto-Aveiro section of Northern Line, a possible solution would be the execution of the High-Speed Rail Line in that section. This section is entitled as Lote A in the original design (see Figure 3) and is connected with the Northern Line in Vila Nova de Gaia (at opposing river bank relatively to Porto) and in Oiã (at 15 km Southeast to Aveiro).



Figure 3 – Lote A of the Lisboa-Porto High-Speed Railway Project. Adapted from RAVE [9]

In order to analyse the proposed solution, a modelling of the High-Speed Rail Line in the Porto-Aveiro section was executed. It was modelled 65 km of the High-Speed Rail Line which will count with approximately 80% of European community finance. According to studies, the execution of this section will represent an investment of about 1,000 million euros [5].

The input of High-Speed Rail Line infrastructure followed a similar procedure used in the Northern Line modelling. In this case study was only modelled a single connection between Northern Line and High-Speed Rail Line, in Oiã station, to simplify the modelling procedure and the travel times comparison after simulations. To make the travel times comparable, a terminus station in Vila Nova de Gaia (Gaia AV) was modelled in the High-Speed Rail Line, being this station and the Gaia station in the Northern Line equidistant to the bridge (a distance of 1.6 km) which connects Vila Nova de Gaia and Porto cities. Since High-Speed Rail Line will be executed with the international track gauge (1435 mm) and the Northern Line is a line with the Iberian track gauge (1668 mm), the circulation between these two lines would have to be done with variable gauge axle trains. The adjustment of the train axle would be performed in Oiã station in a variable gauge system. To simulate this operation, a 500 meters section with a 30 km/h speed limit was modelled. The resulting model of Oiã station, including the variable gauge system, is presented in Figure 4.

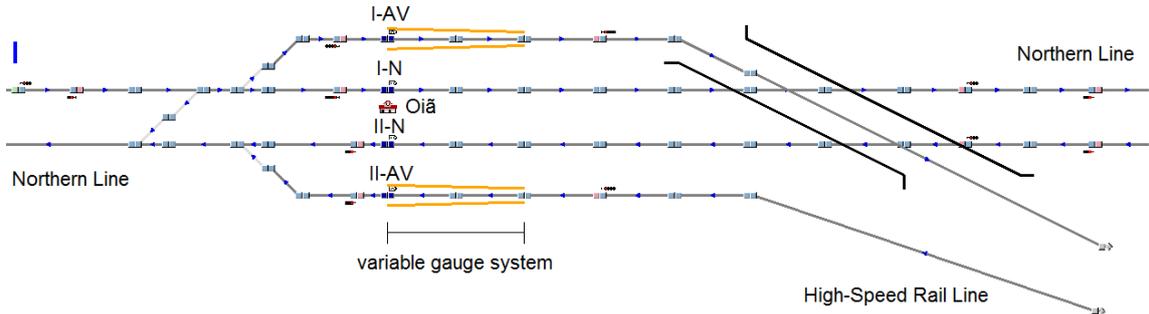


Figure 4 – Layout of the Oiã station model in OpenTrack [6].

As for the input of the rolling stock for this case study, it was modelled two variable gauge axle trains: CAV-S130 (Talga 250), a train used in Spain, limited to a speed of 250 km/h; CAV-S103, a fixed axle train (Siemens Velaro) which was modelled to simulate a train with enhanced characteristics (Talga AVRIL) that will be available to the market in the near future. The tractive effort curves of both modelled trains are displayed in Figure 5.

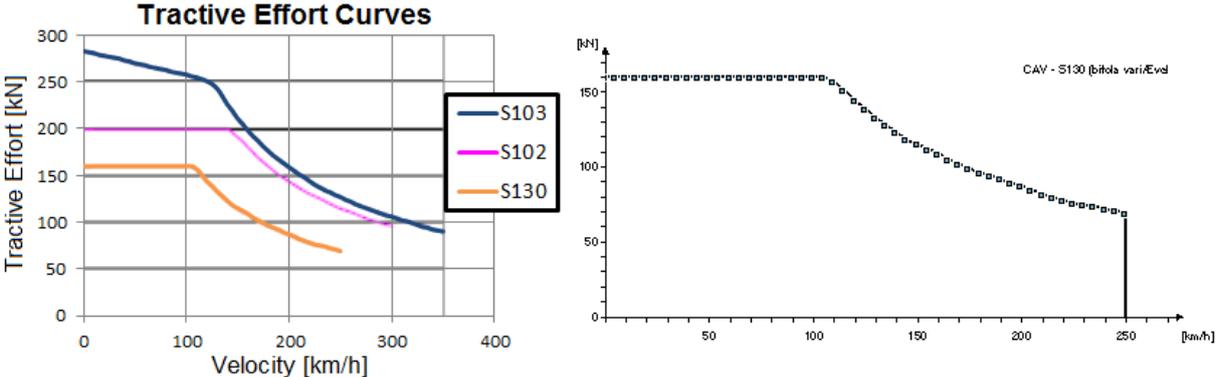


Figure 5 – Source of tractive effort curves and the resulting curve of the CAV-S130 in OpenTrack [6].

Since the modelled High-Speed Rail Line is a new line, there is no actual traffic to consider for the timetable input. For this case study, it was determined that the rapid services currently in circulation on the Northern Line would be diverted to the new High-Speed Rail Line in the Porto-Aveiro section. So, in a way, the timetable input in this case was changing the rapid services in the already modelled timetable. The changes of these services consisted not only in the timetable, but also in modifications of their itineraries and rolling stock. Nowadays, the train that execute the rapid service in the Northern Line is the Alfa Pendular train, an active tilting train. Tilting trains are capable of reaching higher speeds than normal trains in curves due to their faculties to tilt inwards on curves, which reduces the effect of the centrifugal force. Yet the high-speed trains modelled are passive tilting trains. These trains can tilt around 2/3 of the total inclination the Alfa Pendular is capable. Therefore, to determinate the actual performance of the high-speed trains modelled, it was simulated for each train two scenarios: respecting the TVM for normal trains (conventional/non-tilting); respecting TVM for active tilting trains. From those resulting travel times and the 2/3 ratio, the actual travel times of the high-speed trains was then interpolated.

In Figure 6 is displayed the diagram Distance/Time of the actual Alfa Pendular and the CAV-S130 respecting the TVM for normal trains. Without taking into consideration (2/3) of the tilting capability, the high-speed train is already about 8 min. faster than Alfa Pendular.

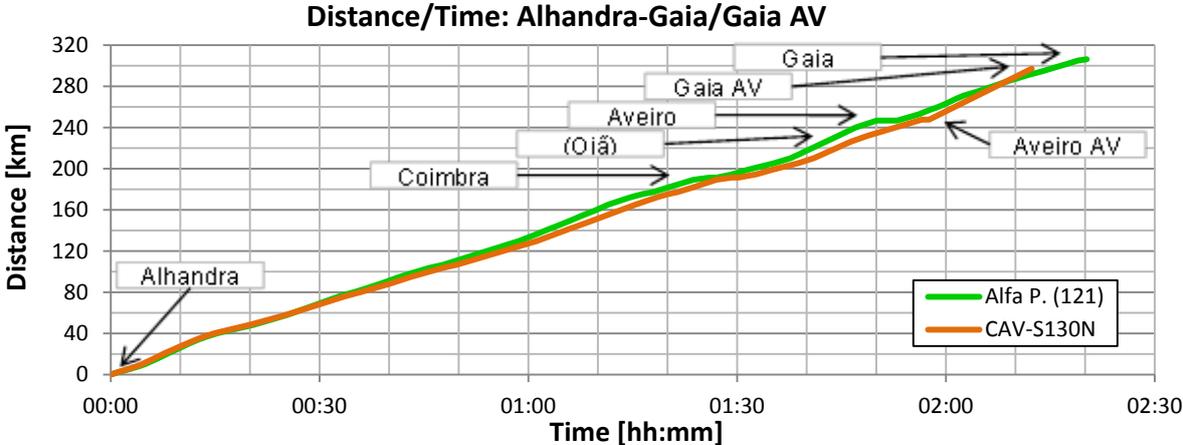


Figure 6 – Distance/Time diagrams of Alfa Pendular and CAV-S130N trains in Alhandra-Gaia section.

Table 1 displays the resulting travel times of the high-speed trains considering the passive tilting faculty, as well the travel time of Alfa Pendular. It was also determined that if the stop in Aveiro AV station was removed, the time gain from that would be little more than 3 min.

Table 1 – Final travel times and commercial speeds with comparisons between trains (with Aveiro).

Results	[km/h]	130	145	149
[hh:mm:ss]	Δt / Δv	Alfa Pendular	CAV-S130	CAV-S103
02:20:49	Alfa Pendular	-	15	19
02:02:37	CAV-S130	00:18:12 (13%)	-	4
01:59:42	CAV-S103	00:21:07 (15%)	00:02:55 (2%)	-

To analyse the effect on Northern Line due to the application of the solution developed in this case study, a capacity analysis accordingly to the UIC code [10] was conducted. It was selected for analysis the section between Porto (Campanhã) and Aveiro stations, at the afternoon peak hour. In the top left of Figure 7 is displayed the actual timetable on the referred section. By applying the UIC compression methodology was obtained the top right diagram, from which was calculated an infrastructure occupation of 79% that surpasses the maximum recommended value of 75%. It was also determined a consumed capacity of 102% when considering between trains a buffer time of 2 min. When diverting the rapid services to the High-Speed Rail Line, it was obtained the lower left diagram, from which results a 66% of infrastructure occupation and a 86% of consumed capacity. Not being the best operational procedure to take, from the released corridors it is possible to add one or two extra services, as denoted in the lower right diagram with an extra urban service (Urbano).

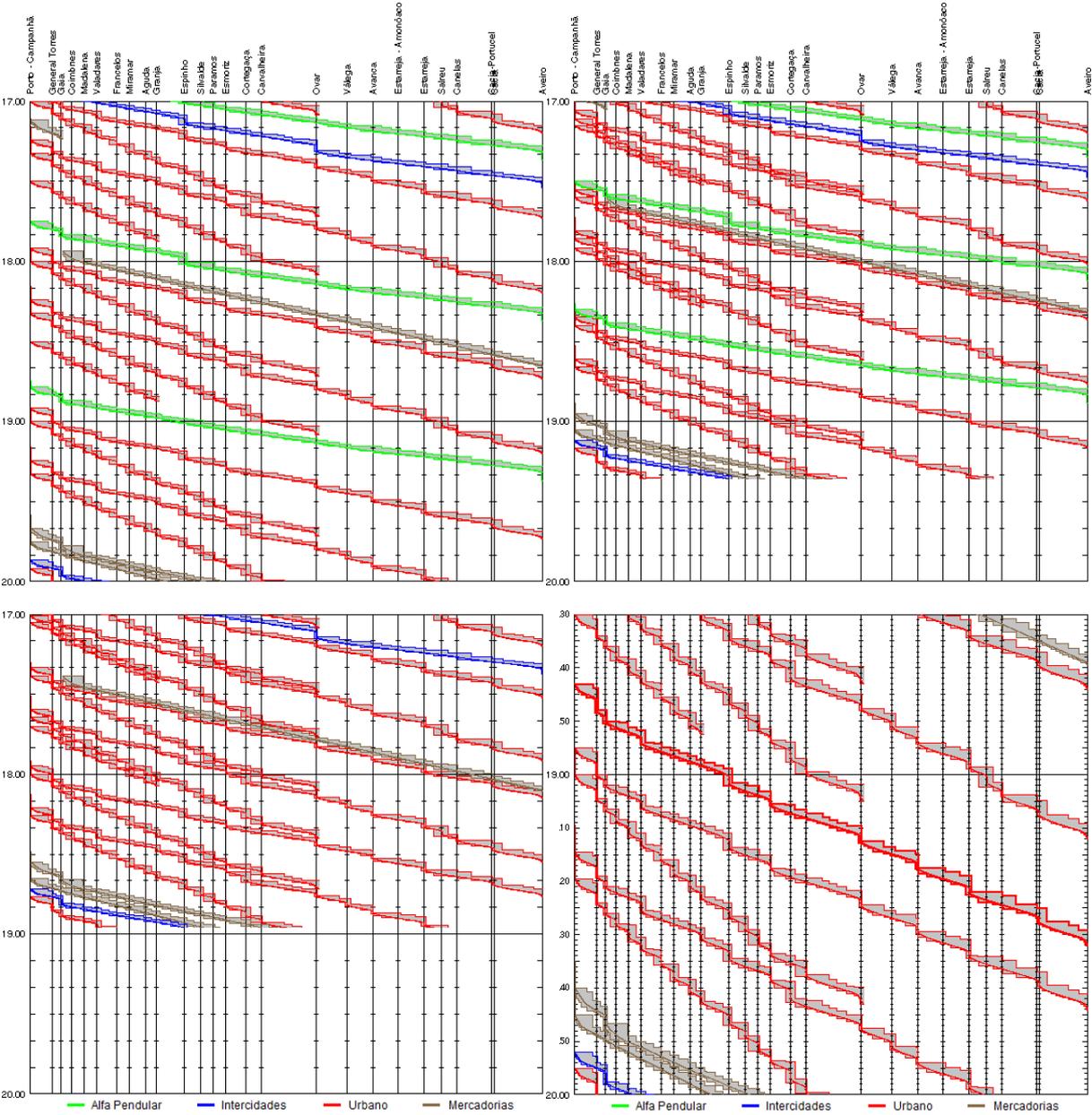


Figure 7 – Train graphs (timetable) of Porto-Aveiro section in Northern Line in OpenTrack [6].

5. CONCLUSIONS

The case study developed in this work focussed in an evaluation of the impact of a phased implementation of the Portuguese high-speed railway project, today a cancelled project. Considering this project a long-term investment needed for Portugal, a hypothetic first phase of execution in the section between Porto and Aveiro was analysed. To make viable the exploitation in this relatively short High-Speed Rail Line section, this line would have to be connected with the actual railway network, at least in this first implementation phase.

To accomplish the analysis, a total of 375 km of double line, from which 65 km correspond to the High-Speed Rail Line, was modelled with the railway microsimulation tool OpenTrack. A total of 522 services in the Northern Line was modelled and simulated with a mean deviation of 4 seconds. The modelled section of the High-Speed Rail Line has a maximum running speed defined at 300 km/h and is approximately 10 km shorter than Northern Line in the corresponding section.

From the simulations it was concluded that travel times of the actual fastest services could be improved in 15%, meaning a 20 minutes faster travels between Lisboa and Porto and a 2 hours of total duration. With the implementation of the High-Speed Rail Line and diverting the rapid services to this line, there would be a reduction of 16% in the consumed capacity in the Northern Line, being 86% the resulted consumed capacity. This means that the Northern Line in Porto-Aveiro section would no longer be considered a congested line by UIC parameters [10].

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