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A study on contestable regions in Europe through the use of a new rail cost function. An application to the hinterland of the new container terminal of Leghorn port.

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Abstract

In this paper, the potential hinterland of the new container terminal of the port of Leghorn (Livorno in Italian) is studied. The study actually consists in an analysis of the competitiveness of some important European ports respect to some of the most contestable regions in Europe. Travel times and monetary costs of rail paths have been determined. For the calculation of travel times and monetary costs, the rail network of a large part of Europe has been modelized through a graph. To each link, which represents a portion of a rail line, a cost function is associated. The travel time of the link is determined from the average speed, which has been determined from the maximum speed via formulas obtained by linear regression. For the computation of monetary costs of a rail link, only a few cost functions exist in the literature and, generally, they are not very detailed. Therefore, a new cost function has been developed. All cost components are determined in detail: the staff cost; the amortization, maintenance and insurance costs of locomotives and wagons; the cost for the usage of rail track; the traction cost. The traction cost has been calculated in detail from all resistances to motion. Moreover, for each rail link, the number of locomotives needed to operate the train and the maximum towable weight have been determined. The monetary value of time in freight transport registers a high variability, therefore three different optimizations, of the paths between each O/D pair, are carried out: by travel times, by monetary costs and by generalized costs. The rate of competitiveness of the ports considered, respect to the European contestable regions examined, has been analyzed.

1. Introduction

The hinterland of a port has been defined as "the area of which the greater part of the trade passes through the port" (Notteboom and Rodrigue [1]). In the hinterland of a port it could be distinguished between the "fundamental hinterland" and the "competitive hinterland" (Rodrigue [2]). The fundamental hinterland is the port core market, and consists of the port captive market, i.e. the areas which mainly, or exclusively, belong to the port market: it is usually formed by regions which are the closest to the port. The "competitive hinterland" is the external area of the port hinterland, which is overlapped with the hinterland of other ports.

The container terminals of the port of Leghorn (Livorno in Italian), currently, show a relevant problem of depths and spaces for ships manoeuvres, in particular considering the development of the newest container ships, 400 metres long, 60 metres wide and 15.5 m of draught. Actually the container terminals can accommodate ships with a maximum length of 300 m, a maximum width of 40 m and a maximum capacity of about 6500 TEUs [3],[4]. The 2015 port regulatory plan provided the development of a new container terminal, the so called “Europe Platform”, which will be able to accommodate container ships with a capacity of around 15,000 TEUs, currently employed in the most important Deep Sea Shipping (DSS) container routes, in particular in the Far East – Europe route.

Presently, the hinterland of the port of Leghorn consists mainly of its fundamental hinterland: some regions of Central Italy. But the port, after the construction of the new container terminal, will be able to attract several new Italian and European regions into its hinterland’s competition margin. Actually Leghorn has a wide flat space on the immediate rear of the port, where an important logistic structure is established: the Guasticce freight village (2,000,000 m^2). Moreover, Leghorn is part of the most important Italian container multi-port gateway system: the Ligurian one, whose ports are crossed by DSS container routes to/from Far East and North and Central America [5]. As stated in Acciaro et al. [6], Switzerland, Austria and southern Germany belong to the potential hinterland of northern Italian ports: these areas are contestable markets between northern European ports and northern Italian ports (also some Slovenian and Croatian ports can serve this area). In particular, Leghorn will be able to attract into its hinterland also several areas of the Padan Plain (in particular in the north-east of Italy) and, thanks to its favourable position respect to the Brenner corridor (Verona-Munich), also some regions of Central-Southern Europe (for example: the area of Munich). On the other hand, Adriatic ports are in the best position, on the land side, to serve north-eastern Italy and several destinations of Central-Eastern Europe (for example: Budapest), but also of Central-Southern Europe (for example Vienna and Munich) as it will be seen in the following. Adriatic ports, however, are currently crossed mainly by feeder routes and are disadvantaged, on the sea side, for the DSS routes to/from the American Continent. Northern Italy, and in particular the Padan Plain, which is the most productive area of Italy, is in the hinterland of the Italian Ligurian and northern Adriatic ports, but it also belongs to the hinterland of northern European ports (it is, at least partially, an “island formation” of the hinterland of northern European ports (Ferrari et al [7] p. 384; Notteboom [8] p. 15).

In any case, it must be considered that the new terminal of Leghorn is necessary in order to simply maintain the current hinterland and foreland (DSS container routes): actually the phenomenon of naval gigantism takes place in all important DSS routes, not only in the Far East – Europe one, but also in the America – Europe routes (Northern and Central American ports are, traditionally, part of the foreland of the Leghorn port) (Lupi et al. [9]).

In this paper, the potential hinterland (competition margin) of the new container terminal of Leghorn is analyzed (Leghorn is the English name of the Italian city and port of Livorno). However, this study actually consists on an analysis of the competitiveness of important European ports, for some of the most constestable regions of Europe. These regions consist of: Switzerland, South Germany, Austria and the Padan Plain in Italy, which are some of the most productive European regions; some Central-Eastern European countries, namely Czech Republic, Slovakia, Hungary, Slovenia and Croatia, which are currently fast emerging. The ports taken into account in this analysis, besides Italian ones, are: some important Mediterranean ports, namely Marseilles – Fos (France), Koper (Slovenia) and Rijeka (Croatia); and five main Northern Range European ports: Le Havre, Antwerp, Rotterdam, Bremerhaven and Hamburg.

The ports concerned have been taken as origins of the considered railway network; the most important cities of Central-Southern and Central-Eastern Europe have been taken as destinations. The studied European railway network, which is a large part of the whole European railway network, has been modelized through a graph. Nodes represent rail terminals, rail junctions, and points where the geometry of rail lines (for example, the slope) changes; links represent rail lines. The optimal rail routes, basing on travel times and monetary costs, from the origin ports to the destination cities, have been calculated. Eventually we have addressed a European problem: indeed we determined the travel times and monetary costs to reach some destinations, among the most contestable in Europe, from the European ports that are in the most competitive positions to serve these destinations.

Generally, optimal paths in a freight transport network are determined according to generalized costs, that is monetary costs plus monetized travel times. But the monetary value of time, in freight transport, is highly variable as it will be underlined in section 2.3. As a result, the optimization by generalized costs is not enough. Therefore, two other separate optimizations have been performed: in the first one travel times were minimized, in the second one monetary costs were minimized; the results of these three optimizations have been compared.

Only a few cost functions for rail transport exist in the literature, and they are not very detailed. Therefore, in this paper, a new cost function for rail freight transport has been developed. The proposed cost function takes into account: all the cost components borne by the rail transport company, and the geometry of the rail lines (in particular their slope).

The paper is organized as follows.

In section 2 a state of the art, about existing cost functions in rail transport networks, is shown.

In section 3 the proposed cost function for rail transport networks is described in detail, and the methodology to calculate travel times and monetary costs on rail links is presented.

In section 4 it is described the collection, in Italy and Europe, of the data, about rail lines, necessary to apply the proposed cost function to the considered European rail network.

In section 5 the calculation of the optimal paths, from origin ports to destination cities, is presented, and the results in terms of travel times, monetary costs and generalized costs are shown and discussed.

In section 6, a sensitivity analysis is performed, which is aimed at understanding which components mostly affect the cost function values.

Conclusions follow.

2. State of the art of cost functions in rail sector and monetary value of time

Several studies have been carried out to evaluate travel times and monetary costs of rail transport, but they mainly deal with passenger transport. In Gattuso [10] rail transport costs have been evaluated in detail, but the research deals with rail passenger transport. In Yaghini et al. [11], a neural network model has been developed to modelize a rail passenger network, but only from the point of view of travel times. Li and Gao [12] used a car following model to predict train delays.

Other studies instead are aimed at simulating, and optimizing, the power consumption and motion of trains: not only passenger trains, but also freight ones. In Keskin and Karamancioglu [13] the electric power consumption in the various phases of the train motion (traction, cruising, coasting, and braking) has been evaluated, and some algorithms aimed at minimizing the power consumption, through specific train operation strategies, have been developed. In Xu et al. [14] a novel method has been proposed to simulate the motion of the train, in particular all the phases of the train motion have been analyzed, and the traction for each phase of motion has been calculated in detail. While these works are very detailed in the power consumption calculation, they determine only a part of a possible cost function of rail transport.

In the evaluation of the cost function of a rail network link, two points of view for the cost can be considered:

- cost for the production of the service,
- cost for purchasing the service.

The cost for the production of the service is, for example, the cost supported by the rail transport companies to put the train in operation. The cost for purchasing the service is the price that rail companies offer to shippers and customers. In this research, we are interested in the evaluation of the cost for the production of the service.

In this paper, it is considered the cost to transport Intermodal Transport Units (ITUs), which are 20 or 40 feet maritime containers (i.e. containers which have been unloaded from container ships, or which are going to be loaded on them).

We will deal with two cost components:
- cost for loading/unloading containers at the rail terminal;
- cost for transporting containers by rail from the origin terminal to the destination.

The cost for loading/unloading an ITU is 32.5 € in Italy (source: Terminali Italia [15]), but, as suggested by interviews to some MTOs (Multimodal Transport Operators) and terminal operators, similar values, comprised between 30 and 35 € per load unit, can be considered also for the other European countries.

2.1. Some cost functions for intermodal transport, based on rail, existing in the literature

Some well known cost functions for intermodal transport, based on rail, are described in the following.

2.1.1. Cost functions taking into account the cost of rail transport in an aggregate way

Several cost functions determine the cost of rail transport, or of intermodal transport based on rail, in an aggregate way: simply an average quantity for the cost of rail transport is given, and no details at all about its cost components, for example the locomotive amortization cost, the driver cost, the traction cost, are provided.

For example, in Kim and Van Wee [16] the cost, in €/container, of the intermodal transport based on rail, depends on: the cost of loading (at the origin) and unloading (at the destination) the container; the monetary cost per unit of distance of rail transport and the distance travelled by rail transport; the cost of transshipment at intermodal terminals; and the pre and post haulage distances and monetary costs (i.e. the distances and costs covered by road transport, from the origin to the loading intermodal centre and from the unloading intermodal centre to the final destination). But, as to the cost of rail transport, only an average quantity per unit of distance is given, and no details on the cost components are provided.

Similarly, Brummersted, Flish and Jahn [17] calculate the price in €/container, of intermodal transport based on rail, as a function of: distance travelled, speed and fares of rail transport; pre and post haulage distances, speed and fares by road transport; transshipment times and monetary costs at rail terminals; monetary value of time in rail and road transport. Only an average value for monetary costs per unit of distance of a rail link is supplied.

Sawadogo et al. [18] developed a route choice model for intermodal (road + rail) transport, which is based on an intermodal graph, where link costs (links could be both road and rail ones) depend on: travel times, monetary costs, damages due to transhipment, pollution, energy consumption, accident risk, noise. As the other authors, also Sawadogo has provided only an average value for monetary costs per unit of distance of a rail link.

Janic [19] supplied two different cost functions, for road and rail transport, in which also external (environmental) costs are taken into consideration. The transport cost by rail, of a given shipment of load units, depends on: the overall weight of the shipment; the internal and the external costs incurred by each train employed to perform the shipment; the cost due to each load unit, both at the intermodal terminal and to transport it by train; the travel time, distance, speed and delay of each train used to perform the shipment. In Janic, similarly to the other authors, simply an average quantity for the cost of rail transport is given, without considering the components of rail cost such as: driver costs, amortization cost, traction costs, and particularly the components depending on the geometric characteristics of the line such as the slope or the number of locomotives used.

2.2. Detailed cost functions for rail transport

Detailed cost functions for rail transport have been proposed by Grosso [20] and Baumgartner [21]. These cost functions provide in detail the monetary costs incurred by each train service. The considered cost components are those supported by rail transport companies. These cost functions were taken as departure point for our research on a new cost function for rail network links.

2.2.1. Grosso

Grosso, after interviews to rail transport companies, has proposed the following cost function:

$$C = (P + I + R/L \cdot n_L + OV) \cdot t + SH \cdot n_{SH} + L/UNL \cdot n_{ITU} + (E + MR/L \cdot n_L + MR/W \cdot n_W + RT) \cdot d \qquad (1)$$

The cost C is expressed in € and it is calculated for each train service, connecting a given origin/destination pair.

The components of this cost function are the following:

- staff cost (P) [€/h]: cost of the train drivers;
- insurance cost of the train (I) [€/h];
- cost for the rental or leasing of locomotives (R/L) [€ /(h · locomotive)].
- n_L = number of locomotives in the train.
- overhead costs (OV) [€/h]: the indirect costs (administrative and operative costs) of the rail transport company;
- t [h] = travel time spent by the train to cover the distance from the origin to the destination of the journey;
- shunting operations costs (SH) [€/operation]: costs for the train preparation at rail terminals;
- n_{SH} = number of shunting operations performed on the train.
- loading/unloading costs (L/UNL) [€/ITU]: costs of the vertical handling of load units to/from wagons at rail terminals;
- n_{ITU} = number of intermodal transport units transported on the train;
- energy cost (E) [€/km].
  In the case of electric locomotives it is relative to the price of the electric energy for traction (€/kWh) multiplied by the electric energy consumption (KWh/km). In equation 1, as for electric traction, it does not depend on the number of locomotives. Instead in the case of diesel locomotives, E [€/km] is deemed depending on the number of locomotives, and in particular it is given by the product of the fuel consumption, l/(km ·locomotive) multiplied by the fuel price in €/l and by the number of locomotives.
- maintenance and repair cost of a locomotive (MR/L) [€ /(km · locomotive)]
- maintenance and repair cost of a wagon (MR/W) [€ /(km · wagon)].
- n_W = number of wagons.
- rail track costs (RT) [€ / km]: price for the usage of the rail infrastructure; it is paid by the rail transport company to the rail infrastructure manager.
- d [km] = distance travelled, by train, from the origin to the destination.

The advantage of the cost function proposed by Grosso is the higher level of detail than cost functions previously examined. But:

- it does not take into account the different energy consumption for different values of slope, and in particular it does not take into account explicitly resistances to motion;
- cost values of the cost function components are not in line with those proposed in the literature, and in particular with those proposed in the Baumgartner cost function, which will be described in the following section;
- the number of locomotives considered for each train, for each network link, is not clearly stated.

However, the cost function proposed by Grosso has been a departure point for our research.

2.2.2. Baumgartner

The cost function proposed by Baumgartner [21] is made of several components. Considering freight trains with electric traction, and flat wagons for containers, the cost function, where the cost is expressed in € per train service (connecting a given origin/destination pair), is the following:

$$C\,[€] = (C_L \cdot n_L + MR_L \cdot n_L + C_W \cdot n_W + MR_W \cdot n_W + T) \cdot d \tag{2}$$

- C_L = electric locomotive purchase / amortization cost [€ / (km · locomotive)]: an average price for a locomotive is around 3 million €; the economic life of a locomotive is around 25 years or 5 million kilometers. Therefore, it could be considered an amortization cost for a locomotive of about 0.6 €/km.
- n_L = number of locomotives.
- MR_L = electric locomotive maintenance and repair cost [€ /(km ·locomotive)]: it is usually equal to 20% of the purchase/amortization cost calculated above. Therefore, if a locomotive amortization cost is about 0.6 €/km, the maintenance cost is 0.12 €/(km · locomotive).
- C_W = flat wagon (for containers) purchase cost [€ /(km · wagon)]: an average price for a flat wagon is around 65,000 € per wagon, with an economic life of around 20 years or 1 million kilometers. Therefore, the amortization cost of wagons is about 0.065 € /(km · wagon).
- n_W = number of wagons.
- MR_W = flat wagon (for containers) maintenance cost [€/(km · wagon)]: the maintenance cost of a flat wagon for containers is around 0.07 €/(km · wagon).
- T = electric traction power consumption (€/km): Baumgartner (2001) proposes the values reported in table 1.
- d = distance (from the origin to the destination) [km].

In table 1 the energy consumption in Wh /(t · km) is reported. The average cost of electricity for a rail traction company is around 0.11 €/KWh. Multiplying the energy consumption in Wh /(t · km) by the total mass of the train and dividing this quantity by 1,000 it is obtained the energy consumption in KWh/km. Multiplying the energy consumption, in KWh/km, by the cost of electricity, in €/KWh, the cost of traction, in €/km, is obtained.

The cost function, proposed by Baumgartner, provides details in several cost components and the proposed cost values are in line with those proposed in the literature: for example, the purchase cost of a locomotive, or the total km travelled in a year by a locomotive or wagons are in line with the values commonly considered by rail transport companies and Multimodal Transport Operators (MTOs). On the other hand, Baumgartner's cost function misses some components: the rail track cost, the staff cost, and the locomotives and wagons insurances.

Table 1. Electric energy consumption, in Wh/TKBC (unit of measure: Wh/(t · km)), according to the slope value. Source: Baumgartner [21]

Distance between two successive stops [km]	Maximum running speed [km/h]	Gradient [‰ or mm/m]	Unit consumption [Wh/TKBC][1)]
100	140	0 to 5	40 (35 to 50)
100	120	0 to 5	30 (25 to 35)
100	100	0 to 5	22 (17 to 27)
100	80	0 to 5	15 (10 to 20)
50	60	0 to 5	15 (10 to 30)
50	60 to 80	25	45 (45 to 50)
5	80	0 to 5	25 (20 to 30)
5	60	25	50 (45 to 55)

(1) TKBC= total gross tonne-kilometre (including the mass of locomotive(s))

2.3. Monetary values of time for rail freight transport in the literature

There is high disagreement in the literature about the monetary value of time (VOT) in freight transport. Indeed it changes according to the typology of freight carried and the mode of transport. An overview of monetary values of time in the literature is presented in Lupi et al. [22]. Regarding road-rail intermodal transport, Jiang and Calzada [23] proposed, for shipments performed in France, monetary values of time ranging from 1.03 €/(t·h) (shipments of chemical products) to 7.77 €/(t·h) (shipments of manufactured products). In De Jong [24] (p. 656, tab. 2) several VOT for rail transport, present in the literature, are reported. Fowkes et al. [25] propose a VOT ranging from 0.08 to 1.21 €/(t·h); De Jong et al. [26] propose a VOT ranging from 0.25 to 1.10 €/(t·h). Other authors propose a VOT ranging from 0.03 €/ (t·h) (in Widlert and Bradley [27]) to 0.96 €/(t·h) (in De Jong et al. [28]).

3. The proposed cost function

As stated in Lupi et al. [29], after interviews to experts in the field, and in Russo [30], monetary costs and travel times are the variables mostly taken into account by carriers and shippers in their transport mode choice.

For modelling a multimodal freight transport network, the following generalized cost function can be used:

$$C_g = C_m + VOT \cdot t \tag{3}$$

where:
- C_g = generalized cost [€],
- C_m = monetary cost [€],
- VOT = value of time [€/h],
- t = time [h].

But, as underlined in the preceding paragraph, a high variability of VOT has been observed in the literature. Consequently, in the analysis carried out in this paper, travel times and monetary costs have been considered separately. However, in this paper also generalized costs have been taken into account. The VOT considered, for the calculation of generalized costs, is 0.96 €/ (t·h), proposed by

De Jong in 2004 [28]. We chose this VOT as it is an average one, and we think it is the most reliable among those proposed in the literature.

3.1. The calculation of travel times

Travel times are calculated from the average speed, of a freight train, in each line section.
The average speed is calculated from the speed in rank A (the maximum speed for freight trains) by a linear formula, calibrated through regression analysis by RFI (Rete Ferroviaria Italiana), the Italian rail network manager:

$$V_m = 0.60231 \cdot V_A \quad \text{[km/h]} \tag{4}$$

Where V_m is the average speed and V_A is the speed in rank A.
The speed rank A, in Italy, refers to freight trains, which tolerate a maximum uncompensated lateral acceleration in curve of 0.6 m/s^2 (the residual part of the centrifugal lateral acceleration is compensated by slope).

The other ranks existing in the Italian rail network are:

- rank B for passenger trains, which can travel up to 140 km/h; the maximum uncompensated lateral acceleration for rank B is 0.8 m/s^2;
- rank C for fast passenger trains which can travel at more than 160 km/h; the maximum uncompensated lateral acceleration for rank C is 1 m/s^2;
- rank P for tilting trains.

The speed values for each rank, and in particular for rank A, refer generally to short line sections (1-3 km long). But, in this research, much longer rail links, namely at least 15-20 km, have been taken into account. Therefore, the speed in rank A, on a rail link, has been taken equal to a weighted average of the speeds of all line sections included in the link, considering as weight the percentage of the length of the link with the given speed in rank A.

Table 2. Summary of the procedure adopted in this paper for the calculation of link travel times

Variable	Formula	Details of the calculation
Average speed: V_m	$V_m = 0.6 \cdot V_A$	The link travel times are calculated from the average speed on each link. The average speed is calculated from the speed in rank A through a factor of 0.6 as proposed by Rete Ferroviaria Italiana (RFI).
Speed in rank A: V_A	$V_A = 0.86 \cdot V_C + 2.87$	The speed in rank A is publicly available only in Italy and in a few other countries. In the other countries only the speed for fast passenger trains, which could be assimilated to the Italian rank C, is publicly available; for these countries, the speed in rank A is calculated from the speed in rank C through a formula which has been calibrated on Italian data.

The values of the speed in rank A are publicly available only in Italy and in a few other European countries, on the website of the rail infrastructure managers, as it will be shown in detail in section 4. But in the other countries the speed in rank A is not publicly available: only the speed in rank C is provided in the websites of the rail infrastructure managers. Therefore, a formula has been set up which determines the speed in rank A given the speed in rank C.

This formula has been determined through linear regression analysis basing on Italian data:

$$V_A = 0.8636 \cdot V_C + 2.8732 \quad \text{[km/h]} \tag{5}$$

Where V_A is the speed in rank A and V_C is the speed in rank C.

The regression has been performed with the help of the statistical software "R". The quality of fit is high as the (adjusted) R^2 value is 0.954.

The formula has been used for data of other European countries for which the speed for fast passenger trains, which could be assimilated to the Italian rank C, were publicly available.

The procedure for the calculation of link travel times is summarized in table 2.

3.2. The calculation of monetary costs

Monetary costs of rail transport have been calculated basing partially on the research performed by Baumgartner [21] and on the methodology proposed by Grosso [20]. In addition, some reference costs, regarding staff, locomotives and wagons, have been determined basing on [31]. The proposed cost function is the following:

$$C\,[€] = t\,[h]\cdot(n_d\cdot P) + l\,[km]\cdot\{n_L\cdot(A_L + M_L + I_L) + n_W\cdot(A_W + M_W + I_W) + R + T(V_A,i,R_c)\} + 2\cdot H\cdot n_{ITU} \quad (6)$$

Where:

- C, expressed in € per train service, is the monetary cost on each rail link, having length l and travel time t.
- P = staff cost [€ /(h · driver)]: cost of the train drivers. The staff cost is not the same in all Europe: in Italy an average cost per hour, for each train driver, of 35 € was detected (the cost comprises not only the net salary but also pension contributions and healthcare) (Source: Trenitalia, relazione annuale [32]), while in Germany it resulted a cost of 42 € per hour per driver [31]. Therefore, for the whole Europe an average staff cost, of 38.5 €/h per European driver, has been considered.
- n_d is the number of drivers of each freight train (independently of the number of locomotives). Two train drivers per freight train have been considered in Italy, while only one driver has been considered in the rest of Europe (sources: interviews to Rete Ferroviaria Italiana and [33]).
- A_L = amortization cost of a locomotive: in [31] it is reported that a reference amortization cost for a locomotive used for freight transport is 330,670 € per year. Mercitalia Rail (the main Italian rail freight company) has provided a reference value for the number of km travelled each year by a locomotive: 200,000 km. Therefore, the average cost of a locomotive, expressed in €/(locomotive · km), has been estimated: 1.653 €/(locomotive · km). It is interesting to note that some transport company provides a contract with the locomotive producer which includes not only the purchase cost but also the maintenance. For example, some Italian MTOs have made contracts with Bombardier for 5 million € per locomotive which includes purchase and maintenance for 10 years.
- M_L = maintenance cost of locomotives: in [31] it is suggested to take it as 5.5% of the amortization cost, that is: 0.091 €/(locomotive · km).
- I_L = insurance cost of locomotives: in [31] it is suggested to take it as 1.5% of the amortization cost: that is, 0.025 €/(locomotive · km).
- n_L = number of locomotives. The number of locomotives depend on the gradient of the rail link, and it ranges from 1 to 2. In some exceptional case, a triple traction (3 locomotives) has been considered. The calculation of the number of locomotives is described in detail in the following.
- A_W = amortization cost of a wagon; Sgns flat wagons for containers have been considered. In [31] it is reported that the amortization cost for a Sgns is 4,898 €/year. Mercitalia Rail has provided a reference value for the number of km travelled each year by a wagon of 50,000 km. Therefore, the average amortization cost of a wagon, is 0.098 €/(wagon · km).
- M_W = maintenance cost of wagons: in [31] it is suggested to take it as 10% of the amortization cost: that is, 0.0098 €/(wagon · km).

- I_W = insurance cost of wagons: in [31] it is suggested to take it as 1.3% of the amortization cost: that is, 0.0013 €/(wagon · km).
- R = rail track cost [€/km], i.e. cost for the usage of the rail infrastructure, paid by the rail transport company to the infrastructure manager. This cost has been determined, for all countries involved in this research, according to the values provided in [34] for Italy and in [35] for the other European countries. The rail track cost is different: from a country to another, from a line to another, and it depends also on the weight of the train. For example, in Austria, the track cost for a train above 900 tons, on the Brenner railway, is equal to 4.968 €/(train · km), the cost on the Westbahn (the line from Vienna to the German border) is 4.474 €/(train · km), while the cost on the Tarvisio – Semmering and Tarvisio – Tauern lines is 3.749 €/(train · km).
- H = cost of handling at rail terminals [€/ITU]. It is available on the Terminali Italia website (source: Terminali Italia [15]), and it is equal to 32.5 € per Intermodal Transport Unit (ITU) for all terminals in Italy; this is the rate for loading an ITU on a train at a rail terminal inside the maritime container terminal, as well as the rate for handling an ITU from a train to a truck at the destination freight village / intermodal centre. It does not comprise the costs for a container idle time at the terminal for a time period greater than 2 days. As far as non Italian terminals are concerned, some terminal operators in Belgium, The Netherlands and Germany have been interviewed: they have provided similar values, equal to around 35 € per ITU.
- n_{ITU} = number of Intermodal Transport Units (ITUs) transported on each train.
- The cost of handling a train at rail terminals is multiplied by 2 because two transshipment movements have been considered: the first one at the rail terminal located in the container terminal of the unboarding port, and the second one at the freight village/intermodal centre of destination.
- $T(V_A,i,R_c)$ = Electric traction cost [€/km]: it has been determined from the power consumption, in kWh/km, multiplied by the cost of electricity, in €/KWh. The power consumption has been calculated considering all resistances to motion. This detailed power consumption determination, as far as the authors know, has never been applied to rail networks as large as the network taken into account in this research. Details on the calculation of the power consumption are provided in the following. Only electrified lines have been considered: in Europe, usually, non electrified lines show bad geometrical characteristics, particularly high gradient and sharp horizontal curves. Therefore, the diesel traction cost has not been taken into account in our research. The traction cost is a function of: the speed in rank A of freight trains on the link (V_A); the link grade (i); the curvature resistance (R_c). The resistances to motion have been calculated from the speed in rank A, i.e. V_A.

In table 3, the proposed cost function is compared with the cost functions existing in literature. Because cost functions by Kim and Van Wee [16], Brummersted et al. [17], Sawadogo et al. [18] and Janic [19] are not detailed, they cannot be compared with the proposed one. Therefore only the comparison with cost functions of Grosso [20] and Baumgartner [21] could be performed, and it is shown in detail in table 3. Again in table 3, a summary of all components of the proposed cost function is provided, and the methodology for their calculation is explained.

Table 3. Comparison of the proposed cost function with similar cost functions existing in literature: namely those proposed by Grosso [20] and Baumgartner [21].

Component	Grosso	Baumgartner	The proposed cost function
Staff cost	Maximum, average, minimum values provided	Not taken into account in the cost function	Two reference values for the driver cost per hour were found in literature: in Italy [32] and Germany [31]. An average of these two values (38.5 €/h) has been considered. Two drivers are necessary to operate a train in Italy, while only one driver is necessary in the rest of Europe.

Number of locomotives	Not explicitly calculated	Not explicitly calculated	Calculated in detail. The number of locomotives depends on the grade and curve resistances of each line section and it has been determined, for each rail line, from the "Operating Rules" ("Norme di Esercizio") [47]. The operating rules used by the rail transport companies, which effectively operate the services, have been assumed.
Amortization / rental / leasing cost of a locomotive	Maximum, average, minimum values provided	Calculated from an average purchase cost of a locomotive	In [31] an amortization cost in €/year, valid for locomotives specifically used for freight transport, is provided. In order to calculate the amortization cost in €/km, the number of km/year travelled by a locomotive for freight transport has been provided by Mercitalia Rail.
Maintenance cost of a locomotive	Maximum, average, minimum values provided	Calculated as a percentage of the amortization cost	Calculated as a percentage of the amortization cost as suggested by [31].
Insurance cost of a locomotive	Maximum, average and minimum insurance costs are provided for the entire train and not for simply a locomotive	Not taken into account in the cost function	Calculated as a percentage of the amortization cost as suggested by [31].
Amortization cost of a flat wagon	Maximum, average, minimum values provided	Calculated from an average purchase cost of a flat wagon	In [31] an amortization cost in €/year for a flat wagon is provided. In order to calculate the amortization cost in €/km, the km/year travelled by a flat wagon have been provided by Mercitalia Rail.
Maintenance cost of a flat wagon	Maximum, average, minimum values provided	Calculated as a percentage of the amortization cost	Calculated as a percentage of the amortization cost as suggested by [31].
Insurance cost of a flat wagon	Maximum, average, minimum values provided	Not taken into account in the cost function	Calculated as a percentage of the amortization cost as suggested by [31].
Handling cost at terminals	Maximum, average, minimum values provided	Not taken into account in the cost function	Calculated according to the costs provided by Terminali Italia [15] and by northern European terminals, as €/load unit. The handling cost at an Italian terminal is 32.5 €/load unit and between 30 and 35 €/ITU in the rest of Europe. The total number of ITUs (Intermodal Transport Units) to be considered for each train has been collected from interviews to the main MTOs operating between Italian and northern European terminals.
Rail track cost	Maximum, average, minimum values provided	Not taken into account in the cost function	Rail track costs, in €/km, have been collected for each rail line. Rail track costs are not only different from a country to another, but often also from a line to another in the same country.
Traction cost	Maximum, average, minimum values provided	Reference values have been provided for different values of line slope	It has been determined from the power consumption, in kWh/km, multiplied by the cost of electricity, in €/KWh. The power consumption has been calculated considering all resistances to motion on each line section.

3.2.1. Details on the calculation of the electric traction cost

As stated before, the electric traction cost, $T\ (V_A,i,R_c)$ [€/km], has been determined from the power consumption, in kWh/km, multiplied by the cost of electricity, in €/KWh. In the Prospetto Informativo di Rete of 2018 [36] (p. 160), it is shown that, currently, the price for electricity for rail freight transport, in Italy, has been raised to 0.434 €/(train · km).

However, the situation in the rest of Europe is different; in addition a traction cost formalized in this way does not take into account the actual energy consumption on each rail link (for example because of the speed and the slope). Therefore, it was decided to take, for the cost of electricity, the average prices, in €/kWh, applied to companies (companies in general, not railway companies in particular), in each European country. For example, in Italy the average price for electricity, in the second half of 2017, for companies, has been around 0.0813 €/KWh (source: Il Sole 24 Ore website [37]; Eurostat [38]). A different electricity price for each European country, has been considered: the electricity price for each European country was taken from Eurostat [38].

The power consumption has been calculated basing on all resistances to motion. The resistances to motion considered in the calculation, as suggested in Micucci and Mantecchini [39], are: the rolling resistance, the aerodynamic resistance, the grade and curve resistances. In the calculation of these resistances, the speed in rank A, i.e. V_A, has been used. The inertial resistance has been neglected because the traction is calculated at regime: acceleration and deceleration transitories have been neglected. Freight trains do not make scheduled intermediate stops from the origin to the destination, but, sometimes, they make some stops to let faster trains pass. Because the localization and the time instant in which stops take place cannot be estimated, they have been neglected in this study The resistances were determined according to the methodology proposed in Vicuna [40], but the formulas for resistances, which were old, have been updated.

The rolling resistance has been calculated according to Szanto [41] (p. 2). The air resistance is due to: the overpressure created on the front surface of the locomotive, the depression created on the rear surface of the last wagon, the friction of the air along the lateral surfaces of the train, the friction along the under-chassis of the train [39]; it has been calculated according to Lai et al. [42] (p. 823). The grade resistance has been calculated considering the slope of each line section in detail while the curve resistance has been calculated from the Von Rockl formula.

The resistances to motion depend on the weight of the train (locomotive + wagons). An E189 locomotive (produced by Siemens) has been considered which has a weight of 87 tons [43]. This type of locomotive is currently used by the rail company "Rail Traction Company" in the international freight transport across the Alpine Passes of Brenner and Tarvisio. This locomotive is multi-tension, therefore it must not be changed at the border between Italy and the other countries: in Italy the electric rail lines (with the exception of the new high speed lines) are operated with direct current (DC) at 3 kV, while in Germany, Switzerland and Austria they are operated with alternating current (AC) with 15.000 V and 16 2/3 Hz.

One of the most common flat wagons, for the transport of containers, is the Sgns, with an unladen weight of 17.5 t/wagon (source: Mercitalia Rail [44]). In order to determine the average number of wagons composing a train, and the average number of TEUs (or ITUs) loaded on each train, four main MTOs (Hupac, Cemat, Kombiverkehr and Lineas Intermodal) operating between Italy and northern Europe, have been interviewed.

The average number of wagons composing each train has resulted the following:

- 1st MTO: 25-26 wagons,
- 2nd MTO: 23-24 wagons,
- 3rd MTO: 25-26 wagons,
- 4th MTO: 21-22 wagons.

The average number of Intermodal Transport Units (ITU) transported on each train has resulted the following:
- 1st MTO: 35-38 ITUs, 63-68 TEUs;
- 2nd MTO: 32-38 ITUs, 58-68 TEUs;
- 3rd MTO: 35-38 ITUs, 63-68 TEUs;
- 4th MTO: 30-33 ITUs, 54-59 TEUs.

For the first 3 MTOs, the conversion factor, between TEUs and ITUs, proposed in the UIR report (Unione Interporti Riuniti [45] p. 6) has been used, therefore 1 ITU = 1.79 TEUs. The 4th MTO instead provided both the number of ITUs and of TEUs transported on each train.

Therefore it could be considered an "average train" of 24 wagons and 62.5 TEUs (35 ITUs) per train, that is 2.6 TEUs per wagon. The average weight of each TEU in rail transport is generally 13.04 t/TEU (source: RFI), but maritime containers usually weight less, around 11 ton/TEU (source: elaboration from Assoporti [46]), because on container ships also empty containers are transported. In this research, the weight of 13.04 t/TEU has been taken into account.

Therefore the total weight of the train (in tons) has been calculated as follows:

$$\mathrm{W}\ [\mathrm{t}] = n_L \cdot W_L + n_W \cdot (W_W + n_{TEU} \cdot W_{TEU}) \tag{7}$$

Where:
- n_L = number of locomotives of the train;
- W_L = weight of each locomotive, i.e. 87 tons in case of the E189;
- n_W = average number of flat wagons on each train, i.e. 24 wagons;
- W_W = average unladen weight of a flat wagon = 17.5 tons/wagon;
- n_{TEU} = average number of TEUs loaded on each wagon = 2.6 TEUs/wagon;
- W_{TEU} = average weight in tons of each TEU, i.e. 13.04 ton/TEU;

The total weight of the train is therefore 1321 tons if only one locomotive is used, and 1408 tons if two locomotives are used. The towed weight is 1234 tons.

Resistances to motion, and consequently the cost of traction for a train in €/km, depend on several factors, but in particular on the speed, on the gradient and on the curve radius of each portion of the line. For example, in Italy (cost of electricity = 0.0813 €/kWh), for an average speed of 60 km/h, the values of traction cost for a train are the following:
- if the line's gradient is 0‰ (1 locomotive) the traction cost is around 0.60 €/km
- if the line's gradient is 5‰ (1 locomotive) the traction cost is 1.01 €/km
- if the line's gradient is 10‰ (1 locomotive) the traction cost is 1.41 €/km
- if the line's gradient is 15‰ (2 locomotives), the traction cost is 1.82 €/km
- if the line's gradient is 20‰ (2 locomotives), the traction cost is 2.23 €/km

In our research the speed, along a link, has been calculated basing on formulas 4 and 5. For the calculation of resistances to motion the speed in rank A has been used. For the calculation of the link travel time (on which the staff cost depends) the average speed V_m has been used.

3.2.2. Maximum towable weight on a rail line section and "Lines with special operation characteristics"

There are two main constraints related to the maximum towable weight on a rail line:

- the maximum towable weight due to the resistance of train couplers, which depends on the geometrical characteristics of the rail line, in particular on the sum of the grade and curve resistances of each line section. In tab. 4 the maximum towable weight, fulfilling the resistance of train couplers, according to RFI, is reported. The towed weight of the train considered in this study is 1234 tons (paragraph 3.2.1). From table 4, the maximum value for the sum of grade and curve resistances, fulfilling the resistance of train couplers, for the towable weight of the train taken into account, is equal to 20 N/kN.

Table 4. Maximum towable weight, fulfilling the resistance of train couplers according to RFI (Italian) rules, expressed in tens of tons, versus the sum of grade and curve resistances, expressed in N/kN.

Sum of grade and curve resistances (N/kN)															
4.5	5.0	5.5	6.0	6.5	7.0	7.7	8.4	9.2	10.0	11.0	12.0	12.9	13.8	14.6	15.8
Maximum towable weight (tens of tons)															
250	250	250	250	244	235	224	214	203	194	183	173	166	158	152	145
Sum of grade and curve resistances (N/kN)															
17.0	18.4	19.8	20.9	21.9	22.7	24.6	25.7	27.8	29.3	30.8	32.5	34.2	37.5	40.5	
Maximum towable weight (tens of tons)															
137	130	123	118	114	111	104	101	95	90	87	83	80	74	69	

- The maximum weight that can be towed by the chosen locomotive. It depends on the geometry of the line but also on the type of locomotive used: each typology of locomotive can tow a different weight, for example, the E655 (six axles) is capable of towing a greater weight than the E189 (four axles) on a same line. The maximum weight that a locomotive can tow on each section of a line is reported in the "Operating Rules" ("Norme di Esercizio") [47]. This type of document is publicly available online only in Italy. If this towed weight value is overcome, the train is allowed to travel on the line, but more than one locomotive it is necessary. For towed weight of 1234 tons and an E189 locomotive (this type of locomotive is widely used by rail transport companies in Europe because it is multi tension) the maximum sum of grade and curve resistances allowable for one locomotive is 12 N/kN.

Therefore:

- if the sum of the grade and curve resistances is less than 12 N/kN, only one locomotive has been used;
- if the sum of the grade and curve resistances is more than 12 and less than 20 N/kN, two locomotives (E189) have been used;
- if the limit of 20 N/kN was overcome on a secondary line, this line has not been included in the modelized rail network; if the limit of 20 N/kN is overcome on a main line, information has been collected about how the trains are operated on this line.

The Disposition n° 18 of 19/11/2015, published by RFI [48], has removed the limit of tab 4. about the maximum towable weight which fulfils the resistance of train couplers, in order to satisfy the requirements of rail transport companies, which aim at improving their productivity operating longer trains. The Disposition precises that the maximum towable weight is determined by the rail transport companies according to specific analyses based also, but not only, on the rail infrastructure characteristics.

In brief, as far as the modelized rail network is concerned, the sum of the grade and curve resistances is greater than 20:

- On secondary lines, which could be domestic Italian (for example, the Parma – La Spezia and the Savona – Altare lines) or non Italian lines (for example the Grenchenberg line in Switzerland): only local freight trains travel on these lines, therefore they have been neglected in our study.
- On some main lines, often those crossing the Alps, and often belonging to the TEN-T corridors. In the following a line of this type is called "*line with special operation characteristics*". For the area of interest (circled in red) in fig.1, they are described in detail in paragraph 4.2 and on these

lines the operation rules used by the rail transport companies, which effectively operate the services, have been assumed.

3.2.3. Remarks on the proposed cost function

The proposed cost function has two main advantages:

- it takes into account, in detail, all the cost components incurred by a rail transport company,
- it takes into account the geometry of the line, in particular the gradient, in order to determine the traction power needed and above all to determine the number of necessary locomotives. Indeed, the costs related to locomotives, i.e. amortization/leasing/rent and maintenance, are a relevant quota of the overall monetary cost of a train journey between an O-D pair; also the cost of traction is relevant, but less than the cost due to the locomotives.

The proposed cost function does not consider the number of tracks of the line section. Indeed, on single-track lines, the travel time increases significantly because of the train crossing manoeuvres at stations. The travel time in this case depends clearly on the number of stations, along a line, where trains can cross each other, but also on the degree of congestion of the line. However it must be noted that:

- RFI usually allocates paths for freight trains in specific time slots in order to avoid crossing operations as much as possible. In addition, single-track lines usually register too high gradient to be used by international freight trains or, in any case, by heavy national/international freight trains: these lines are used at most by light local freight trains. Therefore, only a few single-track lines have been considered in Italy.
- In the other European countries studied in the analysis, single-track lines have been excluded, apart from Slovenia and Croatia, where several important rail lines are still with only one track.

4. The application of the cost function to the European rail network under study and the problems of data collection

4.1. The European regions under study.

Several European regions have been excluded, from the potential hinterland of the future “Europe Platform” of Leghorn, because of their localization. Therefore, Russia, Belarus and Ukraine have been excluded as they are too far. Also Northern Germany and Poland have been excluded because northern range ports are far more reachable than the port of Leghorn from these regions. France has been excluded, because, although it is not far from Leghorn, the position of the Northern European ports of Antwerp and Le Havre, and of the Mediterranean port of Marseilles – Fos, are clearly more favorable than that of Leghorn. Finally, Spain, Greece, Bulgaria and Romania have been excluded because they are close to some important ports with deep sea services: Valencia, Algeciras, Barcelona and Piraeus.

Consequently the following European regions can, potentially, be comprised into the port of Leghorn hinterland (fundamental hinterland and competition margin): central and northern Italy; Switzerland (whole country); southern Germany; Austria (whole country); Slovenia (whole country); northern Croatia (in particular Zagreb); northern Serbia (in particular Belgrade); Hungary (whole country); Czech republic (whole country); Slovakia (whole country). In fig. 1, the potential hinterland of Leghorn is circled in blue (called “the blue area” in the following) which is made up of some the most contestable regions in Europe.

Indeed, this research, which was initially aimed at determining the potential hinterland of the port of Leghorn, actually analyzes travel times and monetary costs to reach some of the most contestable destinations in Europe ("blue area") from some main European Mediterranean and northern range ports. The ports which are in competion to serve the "blue area" are: the Ligurian ports of Genoa, La Spezia and Leghorn; the Northern Adriatic ports. These latter ports, in particular Venice, Trieste, Koper and Rijeka, are in a more favorable position than Ligurian ports for destinations in north-eastern Italy and also for destinations in Central-Eastern Europe. But Ligurian ports (as Leghorn) are in a favorable situation concerning the sea side: in fact, the Adriatic ports are, currently, crossed mainly by feeder routes to/from Far East and are disadvantaged, compared to Ligurian ports, for the routes from/to the American continent; therefore the "blue area" comprises also North-Eastern Italy and Central-Eastern Europe. As far as some Central-Southern European markets are concerned (South Germany, particularly Munich) the Ligurian ports and the Adriatic ports, are in competition also with Northern European ports: especially Antwerp, Rotterdam, Hamburg, but also Zeebrugge and Bremerhaven.

In fig. 1, the potential competitor ports to serve the "blue area" are circled in red. Some of these ports are external to the "blue area", therefore it was necessary to modelize the rail network of a wider area. The European region, whose rail network was necessary to modelize, is made up of the "blue area" but also of: the remaining part of Germany; Belgium, the Netherlands and Luxembourg; the northern and eastern regions of France. The region, whose rail network has been modelized, is circled in red in fig. 1 (and it is called "the red area" in the following).

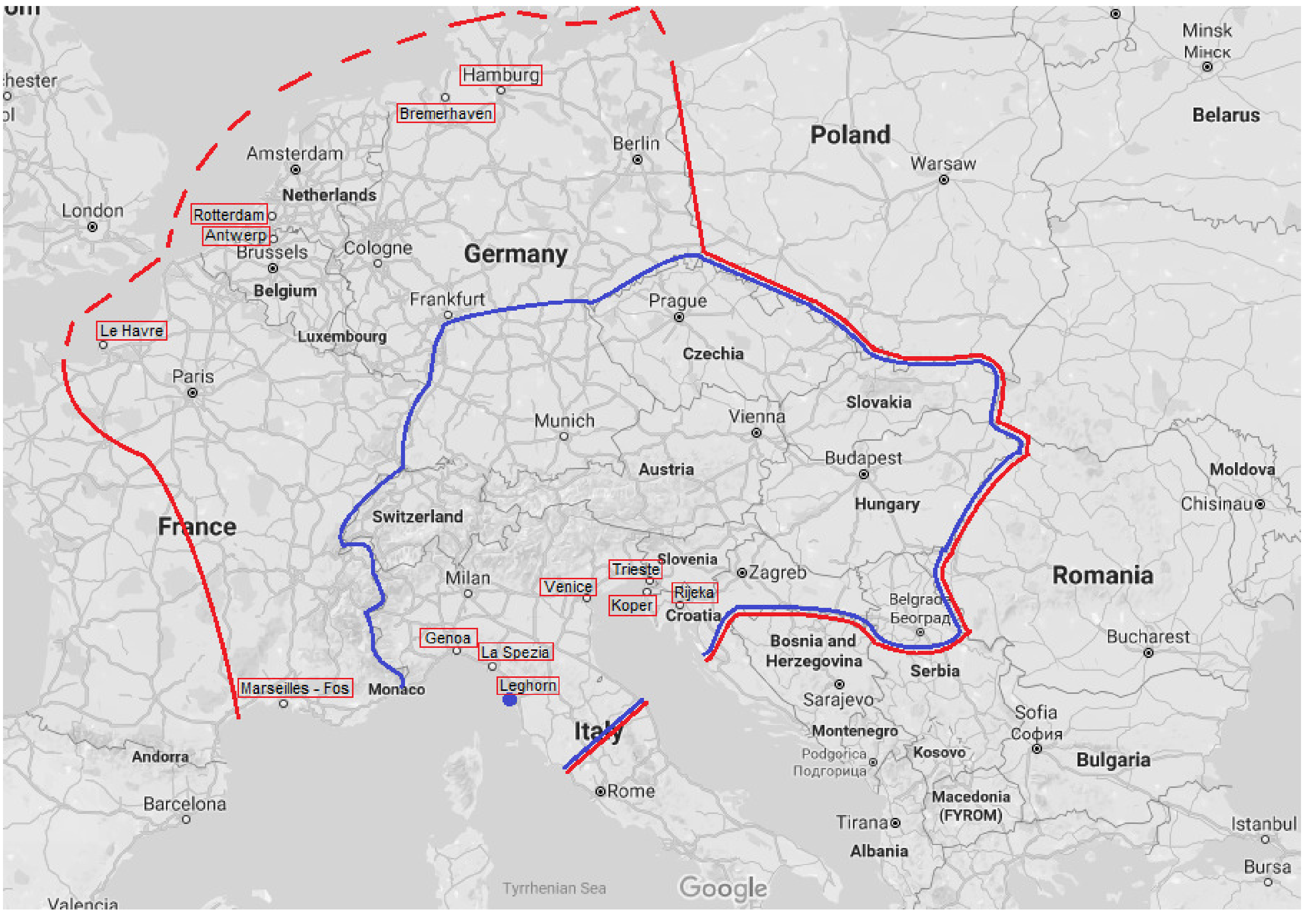

Figure 1. Potential hinterland (circled in blue) of the future container terminal of Leghorn and the European region (circled in red) whose rail network has been modelized (circled in red).

The rail network of the "read area" has been modelized through 571 nodes and 753 links; among these links, 701 are bidirectional and 52 are unidirectional. Bidirectional links have been used in flat or almost flat areas; unidirectional links have been used in mountain regions, because clearly the energy consumption and the travel time in the two directions is different.

4.2. Data collection.

In order to apply the proposed cost function, and to calculate travel times and monetary costs for each line section, the following information was necessary:
- the maximum speed allowed in rank A on each line section,
- the length of the line section,
- the grade and curve resistances of the line section or, at least, the slope and the curves radius.

The first two pieces of information are needed to determine the travel time on each link. The average speed has been calculated from the maximum speed in rank A according to formula 4, section 3.1. The maximum speed in rank A, if not explicitly given, was calculated according to formula 5 from the maximum speed in rank C. All the three data are needed to calculate the monetary cost. The third information, in particular, is necessary to determine the number of locomotives to be used and the electric traction cost.

In Italy, all these informations are publicly obtained from the "route books", where, for each line section, it is reported: the maximum allowed speed, for each speed rank (A, B and C: freight trains belong to rank A); the length of the section, and the sum of grade and curve resistances (this sum is called "degree of performance" in Italy). From the "route books", we also determined the rail lines to be excluded from the modelization, because the maximum towable weight is incompatible with the weight of the train considered in 3.2.1.

In the other European countries all these informations are not public.

Only in Slovenia and Czech Republic some kinds of route books are available to the public, which report, for each line section, the length of the section and the maximum allowable speed in the ranks A, B and C. For the other countries only the so called "network statements", which provide the general characteristics of the lines, are available to the public. These documents report only the length of the section and the maximum speed in rank C of each line section. In order to calculate the speed in rank A, from the speed value in rank C, the formula 5 (section 3.1) has been used.

The "network statements" and the other documentation about rail lines is available, for each country under study, at the following websites: Austria [49], Belgium [50], France [51], The Netherlands [52], Germany [53], Croatia [54], Czech republic [55], Slovakia [56], Slovenia [57], Hungary [58], Switzerland [59]. In Switzerland, only distances were available, therefore, in order to collect informations about the speeds, it was necessary to interview the railway network manager company and some MTOs.

In Germany, Croatia and Slovenia (but only there), also the slopes of the lines were available in the "network statements". In all the other cases, it was necessary to calculate the slopes manually, through "Openstreetmap". The curve resistance of the lines was not available in any other European country, apart from Italy, and it has been again calculated manually: the curve radius has been taken from "Openstreetmap" and the curve resistance has been calculated, given the curve radius, through the Von Rockl formula.

As far as the "lines with special operation characteristics" are concerned, those comprised in the "red area" of fig. 1 are described in detail in the following. In our model, we consider the same number of locomotives as used by the MTOs in the real operations to tow a weight of 1234 t. MTOs generally use similar locomotives to the E189 considered in this paper.

On the Brenner line (on the border between Italy and Austria), the maximum sum of grade and curve resistances is equal to: 26 N/kN on the Italian side, from Bressanone to the Brenner Pass, 51 km; 28 N/kN on the Austrian side from Steinach to the Brenner Pass, 13 km. On the Italian side, from Bressanone to the Brenner pass (51 km), double traction (both locomotives pulling the wagons) is used; on the Austrian side, double traction (both locomotives pulling the wagons) from Innsbruck to Steinach (26 km) and triple traction (two locomotives pulling and one pushing) from Steinach to the Pass (13 km) is used. The information on the number of locomotive was taken from Zurlo [60] and Schmittner [61]. On the Brenner line, it is allowable: a maximum towable weight of 1500 tons on the Italian side and of 1560 tons on the Austrian side (as reported in Schmittner [61]).

On the Frejus line, on the Italian side, the maximum sum of grade and curve resistances is equal to 28 N/kN from Bussoleno to Salbertrand (22 km), and 31 N/kN for only 3 km, between Bardonecchia and the beginning of the Frejus tunnel. From Salbertrand to Bardonecchia, instead, the sum of grade and curve resistances is less than 22 N/kN. On the French side, between Modane and the end of the Frejus tunnel, that is for 11 km, the maximum sum of grade and curve resistances is 31 N/kN (also along the Frejus tunnel). Between Modane (France) and Bussoleno (Italy), and vice versa, it is allowed: a maximum towable weight of 1150t with double traction, and of 1600t with triple traction (Osservatorio [62], in Ferrari [63]). The line on the French side from St Michel de Maurienne to Modane shows a lower maximum sum of grade and curve resistances, equal to 22 N/kN: this part of the line is operated with double traction with a maximum towable weight of 1600t (source: interviews to Novatrans, one of the most important French MTOs, which operates on this line).

As far as the Sempione line is concerned, the section with a sum of grade and curve resistances above 20 N/kN, and equal to 24 N/kN, is very short, only 2 km, close to Iselle station: the line is operated with double traction between Domodossola (Italy) and Brig (Switzerland).

As to the Loetschberg line, thanks to the new Loetschberg tunnel, the maximum sum of grade and curve resistances, which occurred in the north ramp, has been reduced from 29 to 14 N/KN. In this line, single or double traction is operated, depending on the towed weight and the performance of the locomotive, while the resistance values completely fulfil the resistance of the train couplers of tab. 4 [64].

With regard to the Gotthard line, thanks to the opening of the new Gotthard Base tunnel, the maximum sum of grade and curve resistances, which occurred in the south ramp, has been reduced from 27 to 13 N/kN [65], [66]. The new Gotthard line is operated in single traction except for the Ceneri Pass north ramp, whose sum of grade and curve resistances is 26 N/kN, which is operated in triple traction, and the Ceneri Pass south ramp, whose sum of grade and curve resistances is 21 N/kN, which is operated in double traction (source: interviews to the Hupac MTO). However, the Ceneri Base tunnel is under construction.

As far as the Tarvisio line is concerned, it does not have problems of grade and curve resistances. But, it is part of the international path connecting Italy with Vienna; a portion of this path is the Semmering rail line. While the Semmering west ramp (on the side of Murzzuschlag) does not show high slopes, the east ramp (on the side of Gloggnitz) shows a grade resistance of 25 N/kN but in particular a maximum curve resistance of 5.5 N/kN: some curves have a radius of even 150 metres; the maximum sum of grade and curve resistances is 28 N/kN. This line is operated with triple traction between Gloggnitz and Murzzuschlag [67] (Murzzuschlag is close to Bruck an der Mur) and double traction for the rest of the line, between Carnia in Italy and Murzzuschlag, while the rail between Gloggnitz and Vienna is flat and operated with only one locomotive (source: interviews to Alpe Adria, one of the main MTOs operating on this line). It must be remarked that the Semmering line is tortuous and with high slopes for only 40 km; but a new Semmering base tunnel is currently under construction.

The last lines “with special operation characteristics” are those running from the ports of Trieste, Koper and Rijeka to the internal Karst plateau. In particular:

- The rail from Trieste Campo Marzio to Villa Opicina (border Italy – Slovenia), 15 km, shows a sum of grade and curve resistances of 25 N/kN. This rail is part of the Trieste – Ljubljana path and it is operated with triple traction from Trieste Campo Marzio to Villa Opicina (Source: interviews to Alpe Adria, the main MTO operating rail connections to/from the Trieste Campo Marzio rail terminal). Between Villa Opicina and Ljubljana, instead, the sum of grade and curve resistances is below 20 N/kN and the line is operated with double traction.

- A portion, of about 18 km, of the line from Koper to Ljubljana, comprised in the rail line Koper – Pivka, shows a maximum sum of grade and curve resistances of 23 N/kN. This line is operated in double traction (source: interviews to Metrans, the main MTO operating on this line).
- A portion, of 15 km, of the line from Rijeka to Ljubljana, close to Rijeka port, shows a sum of grade and curve resistances of 27 N/kN; this line portion is operated with triple traction and the rest of the line with double traction (source: interviews to Metrans).
- A portion of about 25 km of the line from Rijeka to Zagreb shows a sum of grade and curve resistances of 28 N/kN; this line portion is operated with triple traction and the rest of the line with double traction (source: interviews to Metrans).

5. Optimal paths and comparison of the results

5.1. Optimal paths between each O/D pair

The optimal paths between each O/D pair have been calculated through the Dijkstra algorithm. Origins of paths are the ports marked in red in fig.1. Destinations are the main rail terminals in northern Italy and some important rail terminals near the main cities in Central-Southern and Central-Eastern Europe. The considered destinations are: the Italian terminals of Prato (near Florence), Bologna, Milan Segrate / Milan Smistamento (the two terminals are adjacent), Novara, Busto Arsizio – Gallarate (near Milan), Turin, Verona, Padua; the Central-Southern European terminals of Basel (Switzerland), Zurich (Switzerland), Munich (Germany), Nuremberg (Germany), Stuttgart (Germany), Prague (Czech Republic); the Central-Eastern European terminals of Zagreb, Ljubljana, Budapest, Vienna, Bratislava, Belgrade.

Because of the high variability in the monetary value of time, as highlighted in section 2.3, three distinct optimizations have been carried out: a first optimization which minimizes travel times, a second optimization which minimizes monetary costs, and a third optimization which optimizes generalized costs. For each optimization (basing on travel times, monetary costs or generalized costs), the optimal paths and the related travel times, monetary costs and generalized costs, have been calculated.

5.2. Comparison between the results obtained in the two optimizations

The problem which can arise is that the optimization basing on let's say monetary costs (the optimal path obtained) is very different from that obtained basing on travel times or generalized costs. Consequently all the comparisons among optimal paths, obtained basing on monetary costs, travel times and generalized costs (from the point of view of monetary costs, travel time and generalized costs achieved) have been carried out. Due to lack of space in the paper, only some of these comparisons can be reported: as to the other comparisons, similar results have been obtained.

In tables 5-8, the comparison, regarding monetary costs, between the optimizations by monetary costs respect to the optimizations by travel times and by generalized costs, is shown. Generalized costs have been determined assuming a value of time of 0.96 €/ (t·h), as proposed in De Jong [28]. More in detail:

- in table 6, monetary costs, obtained from the optimization by monetary costs, are shown;

- in table 7, differences, in percentage, of monetary costs, between the optimization by monetary costs and the optimization by travel times, are shown (the optimization by monetary costs is taken as reference).
- in table 8, differences, in percentage, of monetary costs, between the optimization by monetary costs and the optimization by generalized costs, are shown (the optimization by monetary costs is taken as reference). In this table, it can be noticed that differences are less marked than in the preceding comparison (table 7).

Table 5. Monetary costs (in €) per train, from each origin port (shown in the columns) to each destination city (shown in the rows) resulting from the optimization by monetary costs.

	Leghorn	Genoa	La Spezia	Venice	Trieste	Koper	Rijeka	Marseilles	Le Havre	Antwerp	Rotterdam	Hamburg	Bremer-haven
Prato	5654	8038	6554	7517	9769	10801	11517	13505	25128	23847	25499	30395	29449
Parma	7944	6933	8159	7389	9642	10674	11390	12400	22553	21272	22924	28063	27096
Bologna	6900	8338	7801	5985	8237	9269	9985	13805	23958	22677	24329	29224	28278
Milan	8867	6403	7629	7666	9918	10951	11667	11870	20922	19527	21179	26318	25351
Novara	8597	6133	7359	8657	10909	11941	12657	11600	20538	19281	20933	26072	25105
Busto A.Gallarate	9653	7189	8415	8573	10825	11857	12573	12656	20430	19035	20687	25826	24860
Padua	8480	9391	9380	4564	6816	7848	8564	14858	24182	22788	24440	28738	27792
Verona	8254	8163	9154	5634	7886	8918	9634	13630	22954	21559	23212	27510	26564
Turin	9010	6546	7772	10131	12383	13415	14131	11701	19181	20158	21810	27546	26579
Vienna	18497	19408	19397	13821	13315	13617	13544	24876	28422	24312	24415	22872	23209
Basel	14538	12074	13300	13910	16162	17194	17910	15645	14719	13324	14976	20115	19149
Zurich	13431	10967	12193	12802	15054	16087	16803	16435	16208	14813	16465	21604	20637
Munich	16743	16651	17643	13294	12788	13775	13702	22119	21314	18095	19164	19268	18322
Nuremberg	19717	18452	19677	16269	15762	16749	16676	22494	20196	16086	16189	16293	15347
Stuttgart	17817	15353	16578	17188	17005	17992	17919	19395	17097	13878	15040	17561	16615
Zagreb	15292	16203	16192	10616	8663	8845	7889	21671	30925	27706	28774	28878	27932
Ljubljana	12856	13767	13756	8180	6227	6410	6337	19235	28489	25270	26338	26443	25496
Budapest	19281	20193	20182	14606	12653	12835	12585	25660	32141	28031	28134	26052	26389
Prague	24191	24574	25091	19515	19009	19996	19923	29060	26761	21359	19899	16007	16344
Bratislava	19866	20777	20766	15190	14684	14986	14913	26245	29792	25681	25784	23364	23702
Belgrade	20806	21717	21706	16130	14177	14359	13402	27184	36225	32115	32218	30136	30473

Table 6. Differences, in percentage, of monetary costs, between the optimization by monetary costs and the optimization by travel times (the optimization by monetary costs is taken as reference).

	Leghorn	Genoa	La Spezia	Venice	Trieste	Koper	Rijeka	Marseil-les	Le Havre	Antwerp	Rotterdam	Hamburg	Bremer-haven
Prato	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	1.0%	8.0%	0.0%	0.0%
Parma	0.0%	0.0%	8.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	1.1%	8.9%	0.0%	0.1%
Bologna	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	1.1%	8.4%	0.0%	0.0%
Milan Smistamento	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	9.6%	0.0%	0.1%
Novara	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	1.3%	9.7%	0.0%	0.1%
Busto A. - Gallarate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	1.4%	10.0%	0.1%	0.2%
Padua	0.0%	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	1.8%	0.0%	1.1%	8.3%	0.8%	0.9%
Verona Q. E.	0.0%	3.3%	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	1.1%	8.8%	0.0%	0.0%
Turin	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	12.1%	0.0%	0.1%
Vienna	0.0%	1.4%	0.0%	0.0%	0.0%	5.4%	5.1%	1.1%	0.0%	0.0%	0.0%	2.4%	2.4%
Basel	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	1.8%	13.6%	0.0%	0.1%
Zurich	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	12.4%	0.0%	0.1%
Munich	0.0%	1.6%	0.0%	0.0%	0.0%	0.3%	0.0%	1.2%	0.0%	5.3%	0.0%	0.0%	0.0%
Nuremberg	0.0%	0.0%	4.8%	0.0%	0.0%	0.3%	0.0%	2.4%	0.0%	0.0%	0.0%	0.0%	0.0%
Stuttgart	0.0%	0.0%	0.0%	1.9%	0.0%	0.3%	0.0%	2.7%	0.0%	9.1%	1.3%	4.4%	4.7%
Zagreb	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	3.5%	0.0%	0.0%	0.0%
Ljubljana	0.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	3.8%	0.0%	0.0%	0.0%
Budapest	9.4%	10.3%	9.0%	12.4%	25.7%	5.7%	0.2%	8.1%	0.0%	0.0%	0.0%	2.1%	2.1%

Prague	2.0%	1.1%	1.9%	0.0%	0.0%	0.2%	0.0%	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%
Bratislava	0.0%	1.3%	0.0%	0.0%	0.0%	4.9%	4.6%	1.0%	0.0%	0.0%	0.0%	2.3%	2.3%
Belgrade	0.0%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%	1.8%	1.8%

Table 7. Differences, in percentage, of monetary costs, between the optimization by monetary costs and the optimization by generalized costs (the optimization by monetary costs is taken as reference).

	Leghorn	Genoa	La Spezia	Venice	Trieste	Koper	Rijeka	Marseil-les	Le Havre	Antwerp	Rotterdam	Hamburg	Bremer-haven
Prato	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%
Parma	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.1%
Bologna	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%
Milan Smistamento	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Novara	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.1%
Busto A. - Gallarate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.2%	0.1%	0.2%
Padua	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.9%
Verona Q. E.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Turin	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Vienna	0.0%	0.0%	0.0%	0.0%	0.0%	5.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Basel	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Zurich	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Munich	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Nuremberg	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stuttgart	0.0%	0.0%	0.0%	1.9%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zagreb	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ljubljana	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Budapest	9.4%	9.0%	9.0%	12.4%	0.0%	0.0%	0.2%	7.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Prague	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bratislava	0.0%	0.0%	0.0%	0.0%	0.0%	4.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Belgrade	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Of course for each O/D pair, in general, the best path according to travel times can be different from the best path according to monetary costs.

Firstly, the average speed is different from a rail link to another, therefore a longer path could show a lower travel time than a shorter path. However, the monetary cost has several components proportional to the operative distance.

On the other hand, the monetary cost per unit of distance could be very different from a link to another, for the following reasons:

- the traction cost (in €/km) is different from a link to another, as it is the product of the electric energy price (which changes from a country to another) by the power consumption (which depends on the resistances to motion of each link, therefore it is different from a link to another in terms of unit of distance);
- the number of locomotives, which heavily impacts the monetary cost of the link, is also different from a rail link to another;
- the rail track cost (in €/km) is different from a rail line to another (particularly from a country to another); the differences of rail track cost sometimes are very relevant.

Therefore a longer path (by distance) could have a lower monetary cost than a shorter path (by distance), because, for example, it needs a lower number of locomotives or it has a lower track cost.

However, the best path according to monetary costs coincides with the shortest path by distance more frequently than the best path according to travel times. Indeed, in the monetary cost function, only one cost component is proportional to the travel time, that is the driver cost; all the other components, namely the traction cost, the rail track cost, and the amortization, maintenance and insurance costs of locomotives and wagons, are proportional to the distance.

Very often the best paths obtained from the three optimizations coincide or, however, have only slight differences. This is clear in the comparison of monetary costs (reported in tables 5-7) obtained from the three optimizations, but also in the comparison of travel times and generalized costs, which have not been reported due to lack of space in the paper.

The highest differences, between the results of the optimizations by monetary costs and travel times, occur for the destination of Budapest and for all Italian ports of origin (that is Genoa, La Spezia, Leghorn, Venice and Trieste) and for non Italian origin ports of Marseilles and Koper. Indeed, the best path according to monetary costs crosses the Slovenian line from the Adriatic Sea to Ljubljana and Ormoz; the best path according to travel times crosses Austria and in particular the Tarvisio and Semmering Passes. The Slovenian path is very tortuous and characterized by low speeds, while the Austrian path, apart the Semmering section (which is long only 40 km on a total path length of over 300 km), is characterized by higher speeds. On the other hand, the rail track cost of the Austrian lines is much higher than the Slovenian one and similarly the electric energy price is higher in Austria than in Slovenia. As far as the optimization by generalized costs is concerned, the highest differences occur with the optimization by monetary costs, and again occur for the destination of Budapest and for all Italian ports of origin (that is Genoa, La Spezia, Leghorn, Venice and Trieste) and for non Italian origin ports of Marseilles and Koper. Indeed the paths chosen in the optimization by generalized cost, for the above mentioned O-D pairs, are the same as the paths chosen in the optimization by travel times.

Other remarkable differences concern the origin port of Rotterdam and destinations Basel, Zurich, Turin and Busto Arsizio-Gallarate (and consequently other destinations in Italy). For the destination Turin, the optimal path according to travel times crosses Germany and the Loetschberg and Sempione lines, while the optimal path according to both monetary and generalized costs crosses Belgium, France and the Frejus tunnel. For the other three destinations, the optimal path according to travel times crosses Germany, while the optimal path according to both monetary and generalized costs crosses Belgium and France; these paths join in Basel. Indeed, the rail track cost in France is on the average 1.96 €/km, while in Germany it is 2.65 €/km, in Belgium 3.94 €/km and in Switzerland 5.21 €/km; the electric energy price in France is 0.09 €/kWh, in Germany 0.15 €/kWh, in Belgium 0.08 €/kWh and in Switzerland 0.1 €/kWh. Although the track cost in Belgium is higher than in Germany, in France it is lower; in addition the electric energy price is much higher in Germany than in the other countries.

5.3. Railway lines crossing the Alps used to connect the considered O/D pairs

In the past nearly all railway lines across the Alps had high grade and curve resistances therefore they would be all comprised among the lines “with special operation characteristics”. Currently, two base tunnels have been constructed, along the Loetschberg and Gotthard lines, therefore the geometry of these two railway lines has improved considerably. The railway lines across Frejus, Brenner and Semmering passes are among those “with special operation characteristics”, but new base tunnels are planned or under construction.

In this section, the importance of each railway line crossing the Alps (through a pass or a base tunnel) is pointed out in terms of their usage by the optimal paths connecting O/D pairs (only O/D pairs which require the crossing of the Alps have been considered). The results of this analysis are displayed in tab. 8. The main lines across the Alps are schematically represented in fig. 2.

From the table it could be observed that the most used line is the Gotthard one. The Gotthard line, thanks to its geographical position, is the main railway axis between the Padan Plain and northern Europe. This line ends in Milan, but its branches, across Varese and Luino, rapidly connect this line to all destinations in the western Padan Plain (Novara, Turin and the main Italian intermodal centre of Busto Arsizio – Gallarate) and to the ports of Genoa and La Spezia. The Loetschberg – Sempione rail line is less used, and it provides an alternative path to the Gotthard line for the Italian terminals located in Piedmont region (administrative centre Turin): the Gotthard and the Loetschberg lines join in the south of Basel.

Table 8. Railway lines crossing the Alps used to connect the considered O/D pairs. Only O/D pairs which require the crossing of Alpine passes have been taken into account.

Origin	**Destination**	**Pass - optimization by travel times**	**Pass – optimization by monetary costs**	**Pass – optimization by generalized costs**
Leghorn	Vienna	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Leghorn	Basel	Chiasso – Gotthard	Luino – Gotthard	Luino - Gotthard
Leghorn	Zurich	Chiasso – Gotthard	Luino – Gotthard	Luino - Gotthard
Leghorn	Munich	Brenner	Brenner	Brenner
Leghorn	Nuremberg	Brenner	Brenner	Brenner
Leghorn	Stuttgart	Chiasso – Gotthard	Luino – Gotthard	Luino - Gotthard
Leghorn	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Leghorn	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina
Leghorn	Budapest	Tarvisio – Semmering	Villa Opicina – Ormoz	Tarvisio – Semmering
Leghorn	Prague	Brenner	Tarvisio – Tauern	Tarvisio - Tauern
Leghorn	Bratislava	Tarvisio – Semmering	Tarvisio – Semmering	Tarvisio - Semmering
Leghorn	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Genoa	Vienna	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio – Semmering
Genoa	Basel	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard
Genoa	Zurich	Luino – Gotthard	Luino - Gotthard	Luino – Gotthard
Genoa	Munich	Brenner	Brenner	Brenner
Genoa	Nuremberg	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard
Genoa	Stuttgart	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard
Genoa	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Genoa	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina
Genoa	Budapest	Tarvisio – Semmering	Villa Opicina – Ormoz	Tarvisio – Semmering
Genoa	Prague	Brenner	Brenner	Brenner
Genoa	Bratislava	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio – Semmering
Genoa	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
La Spezia	Vienna	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio – Semmering
La Spezia	Basel	Luino – Gotthard	Luino - Gotthard	Luino – Gotthard
La Spezia	Zurich	Luino – Gotthard	Luino - Gotthard	Luino – Gotthard
La Spezia	Munich	Brenner	Brenner	Brenner
La Spezia	Nuremberg	Brenner	Luino – Gotthard	Luino – Gotthard
La Spezia	Stuttgart	Luino – Gotthard	Luino - Gotthard	Luino – Gotthard
La Spezia	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
La Spezia	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina
La Spezia	Budapest	Tarvisio – Semmering	Villa Opicina – Ormoz	Tarvisio – Semmering
La Spezia	Prague	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
La Spezia	Bratislava	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio - Semmering
La Spezia	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Venice	Vienna	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Venice	Basel	Chiasso – Gotthard	Chiasso - Gotthard	Chiasso - Gotthard

Venice	Zurich	Chiasso – Gotthard	Chiasso - Gotthard	Chiasso - Gotthard
Venice	Munich	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Venice	Nuremberg	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Venice	Stuttgart	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Venice	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Venice	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina
Venice	Budapest	Tarvisio – Semmering	Villa Opicina – Ormoz	Tarvisio – Semmering
Venice	Prague	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Venice	Bratislava	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Venice	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Trieste	Vienna	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Trieste	Basel	Chiasso – Gotthard	Chiasso - Gotthard	Chiasso - Gotthard
Trieste	Zurich	Chiasso – Gotthard	Chiasso - Gotthard	Chiasso - Gotthard
Trieste	Munich	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Trieste	Nuremberg	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Trieste	Stuttgart	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Trieste	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Trieste	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina
Trieste	Budapest	Tarvisio – Semmering	Villa Opicina – Ormoz	Tarvisio – Semmering
Trieste	Prague	Tarvisio – Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Trieste	Bratislava	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Trieste	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Rotterdam	Prato	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Parma	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Bologna	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Rotterdam	Busto A. - Gallarate	Gotthard – Varese	Gotthard - Varese	Gotthard - Varese
Rotterdam	Padua	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Verona Q.E	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Turin	Sempione - Loetschberg	Frejus	Frejus
Antwerp	Prato	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Parma	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Bologna	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Antwerp	Busto A. - Gallarate	Gotthard – Varese	Gotthard - Varese	Gotthard - Varese
Antwerp	Padua	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Verona Q.E	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Turin	Frejus	Frejus	Frejus
Hamburg	Prato	Brenner	Brenner	Brenner
Hamburg	Parma	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Hamburg	Bologna	Brenner	Brenner	Brenner
Hamburg	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso

Hamburg	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Hamburg	Busto A. - Gallarate	Gotthard – Varese	Gotthard - Varese	Gotthard - Varese
Hamburg	Padua	Brenner	Brenner	Brenner
Hamburg	Verona Q.E	Brenner	Brenner	Brenner
Hamburg	Turin	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Bremerhaven	Prato	Brenner	Brenner	Brenner
Bremerhaven	Parma	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Bremerhaven	Bologna	Brenner	Brenner	Brenner
Bremerhaven	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Bremerhaven	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Bremerhaven	Busto A. - Gallarate	Gotthard – Varese	Gotthard - Varese	Gotthard - Varese
Bremerhaven	Padua	Brenner	Brenner	Brenner
Bremerhaven	Verona Q.E	Brenner	Brenner	Brenner
Bremerhaven	Turin	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Le Havre	Prato	Gotthard- Chiasso	Frejus	Gotthard- Chiasso
Le Havre	Parma	Gotthard- Chiasso	Frejus	Gotthard- Chiasso
Le Havre	Bologna	Gotthard- Chiasso	Frejus	Gotthard- Chiasso
Le Havre	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Le Havre	Busto A. - Gallarate	Gotthard – Varese	Gotthard - Varese	Gotthard - Varese
Le Havre	Padua	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Verona Q.E	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Turin	Frejus	Frejus	Frejus
Marseilles	All Italian destinations	Ventimiglia	Ventimiglia	Ventimiglia
Rijeka	All Italian destinations	Villa Opicina (Illirska Bistrica)	Villa Opicina (Illirska Bistrica)	Villa Opicina (Illirska Bistrica)
Rijeka	Vienna	Maribor - Semmering	Maribor - Semmering	Maribor - Semmering
Rijeka	Basel	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard
Rijeka	Zurich	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard
Rijeka	Munich	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern
Rijeka	Nuremberg	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern
Rijeka	Stuttgart	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern
Koper	All Italian destinations	Villa Opicina (Presnica)	Villa Opicina (Presnica)	Villa Opicina (Presnica)
Koper	Vienna	Villa Opicina – Tarvisio – Semmering	Maribor - Semmering	Villa Opicina – Tarvisio – Semmering
Koper	Basel	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard
Koper	Zurich	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard
Koper	Munich	Villa Opicina – Tarvisio – Tauern	Karavanke - Tauern	Villa Opicina – Tarvisio – Tauern
Koper	Nuremberg	Villa Opicina – Tarvisio – Tauern	Karavanke - Tauern	Villa Opicina – Tarvisio – Tauern
Koper	Stuttgart	Villa Opicina – Tarvisio – Tauern	Karavanke - Tauern	Villa Opicina – Tarvisio – Tauern

The Semmering route, between Villach and Vienna, is crucial for connections from Italian ports to Vienna and to several Central-Eastern European destinations. Indeed, it is the only alternative to the path across Ljubljana, Ormoz and Hungary, which is tortuous and with low speeds for a wide extent (the Semmering route is tortuous for only a portion of 40 km, on a total route length of 340 km). In addition, Villach is connected to Italy through the Tarvisio line, which has been modernized recently. Also the Tauern line in Austria, between Villach and Salzburg, is widely used, in particular from the origin ports of Trieste, Koper and Rijeka to the destinations in southern Germany. The path across Villa Opicina and Slovenia is used: from Italian ports to the destinations of Zagreb, Ljubljana and Belgrade; from the origin ports of Koper and Rijeka to all destinations in Italy and Switzerland. Although the path across Villa Opicina is tortuous, it is the only possibility to reach these destinations.

The Brenner line is used for paths connecting the origin ports of Genoa, La Spezia and Leghorn (Ligurian ports) with the destination cities of south-eastern Germany: Munich and Nuremberg. Both the origin ports and the destinations which are connected through this rail line are of key importance.

Fig. 2. The main rail lines (represented in red) across Alpine passes (shown in blue).

The Ligurian coastal line, across Ventimiglia, is used by all paths having origin in Marseilles and destinations in all cities of northern Italy.

The Frejus line, instead, is included only in the shortest paths connecting Rotterdam, Antwerp and Le Havre with Turin. Indeed, the most convenient route from these ports to the majority of northern Italian destinations crosses the north of France, the cities of Strasbourg, Mulhouse and Basel, and continues to Italy through the Gotthard line. The path across the Frejus line is convenient, as far as the optimization by monetary costs is concerned, also for the origin port of Le Havre and destinations Prato, Parma and Bologna, although the shortest path by distance crosses the

Gotthard line. Indeed, while the Frejus line requires triple traction, which increases relevantly monetary costs, the rail track cost is, on the average, 1.5 €/km less in France than in Switzerland: in France it is around 3.7€/km, while in Switzerland it is 5.2€/km.

This analysis has been performed taking into account the current situation of rail lines. Indeed, it must be remarked that several base tunnels are currently under construction or planned: Brenner, Ceneri, Frejus and Semmering ones. All these tunnels will avoid the most steep and tortuous line sections.

The construction of these tunnels will increase the competitiveness of all these lines: they will be no longer "will special operation characteristics". As a result, some paths connecting O/D pairs will change. But, the construction of the new Ceneri base tunnel will further increase the competitiveness of the Gotthard line.

In 16 O/D pairs, out of a total of 120, a different Alpine pass is chosen in the optimizations by travel times and by monetary costs. Among them, in 5 O/D pairs the path chosen in the optimization by monetary costs is the same as in the optimization by generalized costs, while in 11 O/D pairs the path chosen in the optimization by travel times is the same as in the optimization by generalized costs. Among these 11 O/D pairs, 5 ones concern the destination Budapest, and the origin ports of Leghorn, Genoa, La Spezia, Venice and Trieste: the path across Tarvisio and Semmering results more convenient than the path across Ljubljana and Ormoz (which is the best path according to monetary costs) not only for travel times but also for generalized costs. For the origin port of Koper and the destinations in southern Germany (Munich, Nurember and Stuttgart), the path across Villa Opicina and Tarvisio is more convenient than the path across Ljubljana and Karavanke (which is the best path according to monetary costs) not only for travel times but also for generalized costs. All the other O/D pairs (among the 16 ones) concern: origins in Italian ports and destinations in Central-Southern European terminals, and origins in northern range ports and destinations in northern Italy. The paths across Gotthard or Loetschberg are chosen, for the optimization by travel times, in alternative to the paths across Frejus or Brenner passes, which are the most convenient ones from the monetary costs point of view.

5.4. The competition of the ports considered (the ports signed in red in fig.1) for the destinations in the "blue area"

In figures 3 – 11 the values of travel times, monetary costs and generalized costs, between the considered O/D pairs, are reported:

- Italian destinations: fig. 3 (travel times), fig. 4 (monetary costs), fig. 5 (generalized costs);
- Central-Southern European destinations: fig. 6 (travel times), fig. 7 (monetary costs), fig. 8 (generalized costs);
- Central-Eastern European destinations: fig. 9 (travel times), fig. 10 (monetary costs), fig. 11 (generalized costs).

The reported travel times are those obtained from the optimization by travel times; the reported monetary costs are those obtained from the optimization by monetary costs; the reported generalized costs are those obtained from the optimization by generalized costs.

Regarding Italian destinations, travel times and monetary costs are reported for: Prato, Parma, Bologna, Milan Segrate/Smistamento, Novara, Busto Arsizio – Gallarate, Padua, Verona, Turin. Milan Segrate and Milan Smistamento are considered together because they are adjacent, and they are the closest terminals to Milan city; however also Busto Arsizio – Gallarate is taken into account, because, as reported in Lupi et al. [68], it is the most important intermodal centre in Italy (it is quite near to Milan).

As far as Central-Southern European destinations are concerned, travel times, monetary costs and generalized costs are reported for: Vienna, Basel, Zurich, Munich, Nuremberg, Stuttgart.

As far as Central-Eastern European destinations are concerned, travel times, monetary costs and generalized costs are reported for: Zagreb, Ljubljana, Budapest, Prague, Bratislava, Belgrade.

For all destinations, the following origin ports, were considered: Leghorn, Genoa, La Spezia, Venice, Trieste, Koper, Rijeka, Marseilles, Le Havre, Antwerp, Rotterdam, Hamburg, Bremerhaven.

As far as the Italian destinations are concerned, the following can be observed.

For the destinations located in the north-western part of the Padan Plain, namely Busto Arsizio-Gallarate (the main intermodal terminal in Italy), Milan Segrate/Smistamento, Turin and Novara, the lowest travel times, monetary costs and generalized costs are shown by Genoa. For the destinations located in the eastern part of the Padan Plain, namely Verona and Padua, the origin port of Venice shows the lowest travel times, monetary costs and generalized costs. For the destinations located in the central part of the Padan Plain, namely Parma e Bologna, the lowest travel times, monetary costs and generalized costs are shown by the origin port of Venice, but similar values are also shown by Genoa (for destination Parma; indeed a little less as far as travel time and generalized cost are concerned) and Leghorn (for destination Bologna). But, it must be underlined that the position of Venice is not very favourable on the sea side (as for the other Adriatic ports), at least until nowadays, because, as shown in [9], it is crossed by only a few Deep Sea Shipping (DSS) container routes to/from Far East and it is disadvantaged in connections to the American continent. Instead, Ligurian ports are crossed by several DSS routes, directed to Far East and to the American continent. Among Ligurian ports, Leghorn shows the lowest travel times and costs for all North-Eastern Italian destinations: Verona, Padua and also for Bologna. Leghorn therefore can be competitive given its favorable sea side position for the routes towards the American continent; regarding the Europe - Far East route, Leghorn can be competitive given the current small number of DSS routes (from Far East) calling at the Adriatic ports of Venice and Trieste. Leghorn is the most favorable port, for the Verona destination and the Brenner rail axis, among the Ligurian ports. This is particularly important because Germany is Italy's top trading partner (12.6% of total Italian exports and 16,3% of total Italian imports, in 2016) [69].

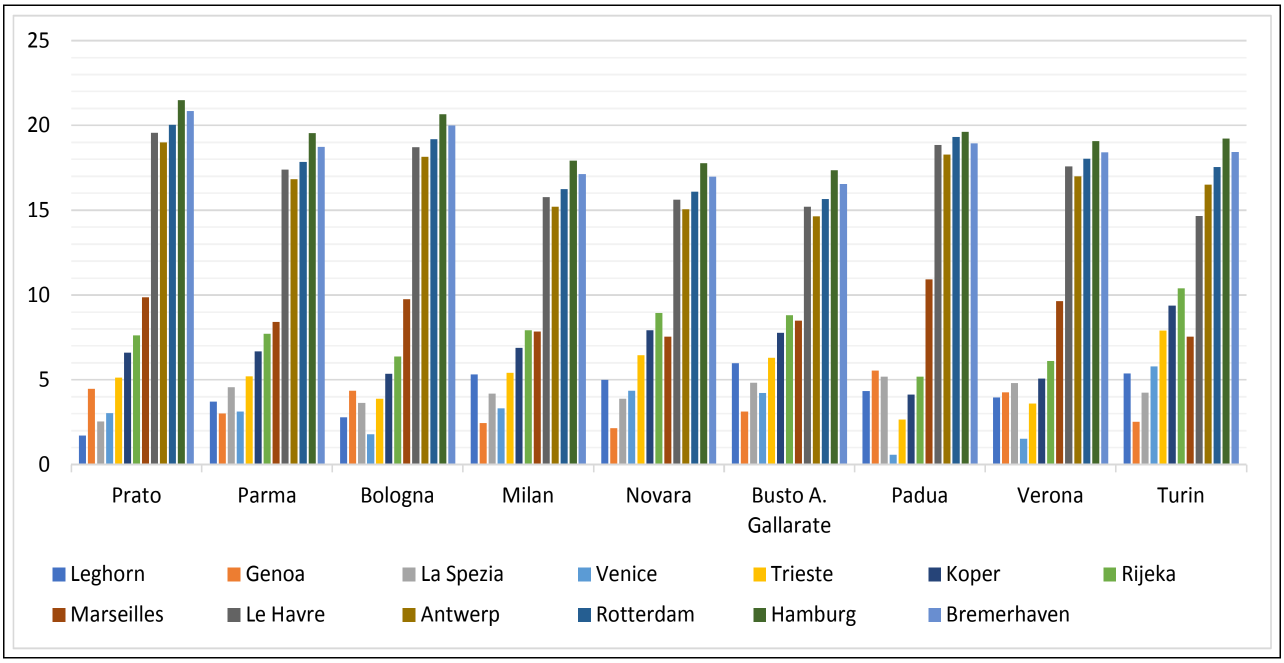

Fig. 3. Travel times (h) from the ports considered in the analysis, towards Italian destinations. Optimization by travel times.

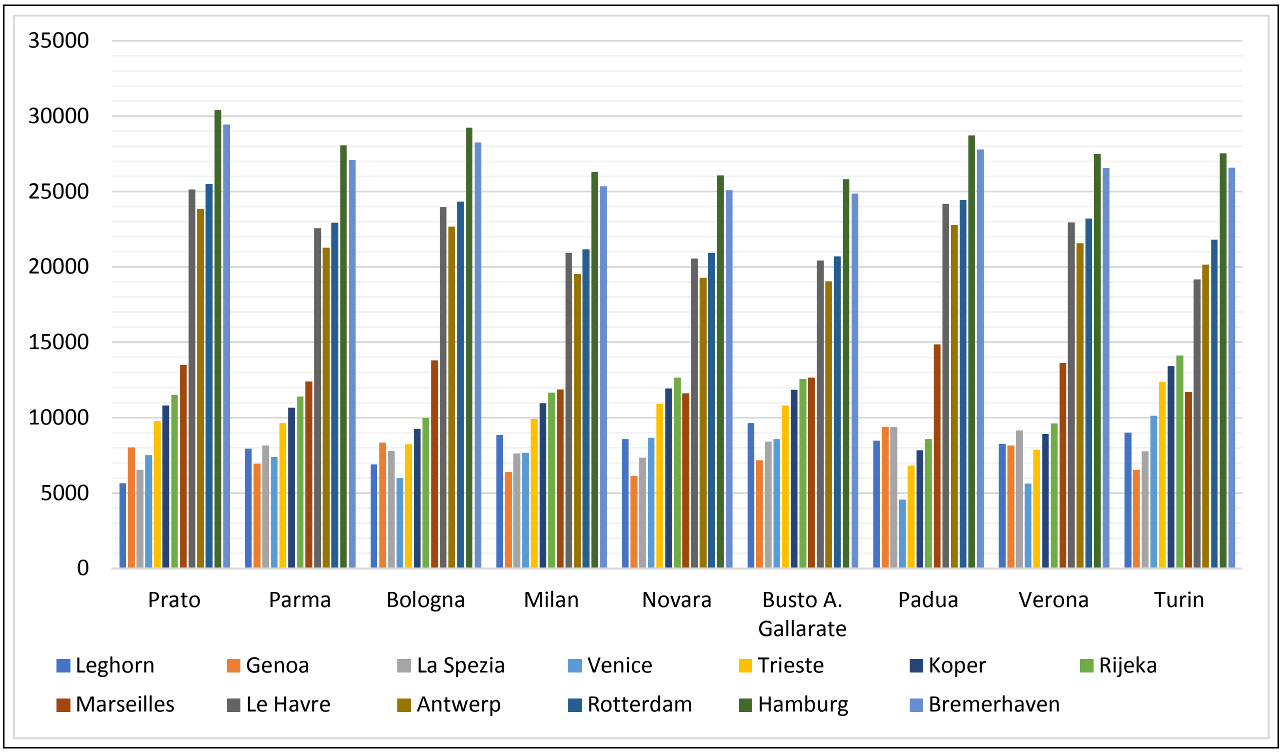

Fig. 4. Monetary costs of a full train (€) from the ports considered in the analysis, towards Italian destinations. Optimization by monetary costs.

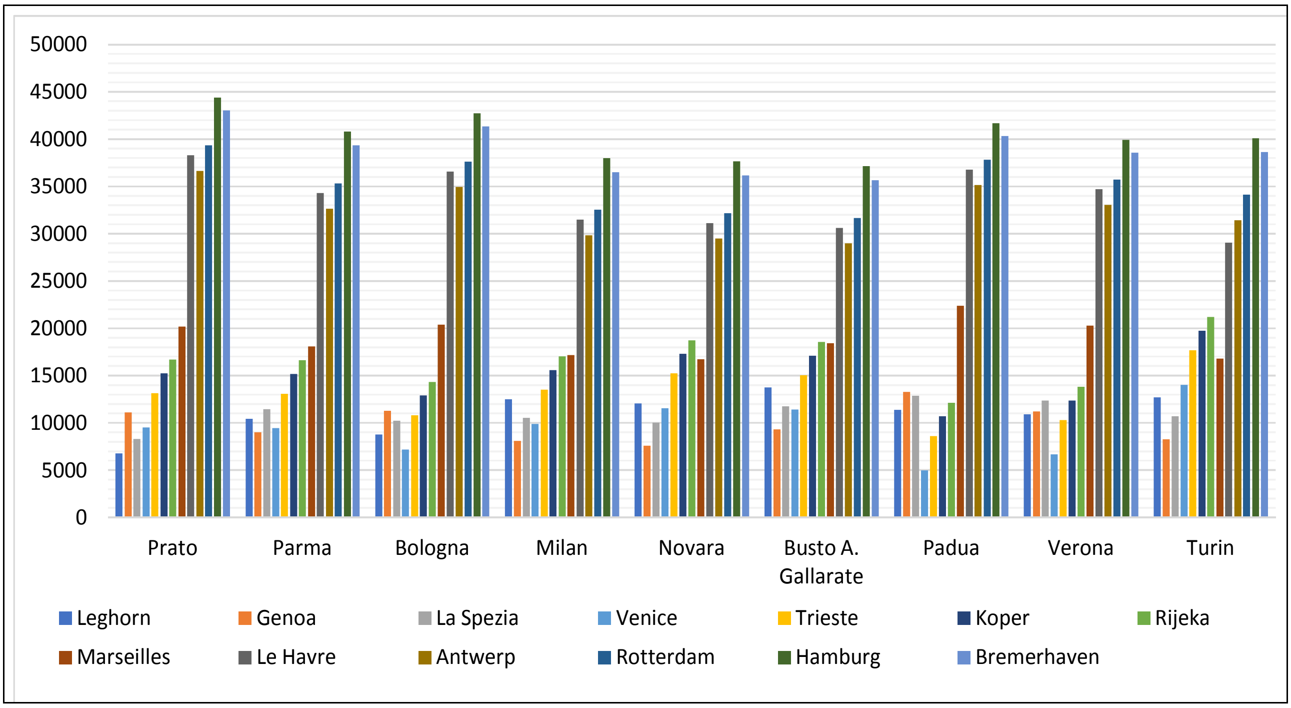

Fig. 5. Generalized costs of a full train (€) from the ports considered in the analysis, towards Italian destinations. Optimization by generalized costs

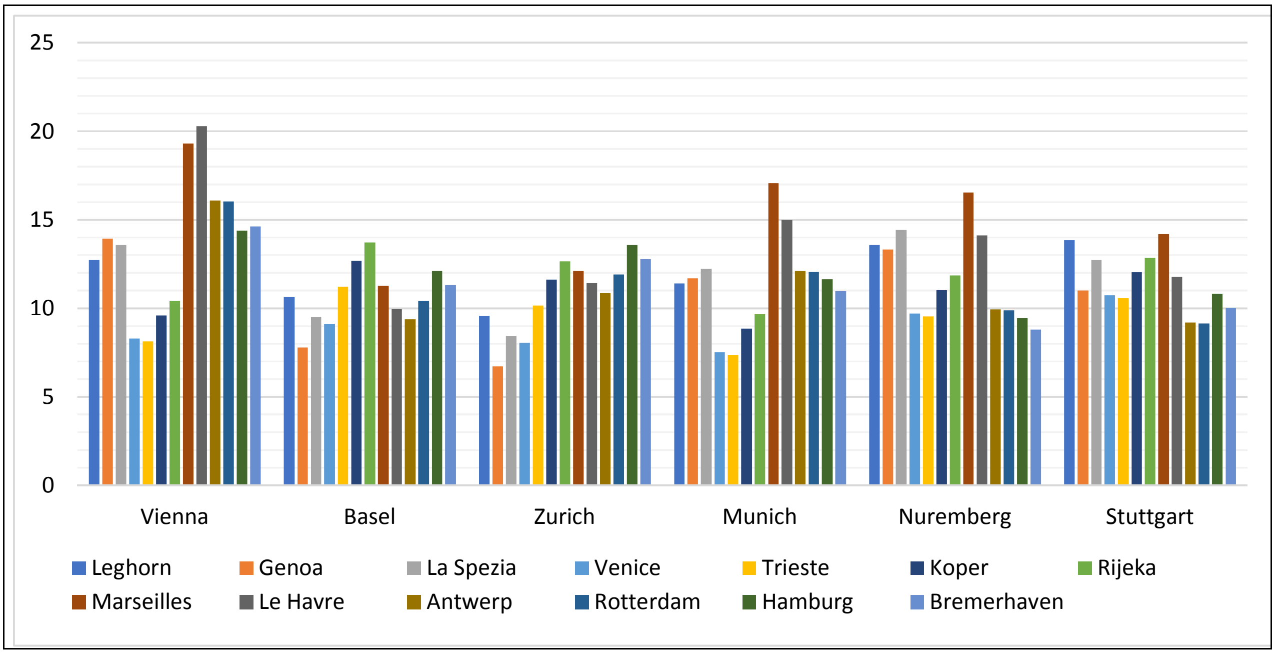

Fig. 6. Travel times (h) from the ports considered in the analysis, towards Central-Southern European destinations. Optimization by travel times.

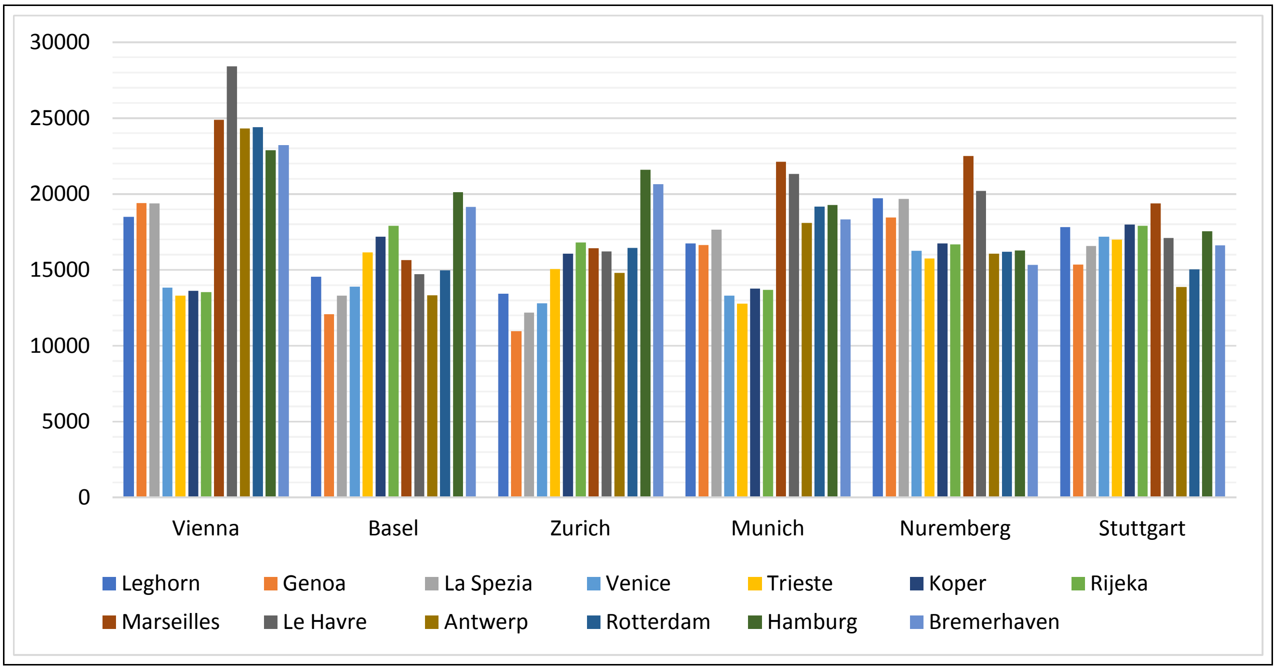

Fig. 7. Monetary costs for a full train (€) from the ports considered in the analysis, towards Central-Southern European destinations. Optimization by monetary costs.

Northern Italian destinations appear in the fundamental hinterland (core market) of Italian ports. But it must be underlined that, in spite of the much higher travel times and monetary costs (and generalized costs), northern range ports unload/load a noticeable quantity of containers with destinations/origins in northern Italy. Musso et al. [70] point out the main variables affecting port competition, which are not very developed in Italian ports: price for port operations, freight rates of shipping companies, port capacity, productivity of port terminals (e.g. number of crane movements per hour), competition among companies operating in the port. In addition, Dekker [71] points out that the idle times of a container at a northern European port are considerably less than those at Italian ports.

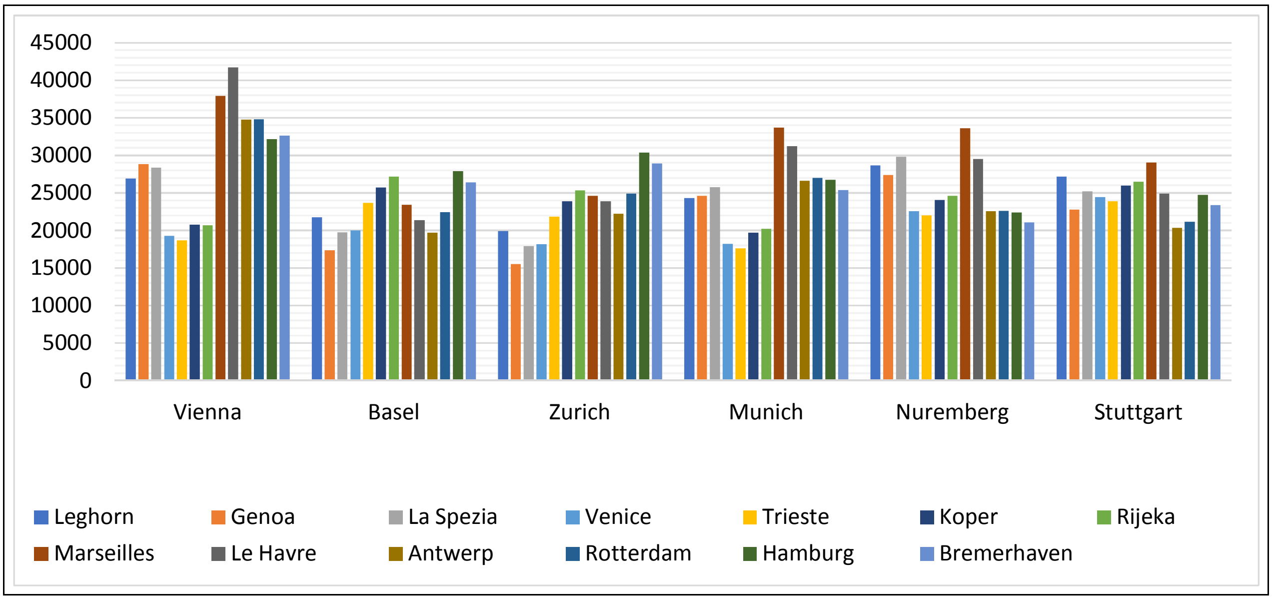

Fig. 8. Generalized costs for a full train (€) from the ports considered in the analysis, towards Central-Southern European destinations. Optimization by generalized costs .

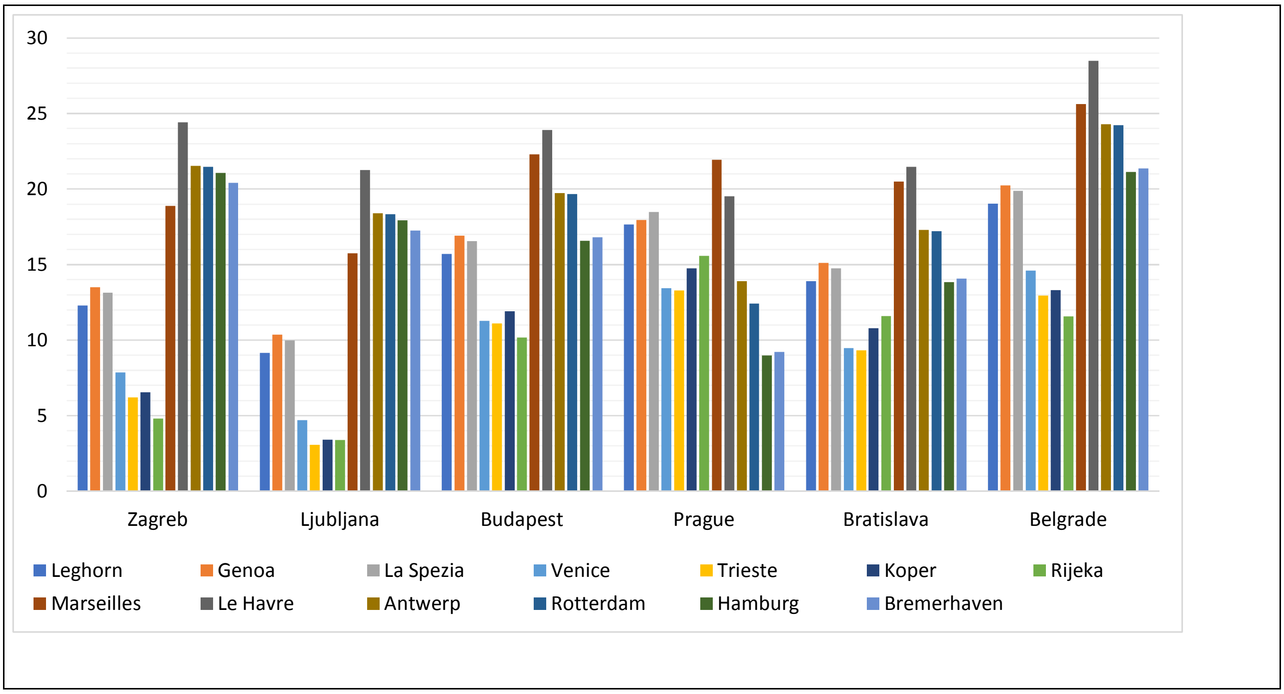

Fig. 9. Travel times (h) from the ports considered in the analysis, towards Central-Eastern European destinations. Optimization by travel times.

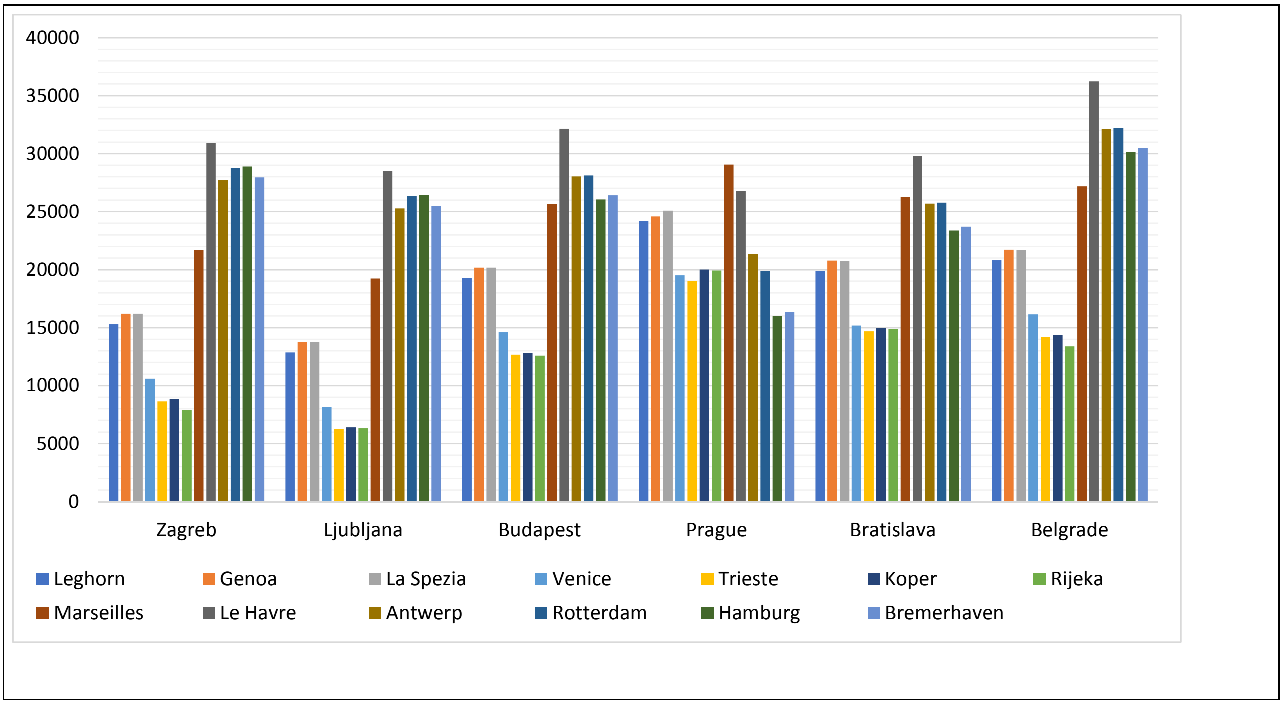

Fig. 10. Monetary costs for a full train (€) from the ports considered in the analysis, towards Central-Eastern European destinations. Optimization by monetary costs.

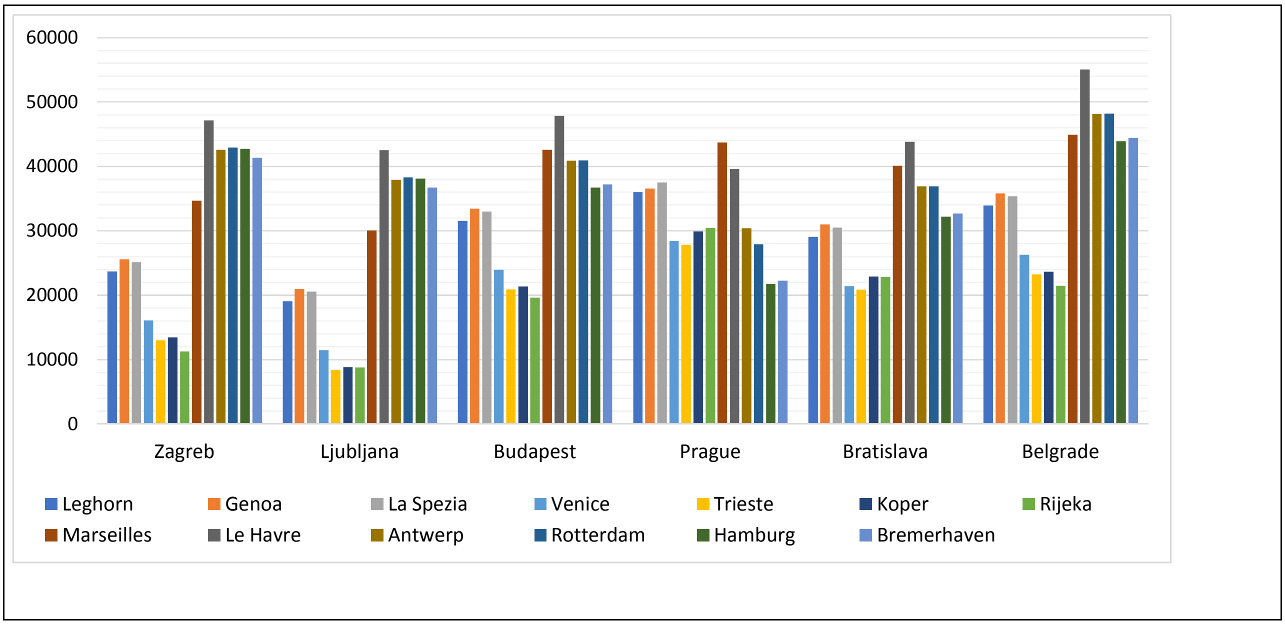

Fig. 11. Generalized costs for a full train (€) from the ports considered in the analysis, towards Central-Eastern European destinations. Optimization by generalized costs.

Concerning Central-Southern European destinations, for Basel and Zurich the port in the most advantageous position, for travel times, monetary costs and generalized costs, is Genoa.

Regarding the important destination of Munich (southern Germany), among Italian ports, the Adriatic ports of Venice and Trieste are the most favourable. But, as noticed before, Ligurian ports can be competitive for this destination: given the more favourable seaside position than Adriatic ports, for the routes towards the American continent; and for the route to Far East too, given the current small number of DSS routes from Far East calling at Adriatic ports. Among Ligurian ports, Leghorn is the most competitive. Among northern European ports, the German ports of Hamburg, and in particular of Bremerhaven, are in the most advantageous position for the destination Munich (indeed also Antwerp as far as the monetary costs are concerned). However, the German ports are farther than northern Adriatic ports: the distance from Trieste to Munich is 536 km, while the distance from Bremerhaven to Munich is 825 km. Travel times from Trieste to Munich are slightly lower than those from Venice to Munich, although Venice is closer to the Brenner rail axis than Trieste. Indeed, the best path from Trieste to Munich crosses the Tarvisio and Tauern lines, which are shorter than the Brenner line and are not "with special operation characteristics". The best paths connecting all the other Italian ports to Munich cross the Brenner rail axis.

As for the German destinations of Nuremberg and Stuttgart, instead, the ports in the most advantageous position are the northern range ones (these two cities are closer to the North Sea than Munich), in particular: Bremerhaven and Hamburg for Nuremberg (but Antwerp and Rotterdam have very similar costs); Antwerp and Rotterdam for Stuttgart. Finally, for the destination Vienna, the most favourable origin port is Trieste, from the point of view of travel times, monetary costs and generalized costs, but Venice is in a very similar situation and indeed, from the point of view of monetary costs, all the northern Adriatic ports are in a similar situation.

As regards Central-Eastern European destinations (Zagreb, Ljubljana, Budapest, Prague, Bratislava and Belgrade), the ports in the most advantageous position (from the point of view of travel times, monetary costs and generalized costs), for all destinations apart from Prague, are the Adriatic ones. Instead, Prague is located more in the north than all the other Central-Eastern European destinations, therefore the most favourable ports for this destination are the German ports of Hamburg and Bremerhaven.

To calibrate the model and validate the calculus, the results, in terms of monetary costs, have been compared with the prices practiced by some MTOs. In particular, a MTO transporting almost exclusively "maritime" containers (i.e. containers which have been unloaded from, or which will be loaded on container ships) applies the following prices:

- transport of 1 TEU by rail from La Spezia to Milan Melzo (10 km to Milan Segrate / Smistamento): 140 €.
- transport of 1 TEU from Rotterdam to Milan Melzo: 380 €.

The total monetary costs resulting from our model on these O/D pairs are the following:

- from La Spezia to Milan Segrate/Smistamento (close to Milan Melzo): 7629€ per train. Considering that each train carries, on the average, 62.5 TEUs, the cost per TEU is 122 €
- from Rotterdam to Milan Segrate/Smistamento: 21179€ per train, therefore, considering 62.5 TEUs carried on each train, they result 339 €/TEU.

6. Sensitivity analysis

In the sensitivity analysis, two different scenarios, which will be called in the following "1st" and "2nd sensitivity scenario", have been studied. Both scenarios concern only changes in the monetary costs calculation, and not in travel times.

In the 1st sensitivity scenario, the number of drivers has been set equal to 1 also in Italy, not only in the rest of Europe. Indeed only in Italy two drivers are needed by railway rules to operate freight trains, which results clearly in an increase of monetary costs. This scenario has been studied in order to quantify the impact of the staff cost on the overall monetary cost of the links.

The second sensitivity scenario has been chosen in order to study the impact of geometrical characteristics of rail lines, in particular of grades and curves, on the monetary cost of links. In order to "isolate" the effect of the line geometry, all the other components, which heavily influence the monetary cost, have been standardized. Therefore, the number of drivers has been taken equal to

1 in the whole Europe (also in Italy), and also the same value for the rail track cost and for the energy price has been taken for the whole "red area".

The rail track cost heavily influences the monetary cost of a link, and it is very different, in terms of €/km, not only from a country to another, but also from a line to another. For example, the rail track cost in Switzerland is very high, especially if compared to France. In this 2nd sensitivity scenario, the same rail track cost, equal to 3.284 €/km, has been considered for the whole "red area": this cost has been calculated as a weighted average of track costs of all lines in the "red area".

Moreover, the electric energy cost (in €/km) is equal to the energy consumption (in kWh/km) multiplied by the electricity price (in €/kWh); the energy cost also affects relevantly the monetary cost of a link. The electric energy consumption (in kWh/km) depends on the line geometry. But, the electricity price is very different from a country to another: for example, it is equal to 0.079 €/kWh in Slovenia and Hungary, 0.142 €/kWh in Italy and 0.15 €/kWh in Germany. As a result, a line in Slovenia with worse geometrical characteristics may show a lower energy cost than a line in Germany or Italy with better geometrical characteristics. Therefore a single electric energy price for the whole "red area" has been taken into account: the reference electricity price proposed in Baumgartner, equal to 0.1 €/kWh, has been considered.

As a result, in the 2nd sensitivity scenario the cost of a link, in €/km, is different, from a rail link to another, only because of quantities which depend on the geometrical characteristics of the link: the number of locomotives and the power consumption. Both these quantities depend only on the grade and curve resistances of each line section.

As far as the first sensitivity scenario is concerned, monetary costs of the 1st sensitivity scenario are compared with monetary costs of the current scenario. In tab. 9, differences, in percentage of monetary costs, between monetary costs of the first sensitivity scenario and monetary costs of the current scenario, are displayed. Only the comparison of monetary costs has been performed because, as stated at the beginning of this section, both sensitivity scenarios involve only changes in the calculation of monetary costs, and not of travel times.

Table 9. Differences, in percentage of monetary costs, between monetary costs of the first sensitivity scenario and monetary costs of the current scenario (the current scenario is taken as reference).

	Leghorn	Genoa	La Spezia	Venice	Trieste	Koper	Rijeka	Marseil-les	Le Havre	Antwerp	Rotterdam	Hamburg	Bremer-haven
Prato	-1.6%	-3.0%	-2.1%	-2.1%	-2.8%	-2.5%	-2.3%	-2.4%	-1.5%	-1.1%	-1.0%	-1.3%	-1.3%
Parma	-2.5%	-2.3%	-3.1%	-2.2%	-2.9%	-2.5%	-2.4%	-2.0%	-1.2%	-0.7%	-0.6%	-0.5%	-0.5%
Bologna	-2.1%	-2.8%	-2.5%	-1.6%	-2.5%	-2.1%	-2.0%	-2.3%	-1.4%	-0.9%	-0.9%	-1.2%	-1.2%
Milan Smistamento	-3.2%	-2.1%	-2.9%	-2.3%	-2.9%	-2.6%	-2.4%	-1.9%	-0.3%	-0.3%	-0.3%	-0.2%	-0.2%
Novara	-3.1%	-1.9%	-2.8%	-2.7%	-3.1%	-2.8%	-2.7%	-1.8%	-0.8%	-0.3%	-0.3%	-0.2%	-0.2%
Busto A. - Gallarate	-3.3%	-2.4%	-3.1%	-2.6%	-3.1%	-2.8%	-2.6%	-2.1%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
Padua	-2.7%	-3.2%	-2.9%	-0.7%	-2.1%	-1.7%	-1.6%	-2.7%	-0.9%	-1.0%	-0.9%	-1.1%	-1.2%
Verona Q. E.	-2.6%	-2.9%	-2.8%	-1.4%	-2.4%	-2.1%	-1.9%	-2.4%	-0.7%	-0.7%	-0.7%	-0.9%	-1.0%
Turin	-3.2%	-2.1%	-2.9%	-3.1%	-3.4%	-3.1%	-2.9%	-1.8%	-0.5%	-0.5%	-0.4%	-0.5%	-0.5%
Vienna	-2.1%	-2.4%	-2.2%	-1.1%	-1.1%	0.0%	0.0%	-2.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Basel	-2.3%	-1.5%	-2.0%	-1.7%	-2.1%	-2.0%	-1.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zurich	-2.4%	-1.6%	-2.2%	-1.8%	-2.3%	-2.1%	-2.0%	-1.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Munich	-2.8%	-3.0%	-2.9%	-1.1%	-1.1%	-0.6%	0.0%	-2.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Nuremberg	-2.4%	-1.0%	-1.4%	-0.9%	-0.9%	-0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stuttgart	-1.8%	-1.2%	-1.6%	-1.3%	-0.8%	-0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zagreb	-2.3%	-2.6%	-2.4%	-1.0%	-0.3%	0.0%	0.0%	-2.4%	-0.9%	0.0%	0.0%	0.0%	0.0%
Ljubljana	-2.7%	-3.1%	-2.8%	-1.4%	-0.4%	0.0%	0.0%	-2.7%	-0.9%	0.0%	0.0%	0.0%	0.0%
Budapest	-1.8%	-2.1%	-1.9%	-0.8%	-0.2%	0.0%	0.0%	-2.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Prague	-1.6%	-2.0%	-1.7%	-0.8%	-0.7%	-0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bratislava	-1.9%	-2.2%	-2.1%	-1.0%	-1.0%	0.0%	0.0%	-2.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Belgrade	-1.7%	-1.9%	-1.8%	-0.7%	-0.2%	0.0%	0.0%	-1.9%	-0.1%	0.0%	0.0%	0.0%	0.0%

As far as the second sensitivity scenario is concerned, again monetary costs of the 2nd sensitivity scenario are compared with monetary costs of the current scenario. Differences, in percentage of monetary costs, between monetary costs of the 2nd sensitivity scenario and monetary costs of the current scenario, are displayed in tab. 10.

Table 10. Differences, in percentage, of monetary costs, between monetary costs of the second sensitivity scenario and monetary costs of the current scenario (the current scenario is taken as reference).

	Leghorn	Genoa	La Spezia	Venice	Trieste	Koper	Rijeka	Marseil-les	Le Havre	Antwerp	Rotterdam	Hamburg	Bremer-haven
Prato	-0.6%	-1.3%	-0.8%	-0.9%	-1.3%	0.6%	1.5%	3.4%	3.7%	-2.0%	-2.0%	-6.4%	-6.4%
Parma	-0.9%	-1.0%	-1.5%	-0.7%	-1.1%	0.8%	1.7%	4.0%	4.4%	-1.9%	-2.0%	-7.6%	-7.6%
Bologna	-0.8%	-1.1%	-0.9%	-0.5%	-1.0%	1.2%	2.2%	3.4%	4.0%	-1.9%	-2.0%	-6.5%	-6.5%
Milan Smistamento	-1.5%	-1.0%	-1.5%	-0.9%	-1.2%	0.6%	1.5%	4.2%	4.3%	-2.0%	-2.0%	-8.0%	-8.0%
Novara	-1.3%	-0.6%	-1.2%	-1.1%	-1.4%	0.4%	1.2%	4.5%	5.4%	-1.7%	-1.8%	-7.8%	-7.8%
Busto A. - Gallarate	-1.6%	-1.2%	-1.7%	-1.1%	-1.4%	0.3%	1.2%	3.8%	4.6%	-1.8%	-1.9%	-8.0%	-8.0%
Padua	-1.0%	-1.4%	-1.1%	-0.3%	-1.0%	1.6%	2.7%	2.9%	3.5%	-2.0%	-2.0%	-5.5%	-5.4%
Verona Q. E.	-0.9%	-1.3%	-0.9%	-0.5%	-1.0%	1.3%	2.3%	3.4%	3.8%	-2.0%	-2.0%	-5.7%	-5.6%
Turin	-1.3%	-0.7%	-1.2%	-1.2%	-1.4%	0.1%	0.9%	4.4%	11.1%	1.2%	0.9%	-7.5%	-7.5%
Vienna	-2.5%	-2.6%	-2.4%	-2.7%	-2.9%	3.9%	5.2%	0.2%	2.5%	-5.6%	-5.6%	-9.2%	-9.1%
Basel	-5.8%	-6.4%	-6.2%	-6.2%	-5.7%	-4.2%	-3.4%	10.8%	11.6%	3.1%	2.5%	-6.5%	-6.4%
Zurich	-5.0%	-5.5%	-5.4%	-5.4%	-5.0%	-3.4%	-2.6%	-0.2%	9.1%	1.2%	0.8%	-7.1%	-7.1%
Munich	-2.5%	-4.8%	-3.5%	-3.2%	-3.4%	-1.4%	2.0%	-1.0%	5.5%	-1.1%	-5.5%	-6.4%	-6.3%
Nuremberg	-3.4%	-7.6%	-7.3%	-4.1%	-4.3%	-2.6%	0.2%	2.6%	6.3%	-5.0%	-5.0%	-6.1%	-5.9%
Stuttgart	-6.8%	-7.4%	-7.2%	-7.1%	-4.6%	-3.0%	-0.4%	4.4%	8.9%	1.1%	-4.7%	-6.2%	-6.1%
Zagreb	4.9%	4.3%	4.5%	7.8%	9.9%	11.1%	8.2%	5.8%	4.8%	0.4%	-2.6%	-3.2%	-3.0%
Ljubljana	1.8%	1.3%	1.6%	3.8%	5.5%	7.2%	6.7%	3.9%	3.4%	-1.6%	-4.8%	-5.4%	-5.3%
Budapest	9.0%	8.4%	8.5%	12.4%	14.6%	15.3%	14.4%	8.8%	4.2%	-2.6%	-2.7%	-9.2%	-9.1%
Prague	-5.6%	-7.1%	-5.4%	-6.5%	-6.7%	-5.2%	-2.9%	-0.7%	1.8%	-6.5%	-6.8%	-7.4%	-7.4%
Bratislava	-3.3%	-3.4%	-3.2%	-3.8%	-4.0%	2.3%	3.4%	-0.5%	1.7%	-6.0%	-6.0%	-11.6%	-11.6%
Belgrade	9.1%	8.5%	8.7%	12.2%	14.1%	14.8%	13.4%	8.9%	6.4%	0.8%	0.7%	-4.7%	-4.7%

The comparison between the 1st sensitivity scenario and the current scenario shows that the driver cost does not have a relevant impact in the overall cost function. Indeed, the maximum decrease of monetary costs, which occurs for O/D pairs where both the origin and the destination are located in Italy, is slightly above 3%. However, competition in freight transportation is very strong; profit margins are low and the price is often the decisive factor on the market. Therefore, a decrease by 3% does not change the situation, but it may be a little help to rail freight companies in intermodal competition.

Comparing instead the 2nd sensitivity scenario with the current scenario (tab.10), it could be observed that the impact of different rail track costs and of different energy prices is relevant: the changes of monetary costs are quite high. The maximum increase, between 12 and 15%, from the current scenario to the 2nd sensitivity scenario, concerns the destination of Budapest and the origins of Trieste, Venice, Rijeka and Koper. Indeed both rail track costs and energy prices in Slovenia, Croatia and Hungary are far below the European average values: the rail track cost in Slovenia is 1.9 €/km, in Croatia 1.59 €/km, in Hungary 1.54 €/km, while the European average rail track cost (taken into account in the 2nd sensitivity scenario) is 3.3 €/km; the energy price is Slovenia and Hungary is 0.079 €/kWh and in Croatia 0.09 €/kWh, while the European average energy price taken into account in the 2nd sensitivity scenario is 0.1 €/kWh.

Another relevant increase of monetary costs, from the current scenario to the 2nd sensitivity scenario, concerns the origin Le Havre and the destinations of Turin and Basel, again because the rail track costs in France are far below the average values: the average rail track cost in France is about 1.96 €/km while the European average rail track cost is 3.3 €/km; the energy price in France is instead 0.09 €/kWh, almost equal to the European average (reference) one.

The highest decreases of monetary costs occur for the origin ports of Hamburg and Bremerhaven and the destination Bratislava: actually the two paths between these O/D pairs cross Germany, Czech Republic and a small part of Slovakia, which show high track costs and energy prices in the current scenario. It is true that the track cost in Germany is 2.646 €/km, a bit below the average European one, but in Czech Republic it is very high: 6.55 €/km (the average track cost is 3.3 €/km); in Slovakia it is even higher: 9.24 €/km. On the other hand, the electric energy price in Germany is 0.15 €/kWh, far above the average value, while in Czech Republic it is 0.079 €/kWh, and in Slovakia 0.11 €/kWh: apart from Czech Republic, also the electricity price is above the average one.

In tab. 11, the crossing of Alpine passes in the 2nd sensitivity scenario, for each O-D pair, is compared with the current situation. The comparison involves both optimizations by monetary costs and by generalized costs. Indeed, in section 5 it was shown that sometimes the best path according to monetary costs crosses a different pass from the best path according to generalized costs. The choices of Alpine passes according to the optimization by travel times are not reported in tab. 11, because they are the same in the current scenario and in the 2nd sensitivity scenario: indeed, the methodology for the calculation of link travel times has not been changed.

Table 11. Railway lines crossing the Alps used to connect the considered O/D pairs. The 2nd sensitivity scenario (called in the table briefly "2nd scenario") is compared with the current one. Only O/D pairs which require the crossing of Alpine passes have been taken into account.

Origin	**Destination**	**Pass – optimization by monetary costs**		**Pass – optimization by generalized costs**	
		Current scenario	**2nd scenario**	**Current scenario**	**2nd scenario**
Leghorn	Vienna	Tarvisio – Semmering	Tarvisio – Semmering	Tarvisio – Semmering	Tarvisio – Semmering
Leghorn	Basel	Luino – Gotthard	Luino – Gotthard	Luino - Gotthard	Luino - Gotthard
Leghorn	Zurich	Luino – Gotthard	Luino – Gotthard	Luino - Gotthard	Luino - Gotthard
Leghorn	Munich	Brenner	Brenner	Brenner	Brenner
Leghorn	Nuremberg	Brenner	Brenner	Brenner	Brenner
Leghorn	Stuttgart	Luino – Gotthard	Luino – Gotthard	Luino - Gotthard	Luino - Gotthard
Leghorn	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Leghorn	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina	Villa Opicina
Leghorn	Budapest	Villa Opicina – Ormoz	Villa Opicina – Ormoz	Tarvisio – Semmering	Tarvisio – Semmering
Leghorn	Prague	Tarvisio – Tauern	Tarvisio – Tauern	Tarvisio – Tauern	Tarvisio –Tauern
Leghorn	Bratislava	Tarvisio – Semmering	Tarvisio – Semmering	Tarvisio – Semmering	Tarvisio – Semmering
Leghorn	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Genoa	Vienna	Tarvisio – Semmering	Tarvisio – Semmering	Tarvisio – Semmering	Tarvisio – Semmering
Genoa	Basel	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard
Genoa	Zurich	Luino - Gotthard	Luino - Gotthard	Luino - Gotthard	Luino - Gotthard
Genoa	Munich	Brenner	Luino - Gotthard	Brenner	Luino - Gotthard
Genoa	Nuremberg	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard
Genoa	Stuttgart	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard	Luino – Gotthard
Genoa	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova

Genoa	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina	Villa Opicina
Genoa	Budapest	Villa Opicina – Ormoz	Villa Opicina – Ormoz	Tarvisio – Semmering	Tarvisio – Semmering
Genoa	Prague	Brenner	Luino – Gotthard – St. Gallen	Brenner	Luino – Gotthard – St. Gallen
Genoa	Bratislava	Tarvisio - Semmering	Tarvisio – Semmering	Tarvisio - Semmering	Tarvisio – Semmering
Genoa	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
La Spezia	Vienna	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering
La Spezia	Basel	Luino - Gotthard	Luino - Gotthard	Luino - Gotthard	Luino - Gotthard
La Spezia	Zurich	Luino - Gotthard	Luino - Gotthard	Luino - Gotthard	Luino - Gotthard
La Spezia	Munich	Brenner	Luino - Gotthard	Brenner	Luino - Gotthard
La Spezia	Nuremberg	Luino – Gotthard	Luino - Gotthard	Luino – Gotthard	Luino - Gotthard
La Spezia	Stuttgart	Luino - Gotthard	Luino - Gotthard	Luino - Gotthard	Luino - Gotthard
La Spezia	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
La Spezia	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina	Villa Opicina
La Spezia	Budapest	Villa Opicina – Ormoz	Villa Opicina – Ormoz	Tarvisio – Semmering	Tarvisio – Semmering
La Spezia	Prague	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
La Spezia	Bratislava	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering
La Spezia	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Venice	Vienna	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Venice	Basel	Chiasso - Gotthard	Chiasso - Gotthard	Chiasso - Gotthard	Chiasso - Gotthard
Venice	Zurich	Chiasso - Gotthard	Chiasso - Gotthard	Chiasso - Gotthard	Chiasso - Gotthard
Venice	Munich	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Venice	Nuremberg	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Venice	Stuttgart	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Venice	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Venice	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina	Villa Opicina
Venice	Budapest	Villa Opicina – Ormoz	Villa Opicina – Ormoz	Tarvisio – Semmering	Tarvisio – Semmering
Venice	Prague	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Venice	Bratislava	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Venice	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Trieste	Vienna	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Trieste	Basel	Chiasso - Gotthard	Chiasso - Gotthard	Chiasso - Gotthard	Chiasso - Gotthard
Trieste	Zurich	Chiasso - Gotthard	Chiasso - Gotthard	Chiasso - Gotthard	Chiasso - Gotthard
Trieste	Munich	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Trieste	Nuremberg	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Trieste	Stuttgart	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Trieste	Zagreb	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova

Trieste	Ljubljana	Villa Opicina	Villa Opicina	Villa Opicina	Villa Opicina
Trieste	Budapest	Villa Opicina – Ormoz	Villa Opicina – Ormoz	Villa Opicina – Ormoz	Villa Opicina – Ormoz
Trieste	Prague	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern	Tarvisio - Tauern
Trieste	Bratislava	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering	Tarvisio - Semmering
Trieste	Belgrade	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova	Villa Opicina – Dobova
Rotterdam	Prato	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Parma	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Bologna	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Rotterdam	Busto A. - Gallarate	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese
Rotterdam	Padua	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Verona Q.E	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Rotterdam	Turin	Frejus	Sempione - Loetschberg	Frejus	Sempione - Loetschberg
Antwerp	Prato	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Parma	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Bologna	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Antwerp	Busto A. - Gallarate	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese
Antwerp	Padua	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Verona Q.E	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Antwerp	Turin	Frejus	Sempione - Loetschberg	Frejus	Sempione - Loetschberg
Hamburg	Prato	Brenner	Gotthard- Chiasso	Brenner	Gotthard- Chiasso
Hamburg	Parma	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Hamburg	Bologna	Brenner	Gotthard- Chiasso	Brenner	Gotthard- Chiasso
Hamburg	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Hamburg	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Hamburg	Busto A. - Gallarate	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese
Hamburg	Padua	Brenner	Brenner	Brenner	Brenner
Hamburg	Verona Q.E	Brenner	Brenner	Brenner	Brenner
Hamburg	Turin	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Bremerhaven	Prato	Brenner	Gotthard- Chiasso	Brenner	Gotthard- Chiasso
Bremerhaven	Parma	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Bremerhaven	Bologna	Brenner	Gotthard- Chiasso	Brenner	Gotthard- Chiasso
Bremerhaven	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Bremerhaven	Novara	Sempione -	Sempione -	Sempione -	Sempione -

		Loetschberg	Loetschberg	Loetschberg	Loetschberg
Bremerhaven	Busto A. - Gallarate	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese
Bremerhaven	Padua	Brenner	Brenner	Brenner	Brenner
Bremerhaven	Verona Q.E	Brenner	Brenner	Brenner	Brenner
Bremerhaven	Turin	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Le Havre	Prato	Frejus	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Parma	Frejus	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Bologna	Frejus	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Milan Segrate / Smistamento	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Novara	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg	Sempione - Loetschberg
Le Havre	Busto A. - Gallarate	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese	Gotthard - Varese
Le Havre	Padua	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Verona Q.E	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso	Gotthard- Chiasso
Le Havre	Turin	Frejus	Frejus	Frejus	Frejus
Marseilles	All Italian destinations	Ventimiglia	Ventimiglia	Ventimiglia	Ventimiglia
Rijeka	All Italian destinations	Villa Opicina (Illirska Bistrica)	Villa Opicina (Illirska Bistrica)	Villa Opicina (Illirska Bistrica)	Villa Opicina (Illirska Bistrica)
Rijeka	Vienna	Maribor - Semmering	Maribor - Semmering	Maribor - Semmering	Maribor - Semmering
Rijeka	Basel	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard
Rijeka	Zurich	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard
Rijeka	Munich	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern
Rijeka	Nuremberg	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern
Rijeka	Stuttgart	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern	Karavanke - Tauern
Koper	All Italian destinations	Villa Opicina (Presnica)	Villa Opicina (Presnica)	Villa Opicina (Presnica)	Villa Opicina (Presnica)
Koper	Vienna	Maribor - Semmering	Villa Opicina – Tarvisio – Semmering	Villa Opicina – Tarvisio – Semmering	Villa Opicina – Tarvisio – Semmering
Koper	Basel	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard
Koper	Zurich	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard	Villa Opicina - Gotthard
Koper	Munich	Karavanke - Tauern	Villa Opicina – Tarvisio – Tauern	Villa Opicina – Tarvisio – Tauern	Villa Opicina – Tarvisio – Tauern
Koper	Nuremberg	Karavanke - Tauern	Villa Opicina – Tarvisio – Tauern	Villa Opicina – Tarvisio – Tauern	Villa Opicina – Tarvisio – Tauern
Koper	Stuttgart	Karavanke - Tauern	Villa Opicina – Tarvisio – Tauern	Villa Opicina – Tarvisio – Tauern	Villa Opicina – Tarvisio – Tauern

In tab. 11 it is clearly shown that the lines through Switzerland are chosen more frequently, especially for the origin port of Genoa, in the 2nd sensitivity scenario. Indeed, the rail track cost of Swiss lines is very high, far above the European average. The usage of the Brenner line, but in particular of the Frejus line, decreases relevantly: the Frejus line, in the 2nd sensitivity scenario, is used only for the origin port of Le Havre and the destination of Turin; instead of the Frejus line, the lines through Switzerland are chosen, specially the Gotthard and the Sempione – Loetschberg ones.

Other differences, between the current scenario and the 2nd sensitivity one, concern the origin port of Koper and the destinations in Austria and southern Germany. In the current scenario, for destinations Munich, Nuremberg and Stuttgart, the path across Ljubljana and Karavanke is chosen, while in the 2nd sensitivity scenario the path across Villa Opicina and Tarvisio is the best one. For the destination of Vienna, in the current scenario the path across Ljubljana, Maribor and Semmering is chosen, while in in the 2nd sensitivity scenario the path across Villa Opicina, Tarvisio and Semmering lines is chosen. This occurs because the electricity price is much higher in Italy than in Slovenia (in Italy it is 0.142 €/kWh while in Slovenia it is 0.079 €/kWh), therefore if the same energy price of 0.1 €/kWh is taken, the lines across Italy decrease their monetary cost, while the lines through Slovenia increase their monetary cost. Also the track cost is higher in Italy than in Slovenia: 2.3 €/km against 1.9 €/km: therefore in the 2nd sensitivity scenario the track cost of Italian lines increases less than the track cost of Slovenian lines. In addition, the lines through Slovenia show greater grade and curve resistances than the line across Tarvisio, which has been renewed completely in two steps in 1995 and 2000.

In brief, taking a single value, for the whole "red area", of rail track costs and of electric energy prices, has shown which would be the most chosen lines because of their geographical position and of their performance. The line across Gotthard, and in particular its branches through Chiasso and Luino, is the most important line for connections between Italian and northern European terminals. Indeed this line has a favourable position, as it is on the way to the ports of Antwerp, Rotterdam, Hamburg, Bremerhaven, but also Le Havre, but it shows also good geometrical characteristics: the new Gotthard base tunnel has been constructed with low slopes, therefore double traction is necessary only for a small portion of the line, across the Ceneri pass, where, currently, a new base tunnel is under construction. On the other hand, the Brenner line requires double traction and, partially, triple traction, while in the Frejus line trains are operated with three locomotives. The construction of the new Brenner and Frejus base tunnels would increase the choice of these lines: the Brenner line is crucial for the Italian economy because Germany is Italy's top trading partner. As far as Central-Eastern European lines are concerned, the most used line crosses Tarvisio pass, because it shows better geometrical characteristics than the path across Ljubljana and Ormoz and the line of Karavanke. The Tarvisio line will further increase its importance when the new Semmering base tunnel, which is currently under construction, will be opened, because it is part of an alternative path to the one across Ljubljana and Ormoz.

7. Conclusions

In this paper, the potential hinterland (competition margin) of the new container terminal of the port of Leghorn was analyzed. However, the study actually consists of an analysis of the competitiveness of some main Mediterranean and northern European ports, to serve some of the most contestable regions in Europe. These regions are: Switzerland, southern Germany, Austria, the Padan Plain in Italy, and some other important destinations in Central-Eastern European countries.
The optimal rail paths, from the origin ports to the destination cities, have been determined. The rail network of a large part of Europe has been modelized through a graph. For the computation of monetary costs of rail links, only a few cost functions exist in the literature and, generally, they are not very detailed. Therefore, in this paper, a new cost function for rail transport has been developed. The new cost function takes into account: staff cost; amortization, maintenance and insurance costs of locomotives and wagons; rail track usage cost; traction cost. All these costs have been calculated in detail for each line; but in particular the traction cost has been determined precisely given all the

resistances to motion. In order to calculate these resistances, in particular the grade and curve ones, and the number of locomotives necessary to operate the train, detailed information on the geometry of each rail line has been collected, with special concern for the lines crossing the Alps (for which also the operation rules used by the rail transport companies, which effectively operate the services, have been assumed).

The monetary value of time in freight transport registers a high variability, therefore three different optimizations, of the paths between each O/D pair, have been carried out: not only by generalized costs, but also by travel times and by monetary costs. The comparison of the optimizations results has shown that the differences, in monetary costs, travel times and generalized costs, obtained from the three optimizations, are not relevant; the most marked differences concern the destination of Budapest and the optimizations by travel times and monetary costs, because a completely different path is chosen in each optimization.

Moreover, the railway lines, crossing Alpine passes, used to connect each O/D pair have been determined. This analysis has pointed out that the most used lines are: the Gotthard line, the Brenner line, and the lines across Tarvisio, Semmering and Tauern passes; but also the path across Villa Opicina and Ljubljana is used for several Central-Eastern European destinations.

A sensitivity analysis has been performed, on some parameters that influence the monetary cost of a link: the staff cost, the rail track cost, the energy price.

The first sensitivity analysis, aimed at understanding the importance of the staff cost, has shown that this quantity does not influence the monetary costs of the O-D paths relevantly.

The second sensitivity analysis has shown that the rail track cost and the electric energy price heavily influence the overall monetary costs of O-D paths. The Swiss lines, which register a high rail track cost (5.2 €/km), much higher than the European average (3.3 €/km), would be used to connect a greater number of O/D pairs if the same rail track cost was taken for the whole Europe. Also the Tarvisio line would be used to connect a greater number of O/D pairs if the same energy price for the whole Europe was considered: the electric energy price in Italy (0.142 €/kWh) is much higher than the average European price (0.1 €/kWh), taken into account in the 2^{nd} sensitivity analysis.

In general, the most favourable rail lines across Alpine Passes, because of their geographical position and of their geometric characteristics (reduced slopes and tortuosity), are: the Gotthard line for Central-Southern European destinations, and the Tarvisio line for Central-Eastern Europe. The Brenner line has a very favourable position, but it is disadvantaged by its geometric characteristics, because double (on the Italian side) and triple (on the Austrian side) traction is required; but a new base tunnel is under construction on the Brenner line.

As far as the competitiveness of the port of Leghorn is concerned, after the construction of the new container terminal, the following has resulted from the analysis performed in this paper.

The port of Leghorn will become competitive, beyond its fundamental hinterland (some regions of Central Italy), not only for north-eastern Italian destinations, but also for some Central-Southern and Central-Eastern European ones.

As regards north-eastern Italy, the research has shown that Leghorn has good possibilities to attract into its hinterland Verona and other destinations on the Brenner rail axis, particularly the German city of Munich. Indeed, for these destinations, Trieste and Venice are in a more favorable position as far as the landside is concerned, but Ligurian ports are crossed by regular DSS direct services to/from Far East, while, currently, Adriatic ports are mainly crossed by feeder routes. Among the Ligurian ports, Leghorn is in the best position. Moreover, the geographic position of Leghorn, and of the other Ligurian ports, is certainly favourable for connections to/from the American continent. In any case, Munich (fig. 6-8) is one of the most contestable destinations in Europe (practically from almost all ports considered in the research).

It is important to notice that Northern Adriatic ports, basing on the results of figures 6–11, are in a very good position, on the land side, to serve several destinations in Central-Southern and Central-Eastern Europe, once they will be crossed by direct DSS routes to Far East.

Leghorn has also the possibility to attract into its hinterland some regions of Central-Eastern Europe. For all these regions, the most favourable unloading/loading ports are clearly northern Adriatic ones. But, basing on the results of the research, Leghorn can be competitive, especially for routes to/from the American continent.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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