POTENTIALITY OF RAIL NETWORKS: INTEGRATED SERVICES ON CONVENTIONAL AND HIGH-SPEED LINES

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ABSTRACT

56,000 km of high-speed rail lines have been built around the world, and another 74,000 km are being built or planned. During the extension of high-speed infrastructures, it is possible to design services that use high-speed lines and conventional lines, in relation to where high-speed has not yet been fully realized. In fact, there is potentiality in existing rail networks, not used for the realization of integrated services that although not of high speed, are better, in terms of travel time, than the conventional ones. An important example is the rail system in Italy, which covers the central and northern areas of the country with high-speed, but it is absent in the south and in Sicily, the large island separated from Italy by a maritime strait. The current services with their travel times from the metropolitan cities of Sicily to Rome, were analysed. An integration of the services is proposed in the hypothesis of no infrastructural changes to the railway lines and terminals and the use of trains and ships available. The results obtained are useful to public planners and technicians of national public departments and railway, as they are able to know what time reductions are possible without any investment. The method used can be applied in other countries where there are high-speed lines and it is possible to create services that use the existing high-speed network and the conventional one.
Keywords: high speed railway, conventional lines, optimization of rail services, integrated service, zero cost and zero time.

1 INTRODUCTION

According to data updated to 2021 [1], the high-speed rail (HSR) lines in the world are: 56,129 km in operation, 22,562 km under construction, 18,781 km medium term planned, 33,005 km long-term planned, for a total of 130,477 km.

From the analysis of the international framework, the benefits of HSR emerge in a very clear way, so much so that all countries are developing impressive programs for the construction of new lines. High-speed networks are increasingly decisive in the development of territories, particularly those less developed [2]. During the extension of high-speed infrastructures, it is useful to analyze the potentiality of conventional and HSR networks to design services that use high-speed lines and conventional lines, where high-speed has not yet been fully realized.

Italy is one of the countries that first built high-speed railway lines. The transport planning documents drawn up by the national government, on the basis of in-depth analyses [3], have established that the extension of the HSR to southern Italy is one of the priorities of the country [4]–[6]. Priority is also set out in all regional plans of the regions crossed [7].

The construction of the high speed for the south, with the stable crossing of Messina Strait, still takes years, and although starting now it would not be completed before a decade. In this context, it is useful and necessary to make the best use of existing infrastructures, reorganizing some significant services. The case study is that of the HSR connection between the capital and the metropolitan cities of Sicily. From the analyzes carried out it emerges the possibility of reducing the current times without any infrastructural intervention, only by

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optimizing the schedules of the services. There is also the possibility of obtaining further reductions with specific interventions on the compositions of the trains.

This problem is of great interest to the set of countries that build new HSR lines. This set first includes the two large blocks of the European Union [8] and China [9], but extends from Saudi Arabia [10] to Morocco, to the trans-Asian lines up to the new lines in the USA [11].

The aim of the paper is therefore to investigate the possibility of creating services with better times than those that take place exclusively on conventional networks, creating routes that take place partly on high-speed lines and partly on conventional lines. The goal is usually shared theoretically by all users, while in practice it is not often pursued.

The method used operates in two stages. In the first phase, the current state of the services available on the infrastructure lines of the two types is reconstructed. In the second phase, a reorganization is proposed with integration between services currently already available. The proposal for integrated services is made on the assumption that no amount is spent on infrastructures and on means: ships and trains. The proposal, based on these characteristics, can therefore be called zero cost and zero time.

In Section 2 the first phase is described. The current situation is presented with a summary of the infrastructural situation of both the HSR network and the conventional network. The structure of the current services is then recalled considering the best services already active on the high-speed network, on the conventional network and on the maritime arcs. In Section 3 the second phase is described. The plans for the construction of the HSR in the south and for upgrading the conventional network are first briefly recalled. Then hypotheses are introduced for an integration of existing services with their combination. The results are presented, demonstrating that, by integrating the services already available on the different infrastructure networks, it is possible to obtain new services that to reduce the current travel times.

The proposed approach can be easily updated, every year, in the system considered as the high-speed infrastructure network grows. The approach can be implemented in all areas where extensions of high-speed networks are being realized, considering that there are 74,000 km under construction. The issue of service integration is therefore of particular interest both to planners operating at national level in the relevant ministries and to service planners within railway companies. The integration of services is of interest to researchers because it allows on the one hand to formulate general models, and algorithms for the use of networks with different characteristics and because it allows to study during the design of new HSR lines, the commissioning of individual parts of the new HSR and conventional lines.

2 ANALYSIS OF THE CURRENT STATE

This section analyzes the current situation of the railway network in the south of Italy and the available rail services with reference to the main route connecting Rome and Sicily. The first part briefly describes the three infrastructure subsystems involved: the HSR network, the conventional network and the maritime connection that allows the transshipment of trains. The second part describes the rail services that are now available to users for long and medium distances considering: connection services between Rome and the extreme south of the peninsula; crossing services; internal services in Sicily.

2.1 Infrastructures

The railway section considered is part of the Scandinavia–Mediterranean corridor which extends from the Russian–Finnish border and from the Finnish ports of Hamina Kotka, Helsinki and Turku-Naantali to Stockholm, passing through southern Sweden, Denmark, Germany, western Austria, Italy up to Malta [12]. The part of this corridor that affects Italy is shown in Fig. 1(a). The HSR network reaches Salerno, further south the network is of the conventional double-track type and in Sicily some sections are single-track. There is also a maritime link that allows trains to pass through the Messina Strait. Fig. 1(b) illustrates the parts of the corridor in southern Italy with the peninsular part from Rome to Villa S. Giovanni (the extension of the HSR network in dashed) and the island parts from Messina to Catania and Palermo.

(a) (b)

Figure 1: Scandinavian–Mediterranean corridor intersecting Italy [12], [13].

2.2 Services

The study of rail services must be developed on the basis of the demand for the use of services. Nationwide services have characteristics of high regularity and models that simulate demand pose the regularity of services as a basic element [14], [15]. Based on the demand it is possible to know the impacts [16], [17]. In the present case, there is a large potential demand for the relations considered [18]. It is interesting to consider the complexity of the case study, which also contains sea links [19]. The demand is estimated in relation to the complete HSR line, but a part can manifest itself with the supply of integrated services that allow to reduce the current travel times on the conventional line.

To analyze the current travel times on the railway routes from Sicily (Catania and Palermo) to Rome, the Palermo–Rome and Catania–Rome routes were considered and, for simplicity of presentation, the analysis reported concerns only even trains (south–north and east–west directions), that is, trains that go from Sicily to Rome. For the routes considered, the direct connections without service breakage (i.e. those in which there is no transshipment of travelers) have been deduced from the Trenitalia timetable consulted on 10 March 2021 with reference to trips made on 11 March 2021. The analyses described below have been conducted by disaggregating the relationships into island and continental sections. The abbreviation IC stands for intercity, the abbreviation RV and R for fast regional train and for regional train.

2.2.1 The route Villa S. Giovanni–Rome

Considering the Trenitalia timetable, it emerges that the route is covered in 6 h 44 min by the IC 728 train. The IC 728 is recalled here because it is one of the fastest trains in the connection between Sicily and Rome. The stop times are 2 min except for the stations of Lamezia Terme, Paola and Salerno (3 min) and central Naples (14 min).

The main factors for the different sections, in terms of time from the timetable, and physical and technological characteristics from line sheets [22]–[25], are shown in Table 1.

Table 1: Characteristics of the sections and of the performance of the IC 728 train on the Villa S. Giovanni–Rome Termini line.

Section	Line type	No. tracks	Traction type	Distance (km)	Time (minutes)
Villa S. Giovanni–Gioia Tauro	Conv	2	3kV	36.528	25
Gioia Tauro–Lamezia	Conv	2	3kV	69.703	36
Lamezia–Paola	Conv	2	3kV	56.870	31
Paola–Sapri	Conv	2	3kV	92.212	48
Sapri–Salerno	Conv	2	3kV	124.492	74
Salerno–Napoli Central	Conv	2	3kV	53.090	40
Napoli Central–Aversa	Conv	2	3kV	19.220	16
Aversa–Formia	Conv	2	3kV	50.077	31
Formia–Latina	Conv	2	3kV	67.225	36
Latina–Rome T.ni	Conv	2	3kV	61.018	34

2.2.2 The crossing of Strait of Messina

The evaluation of the crossing time of the Strait of Messina was carried out considering the time between the arrival at the Messina central station and the departure from the Villa S. Giovanni station for direct connections without service breakage (i.e. those in which there is no transshipment of travelers).

The origins from Palermo and Catania were analyzed. The Milazzo–Lamezia Terme and Taormina–Lamezia Terme routes are examined for the pair of trains IC 728–IC 722 and for the pair of trains IC 730–IC 724. The crossing times are summarized in Table 2.

Table 2: Characteristics of the crossing times of the Strait of Messina.

Train number	Time	
	(hours)	(minutes)
728	2	10
722	1	57
730	1	55
724	2	05

2.2.3 The route Palermo–Messina

The analysis shows that the route is covered in 2 h 50 min by train IC 728 and in 2 h 43 min by train RV 5364. So, it is clear that the RV fast regional train makes two intermediate stops more than the IC but takes 7 min less to travel the route. The RV train will therefore be considered in the subsequent integration proposal.

The stopping times at the stops are 2 min for the IC train and 1 min for the RV train with the exception, for the latter of the S. Agata station where it stops for 4 min. Altogether you have 14 min stop for the IC train and 12 min stop for the RV train.

The main factors for the different sections, in terms of time from the timetable, and physical and technological characteristics from line sheet [20], are shown in Table 3.

Table 3: Characteristics of the sections and of the performance of the RV 5364 and IC 728 trains on the Palermo–Messina line.

Section	Line type	No. tracks	Traction type	Distance (km)	Time (minutes)	
					RV 5364	IC 728
Palermo Central–Termini	Conv	2	3kV	36.415	24	23
Termini–Campofelice	Conv	2	3kV	16.378	9	18
Campofelice–Cefalù	Conv	2	3kV	14.001	10	
Cefalù–S. Stefano	Conv	1	3kV	31.219	23	47
S. Stefano–S. Agata	Conv	1	3kV	27.265	20	
S. Agata–Capo d'Orlando	Conv	1	3kV	13.363	9	9
Capo d'Orlando–Patti	Conv	1	3kV	23.705	18	19
Patti–Barcellona	Conv	2	3kV	21.910	11	12
Barcellona–Milazzo	Conv	2	3kV	7.939	5	5
Milazzo–Messina Central	Conv	2	3kV	31.578	22	23

2.2.4 The route Catania–Messina

The analysis shows that the route is traveled in 1 h 12 min from IC 722 train, 1 h 27 min from IC 724 train, 1 h 34 min from train R 5384, 1 h 24 min from the RV 5386 train.

It can be noted that the IC 724 train, while making the same stops with the same duration, takes 15 min longer than the IC 722 train. In addition, the R train makes seven more stops than the IC 722 train and takes only 7 min longer. Finally, the RV train makes three more stops than the IC 724 train and takes 3 min less. Also, in this case the stopping times are 2 min for the IC trains and 1 min for the R and RV trains with the exception, for the R 5384 train, of the Letoianni station where it stops for 5 min and, for the RV 5386 train, of the S. Teresa di Riva station where it stops for 4 min. Altogether you have 6 min stop for the IC trains, 14 min stop for the R train and 9 min for the RV train. Then there are various possibilities for a decisive improvement in services on national routes.

The main factors for the different sections, in terms of time from the timetable, and physical and technological characteristics from line sheet [21] are shown in Tables 4 and 5.

Table 4: Characteristics of the sections and of the performance of the IC 722 and IC 724 trains on the Catania–Messina line.

Section	Line type	No. tracks	Traction type	Distance (km)	Time (minutes)	
					IC 722	IC 724
Catania Central–Acireale	Conv	2	3kV	13.054	10	10
Acireale–Giarre	Conv	2	3kV	16.757	9	10
Giarre–Taormina	Conv	1*	3kV	17.951	12	12
Taormina–Messina Central	Conv	1**	3kV	47.009	35	49

* Partially double track – from Giarre to Fiumefreddo (8.222 km);
** Partially double track – from Giampilieri to Messina (13.354 km).

Table 5: Characteristics of the sections and of the performance of the RV 5384 and RV 5386 trains on the Catania–Messina line.

Section	Line type	No. tracks	Traction type	Distance (km)	Time (minutes)	
					RV 5384	RV 5386
Catania Central–Acireale	Conv	2	3kV	13.054	11	9
Acireale–Giarre	Conv	2	3kV	16.757	9	10
Giarre–Fiumefreddo	Conv	2	3kV	8.222	6	7
Fiumefreddo–Taormina	Conv	1	3kV	9.729	8	9
Taormina–Letojanni	Conv	1	3kV	4.943	7	13
Letojanni–S. Teresa Riva	Conv	1	3kV	9.873	9	
S. Teresa Riva–Furci	Conv	1	3kV	2.226	2	7
Furci–Roccalumera	Conv	1	3kV	1.514	2	
Roccalumera–Alì terme	Conv	1	3kV	4.643	4	
Alì Terme–Giampilieri	Conv	1	3kV	8.456	6	20
Giampilieri–Messina Central	Conv	2	3kV	13.354	16	

3 INTEGRATION OF SERVICES

This section analyzes the planned situation of the HSR and conventional railway infrastructure network in the south of Italy and the proposal for rail services that can immediately be realized with reference to the main route connecting Rome and Sicily. The projects are first briefly recalled. The railway services available today are examined by verifying the upgrades that can be implemented, based on what was seen in Section 2, at no cost and at no time. The macro characteristics of the means necessary to carry out the services are recalled: ships and trains. Then the integration of the overall long-distance services for the connection between Rome and the metropolitan cities of Sicily is studied and the best configuration is reported.

3.1 Strategic infrastructural planning

Currently, some actions are underway aimed at extending the HSR network towards the south of the Italian peninsula by building a new infrastructure from Salerno to Reggio Calabria. To make train ferry times more efficient it is under development the use of locomotives equipped with a buffer battery to allow autonomous entry on ferries and also the use of trains with blocked composition to save the time due to the recomposition of the trains and the verification of the functioning of the braking system after disembarking from the ferries. Regarding the improvement of the Sicilian infrastructural network, work is being done through by completing the doubling of some single-track sections and by improving the speed rank of the currently existing conventional network.

3.2 Operational planning of rail services

Based on what has been seen in the previous section, it is possible to introduce modest changes to existing services by combining their best features. In the following it is then proposed for each service the modification of some attributes:

- *NS* = the number of stops;
- *ST* = the stopping time at the stations;

- *TT* = the time between two stations, i.e. considering the shortest of all the times used by the trains available today.

These changes are fully compatible with the available networks and result only from the composition of the best available features among the services supplied. In this sense, it is an operational planning of rail services.

3.2.1 The route Villa S. Giovanni–Rome

The Villa S. Giovanni–Rome section has two railway lines that proceed almost side by side: a high-speed line and a conventional line. The high-speed line runs from Rome to Salerno. After an initial period in which the services were closely connected to the networks, for some years services have been available that use the HSR network from Rome to Salerno and the conventional network from Salerno to Villa S. Giovanni. In Italy, the services that are carried out on the HSR networks are called Frecciarossa and Frecciargento. The services operating on the HSR networks and on the conventional networks also take the same names: Frecciarossa and Frecciargento.

To choose the best available service, it is considered to modify the three attributes: *NS, ST, TT*. Therefore, the use of the Freccia is proposed.

To evaluate the travel times on the Villa S. Giovanni–Rome route, consider the Frecciargento service already offered by train 8352 in 2017. The train departed at 06.48 from Reggio Calabria and arrived in Rome at 11.35, taking 4 h 47 min, stopping at the stations of Villa San Giovanni, Lamezia Terme Centrale, Paola and Salerno. The number of stops *NS* is then reduced, the time *ST* is reduced, and the fastest train *TT* between two stations is taken. The service to connect Villa with the capital took 4 h 31 min.

The main factors for the different sections, in terms of time from the timetable, and physical and technological characteristics from line sheets [22], [23], [26], are shown in Table 6.

Table 6: Characteristics of the sections on the Villa S. Giovanni–Rome line.

Section	Line type	No. tracks	Traction type	Distance (km)	Time (minutes)
Villa S. Giovanni–Lamezia	Conv	2	3kV	106.231	49
Lamezia–Paola	Conv	2	3kV	56.870	27
Paola–Salerno	Conv	2	3kV	216.712	91
Salerno–Rome T.ni	HSR	2	25kV	264.091	95

3.2.2 The crossing of Strait of Messina

The crossing of the Strait is a central element of the connections between Sicily and Rome. For the crossing of trains, several hypotheses have been studied relating to the realization of a “stable crossing”. Recently, several hypotheses have been developed for the strengthening of the maritime link. These hypotheses have been called “dynamic crossing”.

In this work, in line with what is proposed for the other infrastructural links, two scenarios are considered, both achievable at zero time and zero cost.

The first scenario is called Scenario 1. It is used as a crossing time (time between the arrival of the convoy at the Messina central station and departure from the Villa central station) the best among the current ones: 1 h 55 min, using only the *TT* attribute.

The second scenario is called Scenario 2. It is assumed to use a block-sized train of shorter length than the available ferry. In the case of a blocked composition, the current ferry times would be significantly reduced as the operations of decomposition and recomposition of the train and the related braking checks would not be necessary, then operating on the *TT* and *ST* attributes. In this scenario, it is necessary to consider the timing of the different operations: transfer from central Messina to Maritime Messina; boarding the ferry; crossing the Strait; disembarkation from the ferry; transfer from Villa Maritime to Villa Central.

The total time, considering the estimated average time for each operation, is 55 min.

3.2.3 The route Palermo–Messina

Three changes are envisaged on this route: use of the best times between the different trains and that is modification of *TT*; decrease in the number of intermediate stops, *NS*; reduction of stopping time, *ST*.

In the assumptions made, a total time of 150 min is obtained. The detail is in Table 7.

Table 7: Characteristics of the sections on Palermo–Messina line.

Section	Line type	No. tracks	Traction type	Distance (km)	Time (minutes)
Palermo C.le–Termini	Conv	2	3kV	36,415	22
Termini–Cefalù	Conv	2	3kV	30,379	17
Cefalù–S. Agata	Conv	1	3kV	58,484	42
S. Agata–Barcellona	Conv	1*	3kV	58,969	38
Barcellona–Milazzo	Conv	2	3kV	7,939	6
Milazzo–Messina C.le	Conv	2	3kV	31,578	20

* Partially double track – from Patti to Barcellona (21.910 km).

3.2.4 The route Catania–Messina

On this route, three changes are hypothesized, similar to those proposed for the Palermo–Messina: use of the best times between the different trains and that is modification of *TT*; decrease in the number of intermediate stops, *NS*; reduction of dwell time, *ST*.

In the assumptions made a total time of 55 min is obtained. The detail is in Table 8.

Table 8: Characteristics of the section Catania–Messina.

Section	Line type	No. tracks	Traction type	Distance (km)	Time (minutes)
Catania Central–Taormina	Conv	1*	3kV	47.762	26
Taormina–Messina Central	Conv	1**	3kV	47.009	28

* Partially double track – from Catania to Fiumefreddo (38.033 km);
** Partially double track – from Giampilieri to Messina (13.354 km).

3.2.5 Variation of attributes

To show, in a quantitative way, the differences between the current service and the proposed one, these variations are summarized in Table 9 in terms of the attributes described above.

3.3 The used rolling stock

The hypotheses made for the crossing with the proposal defined Scenario 2, must be compatible with the available means, in order to respect the basic hypothesis of feasibility in zero time and zero cost.

Table 9: Values of the attributes for the current service and for the proposed one.

Section	Current service			Proposed service		
	NS	ST	TT	NS	ST	TT
Catania Central–Messina Central	3	6	66	1	1	54
Palermo Central–Messina Central	7	14	156	5	5	145
Villa S. Giovanni–Rome T.ni	9	33	371	3	9	262

The ship *Messina* currently in service has an average load capacity of 16 carriages of 26.40 m distributed on four tracks. From the track descriptions contained in [20] it can be seen that the maximum length of track that can be occupied by a single train is equal to just over 133 m. As for the usable material, in order to obtain a convoy of less than 133 m, it is necessary to use a railway material available in other Italian lines.

As seen above, the railway material used for the Frecciargento 8352 that carried out the indicated travel times, was ETR485 material. The composition was nine elements with a length of 236.6 m and a maximum speed of 250 km/h. It is proposed to replace the material of the ETR485 series with the material of the ETR400 series, commonly known in Italy as Frecciarossa1000. The Frecciarossa1000 trains can be configured in versions of four, eight, 12 or 16 carriages, with a driving position at each extreme. The standard composition of the ETR 400 train has eight carriages for a total length of 202 m. There is a four carriage composition, used in 2013 for tests, which has a total length of 102.4 m.

As it is easy to see, the convoy in composition of four carriages can be transported in full on a track of the ferry ships currently in service.

3.4 The integration of services

It is possible to integrate the services obtained with the hypotheses for each section and the two crossing scenarios, respecting the basic hypothesis of zero time and zero cost.

Table 10 shows the times for each route and for each scenario, and the times of the current situation. The percentage reductions obtained for each overall scenario are also reported. The times per route and per scenario are pictured in Fig. 2.

Table 10: Connection times of the Sicilian metropolitan cities with Rome.

Scenario	Attributes	City of origin		
		Palermo	Catania	Messina
Current	Travel time	11 h 38 min	9 h 53 min	8 h 24 min
Scenario 1	Travel time	8 h 56 min	7 h 21 min	6 h 26 min
	Reduction	2 h 42 min	2 h 32 min	1 h 58 min
	Reduction %	23.2%	25.6%	23.4%
Scenario 2	Travel time	7 h 56 min	6 h 21 min	5 h 26 min
	Reduction	3 h 24 min	3 h 32 min	2 h 58 min
	Reduction %	31.8%	35.8%	35.3%

From the analysis of the times reported emerge the strong reductions in time immediately obtainable. On the longer connection, Palermo–Rome the reduction is greater than 20% in Scenario 1 and 30% in Scenario 2. On the connection from Catania the reduction is greater than 25% in Scenario 1 and 35% in Scenario 2.

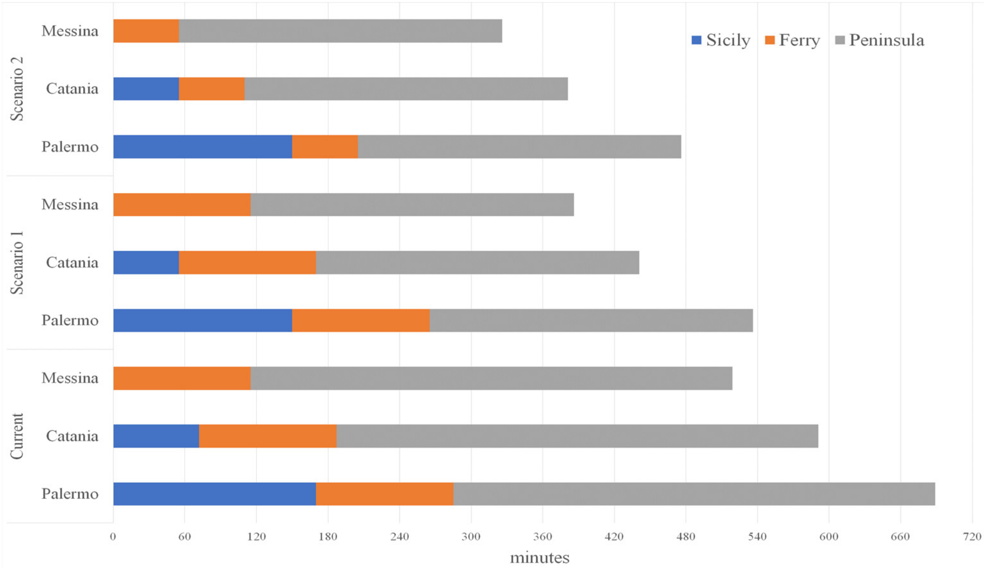

Figure 2: Components of travel times per route and per scenario.

The results obtained are based on the hypothesis of not operating infrastructural intervention and are therefore immediately implementable. Scenario 2 despite being at no cost, because the Frecciarosssa1000 are available to Trenitalia, would still imply a decision by the top management to move some trains on the connection between Sicily and Rome. Scenario 1 does not imply any decision because it would be implemented with the material already available for the connection between Villa S. Giovanni and Rome.

4 CONCLUSIONS

The integration method used is combines exhaustively all the trains currently in operation, first proceeding to local optimizations on three attributes *NS, ST* and *TT*. From the exhaustive combination it is possible to identify the optimal integrated service.

The method is applied to combine existing services on HSR and conventional lines.

The results obtained are interesting in different aspects. On the scientific level they allow: with regard to the supply to investigate and build multi-level optimization models, considering each network as a different layer; with regard to the demand, the ex-ante assessment of the change in the utility of users to the choice of mode of transport. The results can be useful to know what time reductions are possible without any investment. Finally, they are interesting because they constitute the real reference in the evaluation of the alternatives for the realization of the high speed. These times are the ones with which to compare any infrastructure operation proposed for the southern Italy, thus eliminating the use of train times without changes for passengers currently in operation, which are unjustifiably higher and do not respond to the actual current potential.

The proposed method is very simple and can be used by planners and technicians of state departments, in all territorial contexts of any country where the extension of high speed is being planned. The method is also interesting for the technicians and planners of the railway companies that manage the services because they can build new market alternatives to offer to users. Finally, they are interesting for researchers because they allow to develop multi-level optimization models to be applied to the construction of railway timetables.

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