COLLANA DEL DIPARTIMENTO DI GIURISPRUDENZA
DELL'UNIVERSITÀ DI PISA

NUOVA SERIE - *Atti di Convegno*

ENHANCING SUSTAINABLE TRANSPORT

Interdisciplinary Issues

edited by
Andrea Bartalena, Luca Della Tommasina,
Gabriella Iermano, Luca Spataro

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Marco Antonelli-Stefano Maggi-Francesco Alberti

REMOTE AREAS SUSTAINABLE RECONNECTION: THE VOLTERRA RACK RAILWAY CASE

1. *Hystorical and actual context*

The history of the Cecina-Volterra line was thoroughly reported in the book "Ferrovia Cecina-Volterra. Il trasporto pubblico in un territorio isolato", by Stefano Maggi (Nerbini editore, 2011), from which the following lines were extracted and summarized. The construction of the 30 km line "Dal Fitto di Cecina alle Moie volterrane" was approved in March 1860, with a decree of the provisional government of Tuscany, chaired by Bettino Ricasoli, and inaugurated, together with the Livorno-Collesalvetti-Cecina-Follonica, on October 20, 1863. The railway transported goods to serve the salt pans and other companies in the area, such as Larderello and Montecatini. In addition, in 1876 a horse-drawn railway was built which, starting from the Casino di Terra station, through the valley of the Sterza stream, reached the Monterufoli mine. This line, on which steam traction was later used, was used to transport the lignite and magnesite of the local mines but was destroyed during the Second World War and never rebuilt.

The final project for the connection with Volterra, served until then by stagecoaches, was developed in the early twentieth century, together with other summary studies, concerning the connection with the Siena-Empoli railway in Poggibonsi and the junction towards Pontedera, never realized. The train arrived in Volterra in 1912, thanks to the tenacious work of the local administrators and the deputy of the college, the honorable Piero

Ginori Conti. The line profitably carried out its service, also for the transport of goods, such as raw and processed alabaster, coal, groupage.

After the Second World War, however, the lack of modernization and the fierce competition of buses and trucks made the train lose its function. The Volterra train made its last run on November 21, 1958, replaced by a bus service, then entrusted to SITA. At the time, not only they did not predict the inevitable repercussions on pollution, traffic, and road safety, but another important aspect was not considered either: the growth of tourism, which could have found in the train an excellent carrier for the transport of Italians and foreigners. To keep the Saline-Volterra in step with the times, it would have been sufficient to introduce the ALn 56 and ALn 64, used on the Paola-Cosenza, which would have reduced travel times from 40 to about 17 minutes, thus being competitive with buses. In addition, today Volterra would have the rack as an additional tourist attraction.

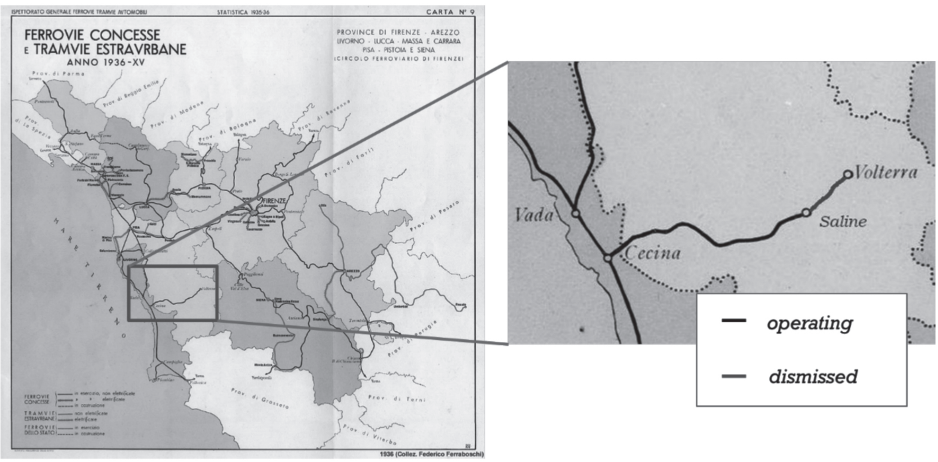

Fig. 3. *Geographical allocation of the line.*

It is not difficult to remember the train of the past. It is more difficult to communicate the value of the train for the future. In Italy, in fact, while the High Speed contends the service to the plane, the secondary railways are seen only as a legacy of the past, where the train has lost contact with the territory crossed. Many secondary railways have been closed since the 50s, and many cities, left isolated without the train, have regretted the old railway. Once the tracks were abandoned, in fact, a perception of isolation remained increasingly felt as global society developed.

The experiences of recovery of secondary railways have mostly developed abroad, but there are also examples in Italy, where the most relevant example is represented by the railway in Val Venosta from Merano to Malles. On this line, closed to traffic in 1991 because it was considered a "dry branch", an effective public mobility network was created using trains and buses, which doubled the number of public transport users, far exceeding expectations.

Even the Cecina-Volterra could find new life, both in tourist use and in the integration of schedules and tickets with public transport by road, in order to create efficient connections between Volterra and neighboring countries on the one hand and Livorno-Pisa on the other. An innovative type of operation is needed, based on the reorganization of the overall transport service in the area, to continue with rolling stock adapted to the line, more attentive to ecology and sustainability, with particular attention to electricity storage systems or alternative fuels. It would benefit not only the railway, but the entire territory, which would see the impact of private cars decrease and would be perceived by residents and visitors as less isolated and more accessible. The train has in fact among its positive characteristics that of giving the perception of a continuous, stable connection, almost a close link between the territories. As detailed in the following section, the restablishment of a rack railway in the abandoned branch between Saline and Volterra can really bring a new life to the entire transport system, due to its intrinsical actractivity and contribute to the economic of the whole Valdicecina territory.

2. *Why a new rack railway and not other transport means?*

The rack railway is not the only technique that allows you to overcome high gradients. In fact, there are also other technologies, each of which has strengths and weaknesses. These include:

- Funicular: mainly used on relatively straight sections and of not high length, it presents the need for a crossing station halfway to allow the two cars to cross, since one acts as a counterweight to the other.
- People mover (evolution of the funicular): it is the evolution of the funicular; it is an interesting system but allows high volumes of traffic if applied to a closed and non-linear route like the one in question. It also has very significant installation costs. An example is the Pisa Mover, installed between Pisa Centrale station and the airport.
- Electric trolleybuses: it is a smart solution but on the route in question it has low load capacity (speed, capacity, no possibility of interchange unless you build a half station). It is also necessary to study an appropriate safety system (automatic driving for example) with appropriate redundancy, given the narrow roadway that can be achieved.

– Cable car: it is a different transport system, very common in the high mountains, need to study another route and install important fixed systems.

In all these cases, the question of "load breakage" is not resolved, that is, the need to transfer passengers to the Saline di Volterra station, which can be soothed depending on the frequency of the trips, but still remains.

The rack, on the other hand, has a relatively high cost of realization but:

It is an "ancient" technique but, at the same time, extremely tested and safe.

The rolling stock can also be used on the other lines, because it is still a train that, with modern technologies, can travel at speeds compatible with other trains on the natural adhesion routes.

Precisely for this reason, it allows to realize the direct connection with the coast (and even beyond).

It therefore solves the problem of "load breaking".

It can reuse the existing path, if available.

It also offers other opportunities, which will be described below.

The criticism that can easily be levelled at this proposal is that it amounts to re-proposing a means of transport that had already proved obsolete over sixty years ago. This report serves precisely to show that it is intended to propose a new transport system which, although it uses the same technique as the pre-existing one, solves the critical issues that led, many years ago, to the disappearance of the old "little train", and which, in the wake of tradition, instead looks to the future with new criteria and design objectives capable of overcoming existing means in terms of safety, speed, possibility of connection with the rest of the regional and national territory and, last but not least, eco-sustainability.

3. *The role of the railway infrastructure within a territory*

As mentioned, the Railway constitutes a kind of "backbone" of the Territory, connecting the various locations to each other in a stable, tangible, permanent way and with the most important centers of the district. We can no longer think of the territory and its transport systems as separate identities, but as two indissoluble elements. The decline of the railway is the signal that the territory is also declining from an economic and social point of view and relaunching a railway means first of all laying the foundations for a recovery of the entire territory.

The relaunch of the Cecina-Volterra railway is aimed at making accessible some places of relevant landscape interest. The line would become the aggregating element of the villages of the Val di Cecina, through a cadenced railway service to locate new functions and equipment useful to the territory. The relaunch project in fact provides for the placement, in the areas adjacent to the stops, of integrative functions, such as small camper areas inserted in the landscape, sports fields, public equipment, etc. To bring users closer to the means of transport, it has been hypothesized the construction of new stops: at San Piero in Palazzi, a populous expanding district on the outskirts of Cecina, at the Cecina Nord exit of the Aurelia highway, where it is planned to build a park ride and lot, as well, a third additional stop to serve the numerous agritourism facilities in the medieval castle of Montegemoli (located about 2 km from the railway). The picture is completed by targeted interventions on the road network, aimed at improving accessibility to stops, the settlement system and environmental resources (rest areas, elimination of level crossings, redesign of some intersections, safety interventions, landscape arrangements, etc.).

Regarding the restoration of the railway connection to Volterra, using suitable rolling stock, the problem arose of how to build the new terminal of the line in Volterra, since due to recent urban transformations, the reuse of the old station is no longer practicable. The intervention consists in the construction of a simple stop a little further downstream, on the ground, suitably remodeled, of the old rack, connected to the station square (and from here, to the city center), with a system of escalators similar to those already in use in other Italian historic centers (Siena, Perugia, etc.).

4. *Touristic user base assessment*

The user base was evaluated through the IRPET 2018 report "REPORT ON TOURISM IN TUSCANY – The 2018 conjuncture", which reports the pre-pandemic situation, and which can be taken as a reference to understand the situation that will arise, once the emergency situation still in progress has been exhausted. It is even foreseeable that rail transport will be a determining factor for the greater space on board and for the lower environmental and energy impact that it entails in relation to road transport, particularly individual transport.

As mentioned, we have not only considered the tourists who stay overnight in Volterra or in the immediate vicinity, but, to a greater or lesser extent, also those who stay overnight in the geographical areas, in which Tuscany is divided, adjacent to that of Volterra. The report (page 51) shows the annual attendance, divided by territorial areas (figure 2). It should be noted that the report speaks of presences and not of arrivals, therefore the estimate of the actual number of tourists was conducted assuming an average stay, differentiated by area. In addition, the degree of interest of tourists for the attendance of the site of Volterra has been considered by introducing a weight, unitary for tourists who visit the area of Volterra and less than one for those who visit the other areas, with decreasing trend with the distance from Volterra. The areas of interest chosen are therefore summarised in Table 3, shown below. Based on the available data and the hypotheses set out above, it is estimated that the number of tourists interested in visiting Volterra, and its surroundings is around 1.5 million.

The number obtained is in line, at least as an order of magnitude, with the number of arrivals estimated by Dr. Roberto De Marco and presented at the conference "A train for a territory", held in Volterra on September 4, 2021. In dr. De Marco's study, the number of tourist arrivals in the "enlarged Val di Cecina" area, also including the municipalities of the southern part of the province of Livorno and the northern part of the province of Grosseto (up to Follonica and Monterotondo Marittimo) was estimated at 1.3 million in the year 2019. This figure concerns tourists who stay overnight in a structure and, of course, does not include those tourists who, instead, visit Volterra within a single day and therefore do not appear in the accommodation facilities.

The user base was calculated by means of a comparison with a reference case, of which the number of tourists and passengers are known. The case taken as a reference is the Cogwheel Railway of Monserrat, Spain, in the vicinity of Barcelona (figure 3).

The monastery of Monserrat is accessible, as well as by bus and car (like Volterra), also via the cogwheel railway in question, the Cable Car of Sant Juan, and the funicular of Santa Cova. The latter is currently out of service and therefore will not be considered in the calculation. The line was inaugurated in 1892 and operates until closure with steam traction. In this case, to overcome the considerable difference in height, the Abt type rack was adopted. The section has a length of about 5 km, overcomes a difference in height of 550 m, with a maximum slope of 156 mm / m and is armed with narrow-gauge track (1000 mm). The line was closed in 1957, due to excessive operating costs and the obsolescence of the plants, but in 2001 the restoration project was undertaken, which was completed in 2003, with a completely rebuilt infrastructure and state-of-the-art rolling stock (figures 3 and 4).

Fig. 4. *Subdivision of Tuscany region into tourist districts.*

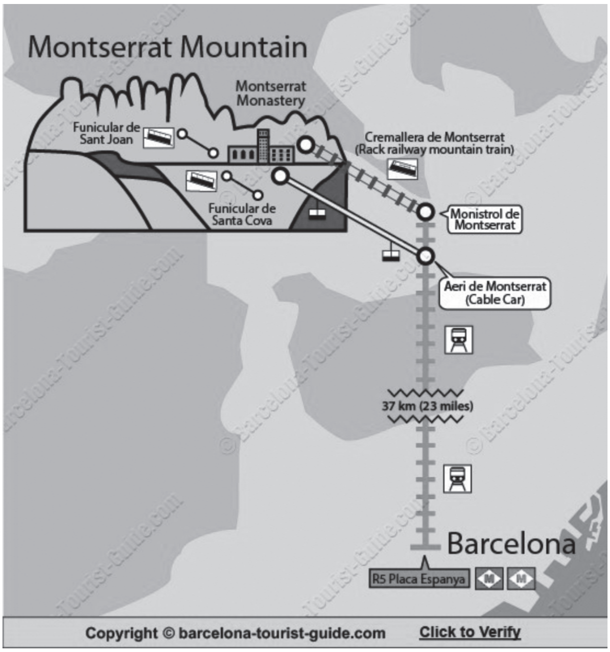

Fig. 5. *Monserrat transport system.*

Fig. 6. *Monserrat infrastructure.*

Fig. 7. *Monserrat typical rolling stock.*

The situation, from the orographic and transport point of view, has similarities: as visible in figure 3, the Monastery is located about 40 km from the sea, and is connected to the city of Barcelona by a wide ordinary gauge line (1676 mm), which, following the valley floor, reaches the slopes of the mountain. From there, the monastery can be reached, as well as by means of the rack line, also through the road and a funicular. For comparison, the Volterra rack railway, closed in 1958 (one year after that of Montserrat), exceeded a difference in height of about 430 m, with a route of 8 km, almost equally divided between a stretch with natural adhesion, with a maximum slope of 25 mm / m, and a section with artificial adhesion, with a maximum slope of 100 mm / m. The gauge, in this case, is ordinary (1435 mm) like that of the main mesh with natural adhesion.

The tourists who visit the monastery, every year, are about two million, so a number comparable with the tourists who visit Volterra, according to the calculation presented on the previous page. This tourist flow generates a demand for transport that is covered by the various means of transport. In particular, the railway in 2019 carried about 700,000 passengers and the funicular about 395,000.

The potential basin of the rack for Volterra has been estimated according to a criterion of proportionality between tourists visiting the place and flow of passengers on public services. Indicating with T_v and P_v the number of tourists and passengers of the Volterra site, and with T_m and P_m the number of tourists and passengers of the Monserrat site, the link between these quantities is expressed by:

$$P_v = P_m \cdot \frac{T_v}{T_m}$$

To consider the fact that in Monserrat there are two similar and competing services (railway and funicular), two limit hypotheses can be made regarding the number of Pm passengers to be taken as a reference:

The number of passengers carried by rail alone (P_m = 700000);

The sum of the passengers carried by the railway and funicular (P_m = 1095000).

As for the number of tourists present at Volterra T_v, reference was made both to the estimate made by Dr. De Marco, indicated as "estimate A", and to that made in this document, indicated with "estimate B". Table 2 shows the results of the calculation with all possible combinations of the number of passengers of Monserrat taken as a reference P_m and the estimated number of tourists to Volterra T_v.

Table 5

P_m	T_v estimate "A"	T_v estimate "B"
	1300	1520
1095	712	832
700	455	532
AVERAGE		644

The number of potential passengers ranges from 455000 (pessimistic estimate) to 832000 (optimistic estimate), with an average of about 644000. It should also be noted that the estimate is by default because it does not consider the possible increase in tourists due to the presence of the rack itself, especially if the use with historical material (steam locomotive) and initiatives aimed at promoting the territory related to the presence of the train were also to materialize.

In any case, the estimate shows unequivocally that the number of potential passengers is of the order of a few hundred thousand, thus demonstrating the strong potential attractor towards tourist users. To these, must also be added residents and all other potential users who do not fall into the category of tourists, but who would still benefit from the new transport system: such as students, commuters for work, users of the NHS who must go to the Volterra Hospital (whose entrance is in the immediate vicinity of the current former station) and others, not falling into the aforementioned categories.

5. *Rolling stock for the new rack railway*

Assuming to establish 20 train rides in the direction of Volterra, it is to be expected a maximum attendance of about 80-100 people per convoy. The service can therefore be conveniently carried out by self-propelled rolling stock (i.e. composed of cars equipped with their own propulsion, called "railcars", consisting of two carriages, equipped with satin bodywork, seats for the disabled and spaces for bicycles, with a capacity of about 100 seats, schematized as in figure 5.

The propulsion system identified is a "bimodal" system, that is, it includes multiple propulsion modes. In this case, the most suitable scheme consisted of a conventional electric drive, powered by an overhead line by means of a pantograph, supplemented by batteries on board. The reason for this choice is that such a designed system is well suited to operation on steeply sloping lines since it allows sufficient power to be installed on board and is also able to recover the energy of the downhill convoy and reduce energy consumption (conceptual diagram of figure 6).

The other interesting feature is that the convoy can continue its run on the coastal line (in the direction of Pisa or Piombino, for example) like any other electric traction convoy, developing speeds comparable to those of the other trains. To do this, of course, it is necessary that the train meets the Technical Specifications for Interoperability (TSI) for circulation on the main lines. Stadler manufacturer, which is world leader in rack railway roll-

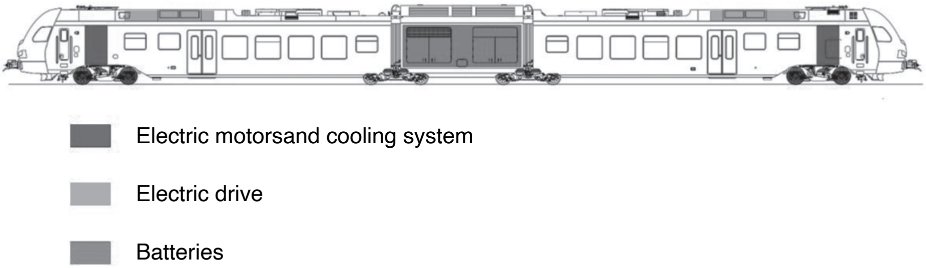

Fig. 8. *Conceptual scheme of a modern rolling stock for the Volterra rack railway.*

ing stock production, confirmed the possibility of building such a train and provided an update previsional design model for this purpose (Figure 7).

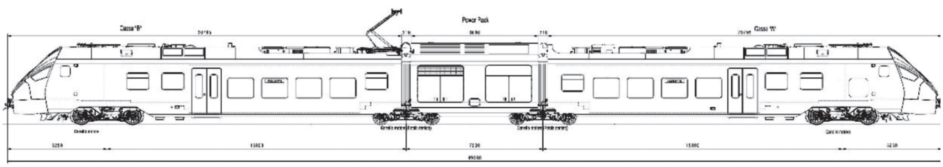

Fig. 9. *Previsional design for the new rolling stock.*

Of course, the newly built branch needs to be electrified (figura 8). A new electrical substation has to fitted in the nearbies of the Saline di Volterra station, without any particular criticality since a high-voltage electrical line is already on site for feeding two industries.

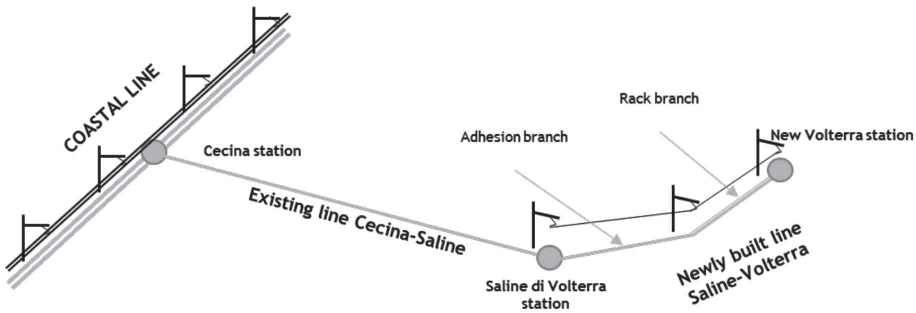

Fig. 10. *Feeding system of the new line.*

6. *Construction cost of the new infrastructure*

The sustainability of the project was assessed by analysing the cost of rebuilding the infrastructure, the operating costs and the revenues for the year. As will then be described more extensively in the following paragraph, it has been hypothesized to terminate the line before the regression, placing the new station below the old one, and connecting it to the street level by a succession of escalators.

The cost of building the infrastructure was determined taking into account data reported in the literature, and precisely in the book "Lineamenti di Infrastrutture Ferroviarie" (F. Policicchio, Firenze University Press, 2005) and updated to the current year, taking into account an annual inflation rate of 3%. The costs were divided into costs distributed per unit of linear length of the line (e.g. laying of the track, reconstruction of the seat, etc.) and costs for body works (e.g. overpasses, reinforcing walls, etc.).

The costs distributed include the cost of construction of the track itself, detailed in its various components and compared to the line meter, the cost of signaling and reconstruction of the road, also the latter two compared to the line meter. The cost of the track equipped with a rack has been calculated in an approximate way, assimilating it to a track equipped with three rails, of which the central has a cost increased by 25% to consider the fact that it is toothed. Obviously, the number of clasps, rubber plates and insulators has been increased accordingly.

It was decided to integrate the cost per unit of length by including the construction of a 1 m height survey, accompanied by the drafting of an asphalt surface to create a type C road, probably not necessary, considering the type of line, but still considered to obtain a precautionary cost estimate. The cost required for signalling was determined considering the installation of the Pipeline Support System (SSC) with Centralized Traf-

Table 6

WORK	Adhesion	With rack
Rail with ballast (M€/km)	0,98	1,35
Road work (M€/km)	1,55	
Signalling (M€/km)	0,28	
Electric line	0,15	
Cost per kilometre(M€/km)	2,95	3,33
Extension (km)	3,92	3,12
TOTALE (M€)	11,56	10,39

fic Control (CTC), as well as the ground-train signalling system. Adding up all the contributions, we obtain that the cost of a kilometer of line in natural adhesion amounts to € 2.95 million, while the cost of a kilometer with artificial adhesion (with rack) amounts to € 3.33 million. The cost of the two sections is obtained by multiplying the cost per kilometre by its extension and amounts to 11.56 and 10.39 M€, respectively.

Fig. 11. *Fonte Pippoli wall.*

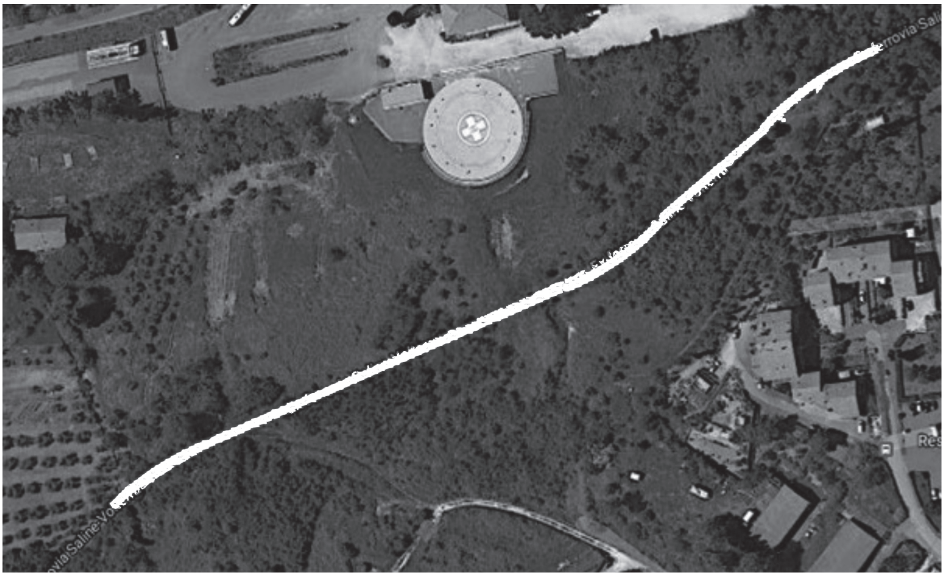

Fig. 12. *Collapsed portion of line.*

During an inspection of the final portion, it was found that consolidation works are necessary in the last 400-500 m, due to landslides due to the clayey nature of the soil. The track is instead well straight and aligned even in the sections prior to the collapsed one. The presence of the original containment works, such as the wall of Fonte Pippoli (Figure 9) still allows the track to maintain its shape without presenting obvious signs of depression. The section of the line to be consolidated (figure 34) appears to be limited to a few hundred meters and coincides with the place dedicated to the construction of the new station. The consolidation works of the section would therefore consist of the civil works of construction of the support embankment for the new station, for which an extension in length of around 200m is to be expected, given the brevity of the compositions of the convoys that would be used.

The construction of a retaining wall, with a height of 5 metres and an extension in length of 300 m before the station, a retaining wall with a height of 8 metres for the consolidation of the station itself, with a length of 300 metres, and a counter-slope wall on the upstream side of the station, were therefore considered in the list of costs, with a height of 5 meters and an extension of 250 meters. The cost of the containment works (Table 10) is c 2.48 million.

Table 7. *Reinforcement works cost*

	Year 2005 (M€/km)	Year 2022 (M€/km)	Length (km)	Cost (M€)
Counter-slope wall h=5m	1,27	2,10	0,25	0,52
Retaining wall h=8m	2,57	4,25	0,3	1,27
Retaining wall h=5m	1,38	2,28	0,3	0,68
TOTALE				2,48

The station will be of limited extension due to the reduced composition of the trains that will travel the line, and will be limited to a pair of trunk tracks (one of correct layout and one of doubling), surrounded by a station platform, by appropriate canopies (perhaps with photovoltaic cover) and the escalator to get to the upper street level. While the track of correct track is already included in the line costs, the doubling track and its diverter must instead be considered. Assuming a doubling track length of 200 m, the relative cost, including the diverter, is about 0.3 M€. For the escalator and the station building, and all the works that follow, a flat-rate cost of € 1.2 million was considered. The total cost for the construction of the station was therefore calculated at 1.5 M€.

The work must be completed by including the artifacts to be built or restored along the line. Among these, there are those necessary to bypass the nearby streets, to allow access to the houses, which can now be reached by crossing the railway headquarters. The cost of each overpass was estimated at about 0.18 M€. Along the line, 4 overpasses were noticed to be built or reinforced, resulting in a total cost of about € 0.73 million (table 11). In addition, it was considered to renovate the three toll booths next to the railway, for an amount of 600000 € in total (200000 € each). The total amounts to 1.33 M€.

Finally, the cost for the construction of the works necessary for electric traction was calculated. It should be considered that in the vicinity of the station there are the plants of the Salina di Stato and Altair Chimica, powered by a 132 kV power line. There are therefore no problems with the power supply of a possible substation for the supply of the 3 kV direct current necessary for railway uses. The total cost of electric traction systems is 2.8 M€.

The total cost of construction, as the sum of all the items listed so far, can be calculated at 30.1 M€(Table 14).

Table 8.

COSTS (M€)	
Stretch in natural adhesion	11,6
Rack and pinion stretch	10,4
Consolidation works	2,5
Station	1,50
Other works	1,3
Electric traction system	2,8
TOTAL	30,1

For comparison, the reconstruction of the Vinschgau railway cost, considering only the railway infrastructure and excluding, therefore, the cost of renovating the station buildings, about 127 million euros, taking into account the annual inflation rate from the year 2000 to today. Since the Vinschgau line is 60 km long, you get a reconstruction cost of about 2.1 M€/km. In the case of the Saline-Volterra railway, which is about 7.1 km long, the cost per kilometre amounts to 4.23 M€/km, or 102% more. The difference is clearly due to the worst state of conservation of the structure, with the fact that it is a partially armed line with rack and that electrification is planned.

7. *Sustainability of the operation*

The operating costs have been calculated considering the following items:

- Personnel costs
- Rolling stock costs
- Infrastructure costs.

The calculation of the operating cost presupposes to make assumptions about the operating model of the line. It was hypothesized to manage the Saline-Volterra line together with the Cecina-Saline section, so as to look at the entire Cecina-Volterra section as a single line, thus realizing that mobility model hypothesized from the beginning. It has been hypothesized that a rather frequent service is carried out on the Saline-Volterra trunk, to make the use of the service attractive and encourage the use of exchanger parking lots, to be built in Saline, and decongest the city of Volterra, and a less frequent service but still distributed over the whole day in the direction of Cecina. In more detail, it has been hypothesized to establish 20 races between Saline and Volterra and 8 between Cecina and Saline.

Given the extension of the service over the whole day, from morning to evening, it is expected to ensure the presence of two crews (Driver + Train Conductor) in simultaneous service on two daily shifts. The theoretically necessary people are 4 per shift, for a total of 8 employees, but in order to ensure rotation for illness and holidays, a total of 12 people is needed. At the same time, there are two trains in operation but, always to ensure the reserve and, possibly, the reinforcement in periods of high affluence, at least 3 convoys are needed.

The cost of personnel has been quantified considering an average annual salary cost of € 50,000 per person, without distinction between driving personnel and personnel on board the train. Multiplying the average cost by the number of salaried people, which is 12, we get the annual cost of personnel, which therefore amounts to € 0.60 M€.

The cost of rolling stock consists of various items, which can be divided into depreciation and maintenance. The depreciation cost derives from the distribution of the purchase cost over several annual years. The depreciation cost is calculated by dividing the cost of purchasing the trains by the expected useful life of the trains. In this case, it was considered to buy 3 trains, at a price of € 10 millions each, with a foreseeable useful life in 25 years. The annual depreciation cost therefore amounts to €1.2 Mv per year. The maintenance cost includes repairs and replacements of worn components, costs arising from unexpected failures, cleaning and current maintenance operations (level control and top-ups, etc.). As a forecast, the maintenance cost was calculated as a fixed rate of the depreciation cost, and it was considered that the maintenance cost amounts to 25% of the depreciation cost and therefore equal to € 0.3 million per year.

Every journey made by a train on a railway network entails, for the operating company, a cost per kilometre, or a toll. For the kilometers traveled on the Cecina-Saline section, the toll ordinarily paid by Trenitalia to RFI (calculated by the 2023 Network Prospectus) was considered (1.94 €/km), while for the Saline-Volterra section, on the other hand, which is newly built, it was assumed precautionarily that the Region alone supports the total cost of the infrastructure. The fee for the Cecina-Saline route, taking into account that the kilometers traveled annually on the Cecina-Saline section are about 170000, amounts to about € 0.3 M€. Regarding the cost of the Saline-Volterra section, it has instead been assumed that the Region pays the maintenance costs in full, without any contribution from the State. A cost of € 64500 per year per kilometer of line was taken as a reference, derived from the 2020 monitoring of Emilia Romagna. To consider the presence of the rack, the annual cost has been increased, considering a number of "equivalent kilometers" of the rack section 50% higher than the actual ones. The added line kilometers (Saline-Volterra section), for the purpose of calculating costs, are considered equal to 3.99 km (natural adhesion 3.59 km plus another 200 m of doubling, plus another 200 m as equivalent length to consider the presence of the diverter) plus another 4.68 (3.12 km with artificial adhesion increased by 50%), for a total of 8.67 km. The total annual cost of the Saline-Volterra section is therefore equal to € 0.6 M€.

The total cost of management is given by the sum of the individual items, for a total of € 3.0 million per year.

The forecast of operating revenues was conducted assuming an average attendance of the trains, differentiated according to the stretch. More specifically, the attendance assumed for each race consists of 30 tourists and 10 residents for the Saline-Volterra section and 15 tourists and 10 residents for the Cecina-Saline section. To verify the congruence of this hypothesis with the forecast of the catchment area exposed above, the number of tourists transported on the Saline-Volterra section was calculated, which was 219000, that is to say about half of the minimum value provided for in paragraph 4.

The pricing of the trips has been provided for differentiated according to the sections:

- For the Saline-Volterra section, a return ticket price of € 10 has been assumed, in consideration of the fact that the price for the Cremallera de Monserrat, shorter, is 11. 5€. For residents, students, commuters and users of the NHS, a reduced ticket of € 5 has been assumed.

– For the Cecina-Saline section, the ticket price is the one provided by Trenitalia, or 7. 2 € for the round trip.

Total pricing income amounted to € 3.1 million. The proceeds from tourist attendance allow to manage the operation of the line with very low costs for the Region, thus allowing to distribute the benefits of the work directly on the territory. It can therefore be said that the proceeds from the tourist use of the line repay the territory allowing to offer a comfortable, safe, and eco-sustainable service to residents and to all the people of the territory who will use the service, from students, to workers, to users of the National Health Service.

8. *Travel time assessment*

The travel time of the section is an aspect of considerable importance, just think that uphill, at the time of suppression, it amounted to 40 minutes, resulting from the low speed achievable by the steam locomotives of the time and their weak acceleration, due to the poor ratio between the mass of the train and the available power. Already in the 50s a study by the Tecnomasio Italiano Brown Boveri (TIBB) indicated that, with the use of railcars equipped with an internal combustion engine (with a more favorable power/mass ratio) it would be possible to more than halve the travel times (information taken from the aforementioned book by S. Maggi).

The operation of the line included the following phases: the train, which departed from Saline, faced a first stretch of 3590 m in natural adhesion, with a maximum slope of 25 mm / m (figure 11). In that section, the type 980 steam locomotives allowed a maximum speed of 40 km/h. At the end of this section, near the second toll booth, the train had to decelerate at about 5 km/h to allow the rack to be grafted. The artificial adhesion section, with a length of 3791 m, had a maximum gradient of 100 mm/m and the power of the 980 allowed a maximum speed of 15 km/h. At this point, the train abandoned the rack and entered a 120 m long regression trunk by means of an exchange, stopped, and left backwards to enter the station. The overall length of this section, practically flat, was 991 m.

The calculation of the travel time of the newly built line considers the displacement of the station beneath the hystorical one (figure 12), as hypothesized in the thesis by F. Baroncini «Una pista d'argento nella Valle del Sale» (School of Architecture, University of Florence, 2017). Therefore, the line becomes shorter than the older of about 1 km, thus reducing the cost for its construction and arguably the travel time. In addition, the

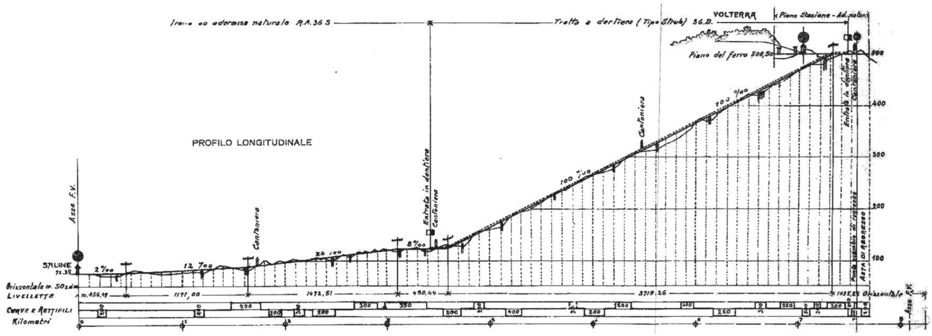

Fig. 13. *Plano-altimetric map of the Saline-Volterra branch.*

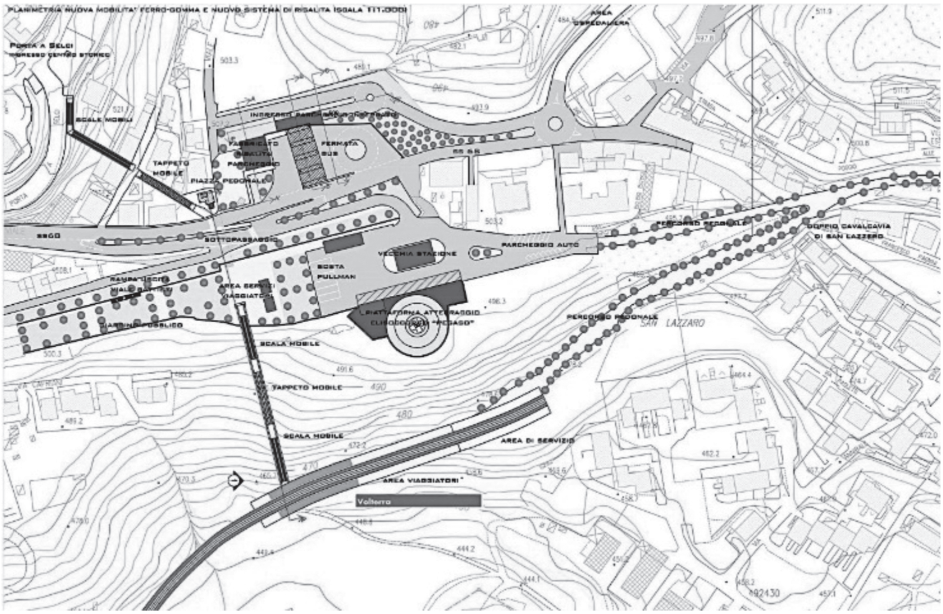

Fig. 14. *Construction plan for the new terminus below the former station.*

new train obviously allows higher velocities and accelerations than the old steam locomotives (table 4).

The outcome of the calculation must not surprise the reader: the combination of track length reduction and much higher velocities leads to the expected result that the travel time is reduced to about one third. The old steam locomotive allowed to climb from Saline to Volterra in about 40 minutes, while the travel time of a modern railway is about 13 minutes. The train travel time is shorter than bus (20 minutes) and competitive with private car, not forgetting the much larger safety and comfort.

9. *Dioxide carbon emissions reduction*

Train is intrinsically a low-carbon dioxide emission transport mean. Here, the reduction in carbon dioxide emission was calculated by comparing the emissions due to the trains with the emissions generated if the same passengers were transported with private cars over the same travelling routes.

The carbon emissions of the trains were calculated by means of the following assumptions:

- The train draws electric energy from the national net, for which an average emission of 400 g/kWh can be a realistic or even conservative guess.
- The energy consumption of train was calculated by considering the energy needed to overcome the gravity force, the inertia during acceleration and the rolling and aerodynamic friction.
- During deceleration and downhill the energy was partly (80%) recovered and only part of it was used for propulsion (85%) due to the battery charging/discharging cycle losses.
- The line between Saline and Cecina was assumed to be practically in plain

On the other hand, the carbon emissions generated by the private cars were calculated upon the following assumptions:

- Each car transported 1.5 passengers (EU average car occupancy).
- Car economy was assumed equal to 15 and 20 km/L of diesel fuel over the Saline-Volterra and Saline-Cecina travels, respectively.
- Specific carbon dioxide emission was 2.6 kg/L of diesel fuel.

The specific emission per passenger-km (pkm) was cutted by 79%, from 168 to 35 g/pkm (figure 13), while total emissions were reduced by 83%, from 1787 to 296 t/y (figure 14).

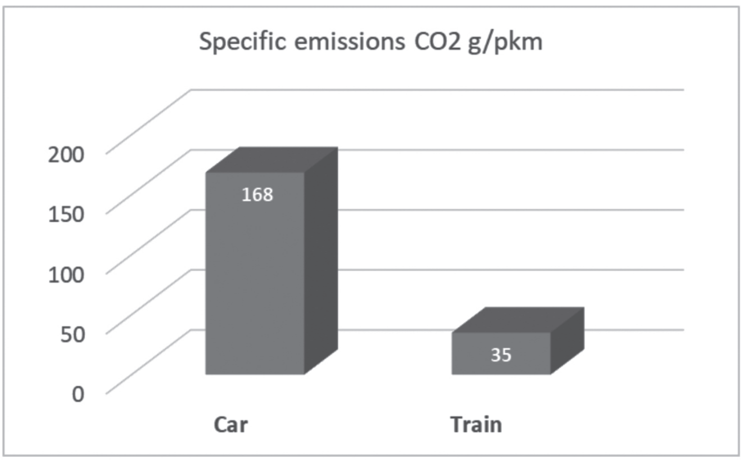

Fig. 15. *Specific carbon dioxide emission reduction.*

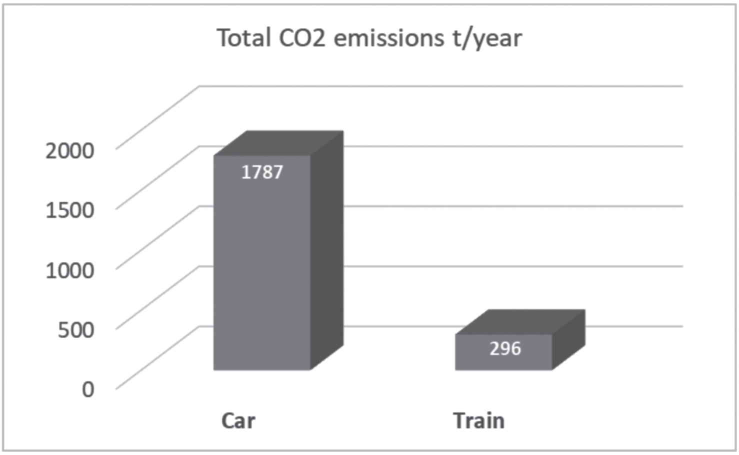

Fig. 16. *Total carbon dioxide emission reduction per year.*

10. *Historical steam trains on the rack: a dream?*

As above mentioned, we must not forget the tourist opportunity that this line would represent per se and that would constitute a further reason for attraction, not only for the city of Volterra, but for the whole territory. Elsewhere in the world, cogwheel railways, where they exist and are preserved functioning (Switzerland, Austria, Greece, but also in Italy), generate very intense tourist flows, even in places much less rich in historical, cultural, and gastronomic attractions than Volterra.

The ordinary operation should be conducted with material suitable for traveling on rack and pinion routes, of a modern type, as seen in the previous pages, in order to achieve commercial speeds, and therefore travel times, not only appropriate but even competitive with the self-service. However, this does not mean that historic trains can be made, for tourist purposes, by

Fig. 17. *Strub system rack.*

steam, provided that the same type of rack used in the past is reused (Strub system, figure 15), even with all the technological adaptations of the case.

In this regard, although the locomotives of the 980 class have all been demolished, with the exception of the 002, preserved static in Pietrarsa (figure 16, left), there are at least two machines of the group 981, which served on the "twin" line of the Saline-Volterra, namely the Paola-Cosenza, which are being restored, one in Foligno (number 005, figure 16, right) and one in Pistoia (number 008). Restablishin a touristic service during the weekends with the steam locomotive would be a wonderful attraction for many tourist, no matter if railway enthusiasts or not.

Fig. 18. *Locomotive class 980 at the Pietrarsa Museum (left) and class 981, in Foligno workshop.*

11. *From Cecina to Saline and beyond: a wider project for the whole Tuscany*

The eventual restoration of the stretch would not hinder, but rather would favor the development of a project to connect Valdicecina with the Valdelsa, as already hypothesized at the beginning of the last century, a project that would constitute a real milestone in the mobility of people and goods from inland Tuscany to the ports of Piombino and Livorno, in full agreement with the intentions of the National Recovery and Resilience Plan.

The detachment from the Saline-Volterra would take place at the second toll booth (figure 17), where the cogwheel section began, at the end of the natural adhesion section, which has a maximum slope of 25 mm / m, fully compatible with regular passenger and freight traffic. Especially for the industries of the Valdelsa, this link would be an undoubted factor of economic competitiveness. Not to forget the possibility of connection with the Interporto of Guasticce through the Vada-Collesalvetti line and the Collesalvetti-Guasticce-Livorno reconstruction. The Cecina-Volterra line would in fact be at the center of an intra-regional mobility project of primary importance.

12. *Conclusions*

In the last century many regional railways were closed, especially in the decade 1955-1965. At that time, the train was considered as the transport mean of the past, which should leave the pace to private car, which was retained faster, more flexible in use and more suited to the new way of living. In the last twenty years, however, a different environmental sensitivity led people to reconsider different mode of transport, included the train, which, due to its intrinsical low energy need, is the best candidate to drive the expected energy transition amongst the transport sectors.

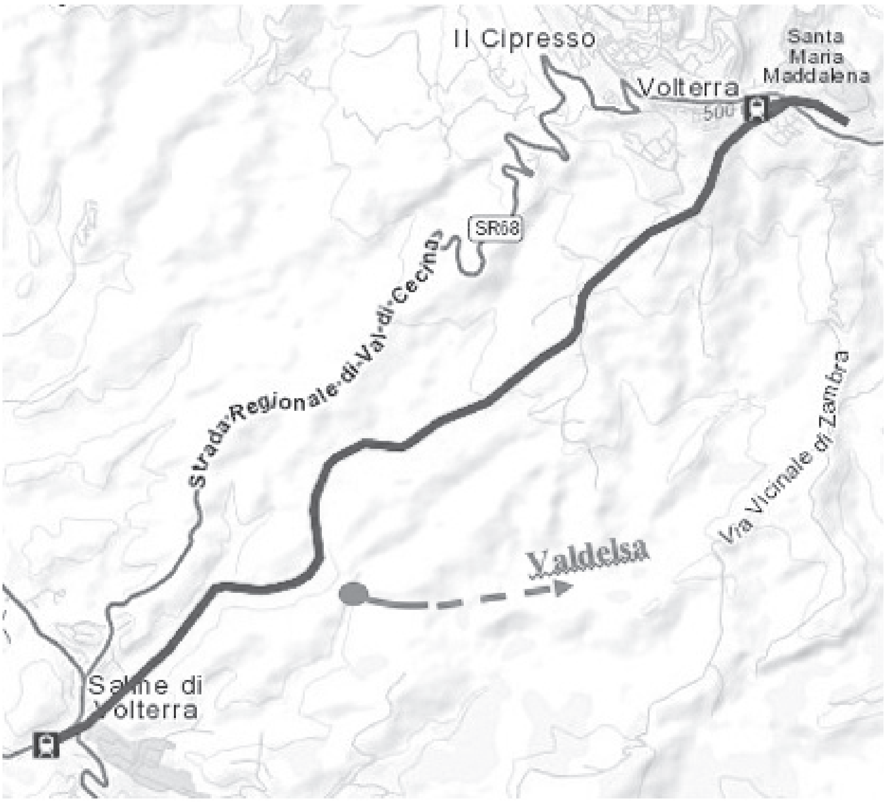

Fig. 19. *Starting point of a possible branch in direction of Siena*

Reconnection of remote areas with the coast, reduction of carbon dioxide emissions, modal shift in tourism are the keywords of this project. A significant reduction in travel time is allowed by using a modernly conceived train, able to provide a state-of-the-art comfort and performance. At the same time, it is very efficient in the use of primary energy, thereby resulting in a dramatical reduction (nearly 80%) in carbon dioxide emissions if compared to the use of private car.

Based on a similar case, the user base can be relatively wide, because it is not limited to the inhabitants, but also involves a large part of the tourists which every year visit Volterra and the potential is expected to be in the range 450000 – 830000 passengers per year. Besides this prediction, the new railway proved to be economically sustainable even with an amount of passengers far below the lower threshold.

This study proves that the hypothesys of reconnecting Volterra with the coastal line through the construction of a new rack railway on the same track of the older one is not only possible, but also recommended, because it is sustainable not only from the environmental but also from the economical point of view. It also puts a definitive stop to the idea of dismantling the remaining branch to Cecina and replacing it with a bike path.

This project has encountered the favour of the main regional authorities, namely the President of the Region and the President of the Regional Council, which endorsed the idea. They also recommended the local communal administrations to support it with an official letter to ask for the inclusion of the line in the Regional Develop Plan, to incorporate the cost of the feasibility study in the annual regional budget.

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