MULTIDISCIPLINARY
PROJECT FINAL REPORT

IHSRL (Italian High Speed Railway Lines)

THE MI-TO IMPACT

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1 Executive Summary

High speed railway lines represent one of the most important technological and socio-economical challenge of the recent years. As people's demand for a fast and efficient mean of transportation, operating on a large scale, has dramatically increased, a constant technological innovation involving the whole railway infrastructure has progressively permitted the realization of much more fast trains. As a consequence, the creation of a fast-mobility network connecting all the most populated and industrialized nodes opens new economical opportunities, by improving the efficiency and competitiveness of internal market, and has a noticeable social impact, because cuts down travel times, permits to better balance the mobility plan and boosts up the attractiveness of the interested territory. On the other hand, the invasiveness of this infrastructure on the territory is very deep, because the environmental impact as well as structural problems gain importance when trains run at high speed, and require a very careful design of appropriate countermeasures to preserve surrounding environment and safety. Moreover, the extremely high requirements in terms of investments for the realization of this advanced infrastructure imply an accurate widespread cost analysis that takes into consideration all the present and future advantages and drawbacks.

Looking at the European background, the large-scale mobility chart identifies a set of *Corridors*, which are high speed terrestrial tracks running across Europe and interconnecting all the most populated, industrialized, resourceful and trade-exchanging poles. Hence, the creation of a fast internal mobility network speeds up passengers and goods transportation, improving the efficiency of European market. In particular, *Corridor V*, that runs from Lisbon to Kiev, involves the northern Italy territory, across the Turin-Milan-Venice route. Thus, the realization of a high speed railway line interconnecting these nodes represents a great chance for increasing competitiveness and opens up to new opportunities.

For these reasons, the decision to integrate the standard railway system with a new high speed and high capacity (*AV/AC – Alta Velocità/Alta Capacità – High Speed/High Capacity*) railway line comes out looking in the direction of an empowerment of the existing rail network in a reborn logic of innovation and modernisation, trying to achieve high standards of rapidity, frequency, quality and security of the rail transport offer. In particular, the Turin-Milan bipole involves two of the largest and most productive Regions in Italy, Piemonte and Lombardia, which both together represent about 24% of the entire population in Italy and 28% of the national PIL, and consequently are the best candidates for supporting the realization of a high speed route.

The considerable reduction in travelling time is of course the most evident aspect related to the new infrastructure. The actual Eurostar service takes about 4 h 10' to go from Turin to Venice – 1 h 30' from Turin to Milan – and the introduction of the High Speed service would save approximately1 h 30' that is the 37% of the whole travelling time – from Turin to Milan the reduction is about 30' (-33%). Yet, the other peculiar feature is the High Capacity of the infrastructure both for passenger and goods transportation. The introduction of the 25 kV line, as an example, permits to create a more powerful system that lets the use of a greater number of trains with a larger towed weight that can go all over Europe thank to the interoperability of the new system of transportation. This upgrade of the transportation network produces and will produce several social and economical benefit on the interested territory, in terms of industrial development, better resources' allocation and increase in the territory attractiveness that would bring to more settlements of factories and services near the new line stations, leading to a new scenario in which fast transportations and a wide catchment area support industrial and technological advances.

On the other hand, the realization of a new railway line has a strong impact on the involved environment, and this drawback is amplified by the high speed. Acoustic pollution, vibrations, electromagnetic emissions as well as invasiveness related to the structural aspects of the infrastructure affect the surrounding area and need to be appropriately minimized. The key-concept is *interoperability*: the realization of a high speed-high capacity railway line must not affect in any way the functionality of the whole transportation network and the surrounding environment, so that the insertion of this infrastructure does not noticeably modify the quality of the location. However, countermeasures for limiting pollution sources and the other side-effects related to the railway require extremely high investments: an accurate cost-benefit analysis must be performed, with the purpose of achieving a global optimization of the *AV/AC* railway line, allowing to satisfy all the requirements of low environmental impact but avoiding overall costs to burst. An accurate plan of interventions criteria permits to minimize the amount of modifications and to use components already employed in standard railway lines.

The aim of this project activity is to perform a feasibility analysis of the Turin-Milan *AV/AC* railway line, from the point of view of the social, economical and environmental impact. At first, starting from a global-scale overview of the operative context, we outline a new scenario including the transportation improvements due to the high speed railway introduction, determining the social and economical benefit that will be available both in short and long time. In this way, we are able to evaluate the socio-economical impact of the infrastructure on the Turin-Milan bipole, pointing out the new opportunities that will be available. Then, we focus on the environmental impact of the *AV/AC*, investigating the nature of acoustic noise and the sources of vibration, and designing a set of specific countermeasures to minimize its impact. As European normative provides the noise emission limits that must be respected, the problem is to jointly optimize the several aspects (noise barriers, anti-vibration sleepers, noise reduction on the rolling stock) by analyzing the cost related to every component and their impact on the overall noise reduction. In particular, this analysis relies on the design of a new kind of noise barrier, that permits an excellent noise reduction with a low aesthetic impact. Hence, we are able to define an intervention strategy to be applied for minimizing the environmental impact of the high speed railway line.

Chapter 2 introduces the operative context of the *AV/AC* railway line, providing a description of the involved area and pointing out the key-points that lead to the realization of this infrastructure. A brief description of the European mobility plan and of the role Italy plays in the innovative global transportation network is given to validate the realization of a high speed line. At the same time, an overview of the state of the art of high speed railway lines is presented, looking at foreign experiences; undoubtedly this infrastructure is very closely correlated with the involved territory, but, especially for the solution of the environmental impact problem, the knowledge of the state of the art is a useful support for our analysis. In order to identify the Turin-Milan area, and the *AV/AC* potential catchment area, a characterization of Piemonte and Lombardia regions in terms of population, industrialization, urbanization, productivity and technological level permits to evaluate the socio-economical impact on the territory. As will be documented, the progressive reduction of travelling time and the increase of overall capacity, compared with the actual offer, will lead to a faster transportation route. In this section, therefore, a validation of the *AV/AC* project based on socio-economical aspects is presented.

The next sections will deal with the problem of environmental impact and its repercussions on the overall costs. Chapter 3 introduces the problems of noise pollution and vibrations from a physical point of view, defining the perception of noise and the attenuation due to noise barriers. In particular, the guidelines for designing efficient barriers, that fulfil requirements of dimensions, safety, aesthetic impact, and reliability are presented; starting from these requisites, a new kind of noise railway barrier will be developed.

In Chapter 4 discusses the core of the environmental impact study, describing how noise pollution affects surrounding population and finding the close relationship between the effectiveness of countermeasures and their costs. The first step is the definition of economic costs: since there is no standardization for the evaluation of noise costs, in accordance to European guidelines for estimating costs related to noise pollution, we developed a model that includes the willingness to pay, reliability, medical expenses and removal of unused components. European normative define the noise and vibration emission limits and the extension of the critical range, in which population is significantly affected by noise emitted from the railway line. This sets the basis for the following optimization process: fixing the maximum noise emission constrain, the goal is to find the set of countermeasures that reduce the overall costs, evaluated with our economical model. On the other hand, it is necessary to evaluate also the perceived benefit of noise barriers and the other interventions, in order to achieve a complete cost-benefit characterization; by employing standards and experimental analysis, it is possible to define the perceived benefit as a function of barriers characteristics.

After the definition of the model for cost-benefit analysis, the last step is to solve this optimization process, defining the intervention strategy to be applied. Different scenarios, including noise due to rail-track interactions, aerodynamic noise produced by pantograph, noise and vibration reduction on the trackwork and acoustic barriers, will be discussed. Moreover, the project of a new kind of acoustic barriers, designed with computational fluid dynamic simulations using more then 2 millions tetrahedric finite volume elements, will be detailed; these barriers allow a better efficiency in terms of noise reduction and present a low aesthetic impact because of its particular shape. Finally, the cost-benefit analysis is completed by evaluating overall costs, cost per train, cost per track meter and the whole perceived benefit. Consequently, we are able to define the optimum interventions criteria for minimizing the environmental impact of the *AV/AC* railway line.

The last section draws the conclusions of the project activity and resumes the results of the cost-benefit performed analysis.

2 The context

2.1 Principal documents for the mobility planning

2.1.1 "Libro Bianco sui trasporti" (2001)

In the "Libro Bianco sui trasporti" – *Transport White Paper* – the European Committee characterises three major areas where to act within the members of EU:

- *Balancing of different types of transport*: it is common opinion that the massive use of road transport, both cars and lorries, can be a serious problem in terms of environmental impact, development quality, speed of delivery and, not least, costs.
- *Empowerment and integration of the European Transport Network*: the aim is to create a homogeneous European Network, which connects all the different countries, operating either on linear infrastructures or on strategic nodal points.
- *Internationalising of external transport costs*: the massive use of road transport, which is itself cheap, generates considerable damage and external costs that are never paid for by anyone. The absence of market price for these sorts of costs lead the European Union to levy specific taxes trying to limit this trend.

Balancing of different types of transport

Balancing of different types of transport is considered as one of the most important community target and thus it was the object of discussion by the European Council in Goteborg in 2001. The most significant aspect that turned out in such an occasion was the promotion of the so-called inter-modality regarded as a fundamental measure to develop real alternatives to road transport.

The program "Marco Polo" tries to face the rise of goods trading (estimated +50% between 1998 and 2010) by attempting to shift one fifth of the whole international traffic from the road transport to other means of transport, the first of which is rail transport. The main action is the creation of multi-modal corridors, which principally use existing European infrastructures, dedicated first to goods, starting from the consciousness that railways are not in the short term an efficient alternative means of transport because of the passenger traffic that goes on the same infrastructures. In such a vision it has to be considered as essential the distinction of railway tracks dedicated to goods to the one dedicated to passenger traffic in all those areas that create a bottleneck for circulation, urban areas in particular.

Another important aspect is the railway access to seaports that can be gathered as an essential link for the development of short distance sea traffic that could relieve the intense traffic through the Alps and the Pyrenees. The key role of European sea transport is enlightened by the program "Sea motorways" that tries to relaunch sea and fluvial goods trade by means of efficient and simplified services. Furthermore, the European Union enlisted a close river network connected by artificial canals that enter into the Atlantic Ocean and the North Sea and recently linked to the Danube by means of a new ship-canal, which is now used by 9% of all the goods traffic.

Empowerment and integration of the European Transport Network

Motorways, railways and airports are all together part of the so-called Trans European Network of Transport (TEN-T). Nowadays this network is formed by up to 75.000 km of roads, 78.000 km of railways, 330 airports, 270 international seaports, 210 local ports for home trade and it is daily used by the half of all the passenger and goods traffic. The priority given by the EU to the development of this kind of network is defined through several project directly financed by the EU itself. The last orientations for the network are specified in the "Libro Bianco sui trasporti" (2001) in which precedence is given to those projects capable of eliminating bottle-necks, completing links between existing infrastructures and decongesting main traffic axis. In such a context the principal projects involve railways and, specifically for Italy, Brennero and Moncenisio railway tunnels as well as AV/AC railway lines can be listed.

The most important points of the TEN-T program are the concepts of interoperability and inter-modality, that means that all the different networks have to be strictly connected one to another in order to reduce the costs and the quality of the transport, the road traffic congestion, the environmental impact and the differences between the countries in the EU.

During a conference held in Crete in 1994 nine main European corridors have been identified to facilitate the connection between the EU members. Participating Countries have to specify precise "Protocolli d'Intesa" – *Protocols of Intent* – in which all technical aspects related to tracks and infrastructures can be indicated. Moreover, in 1997 the Helsinki Conference introduced another corridor. The corridors are fundamentally terrestrial trade tracks with either one or both the ends in a seaport to facilitate the connection with sea trade networks, with great advantages for inter-modal transport.

Four important corridors are strategic for Italy and for the entire Mediterranean area:

- *Corridor I*: runs from the North to the South of Europe from Berlin to Palermo.
- *Corridor V*: goes from Lisbon to Kiev passing through Turin, Milan, Venice and it is interested most by the construction of the AV/AC railway line.
- *Corridor of the "Two Seas"*: connects two important seaports, Genoa and Rotterdam, which are links for trade in Africa in the South and America in the North.
- *Corridor VIII*: starts in Bari and finishes in Varna connecting the Adriatic to the Black Sea.

In 2003 the European Committee modified the initial orientations for the TEN-T in order to involve the new EU Eastern Members.

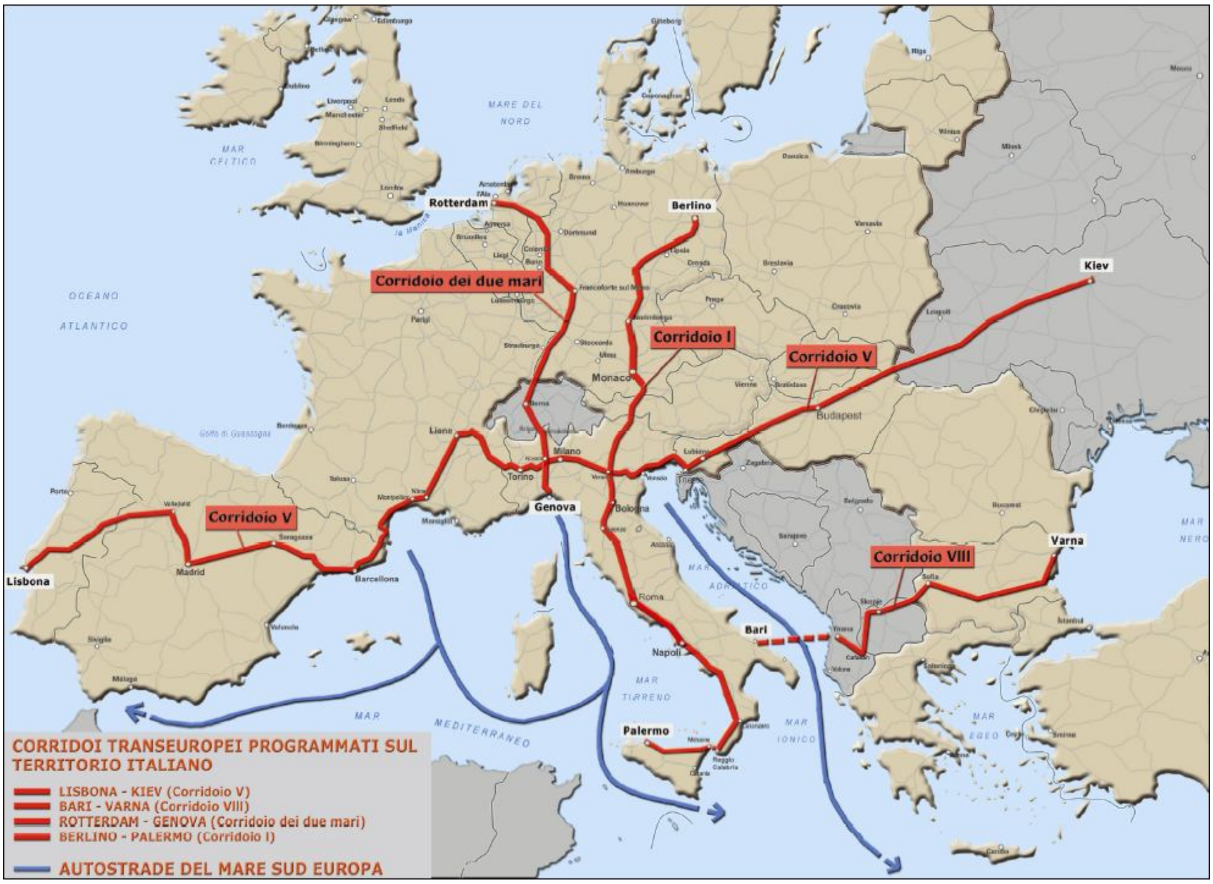

Fig. 2-1 – Map of the European Corridors.

Internationalising of external transport costs

The construction of new infrastructures often causes high tensions because it involves different contrasting interests starting from environmental protection, local community welfare, opportunity of development, economical benefits. The equation Infrastructure-Cost is too simple to work properly since sometimes leaving things in the present state may lead to unaffordable situations either talking about economical aspects or in terms of environment.

Nowadays there is a tendency to concentrate the production of goods in few great worldwide sites and to get raw materials all over the world where costs are cheaper. This leads to a rise of the demand of transport with an inevitable increase of pollution and congestion that is not sustainable for a long time. This scenario is the object of lots of political debates since it involves the entire society and metropolitan areas in particular. Increase of air pollution, acoustic pollution, mortal accidents, traffic jams are just some of the negative aspects related to the problem of external costs of transport.

External costs – Year 2000 *(million of euro)*

	Greenhouse Gas	Pollution	Noise	Accident	Congestion	Total
Road	**8.412**	**36.628**	**11.066**	**27.727**	**11.147**	**94.980**
Passenger	5.846	18.704	5.907	25.829	7.815	64.101
- Private	5.618	17.100	5.559	25.580	7.508	61.364
- Public	228	1.604	348	249	307	2.736
Goods	2.566	17.924	5.159	1.898	3.332	30.879
Train	**234**	**590**	**2.095**	**94**	**36**	**3.049**
Passenger	154	432	1.078	81	36	1.781
Goods	81	158	1.016	13	-	1.268
Plane	**708**	**630**	**998**	**79**	**6**	**2.421**
Passenger	644	573	908	79	6	2.210
Goods	64	57	90	-	-	211
Total	**9.355**	**37.848**	**14.158**	**27.900**	**11.188**	**100.450**

Source: Amici della Terra (2001)

One of the most common ways to estimate external costs is to monetize them. As shown in the table above the most part of the costs comes from road transport (95%) of which 65% is due to private means of transport, as could be easily imagined. Train transport and air transport generate very few costs, also due to the fact that these kinds of transport are less used at the moment. What is particularly interesting is that accidents and congestion for these two modes of transport are very close to zero whereas the discomfort categories that show the highest values are pollution and accident.

Another way that has been proposed to evaluate external costs is that of the physical quantification of costs in terms of environment consumption. In such a vision all the costs are quantified through a measuring unit called "global hectare" related to a medium productive biological area. Some evaluations of the disposable quantity of this kind of area pro-capite show that in the year 2000 was about 1,9 hectares for about 6 billion people but in 2050 it could decrease till 1,2 hectares estimating a population of 9,5 billion people. Looking closer to external costs it has been found that a car medium use of environment is about 0,9 m^2 for every passenger/kilometre, much higher than the values related to bus and train (0,3 m^2) and even plane (0,75 m^2). The situation is a bit different for goods: the worst position is held by air trade (3,2 m^2 tons.km), followed by road trade (0,7 m^2) and train trade (0,1 m^2). However, it has to be said that this sort of external cost estimation is more suitable for global evaluation rather than local impact. As a matter of fact it has to be kept in mind that negative aspects often involve a local dimension whereas benefits are usually shared by a greater part of society.

In such a scenario the key role of train transport is clear. First of all, there is the need of warranting a real competitive market in road transport with EU and national policies to promote alternative means of transport. Passenger train transport needs to exploit properly the advantageous position of stations, which are deep into city areas, trying to compete with air transport even on long distance travel. Moreover, train transport has to get the chance to connect its network with seaports, airports and roads in a multi-modal view of goods trade.

2.1.2 Piano Generale dei Trasporti e della Logistica (2001)

The document called "Piano Generale dei Trasporti e della Logisitica" – *Transport and Logistics General Plan* – was approved in 2001 and defines the strategic orientations of the national transport policies. The main objectives are:

- Increase of the general accessibility in three directions:
    - Reduction of the existing gap between North and South in terms of infrastructures;
    - Empowerment of the connections with the rest of Europe through the Alps;
    - Connection of the seaport network with the terrestrial main tracks.

- Reduction of transport costs and improvement of the quality of the transport service in order to become more competitive in Europe
- Environmentally sustainable offer of transport through an increased use of public transport in urban areas and programs of infrastructure recuperation for what concerns air and noise pollution and environmental impact.

With the purpose of evaluating the national transport system the so-called "Sistema Nazionale Integrato dei Trasporti" (SNIT) – *Integrated National System of Transport* – was created, whose aim is to detect the critical aspects, such as missing links in the infrastructure network, and the projects having the right of priority to facilitate the resources' allocation.

A new way of approaching the problem is then identified. The transport system is not considered by type of transportation any more but by sub-systems:

- *Urban Transport*: the most important innovation is the proposal of the "Piano Urbano della Mobilità" (PUM) – *Mobility Urban Plan* – by means of which the Public Administration can identify properly the targets for the urban mobility.
- *Long distance passenger transport*: priority is given to all those measures that are capable of facilitating the competition between different means of transport in a larger vision of inter-modality.
- *Goods transport*: the goal is to create an efficient logistic network capable of relaunching Italy in the European context.

2.1.3 Patto per la Logistica (2005)

In the past 30 years the remarkable growth of national economy was not followed up by the appropriate attention to mobility planning. Such behaviour resulted in a remarkable gap between the demand of transport and the related offer that now has to be filled in a period of lack of public resources if Italy wants to gain primary importance in Europe again.

The document "Patto per la Logistica" – *Pact for Logistics* – identifies several strategic projects within different areas:

- road trade
- railway system
- inter-modality system
- cargo planes
- urban logistics

The key role of the railway system is again underlined by means of numerous programs of infrastructure network empowerment related to mountain passes and the development of European Corridors as well as other important national trade axis. The necessity to have a general coherence between greater and smaller infrastructures is also highlighted, due to warrant the efficiency of the delicate aspect of the so-called "last mile", that is mainly related to goods delivering between different logistic poles spread all over the territory.

2.2 Characterization of the areas of Piemonte and Lombardia

It has been shown that the infrastructure network is one of the fundamental aspects for the development and the economic growth of a Nation. Italy presents a peculiar distribution of logistic poles which are mainly located in the North and strongly connected with the existing road and railway network. The principal seaports that are now part of this network are Genoa and La Spezia.

The most problematic aspect is the congestion of several important roads such as A4 motorway (Milan-Venice), A1 motorway (Milan-Bologna), ring-road of Milan and Mestre as a consequence of a general preference for road transport both for passengers and goods.

First of all it has to be said that Italy presents a territory that is 80% mountainous with a general sprawl of little towns and cities all over the Country with very few important metropolises such as Milan, Turin, Naples, Venice, Verona, Rome, Florence, Bologna, Palermo almost incomparable to greater European metropolises.

Passenger traffic by means of transport - Year 2003 *(thousand)*

Mean of transport	Total traffic	International traffic	National traffic		
			Passengers	Urban	---
Trenitalia (F.S.)	497.936	67.605	430.331	-	-
Other railways	210.059	-	210.059	-	-
Underground	651.400	-	651.400	-	-
Tram	299.000	-	299.000	295.400	3.600
Coach-Bus	3.824.900	-	3.824.900	2.933.300	891.600
Sea navigation	82.574	5.694	76.880	-	-
Fluvial navigation	107.077	-	107.077	-	-
Plane	100.108	51.033	49.075	-	-
Total	**5.773.054**	**124.332**	**5.648.722**	**3.228.700**	**895.200**

Source: Elaboration from Conto Nazionale dei Trasporti

Goods traffic by means of transport - Year 2003 *(thousand of tons)*

Mean of transport	Total	International	National
Trenitalia (F.S.)	82.107	51.618	30.489
Other railways	3.488	-	3.488
Road	1.243.073	35.804	1.207.269
Sea navigation	477.025	341.393	135.632
Fluvial navigation	641	-	641
Plane	778	623	155
Total	**1.807.112**	**429.438**	**1.377.674**

Source: Elaboration from Conto Nazionale dei Trasporti

As you can see from the tables above bus is the most common mean of transport (66%), especially in urban areas. Train is used by about 13% of all the passengers and plane by just 2%. Yet, the international traffic is almost divided in two between train and plane.

Analysing total goods trade you can find again that approximately 69% of goods are carried by lorries, 26 % by ships and just 5% by trains. Internationally sea trade presents the highest values (79%) whereas road trade is about 88% of the total national traffic. Train trade is again just 2% of the total.

Travels by destination and main mean of transport - Year 2004 *(thousand).*

Mean of transport	Destination											
	North		Center		South		Italy		Abroad		Total	
Plane	1.748	4,6	1.445	7,5	2.072	8,4	5.265	6,4	8.914	56,3	14.179	14,5
Train	4.247	11,1	2.505	13,0	2.080	8,4	8.831	10,7	637	4,0	9.469	9,7
Car	29.852	78,2	12.645	65,5	17.029	68,7	59.525	72,3	3.927	24,8	63.452	64,7
Other	2.337	6,1	2.717	14,1	3.614	14,6	8.668	10,5	2.352	14,9	11.020	11,2
Total	**38.184**	**100,0**	**19.312**	**100,0**	**24.794**	**100,0**	**82.290**	**100,0**	**15.830**	**100,0**	**98.120**	**100,0**

Source: Istat, Indagine trimestrale "*Viaggi e vacanze*".

Comparing means of transport (including car) and destination it can be said that in the North car is preferred by about 78% of the people and only about 4 million people (11%) used the train in 2004. National travels are mainly made by car (72%) and train and plane are almost comparable (respectively 10,7% and 6,4%). On the other hand, international travel presents 56% in the use of plane due to the longer distances to be accomplished. In this case train was used by 4% of all the people and 24,8% used their own car.

Travels by type of travel, destination and main mean of transport - Year 2004 *(thousand).*

Destination and mean of transport		Type of travel									
		Holiday 1-3 nights		Holiday 4+ nights		Holiday		Work		Total travels	
ITALY	Plane	890	2,5	1.897	5,5	2.787	4,0	2.478	20,6	5.265	6,4
	Train	3.271	9,2	3.226	9,3	6.498	9,2	2.334	19,4	8.831	10,7
	Ship (a)	227	0,6	1.771	5,1	1.999	2,8	153	1,3	2.152	2,6
	Car (b)	28.027	78,8	25.307	72,9	53.333	75,9	6.192	51,4	59.525	72,3
	Bus (c)	1.906	5,4	1.460	4,2	3.365	4,8	596	4,9	3.961	4,8
	Caravan	1.042	2,9	864	2,5	1.905	2,7	-	-	1.905	2,3
	Other (d)	190	0,5	168	0,5	358	0,5	292	2,4	649	0,8
	Total	**35.552**	**100,0**	**34.694**	**100,0**	**70.245**	**100,0**	**12.045**	**100,0**	**82.290**	**100,0**
ABROAD	Plane	941	37,4	5.929	57,2	6.871	53,3	2.043	69,5	8.914	56,3
	Train	102	4,1	466	4,5	568	4,4	69	2,3	637	4,0
	Ship (a)	48	1,9	820	7,9	868	6,7	29	1,0	897	5,7
	Car (b)	1.069	42,5	2.180	21,0	3.248	25,2	678	23,1	3.927	24,8
	Bus (c)	310	12,3	655	6,3	965	7,5	79	2,7	1.043	6,6
	Caravan	47	1,9	300	2,9	346	2,7	5	0,2	352	2,2
	Other (d)	-	-	26	0,2	26	0,2	35	1,2	61	0,4
	Total	**2.517**	**100,0**	**10.375**	**100,0**	**12.891**	**100,0**	**2.939**	**100,0**	**15.830**	**100,0**
TOTAL	Plane	1.831	4,8	7.827	17,4	9.658	11,6	4.521	30,2	14.179	14,5
	Train	3.374	8,9	3.692	8,2	7.066	8,5	2.403	16,0	9.469	9,7
	Ship (a)	275	0,7	2.591	5,7	2.866	3,4	182	1,2	3.049	3,1
	Car (b)	29.095	76,4	27.487	61,0	56.582	68,1	6.870	45,9	63.452	64,7
	Bus (c)	2.216	5,8	2.114	4,7	4.330	5,2	674	4,5	5.004	5,1
	Caravan	1.088	2,9	1.163	2,6	2.251	2,7	5	0,0	2.257	2,3
	Other (d)	190	0,5	194	0,4	383	0,5	327	2,2	710	0,7
	Total	**38.069**	**100,0**	**45.068**	**100,0**	**83.137**	**100,0**	**14.984**	**100,0**	**98.120**	**100,0**

(a) *ship* means: ship, boat, motorboat;

(b) *car* means: own car, relative car, friend car or rent car;

(c) *bus* means: tourist bus or line bus;

(d) *other* means: other type of transportation not mentioned above such as motorbike, bicycle, etc.

Source: Istat, Indagine trimestrale "*Viaggi e vacanze*".

Looking for the reason of travelling it can be stated that about 85% is held by holiday. Again in Italy car is the most common mean of transport both for holiday (75,9%) and work (51,4%), whereas for international travel plane is more used (56,3%). Train is quite used for work travels in Italy (19,4%) and it is comparable to plane (20,6%).

Travels in Italy by type of travel and destination - Year 2004 *(thousand).*

Destination	Type of travel									
	Holiday 1-3 nights		Holiday 4+ nights		Holiday		Work		Total travels	
Piemonte	2.031	5,7	1.356	3,9	3.386	4,8	493	4,1	3.880	4,7
Valle d'Aosta	389	1,1	422	1,2	811	1,2	13	0,1	824	1,0
Lombardia	3.853	10,8	2.235	6,4	6.088	8,7	2.161	17,9	8.249	10,0
Trentino-Alto Adige	1.448	4,1	2.819	8,1	4.267	6,1	218	1,8	4.484	5,4
Veneto	2.369	6,7	1.921	5,5	4.290	6,1	531	4,4	4.821	5,9
Friuli-Venezia Giulia	729	2,1	635	1,8	1.364	1,9	182	1,5	1.546	1,9
Liguria	2.987	8,4	2.574	7,4	5.561	7,9	343	2,8	5.904	7,2
Emilia-Romagna	3.671	10,3	3.255	9,4	6.926	9,9	1.549	12,9	8.475	10,3
Toscana	3.690	10,4	2.783	8,0	6.473	9,2	1.050	8,7	7.523	9,1
Umbria	1.049	3,0	426	1,2	1.476	2,1	302	2,5	1.778	2,2
Marche	922	2,6	973	2,8	1.895	2,7	596	5,0	2.492	3,0
Lazio	3.311	9,3	2.051	5,9	5.363	7,6	2.156	17,9	7.519	9,1
Abruzzo	1.425	4,0	1.076	3,1	2.501	3,6	222	1,8	2.723	3,3
Molise	143	0,4	210	0,6	354	0,5	2	0,0	355	0,4
Campania	3.040	8,6	2.320	6,7	5.359	7,6	659	5,5	6.018	7,3
Puglia	1.047	2,9	2.500	7,2	3.547	5,0	297	2,5	3.844	4,7
Basilicata	232	0,7	277	0,8	510	0,7	113	0,9	622	0,8
Calabria	748	2,1	2.652	7,6	3.400	4,8	221	1,8	3.620	4,4
Sicilia	1.525	4,3	1.955	5,6	3.480	5,0	670	5,6	4.150	5,0
Sardegna	943	2,7	2.251	6,5	3.194	4,5	266	2,2	3.460	4,2
Total	**35.552**	**100,0**	**34.694**	**100,0**	**70.245**	**100,0**	**12.045**	**100,0**	**82.290**	**100,0**

Source: Istat, Indagine trimestrale "*Viaggi e vacanze*".

Splitting the previous statistics referring to Italy, it can be found that Piemonte and Lombardia attract about 15% of all the passenger traffic that is about 32% of all the travels in the North. 22% of people travel to Piemonte and Lombardia for working reasons and this is an important point since it has been shown that train and plane are used more for this type of travel.

In the last few decades there has been a significant increase in the transport demand related to the growth of the world economic market. Italy was unprepared for such a growth due to weak transport firms, lack in the management of transport assets and slowness of infrastructure construction.

Transport infrastructure - Year 2000 *(EU average = 100)*

	Railway	Road	Airport	Seaport
Germany	159,3	101,5	110,1	83,4
Spain	35,8	51,4	67,9	74
France	109,3	94,6	92,2	68,9
Italy	91,6	94,5	127,5	115,5
United Kingdom	136	218,2	135,8	229,8

Source: CNEL elaboration from Ecoter

CNEL (Consiglio Nazionale dell'Economia e del Lavoro – *Economy and Work National Council*) created a synthetic index to evaluate the infrastructure network of different Countries in EU. The table above shows that Italy is a bit lower than the average value concerning road infrastructures (94,5) and railway infrastructures (91,6). It has to be noted that the index mentioned is a physical index which cannot be directly related to the real degree of service given to the population and the productive system. Moreover, CNEL considered another index related to the distribution of infrastructures all over the Country to check the effective concentration of the transport network in the State considered.

In the table below the transport infrastructure index and a general index of the infrastructure apparatus, including ITC, energy and education, for different regions in Italy is shown.

Infrastructure apparatus - Year 2000 *(EU average = 100)*

Region	Transport	General Index
Piemonte	106,2	110,6
Valle d'Aosta	36	86,4
Liguria	198,4	172,2
Lombardia	111,9	124,8
Trentino Alto Adige	54,2	67,9
Veneto	120,2	118,5
Friuli Venezia Giulia	113,2	107,3
Emilia – Romagna	94,5	111,3
Toscana	101,1	103,2
Umbria	85,8	75,2
Marche	109,4	89,8
Lazio	136,6	131,2
Abruzzo	99,8	88,8
Molise	77,3	60
Campania	132,4	97
Puglia	95,9	84,3
Basilicata	59,8	69,3
Calabria	105,3	72,2
Sicilia	104,5	86,5
Sardegna	51,5	61,7

Source: CNEL elaboration from Ecoter

From the table it appears that the transport infrastructure is not uniform all over Italy. First, it has to be said that Liguria shows the highest value of the index due to the limited area, the geography and the presence of three important seaports, Genoa, La Spezia and Savona, two of which are well connected to the road and railway network. On the other hand, Valle d'Aosta and Trentino-Alto Adige show low index but the situation seems not to be so hard because of the low population density as a consequence of the extension of the mountainous territory. What emerges is the fact that the South presents a situation of underdevelopment in terms of infrastructure apparatus, except Campania, Calabria and Sicilia owing to the presence of international seaports and the key role of these regions.

Comparing the general indexes the situation looks a bit worst and the discrepancy between North and South becomes greater. Lombardia stands in third place in the national rank and Piemonte is the sixth, yet not far from Emilia Romagna and Veneto, proving again the importance of this area for the Italian development.

If the infrastructure apparatus is compared to the productive dimension some problems related to the future development opportunity come into sight.

In the following tables population, occupation indexes and PIL for different Regions are compared.

Population and occupation indexes - Year 2004

Region	Population 15+ y.o. (thousand)	Working Population 15-64 y.o. (thousand)	Activity rate 15-64 y.o. (%)	Employed 15-64 y.o. (thousand)	Employment rate 15-64 y.o. (%)	Unemployment rate 15-64 y.o. (%)
Piemonte	3.707	1.895	66,9	1.796	63,4	5,3
Valle D'Aosta	105	57	69,1	56	67,0	3,0
Lombardia	7.951	4.327	68,3	4.152	65,5	4,0
Trentino - Alto Adige	798	451	69,5	438	67,4	2,9
Veneto	3.965	2.133	67,2	2.042	64,3	4,2
Friuli - Venezia Giulia	1.044	520	65,1	500	62,5	3,9
Liguria	1.394	644	63,9	607	60,2	5,8
Emilia Romagna	3.561	1.917	70,9	1.846	68,3	3,7
Toscana	3.115	1.569	66,7	1.488	63,2	5,2
Umbria	738	360	65,2	340	61,4	5,7
Marche	1.301	669	67,4	633	63,8	5,3
Lazio	4.443	2.255	63,6	2.076	58,5	7,9
Abruzzo	1.105	520	61,2	479	56,3	7,9
Molise	276	123	58,7	109	52,0	11,3
Campania	4.709	2.088	53,5	1.761	45,0	15,6
Puglia	3.375	1.461	53,4	1.235	45,0	15,5
Basilicata	505	222	56,4	194	49,1	12,8
Calabria	1.683	724	53,7	620	46,0	14,3
Sicilia	4.150	1.739	52,3	1.439	43,2	17,2
Sardegna	1.416	689	59,6	593	51,2	13,9
Italy	**49.338**	**24.365**	**62,5**	**22.404**	**57,4**	**8,0**

Source: Personal elaboration

Population density and PIL - Year 2004

Region	Area (km^2)	Population 15+ y.o. (thousand)	Popolation density (pop/km^2)	PIL (thousands of euro)	PIL pro-capite (euro)	PIL pro-capite (%)
Piemonte	25.399	3.707	146	108.940	29.391	111,5
Valle D'Aosta	3.262	105	32	3.543	33.750	128,0
Lombardia	23.804	7.951	334	260.306	32.739	124,2
Trentino - Alto Adige	13.613	798	59	28.353	35.547	134,8
Veneto	18.378	3.965	216	116.478	29.380	111,4
Friuli - Venezia Giulia	7.864	1.044	133	30.998	29.692	112,6
Liguria	5.411	1.394	258	39.604	28.410	107,7
Emilia Romagna	22.123	3.561	161	113.819	31.962	121,2
Toscana	22.990	3.115	136	87.524	28.095	106,6
Umbria	8.456	738	87	18.034	24.448	92,7
Marche	9.692	1.301	134	33.589	25.823	97,9
Lazio	17.199	4.443	258	134.179	30.203	114,5
Abruzzo	10.792	1.105	102	24.475	22.144	84,0
Molise	4.440	276	62	5.655	20.507	77,8
Campania	13.595	4.709	346	87.882	18.663	70,8
Puglia	19.347	3.375	174	61.446	18.205	69,0
Basilicata	9.988	505	51	9.371	18.567	70,4
Calabria	15.077	1.683	112	29.110	17.301	65,6
Sicilia	25.707	4.150	161	77.370	18.644	70,7
Sardegna	24.089	1.416	59	28.812	20.348	77,2
Italy	**301.226**	**49.338**	**164**	**1.300.929**	**26.367**	**100,0**

Source: Personal elaboration

Piemonte and Lombardia are two of the largest Regions in Italy. Although Lombardia is the largest one, the population density is the highest, about twice the average. The activity rate and the employment rate for both the Regions are much higher than the average and there is a very little unemployment rate. PIL pro-capite shows quite the greatest values if compared to the other Regions.

The discrepancy between North and South becomes visible again and suggests that statistics on infrastructure apparatus have to be read taking into account these economic aspects.

Transport infrastructures could rapidly turn into a bottle neck for global economic growth due to the inevitable congestion of more developed areas. The demand of transport and its differentiation is then much higher in the North where the logistic poles and the production are denser. As a matter of fact it appears that even if well equipped in terms of infrastructures all the Regions in the North are underdeveloped weighed against the achieved productive level. Actually, Piemonte and Lombardia in particular are in this troublesome situation out of which they are expected to get out of as soon as possible.

2.3 The new mobility vision

The new *Italian High Speed Railway Line* is definitely part of a reborn logic of innovation and modernisation that directly comes from a global European vision of a unique great system of transportation that goes all over the different countries, actually with no border. The empowerment of the existing rail network with the construction of a new specialised and modern network with high interoperability is deem to be as essential to offer a larger range of services and connections both within Italy itself and with other foreign Countries characterised by high standards of rapidity, frequency, quality and security.

The railway line that goes from Turin to Milan and that is object of the present study is part of the so-called *Corridor V* that runs from Lisbon to Kiev, which is itself just one of the terrestrial trade tracks within the Trans European Network of Transport (TEN-T) that have the right of priority to create an interoperable and multi-modal transport service useful to the whole Europe. Some of the criticism brought by opponents do not properly take into account this fundamental aspect since they concentrate just on the local features without looking at a greater dimension both in a spatial and a temporal dimension.

2.4 Infrastructures and development

Lots of studies demonstrate that an increase in the number and efficiency of infrastructures is the basis for the development of a Nation. However, there are some points that have not already been solved. One of these is the identification of the real cause-effect relation: is an efficient infrastructure the outcome or the origin of an increase in the economical competitivity? Transport infrastructures in underdeveloped areas are not themselves sufficient to guarantee economical development, whereas an empowerment of the existing transport network in more developed areas could just be a marginal addition to a system with a troublesome situation in terms of traffic congestion with no real effects on the actual mobility of people and goods. In both cases the infrastructure is just an opportunity that must be managed properly to obtain the maximal positive effects. The fundamental importance of an appropriate and effective public policy in order to change people's habit of using intensively road transportation is therefore evident.

It has been then proved that the richness of a Nation is strongly connected to the mobility of human and material resources and the environmental impact is somehow considered as an inevitable consequence that the entire society must bear. The infrastructure development is then a much more relevant factor for those regions where a better connection provides a visible reduction in costs of production and transportation of goods first and people then. Furthermore, infrastructures could represent a valid aid for less developed areas to keep in touch with more industrialised regions increasing the general mobility and the working opportunities. Moreover, a better transport system contributes to raise the education level in general since a better mobility lets people to attend different types and more distant schools and universities, in particular.

The empowerment of the transportation network is also an incentive for economical activities. Factories, firms and services tend to concentrate in those areas where the accessibility is easier in order to attract more clients and be more competitive in the market. First of all the infrastructure promotes goods and people mobility inside a certain region and then the connection between that area and the rest of the world. In other words, one of the most evident consequences is the increase in the territorial accessibility.

2.5 Foreign experiences

2.5.1 Japan: the Shinkansen

Japan is the first Nation that adopted the High Speed Railway Line called Shinkansen. In 1964 the first High Speed train travelled from Tokyo to Nagoya passing through Osaka. Nowadays, the 16 most important cities in Japan are strongly connected with the Shinkansen network, whose success is firstly due to the high population density that makes this type of transportation offer extremely attractive since there is no real possibility that people live all together in the same place. Another important fact is the strong public policy against the use of cars that accompanied the Shinkansen railway construction.

Fig. 2-2 – The Shinkansen.

The first effect that has been noticed was the increase in the population in the cities where there was a station of the new High Speed line. The population there increased about 22% more than the augment registered in those cities where the Shinkansen had no stops.

Looking at occupational indexes in different economical fields it has been found that before the opening of the High Speed line those cities now with a Shinkansen station showed a lesser growth rate than those without the station but in the ten following years the same cities registered an evident opposite trend. As an example wholesale trade and retail trade had a growth of about 34% and 12%, respectively, and occupation increased more than 26% just around the stations as a consequence of the increased attractiveness of those areas after the construction of the High Speed railway line. As a comparison, the growth registered in other cities without the Shinkansen was only 7%.

Positive effects were noticed also regarding tourism that showed a better increase in those cities with the new stations accompanied by a similar reduction in the cities without the High Speed station. The most evident result is the greater number of hotels built after the opening of the Shinkansen line.

Moreover, real estate quotations revealed a remarkable rise of about 67% concerning commercial properties around the Shinkansen stations underlining the actual attractiveness of those areas.

On the contrast, it has to be pointed out that the Shinkansen line contributed quite nothing to the development of suburban areas since the greater part of economical activities concentrated most in the industrialised cities of Tokyo and Osaka, both connected with the Shinkansen network.

2.5.2 France: TGV

In1981 the first High Speed connection between Paris and Lyon was opened and nowadays that track is strongly interconnected with the traditional railway line. 40% of travels are made for tourist reasons, 25% for work necessity and the rest 35% are inside travels such as relative visits, shopping and commuting. The reallocation of production factories and firms was strongly influenced by the presence of the High Speed stations in 15% of cases.

TGV had a fundamental role in the living distribution of people around Paris. The presence of the High Speed line and the increased number of trains on the traditional line devoted to commuter mobility allowed families to settle in the suburbs of the Capital where air pollution and acoustic pollution are less and living conditions are better. The border of Paris then virtually enlarged and the number of commuters rose visibly.

The city of Vendome is the clear example. The previous travel to Paris by the traditional railway line took about 2 hours and 10 minutes but with TGV the travelling time decreased to only 42 minutes, becoming an attractive alternative to Paris to live in. In contrast, firms and factories continued to accord preference to Paris even if in Vendome a High-Tech pole was build in order to attract more production activities and services.

On the other hand, Lyon registered an increase in the number of commercial activities moving from the Capital. As a matter of fact, from 1983 to 1990 the office area around the High Speed station enlarged of about 43%.

On the contrary, Lille and Nantes, both connected to the TGV network, did not registered such positive effects due to the initial difficult situation in terms of unemployment, old industries, low educational level and low life quality that prevented firms to reallocate there. A similar situation was noticed in Le Mans where the reduction in travelling time to Paris from 2 hours to just an hour caused the closure of branch offices in favour of the head offices in the Capital.

Another remarkable consequence is the reduction in air connections shorter than 500 km: flights between Paris and Bruxelles and London almost halved and flights between Paris and Lyon quite disappeared.

2.5.3 Spain: AVE

The first High Speed railway connection in Spain opened in 1992 from Madrid to Seville and was 470 km long. Except that, the High Speed line is still under construction and then the socio-economical effects are not yet concluded and not even clear at all.

In 2003 the section between Madrid and Lerida opened and in 2007 the connection between Madrid and Barcelona will be operative. In the first 6 months almost one million passengers travelled on the line Madrid-Lerida with a rise of 40%, comparing the previous situation with the traditional train service.

An important Government plan was then subscribed to empower the entire rail network in order to connect all the principal cities in Spain to Madrid in a time lesser than 4 hours and Barcelona in 6 hours. However, in Spain lesser than 5% of the entire population uses the train as an inside mean of transportation basically because of the poor service quality of the traditional railway line, concerning either the speed and the comfort. As an example the 600 km long travel between Madrid and Barcelona takes about 7 hours whereas the High Speed service would diminished the travelling time to just 2 hours and 30 minutes with a maximum speed of 350 km/h.

Despite the competitive market concerning low cost internal flights, the High Speed line seems to be a valid alternative since Madrid, with a population of 2,9 million people and 2,5 million dwellers in its suburbs, is located right in the middle of the Country and all other cities are just 400-600 km apart, distance that is reckoned to be as ideal for a High Speed railway service. As a matter of fact, the introduction of AVE service between Madrid and Seville brought to a contraction in the flight market quota from 67% in 1991 to 16,4% in 2000 with a remarkable corresponding increase in the use of train.

2.6 The Italian High Speed Railway Line

2.6.1 The AV/AC MI-TO line

The group *Ferrovie dello Stato* started in 1994 an intense plan of re-qualification of the existing railway equipment either concerning the line, the trains and the stations in view of a transformation of the Italian railway network in a High Capacity network according to the European guidelines that try to achieve a new balance between different types of transportation.

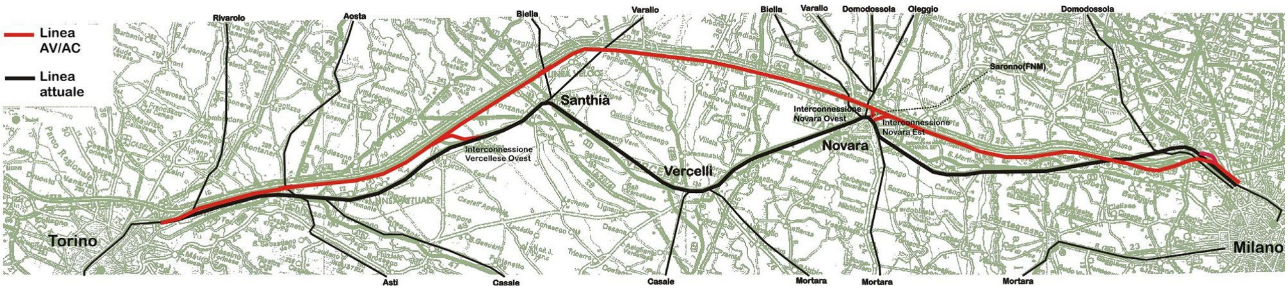

Fig. 2-3 – Territorial overview of the *AV/AC* railway line.

The AV/AC – *Alta Velocità/Alta Capacità*, *High Speed/High Capacity* – project involves a massive construction of new infrastructures between Turin and Milan, from East to West, and between Milan and Naples, from North to South. The new dedicated High Speed/High Capacity line is formed up by a double-track line that uses a 25 kV electrification in order to achieve the maximum European interoperability standard and in the same time to allow a larger towed weight and the use of a greater number of trains with increased speed.

The AV/AC Turin-Milan-Naples project

888 km	Total length of High Speed line
254 km	Length of operating lines under re-qualification
634 km	Length of new lines
143 km	Total length of tunnels
491 km	Length of viaducts, bridges, railway cuttings and elevations
56 km	Total length of new interconnections
4	New stations

Source: TAV

In the table above some data concerning the High Speed track between Turin, Milan and Naples are shown. The new AV/AC line between Turin and Milan runs parallel to the A4 motorway in order to reduce the environmental impact and form a sort of territorial strip dedicated to the connection between the two cities. The High Speed line starts in *Torino Stura* station and ends in *Milano Certosa* station with a total length of about 125 km. In addition, there are two urban sections that directly connect the AV/AC stations with the main stations of the cities, respectively *Torino Porta Nuova* and *Milano Centrale*. These tracks cannot operate with the 25 kV due to environmental problems related to the high population density and, therefore, the speed has to be relatively low in order to reduce noise and vibrations. These problems represent the real limit to a more evident reduction in travelling time between Turin and Milan than the designed situation. As a matter of fact, the two urban sections take almost half of the total travelling time from Turin to Milan.

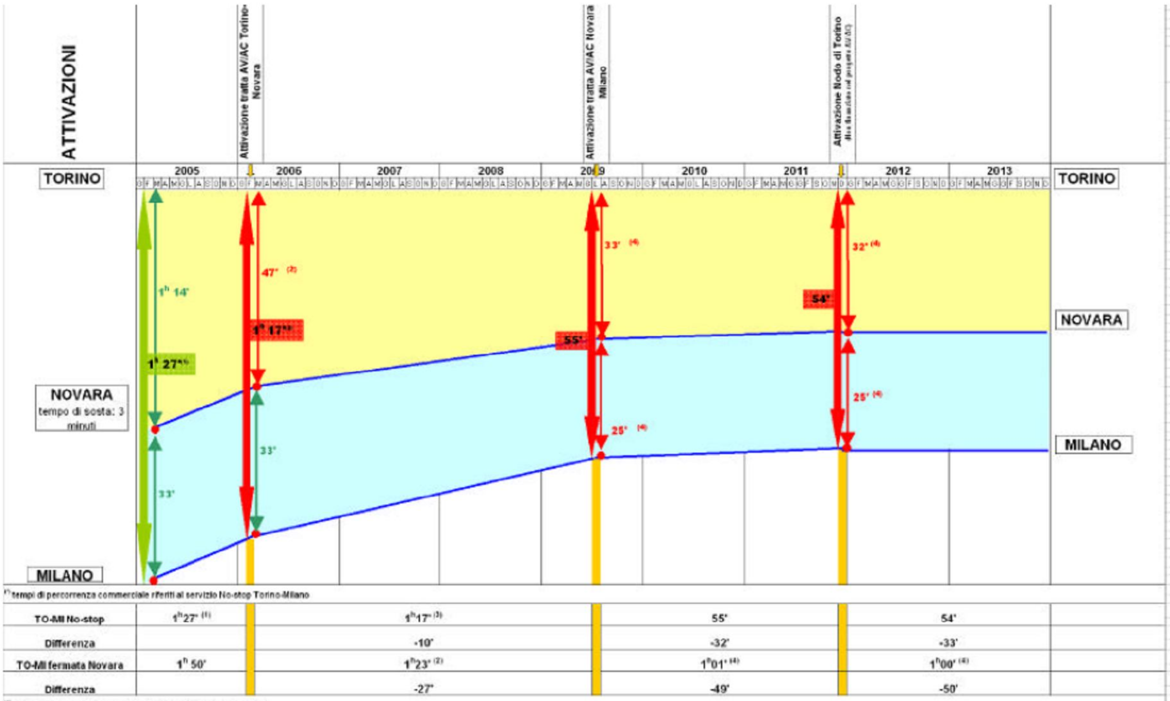

Fig. 2-4 – Future developments of the *AV/AC* line.

In the figure above the travelling times from Turin to Milan are represented, comparing the actual situation and the future offer. With the completion of the entire AV/AC railway section the direct travel with no stops from Turin to Milan would save approximately 33 minutes – from 1h27' to 54' – and the journey with the intermediate stop at Novara would took just an hour instead of 1h50' with a reduction of 50' that is about 45% of the travelling time in the present situation.

The first point that immediately comes out is that the new railway line, whatever speed and modern could be, cannot be imagined and designed alone without looking at the existing infrastructures, trying to interconnect as much as possible the new with the old, the future with the present.

The higher the connections, the higher should be the efficiency of the entire traffic network in a greater vision of inter-modal mobility. Trying to achieve this goal, there is a strong effort to draw up global plans for the reorganisation of urban and metropolitan mobility to provide a better and more organised service for commuters creating new interchanging points with the AV/AC line and the re-qualification of the existing line that would turn into a line dedicated to local travelling with an offer of trains in terms of frequency much closer to underground standards than the traditional train service, basically based on timetables.

Fig. 2-5 – High speed trains.

Moreover, the new railway infrastructure tries not only to minimise the impact on the surrounding territory but also to improve the general environmental and urban quality. The High Speed railway line dedicated to long range travels are strongly interconnected to the existing network and to the principal logistic poles, such as ports and airports. These interconnections, formed up by a couple of tracks to be build or to be renovate, would guarantee the stop and the routing of fast trains to the traditional line, playing a fundamental role in goods trade. In such vision, AV/AC trains can also connect the principal cities not provided with a specific station on the new line, such as Novara.

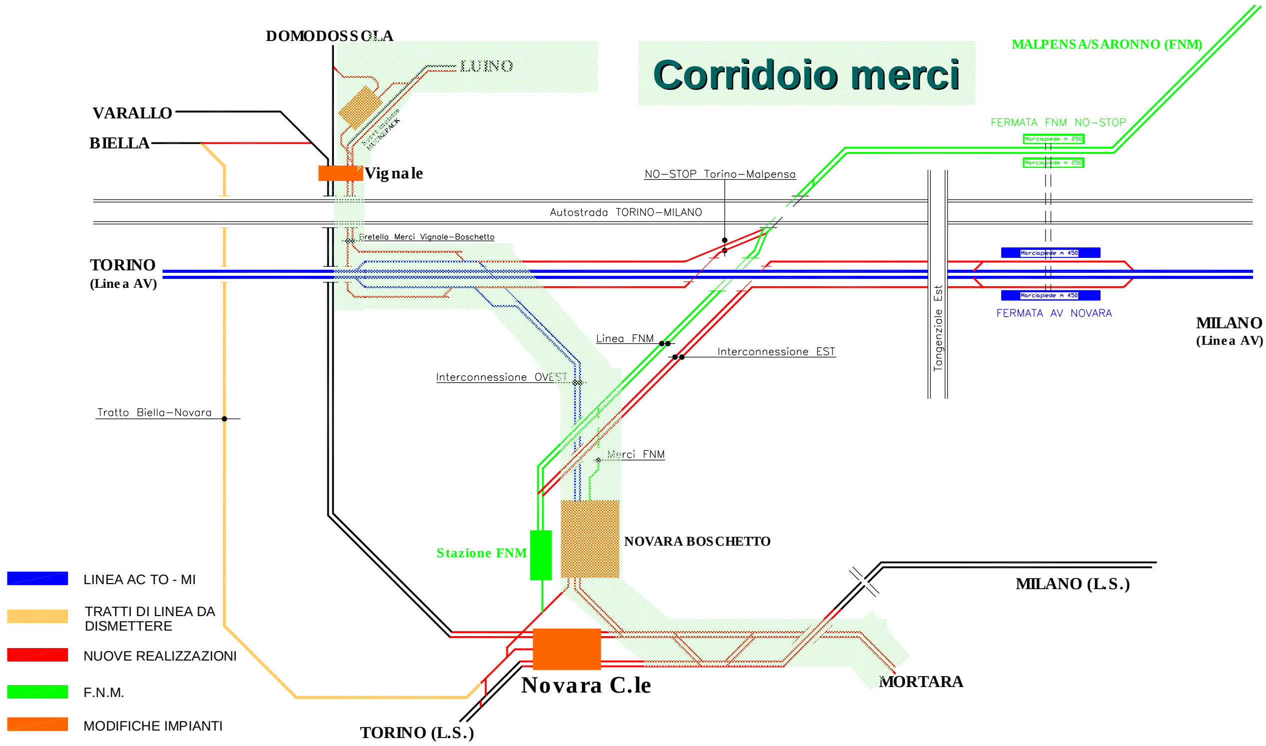

Fig. 2-6 – A schematic of the node of Novara.

In the scheme above the node of Novara is represented. It can be noted the high level of interconnection that interests this area, both for passenger transportation – connections to Malpensa Airport and between the AV/AC stop on the High Speed line, *Novara Centrale* and the *FN* stop – and goods transportation with the creation of a dedicated corridor from North to South that skips the passenger line.

2.6.2 The offer

The passenger long-range service would use well-known types of existing trains such as *Eurostar ES*, *Intercity IC* and *Eurocity EC* and also *Night Express Trains*. The local transportation would use only the traditional line with *Interregional IR trains* and the so-called *Diretti*, *Regionali* and *Metropolitani*. The new timetable is organised on the metropolitan idea of frequency with a proper intensification during rush hours; according to this approach, commuters can go to the train station without having in mind exactly when the train leaves but just having the certainty that a train would leave every 20 minutes, as an example.

Furthermore, goods transportation is shared by the traditional line and the AV/AC line, following a criterion of optimisation of the infrastructure use. The new line would be then interested by all those long range goods transportation with a commercial speed of minimum 120 km/h, whereas goods trains with a speed of about 60 km/h would go through the traditional network.

Goods transportation is now limited by the presence of 5 different ranges of speed on the existing railway network that prevent the full utilization of the line. Moving long range trains that are in the class 250-300 km/h to the new line permits to have a more homogeneous traffic with a consequently increase in the possible traffic that could interest the traditional line.

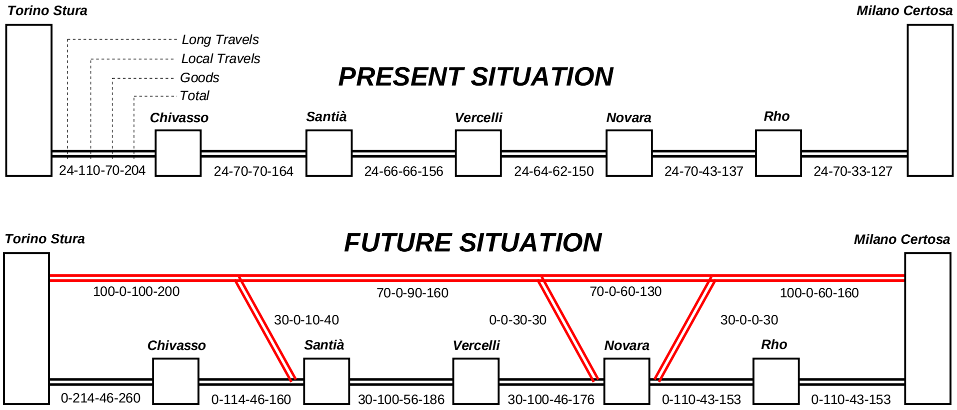

Fig. 2-7 – Future layout of the High-Speed line.

In the scheme above the present situation and the future offer assumed in the design of the new line are compared. It can be easily noticed that local trains run entirely on the old line whereas goods trains use both the line depending on the destination. The same things can also be said for the High Speed trains that would reroute on the traditional line when having an intermediate stop in Novara.

3 General introduction to noise and vibration problem

3.1 Perception of noise

Sound may be defined as any pressure variation that the human ear can detect. Compared to static air pressure (about $10^5\ Pa$), audible sound pressure variations are very small ranging from about $20\ \mu Pa$ ($2 \cdot 10^{-5}\ Pa$) to 100 Pa. 20 µPa corresponds to the average person’s “threshold of hearing”. A sound pressure of approximately 100 Pa is so loud that it causes pain and is referred to as the “threshold of pain”.

The ratio between these two extremes is more than one million to one. A direct application of linear scales (in Pa) to the measurement of sound pressure leads to large and unwieldy numbers. As the human ear responds logarithmically rather than linearly to stimuli, it is more practical to express acoustic parameters as a logarithmic ratio of the measured value to a reference value. This logarithmic ratio is called a “decibel” or “dB”.

$$SPL = 10\log\left(\frac{p}{p_0}\right)^2 = 20\log\left(\frac{p}{p_0}\right)$$

The advantage of using dB is that a linear scale, with its large numbers, is converted into a manageable scale ranging from 0 dB at the threshold of hearing ($p_0 = 20\ \mu Pa$) to 130 dB at the threshold of pain (~100 Pa).

Sensitivity to noise is also determined by the frequency of the noise source. The number of pressure variations per second is called the “frequency of sound” and is measured in hertz (Hz). The normal hearing for a healthy young person ranges from approximately 20 to 20,000 Hz (20 kHz). Hearing is less sensitive at very low and very high frequencies and consequently several different frequency weighting curves have been introduced, depending on the sound level considered. The most common frequency weighting in current use is the “A-weighting” the results of which are often denoted as dB(A), which conforms approximately to the response of the human ear.

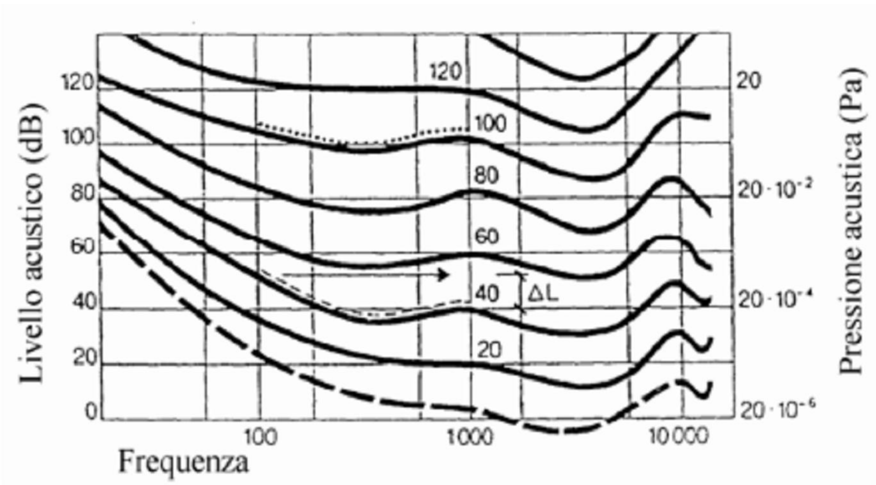

Fig. 3-1 – Acoustic level and pressure as a function of frequency.

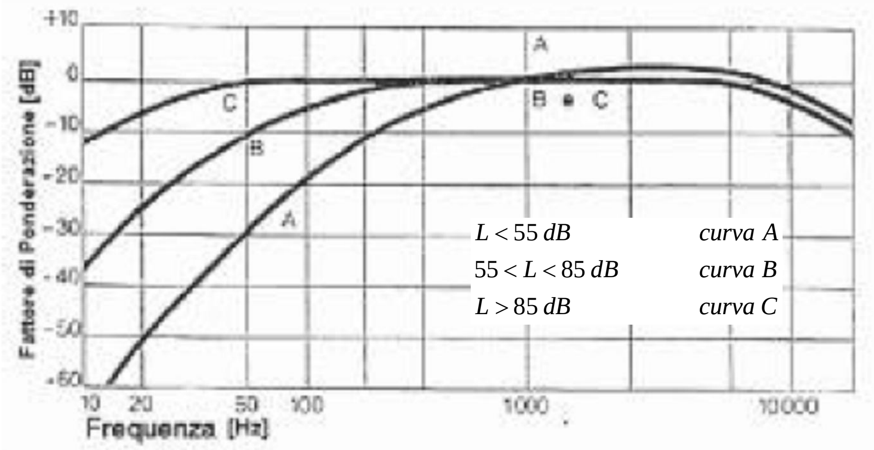

Fig. 3-2 – Normalization factor for A-weighting.

Many people are unfamiliar with dB(A) and other noise descriptors are difficult to explain. In order to help people understand noise levels, the FHWA (Federal Highway Administration) in the United States related noise levels in decibels to common experienced sounds and several other examples like this can be found in literature.

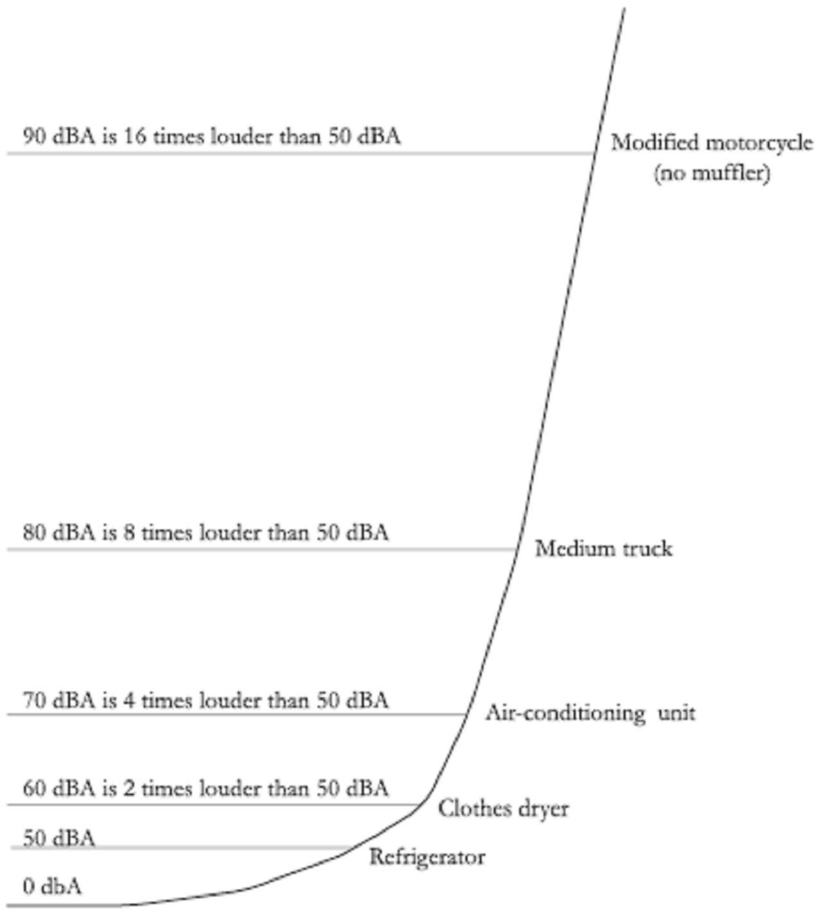

Fig. 3-3 – Examples of noise representation in dBA.

	A-weighted sound pressure level (dB(A))
Auditory threshold at 1000hz	0
Felt as complete quietness	0-20
Slight rising of leaves	25-30
Calm urban area in a city between 2 and 4 am	35-45
Normal conversation (indoor)	45-55
Passenger car, idling 7.5m (Otto engine)	45-55
Passenger car 50 km/h, 7.5m	60-80
Heavy goods vehicle 50 km/h, 7.5m	80-95
Motorcycle 50 km/h, 7.5m	75-100
Peak level of a passing freight train 100 km/h, 7.5m (diesel engine)	95-100
Discotheque (indoor, Leq)	85-100
Peak level of a passenger train (Intercity, 200 km/h, 7.5m)	95-100
Peak level of a passenger train (ICE, 250 km/h, 7.5m)	95-100
Peak level of a high-speed train (TGV, 300 km/h, 7.5m)	105-110
Jet aeroplane (>100 t, take off, 100 m)	110-115
Military low-level flights	105-120
Hearing damage possible even for short-term noise exposure	> 120

In terms of sound pressure levels, audible sound ranges from the threshold of hearing at 0 dB to the threshold of pain at 130 dB and over. Although an increase of 6 dB represents a doubling of the sound pressure, an increase of about 8 to 10 dB is required before sound appears to be significantly louder, perceived as approximately a doubling of loudness. Similarly, the smallest perceptible change is about 1 dB in a good environment. Typically, however, only a 3 dB change is perceptible. A very important fact is that if the difference between two sounds is greater than 15 dB than the addition of the lower level produces negligible effect. In other words, the higher sound masks the lower one. However, total masking only occurs if the sounds are of similar frequency structure, such two trains. As a matter of fact, sounds like telephone warblers are designed to have distinctive frequency structure that can be heard in spite of higher surrounding sound levels.

Noise is usually defined as any unwanted sound. At very high levels, over 75-80 dB(A), noise can cause hearing loss and tinnitus, such as ringing in the ears. Although traffic can produce fairly high levels of noise, it is not likely that people will be exposed to it for long enough to cause actual hearing loss or damage. Health effects are thus not the central issue with traffic noise. What generally matters in impact analysis is the aggravation that such noise may cause neighbouring residents. In general, people have varying tolerances for and perceptions of noise.

Sound level is only one factor in determining noise nuisance. Pitch is also important, as is whether a sound is continuous, random, or repeated in a regular pattern. In general, people tend to dislike traffic noise since in surveys it often tops the list of obnoxious noises heard in outdoor areas like parks and yards and it is also consistently rated as the worst outside noise heard inside homes.

Other factors that should be taken into account with regards to perception of noise therefore include:

- *Continuous noise*: produced by machinery that operates without interruption in the same mode. Tones or low frequencies can be readily identified and analysed if present
- *Intermittent noise*: the noise source operates in cycles and the noise may rise and fall of rapidly such as that of an aircraft passing overhead
- *Impulsive noise*: abrupt and usually upsetting noise such as from an impact or explosion. Such noise are usually perceived as the most annoying form of noise.
- *Tonal noise*: annoying tones are typically created by machinery with rotating parts such as motors, gearboxes, fans and pumps. Tones can be identified subjectively by listening, or objectively using frequency analysis.
- *Low frequency noise*: low frequency noise has significant acoustic energy in the frequency range 8 to 100 Hz. Noise of this kind is typical for large diesel and power plants. It is difficult to suppress low frequency noise and consequently it can propagate easily in all directions for significant distances. Low frequency noise is more annoying than would be expected from the "A-weighted" sound pressure level since considerably contributes to the so-called environment background noise.

3.2 Acoustic barriers

3.2.1 How acoustic barriers work

Acoustic barriers represent one of the most common measure to control outside environmental noise and in particular for road and rail noise. Barriers act on the sound propagation path and are reckoned as the simplest, most rapid and most effective way to limit noise exposure level.

Placing a barrier in the direct path between the source and the receiver significantly reduces the sound energy directly reaching the receiver. However, the pressure waves hitting the top of the barrier will be diffracted downwards and some of this sound will still be received. A small amount of the incident sound may also pass through the barrier which needs to be sufficiently dense and continuous to reduce this directly transmitted sound to an insignificant level compared with the sound diffracted at the top of the barrier. Concrete and masonry are the most widespread materials that are ideal for this as their inherent mass will always meet this requirement.

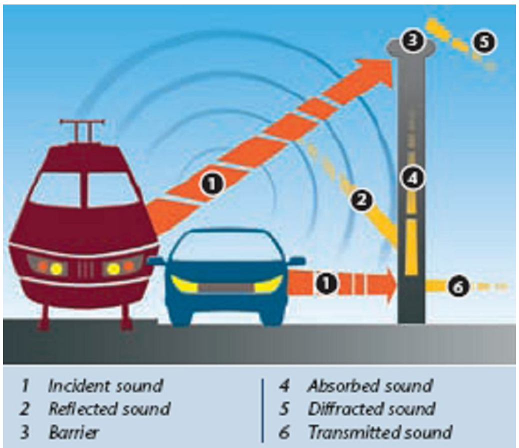

Fig. 3-4 – The effect of noise barriers.

The simplest noise barriers are constructed from solid homogenous materials that reflect the sound waves incident on them. This may not be a problem if there are no noise sensitive receivers on the noisy side of the barrier, but often there may be houses on both sides of a road. Providing a reflective barrier to protect people on one side may increase the noise for people on the other side. Sound absorptive barriers should be used in these cases. These are either made from, or faced with, porous or cellular materials that dissipate the energy in the incident sound waves as they pass through the cavities in the material.

3.2.2 Aspects to be considered when choosing a barrier

When designing a noise barrier there are many acoustic and non-acoustic decisions to be made. Here after the main aspects are presented:

- *Height and length*: the key acoustic considerations are the height and length of the required barrier. The taller the barrier the greater the attenuation that can be achieved. In addition, its length must extend far beyond the area to be protected to avoid its performance being compromised by noise diffracted around the ends of the barrier.
- *Location*: barrier location is also a vital decision. Optimum performance can be achieved by maximising the difference between the direct line between the source and the receiver and the diffracted path over the top of the barrier. On level ground it is normally desirable to place barriers as close as possible to the noise source, but where roads and railways are in cuttings or embankments, placing the barrier further away at the top of the slope is usually the best solution.

- *Aesthetics*: the optimum position for a barrier can also be its most visible location in order to maximize noise reduction. With barrier size increasing, it is essential that aesthetic issues are considered at an early stage in design. The design of the barrier must reflect its context and, since barriers are always used in a man-made environment, the use of manufactured materials is generally more appropriate than natural materials. The design team should include a landscape architect who would consider the materials to be used, the colour and shape of the barrier and whether a single design or a pattern that changes along its length would be most appropriate. At the design stage the incorporation of greening solutions such as climbing plants should also be considered in order to meet the preference of the population.
- *Durability*: once acoustic and aesthetic parameters have been established, a range of non-acoustic design considerations have to be addressed. Durability is a major concern and, as an example, road traffic noise barriers are required to last for 40 years without major maintenance. Structural integrity requirements are defined in standards and are particularly important where a porous material, which can absorb water, is incorporated in the barrier. Barriers located close to a road should be designed to suffer only superficial damage when hit by stones and must also resist any dynamic loading such as overpressure generated by vehicles. In addition, the extent of damage caused by highway verge fires should be minimal. Potential damage due to vandals, vermin and insects such as termites also needs to be considered when selecting materials.
- *Safety*: safety is a vital design consideration. Where there is a possibility of vehicle impact the barrier should not present a hazard to either the driver or others. A barrier is only considered safe if, when struck by a vehicle, no parts of the barrier would penetrate the vehicle and the vehicle would remain upright. Secondary safety must also be considered and the design should prevent injury to people outside the road corridor due to falling parts from the barrier, particularly where the road is on an overbridge. An other important aspect is the necessity of emergency exits at given distances in order to facilitate the escape of people and the access of emergency teams to the infrastructure in case of accident.
- *Sustainability*: increasingly, a holistic approach is taken by designers to environmental issues and the disposal of barrier materials at the end of their life must now be considered. Materials containing chemicals that cannot be recycled or safely disposed of are now avoided.

3.3 Perception of vibration

The vibration is concidered, like noise, as an enviromental stress factor. Vibrations from various sources, such as rail and road traffic, industrial premises and construction sites result in considerable disturbance. A systematic survey of data on this disturbance of the overall population does not appear to exist. Woodroof and Griffin gave an assessment of the disturbance for rail traffic. They reported that only 1-4% of the adult population of Scotland who experienced vibration were disturbed. In addition it was concluded that “vibration was regarded as one of the least annoying aspects of the railway presence in a neighbourhood.” Zeichart reported that 46% of those affected on the average feel “moderately” to “highly” annoyed at distances of up to 60 m to each side of the railway line.

In literature there are some findings from the study “Vibration effects from rail traffic”. In the field study mentioned above the effects of three factors and the possible interactions between these factors were analyzed. The factors included vibration levels frequency of trains and noise levels. Study areas were selected to meet specific combinations of these three factors. The subjective effects were determined by means of a standardized questionnaire and the noise and vibration exposures determined by measurement. A total of 1056 questionnaires were completed from 454 households. Noise and vibration data were obtained for each of these households.

The questionnaire included the following groups of questions:

- Vibration reactions: perception of annoyance from vibrations caused by disturbance to activities at night during the day and overall (some of the questions concerned with vibration were also allocated to rail traffic noise in analogue form);
- Noise reactions: annoyance from rail traffic noise again caused by disturbance to activities at night during the day and overall;
- Questions to enable comparison of effects of vibration and noise;
- Concerns regarding loss in property values because of damage caused by vibration;
- Questions on non-physical aspects or other factors including amongst others sensitivity to noise or vibration sensitivity to everyday stress general health;
- Socio demographic features and information on living situation.

If we pass to treat the problem with a most analytical approach, we could define a limit value for the vibration parameters. In the context of different railway infrastructure projects in Italy new standards for vibration mitigation measures have to be developed and introduced for various track system, sites and conditions: tunnel and surface lines, ballasted or slab track, low and high speed, light and heavy vehicles. Earlier applications of mats under ballast showed that the ballasted track on a softer subgrade became instable. Therefore, as a first step the technical feasability of new layouts and their stability had to tested, especially for mixed traffic of high speed and heavy trains on ballasted surface lines. Long-term behaviour and effectiveness of installed mass-spring systems in S-Bahn tunnels were reviewed and served as a basis for extrapolation for newer developments under other conditions. For technical system optimization the exact understanding of the forces and movements is important; this will be further investigated within the framework of RENVIB II on installations located and tested in Italy. It is important for the future of railways both to reduce the impact of the vibration and structure-borne noise of rail systems on the neighbourhood and to minimize the cost of installation and maintenance of possible insulation systems. In order to achieve this, a reasonable cost-benefit relation must be predicted.

Both vibration and structure by bornenoise generated by the railway traffic are phenomena which previously unexposed persons cannot, as a rule, envisage the effect it will have on them. Therefore, they cannot judge if vibration will affect health or if it will threaten acceptable living conditions.

It is not easy for railway developers to convince people that a certain project will ensure their well being. The fact that, no agreed national limits exist for vibration or re-radiated noise does not help. Only standards with desirable impact limits (for instance DIN 4150) are available. However, these limits are so restrictive (mostly at the perception thresholds) that no existing line and virtually no new lines can meet them. Based on the Swiss experience with complaints, there people will accept much higher levels alongside a railway line. Therefore, proposals to the Swiss Ministries of traffic and environment were made some 10 years ago defining a specific scheme of limits that could be guaranteed projects (see Tables 1 and 2). Even within difficult situations in the city of Zurich no complaints have been received to date. Thus, it has been possible to convince the decision makers that reasonable levels could be defined that would not impose an unreasonable degree of noise control.

However, the discussions taking place on the revision of DIN 4150 have highlighted the continuing need to convince ministries and planners that railway vibration at much higher levels than the threshold of perception are felt to be acceptable by the population, therefore limits can be higher than the threshold of perception.

TABLE 1

Standard for design of new railway lines

Target levels SBB related to	Vibration v_{rms} (mm/s) Day/night	Re-radiated noise L_{eq} dB (A) Day/night
Pure residential areas; areas for public use (schools, hospitals)	0·3/0·2	35/25
Mixed areas; urban city areas and rural village areas	0·4/0·3	40/30

TABLE 2

Standard for design of extension railway lines

Target levels SBB related to	Vibration v_{rms} (mm/s) Day/night	Re-radiated noise L_{eq} dB (A) Day/night
Pure residential areas; areas for public use (schools, hospitals)	0·4/0·3	40/30
Mixed areas; urban city areas and rural village areas	0·5/0·4	45/35

Recently, many consultants and experts with little experience have received contracts to evaluate vibration problems. In this process they often trigger problems for railway companies by overestimating the impact of new lines or ignore the technical constraints of such systems.

Decisions to install such complex technical systems, influenced by many different parameters such as traffic olw, axleload, trainspeed or geology and with tremendous cost consequences, are sometimes based on inadequate informations and lead to the demand for the highest degree of vibration reduction with little consideration of the absolute impact level.

Experts often overrate vibration impact because of unknown properties of track and traffic and unknown propagation factors through the ground and into houses. There is always a tendency to be cautious but for railway owners this may be too pessimistic and therefore too expensive.

In Switzerland there have been at least three cases in the past, in which built-in mass-spring systems have been installed in situations where afterwards the measured impact levels were below the allowed limits by more than the estimated effect of the mitigation measure. The cost-intensive insulation system was shown to be unnecessary. It is always worthwhile to confirm the plausibility and quality of any predictions by railway experts, although private consultants or industrial partners unwilling to give any guarantee for the accuracy of predicted levels or insulation values. The cost over overestimtaing the required insulation must always be carried by the railways, even in the age of privatization and uncompetitive costs of railway traffic.

Therefore, a good calculation program with a high degree of acuracy and a database of measured values is still one of the most important targets in research strategy.

4 Effects of noise and vibration on population

4.1 Estimates of external costs of noise

The quite recent document “European Commission Green Paper on Future Noise Policy (1996)” reckons noise as one of the most serious environmental hitches, especially in urban areas, both for the importance of social and health consequences and the technical and economic effort needed to resolve it. As a matter of fact, it has been estimated that about 20% of the European population (80 million people) is exposed to a daytime level of noise that exceeds 65 dB(A) and 170 million people live in places where noise level is between 55 and 65 dB(A).

Society pays in general two different type of costs related to noise pollution: damage costs and abatement measures costs. Mitigations, however, do not eliminate the entire damage costs endured by exposed population but just limit them.

The economic costs of noise have been examined in numerous different ways and there are no benchmarks for standardised evaluation of costs. Almost all this research is limited to transportation noise in general and the most common methods used have been:

- *Willingness to pay* (WTP) based on social surveys
- Change of the market value of properties; *hedonic pricing*
- *Cost for abatement measures*
- *Cost of avoidance or prevention*
- *Cost of medical care and production losses*

An overview of these studies produced in 1993 (Quinet) found that the estimated costs of noise pollution vary between 0,2% and 2% of Gross Domestic Product (GDP). Generally studies based on the avoidance cost approach give low values for noise costs, below 0,1% of GDP, while studies using the WTP approach give higher values. All the studies on WTP have been carried out in countries with a high per capita income and showed that WTP is undoubtedly dependent on the ability to pay and therefore noise would probably not be valuated so high in less rich countries.

In Germany a number of studies have been based on the WTP for a better noise environment approach and show that on average an individual would be prepared to pay around 10 € per 1 dB(A) improvement per person per year if the noise levels exceed 43 dB(A).

The study carried out for the UIC (International Union of Railways) in 1994 made an overall estimate for 17 European countries based on the WTP approach which shows the total cost of transportation noise to be 38 billion Euros per year or 0,65% of GDP. These annual costs related to transport volume turn into the following values for railway transportation: passenger – 3,1 €/1000 pkm, freight 4,7 €/1000 tkm.

Studies into the decrease in housing value (Hedonic Price technique) depending on noise exposure for a variety of countries over the past 25 years have shown that in the 80s the average rate of depreciation can be estimated at approximately 1% per dB(A) if noise exceeds 55 dB(A), whereas the studies covering the 70s show a depreciation rate of about 0,6% per dB(A). On the basis of these depreciation rates global evaluations of total damage caused by traffic noise have undertaken for cities and countries. For France this was estimated to be 800 million Euros per year or an average of around 30 €/dB(A) per inhabitant exposed to over 55 dB(A).

A study on the ring-road of Turin (Masoero et al., 2000) using the WTP method found that the average value for every dB(A) varies between a minimum of 0,45 € for a noise level of 48 dB(A) up to a maximum of 0,70 € for a level of 72 dB(A).

4.2 Estimates of external costs of vibration

In addition to noise from railways appreciable vibration which can cause nuisance is often felt in the vicinity of railway lines. A field study carried out by OBERMEYER on the effect of vibration from rail track showed that many people are seriously disturbed in their homes by vibration from rail track. It was however shown that reactions to vibration at the same level of vibration load vary widely that annoyance from vibration is less than that from noise and that the statistical relationship between the degree of annoyance from vibration and the vibration intensity is not clear.

Political demands have contributed to this revival the governing principle being the need to transfer road traffic to railways particularly for long distance traffic. However these measures can result in undesired effects such as noise and vibration which can create new problems and even possibly aggravate those which already exist. Thus the task of engineers and scientists is to minimize these negative effects and to assist those who have to answer for political decisions. Finally standards have to be set that is acceptable levels of annoyance have to be defined above which the effects of noise and vibration are deemed to be unacceptable.

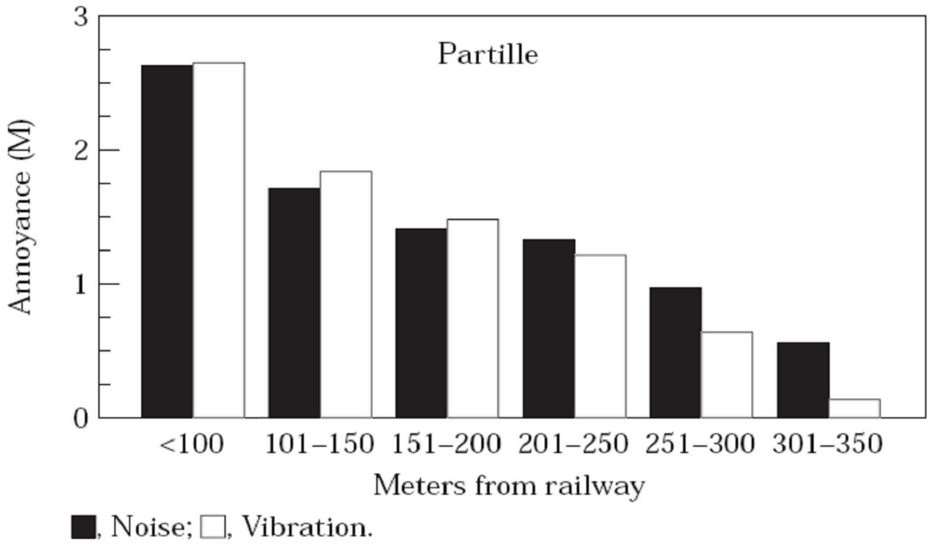

Fig. 4-1 – Annoyance to noise and vibration at different distances from the railway line

4.2.1 National and international legislation

The evaluation of environmental noise level is performed using two different criteria that have to be introduced properly in advance:

- *absolute criteria*
- *differential criteria*

The *absolute criteria* is based on the description of the territory in terms of urban characteristics and considers that in those areas where there is an higher level of human activities the accepted noise level is higher than in those quieter areas, such as rural neighbourhoods. For every zone, maximum day-time and night-time noise exposure levels are defined. However, it is quite difficult to define uniform territorial areas since quiet areas and louder ones are often close to each other and limits are frequently broken, even in absence of the noisy source in the area considered.

The *differential criteria* needs the definition of two different situations of noise exposure. The *environmental noise*, i.e. the noise level in presence of a particular source, and the *residual noise*, i.e. the noise level when the source is turned off. The maximum acceptable differences in terms of dB(A) between these two situations are regulated by the law, both for day-time and night-time.

The reference national legislation on noise pollution is the Law 447/1995 “Legge quadro sull’inquinamento acustico”, which partially repealed DPCM 01/03/1991 concerning environmental noise. The territory is divided into 6 different zones, to be defined by Comuni with PCCA – Piani Comunali di Classificazione Acustica – and each characterised by noise exposure limits shown in the tables below, but such a classification is far to be finished. “Emissione” means that noise level is measured at the source whereas “immissione” means that noise level is measured at the receiver.

Valori limite assoluti di emissione - Leq in dB(A)

classi di destinazione d'uso del territorio		*tempi di riferimento: diurno (6.00-22.00) notturno (22.00-06.00)*	
I	aree particolarmente protette	45	35
II	aree prevalentemente residenziali	50	40
III	aree di tipo misto	55	45
IV	aree di intensa attività umana	60	50
V	aree prevalentemente industriali	65	55
VI	aree esclusivamente industriali	65	65

Valori limite assoluti di immissione - Leq in dB(A)

classi di destinazione d'uso del territorio		*tempi di riferimento: diurno (6.00-22.00) notturno (22.00-06.00)*	
I	aree particolarmente protette	50	40
II	aree prevalentemente residenziali	55	45
III	aree di tipo misto	60	50
IV	aree di intensa attività umana	65	55
V	aree prevalentemente industriali	70	60
VI	aree esclusivamente industriali	70	70

The imposed limits for the differential criteria are, on the other hand, 5 dB(A) during day-time and 3 dB(A) for night-time and are not applicable to industrial areas (VI).

Since 1998 in Italy rail noise pollution is regulated by an articulated legal act (DPR 458/1998 “Regolamento recante norme di esecuzione dell’articolo 11 della legge 26/10/1995 in materia di inquinamento acustico ferroviario”) that sets day-time and night-time limits on receptors, depending on their vulnerability and distance from the railway. Residential areas or vulnerable receptors, such as schools and hospitals, have therefore lower limits than less vulnerable ones. Reception limits refer to a precise spatial area along the railway, which include receptors within 250 m from the railway. Such area is divided into two portions, the so-called “Zona A” and “Zona B”, respectively 100 m and 150 m far from the railroad track and characterised by different receptions limits.

Zona	Diurno $L_{Aeq(6-22)}$	Notturno $L_{Aeq(22-6)}$
per scuole, ospedali, case di cura e case di riposo (per le scuole vale il solo limite diurno)	**50**	**40**
per gli altri ricettori all'interno della **fascia A**	**70**	**60**
per gli altri ricettori all'interno della **fascia B**	**65**	**55**

Almost one decade after the definition of the Italian national noise regulation, the implementation of the required noise abatement measures is still largely incomplete, and only very recently we have assisted to the rise of a national debate on how to proceed in order to abate rail noise below the limits.

Generally, rail transport is assumed environmental friendly, but, in some cases railway lines, either old or new, do not get acceptance from the people living close to these infrastructures due to concern about unacceptable noise levels, which are often over the current cut-off limits set by the international and national legislations. The “European Commission Green Paper on Future Noise Policy (1996)” states that the “public’s main criticism of rail transport is the excessive noise level”, which can potentially origin both physiological and psychological consequences for people exposed. Moreover, the European Commission "Position Paper on the European Strategies and Priorities for Railways Noise Abatement" (CEC, 2003) underlines that, in order to protect the current population exposed to rail noise pollution, it will be necessary, on average, to reach a noise reduction by 10-15 dB(A).

Therefore, railway noise abatement has acquired an important priority in the European environmental policy agenda. Therefore, there is a high potential for the reduction of railway noise in Europe, because the technical instruments for the abatement of noise are available (CEC, 2003). In the current EU policy panorama, though, the main issue is the economically viable implementation of such expensive noise abatement measures and, therefore, the choice of the most cost-effective type of possible interventions.

A crucial question is, therefore, whether the social benefits of reduced noise can justify the high costs of noise mitigation. The implementation of noise abatement measures involves in fact a significant financial cost that is associated either to an investment in the train technology, including wagons and railway tracks, or to an investment in noise barriers, or a combination of both. The effectiveness of the noise abatement will depend on the type of policy intervention adopted, i.e. on the type of noise abatement instrument adopted. Having an economic estimate of social benefits of reduced noise then might allow us to identify the combination of measures providing highest social benefits per euro of costs, i.e. highest benefit-cost ratios.

In addition, alternative noise mitigation policies will also have different effects in terms of landscape-aesthetics and cost, which should also be considered to provide an overall evaluation of the goodness of the possible noise abatement alternatives actually available. Environmental valuation methods can be employed to estimate the economic value of changes in noise levels and, therefore, to provide a decision support for managers and national authorities entitled to plan noise abatement measures.

Literature on noise has been dominated by the use of the so-called Revealed Preference methods and in particular Hedonic Price techniques, the main strength of which is that they rely on actual behaviour in the housing market, where individual preference for noise and other environmental characteristics can be observed, though indirectly. However, Hedonic Price techniques are not able to capture non-use values or non-welfare impacts that pertain noise level increases or decreases, such as reduced enjoyment of desired leisure activities, discomfort and inconvenience, anxiety, concern and inconvenience to family members and others.

As for other environmental and health disturbances, individual can perceive and react to the same level of noise exposure with different intensity, depending to their sensitivity to noise and starting level of exposure. It is therefore likely that perception and reaction to equal noise reduction vary from person to person. In addiction, even though we assume individuals with identical noise perception, still there is the problem of explaining what a certain noise reduction, say expressed in decibel, would mean to them in terms of actual noise feeling and potential health diseases.

4.2.2 Different approaches to the same problem

The reduction of railway noise reception levels can be achieved by three essential types of measure:

- *on the source*, including train vehicles and tracks
- *in the sound propagation path*
- *at the receptor*

In the past, the latter type of measure was most common. As current practice in Europe, measures such as barriers, with related high cost, or sound insulation windows, with limited effect, are mostly chosen instead of more cost-effective source-related measures. The reason for this is articulated and includes several issues. Firstly, the sound propagation measures were normally taken due to noise reception limits which have to be observed locally, whereas vehicles are often of broader origin and beyond the influence of the local authorities. Secondly, vehicle emission limits, which could enforce measures on the rolling stock, exist only in few countries, whereas the application of traditional barriers and sound insulating windows does not need much innovation. In addition, the instruments to evaluate the best solutions from a cost-benefit point of view and to apportion the contributions of vehicles and tracks and the associated responsibilities have been applied only recently in this field.

In Italy, a decree of the Ministry of the Environment (DMA 29/11/2000), which is consistent with what is stated in the more recent "Position Paper on the European Strategies and Priorities for Railways Noise Abatement" (CEC, 2002), indicates that preference should be given to noise measures at the source (i.e.: either on the vehicles and on the tracks) rather than to barriers and buildings insulation systems. Still, local authorities in charge to define noise actions can operate discretionally and need advice to select the strategy that, better than others, can guarantee higher benefits for local communities. Even if some technical guidelines are available, the evaluation of noise measures needs to take into consideration local territorial conditions and, possibly, the preferences of the affected population for alternative policy solutions.

Two radical positions are currently debated. On one side, the local Environmental Protection Agency is recommending to intervene along the railroad track gradually, with low noise barriers (perhaps still not sufficient to reduce noise below the limits) to be combined, during a second phase, with some technological innovation in wagons and railroad tracks. This would guarantee, in two steps, the required level of noise reduction, minimizing the drawbacks of noise barriers for people living or working in the vicinity of the railroad, in terms of aesthetics, landscapes and micro-climate changes, such as lower lighting in case of deadening barriers, or green-house effects during summer in case of transparent barriers. On the other hand, the Italian railway company (RFI), is strongly recommending actions with high barriers and no technological advance that would be able to guarantee immediately the required level of noise reduction but with higher collective costs in terms of aesthetic and environmental drawbacks. Time of provision and infrastructure costs are, obviously, expected to be higher in the former case.

4.3 Investigating population noise and vibration experience

4.3.1 General

In Italy there is almost no experience on the evaluation of the perceived effects of the exposure to traffic noise and just three researches have been performed since 1999, one of which concerning noise pollution due to the ring-road of Turin in 2000. Consequently, some international data referred to High Speed railway noise have been analysed in order to better understand and estimate how the problem is perceived by population.

4.3.2 The High Speed TGV Atlantique Line

In 1993 a social survey was carried out to assess the impact of noise experienced by residents living in the vicinity of the new High Speed TGV Atlantique line, along which noise protection, such as barriers and earth berms, was provided to ensure compliance with the noise guideline during daytime from 8 a.m. to 8 p.m. that fixes the limit of 65 dB(A) for the A-weighted noise equivalent level.

Depending on the site, traffic varied between 65 and 140 trains per 24 hour period, mainly between 6.30 a.m. and 10.30 p.m., travelling at a maximum speed of 300 km/h. Three major topics were discussed in interviews:

- Attitudes to the railway line and fears concerning the opening of the line
- Perception of the noise generated by the TGV, overall annoyance, activities disturbed (TV, conversation, sleep…), behavioural patterns (closing windows, insulating windows, soundproofing facades, need for medication, decision to move…) and acceptance of the noise after the opening of the new High Speed line

- Noise protection measures: level of satisfaction, opinions on effectiveness, appearance and visual intrusion.

Daytime TGV traffic noise levels measured were all below the 65 dB(A) limit, thus the noise guideline seems to have been applied satisfactorily in the areas surrounding the new railway line. This result is due primarily to the choice of the route for the railway line, which crosses low density population areas, and, secondly, to the implementation of noise protection measures, such as noise barriers, track in cuttings and earth berms, in the vicinity of the most exposed dwellings.

It has also been found that noise exposure levels are quite the same during all daytime from 6 a.m. to 10 p.m. due to the constant average hourly volume of traffic during the entire day. On the other hand, night-time equivalent noise levels are lower, less than 45 dB(A) for 70% of people.

Nevertheless, significant variations in excess of 10 dB(A) and even 15 dB(A) in noise exposure were recorded after the new line opened, particularly early in the morning and in the evening. In order to compare the findings, variations of the equivalent noise level in the range of 3-5 dB(A) are considered as slight, without significant effect on people, and 6-10 dB(A) is moderate. However, variations of more than 10 dB(A) are substantial to severe since an increase of sound pressure level (SPL) of 10 dB(A) results in a twofold change in loudness, as already stated previously.

Noise from the TGV is most often described by residents as a whistling or a thundering and is sometimes compared to aircraft noise. Furthermore, it was found that the volume of traffic, the vibration and the intensity of the noise are the three main factors that are considered most annoying and are all the more annoying when residents are exposed to high noise levels. As imaginable, noise is a daily annoyance particularly in the morning and in the evening and got its highest peak at weekends and during the summer, when people look for more quite environment to live in. The major disturbances noted are when listening to the TV or radio, phoning and conversing indoor, especially when windows are open.

Alternative behavioural responses to noise exposure have been identified in the social survey: closing windows, insulating windows, intending to move and, also, changing the use of the rooms. It has also been found that noise levels over 55 dB(A) have significant effect on these types of behavioural responses, confirming that a noise level over this is not appreciated by most of the residents.

Yet, correlations between annoyance and noise exposure indices are quite low, highlighting the subjectivity of the phenomenon perception. However, if the equivalent A-weighted noise level is the most effective index for minimising the likelihood of underestimating noise annoyance, in the early morning and in the evening the number of noise events, or their total duration, exceeding 70 dB(A) seems to be a more relevant noise index related to noise annoyance.

Furthermore, the relationship between levels of annoyance and noise levels seems to depend on parameters other than noise itself, including opinions about TGV as a new transport mode, the attitude of residents to the new railway line, the usage of train as an alternative mean of transport and the satisfaction of the residents with already adopted noise protection measures, again revealing the extremely subjectivity of the annoyance perception.

4.4 Noise costs analysis

4.4.1 The Brennero railway Choice Experiment

The Brennero railway, which is located in the north east of Italy in the province of Trento, is the first example in Italy for which noise abatement plans are currently under analysis. In 2006 a research was performed by “Fondazione ENI Enrico Mattei” examining the use of Choice Experiments to assess the economic value of alternative rail noise reduction interventions on that specific railway track. Choice Experiment is a non-market valuation method that allows to infer people’s preferences for a set of alternatives, described by a set of relevant attributes. This technique has been first developed in market research and has then been widely applied in several other fields with the purpose of analysing choice behaviour, including transportation research, health economics and environmental economics.

In a typical Choice Experiment survey, the researcher presents two or more alternatives to the respondents, and asks the respondents to choose the most preferred one. The alternatives are described as bundles of factors, known as 'attributes', which are expected to influence respondents preferences for the proposed alternatives. The alternatives comprised of bundles of attributes are called "profiles". A combination of two or more profile is called "choice set" or "card". This scheme allows researchers to examine the attributes that influence choices and the relative importance of each attribute, through observation of the choice behaviours of the respondents.

Choice Experiment presents some attractive features as a technique for evaluation. First, since choice behaviour is observed in daily life, typically in the form of shopping, the respondents answer the Choice Experiment questions more easily than other Stated Preference techniques, such as rating, ranking, and pair-wise techniques, which instead do not involve any choice behaviour in decision-making. Second, the hypothetical goods or polices can be used as alternatives so that the respondents' preferences for those goods and policies can be analysed. In the case-study, for instance, researchers used different rail noise reduction policies as alternatives. This is a valuable improvement over Revealed Preference method, such as Hedonic Price approach, where the range of noise reduction is usually not clearly measurable and irrelevant to policy. In addition, the WTP for noise decrease can be calculated on the basis of the preferences of a selected sample, whereas it is the householders' preferences that are usually elicited in the Hedonic Price approach. The underlying assumption when assessing the economic valuation of alternative noise abatement programs is, of course, that monetary value reflects respondent's behavior.

The results of the Choice Experiment revealed that a policy noise abatement strategy that relies in an investment both on train or tracks together with a noise barrier set at a minimum level (at most 6 meters) is highly appreciated by the respondents showing a WTP of about 156-230 € per household for 2006, depending on the way of financing the noise policy. However, if one portrays a maximum decibel abatement, namely 12-14 dB(A), just increasing barriers up to 8 meters, then the WTP decreases to a range of 31 € per household. It can be then understood that respondents have a strong preference for a policy that provides a certain noise abatement, namely 10-12 dB(A), thanks to an increase of trains or rails technology rather than just increasing the height of noise barriers. These results suggest that, as expected, the height of the barrier is perceived as a major drawback of the noise policy. This result can be interpreted as signalling a strong disutility from the powerful negative aesthetic impact of such a construction. In particular the height of the noise barrier is perceived as a cost priced at about 30 € per household per unit increase.

An other important point that was investigated in the Choice Experiment was the way of financing such noise abatement strategies. The reallocation of taxpayers money from the administrative budget, rather than with the reallocation of taxpayers money within the transport budget, has a positive in the respondent's utility and therefore in choosing the protection program and, even more, they are more inclined to pay for a noise policy that is financed reallocating a quota of the resources normally destined to other public services than for one financed with a new local tax.

4.4.2 Laboratory experiments on noise barrier attenuation

Transportation agencies have a need for models of barrier benefit which can be used in advance of construction. It is usually desirable to "prioritize" noise barrier candidate sites to select those for construction according to their ranking on a benefit-cost list. Such rankings therefore have to have a model for "benefit". A similar need then arises after a site is selected for construction to finalize the barrier alignment, height and length to obtain the best benefit-cost.

The definition of noise barrier “benefit” can be narrow or extremely wide. A narrow definition could limit itself to “barrier noise reduction” in dB(A). At the other extreme, a wide definition would include consideration of the following factors:

- barrier noise reduction
- pre-barrier construction sound level
- other-than-highway/railway sound levels
- non-acoustic factors which have proved important, such as residents perception of noise
- socio-economic-political benefits of reduced noise complaints which can manifest themselves electorally

A laboratory experiment was performed by the Acoustic Office of the Ministry of Transportation and Communications in Canada in which 82 subjects judged, on a scale that varied from 0 to 10, the benefit of a noise barrier by listening to tape recordings of before-barrier and after-barrier traffic noise. These perceived benefit judgments were related by regression analysis to the barrier attenuation, the before-barrier traffic sound level, and a music background level, all of which were varied over the course of the experiment. Prediction equations were developed for barrier benefit in terms of these sound levels, their purpose being to provide a model for barrier benefit that can be used in barrier site selection and design. An unexpected finding was that barrier benefit was highest when before-barrier sound levels were lowest: i.e., subjects preferred a noise barrier that solved a moderate noise problem over an equally attenuating barrier that only partially solved a more severe noise problem.

The noise stimuli involved in the experiment were as follows. There was a “before-barrier traffic noise”, whose equivalent sound level was designated L_1. There was an “after-barrier traffic noise”, whose equivalent sound level was designated L_2, and which differed from L_1 by the “barrier attenuation” designated ΔL. There was a “background noise”, music, whose equivalent sound level was designated L_b.

Of particular interest physically was the negative correlation found between perceived benefit, B, and before-barrier traffic noise. This meant that perceived benefit did not increase, as expected, with an increasing level of non-attenuated traffic noise, as previously outlined. In other words a given level of noise barrier attenuation was perceived as less beneficial when the original traffic sound level was severe than when it was not severe. As a confirmation to the findings, the same institution had social survey results for two similarly-attenuating noise barriers which showed that the one installed on a lightly-trafficked freeway (L, = 65-70 dB(A)) produced more satisfaction than the one on a heavily-trafficked freeway (L, = 75-80 dB(A)). A possible explanation for this may lie in the fact that the attenuated sound levels, in instances when the before-barrier sound levels were high, were still high enough to disturb the subjects’ activities. In other words, barrier benefit was judged principally by the environmental quality which pertained after the barrier had been “installed”. It appears, therefore, that people may judge barrier benefit in terms of barrier attenuation first, and the quality of their auditory environment after a barrier is installed second, preferring a barrier that solves their noise problem to an equally-attenuating barrier that does not.

In the end the following equation can be presented

$$B = 5,281 + 0,566 \cdot \Delta L - 0,063 \cdot L_1$$

where benefits B are related just to the attenuation sound level ΔL and the pre-barrier noise level L_1.

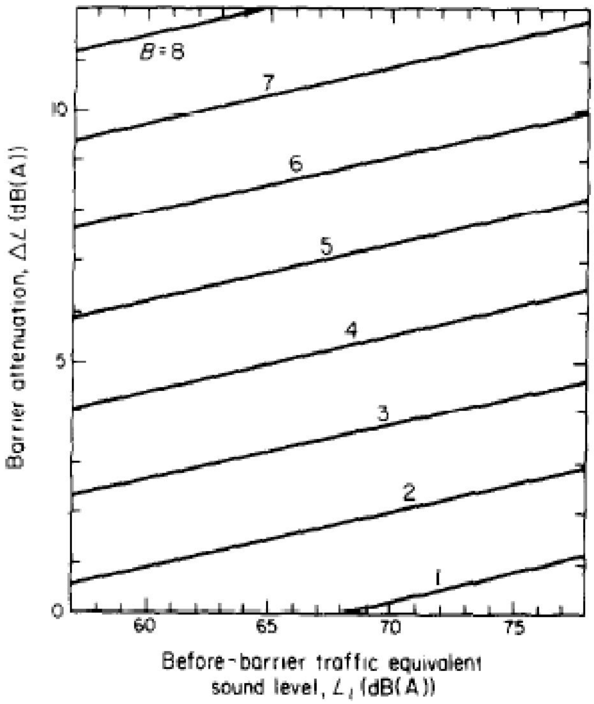

Fig. 4-2 – Noise barrier attenuation.

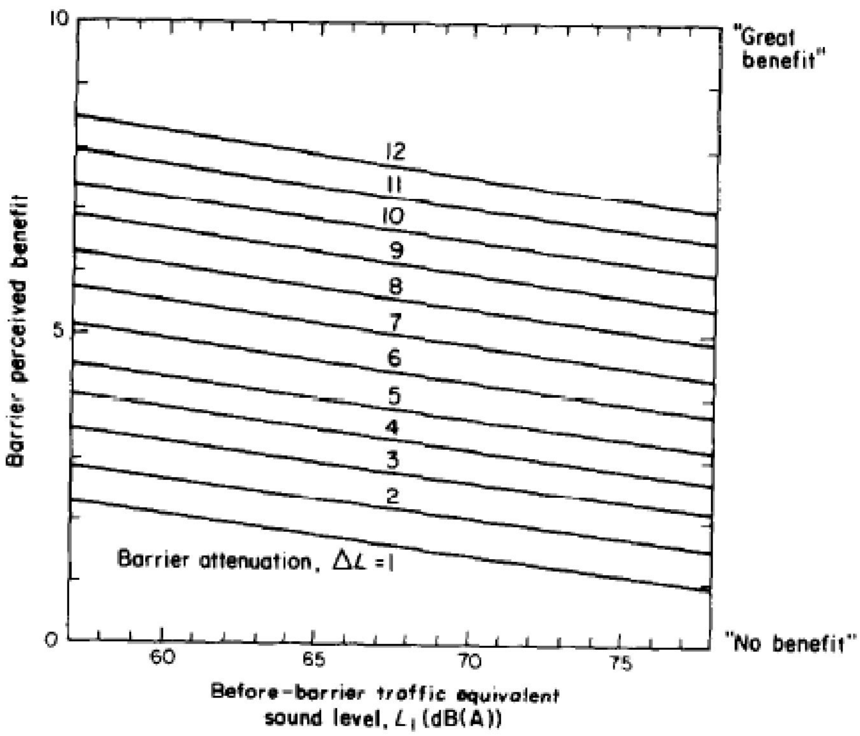

Fig. 4-3 – Noise barrier perceived benefit.

4.4.3 Our cost-benefit hypothesis

In the previous sections several results concerning different evaluations of cost-benefit of noise abatement measures have been presented. Properly taking into account these findings an hypothesis on monetary benefits perceived by population can be outlined.

Our working conjecture is then that every point of the scale for benefits B used in the experiment performed by the Canadian Acoustic Office, which just estimated the perceived benefits concerning the noise attenuation in dB(A), can be valued as 35 € so that an attenuation of 12-14 dB(A) starting from a before-barrier traffic equivalent noise level of 75-80 dB(A) brings to a social benefit of about 271 €. Assuming that the eight of the barrier can be priced at about 30 € per unit increase, according to the results of the Choice Experiment regarding the Brennero railway, it can be stated that an 8 meters noise barrier costs to the society in term of aesthetics, which is the major drawback, about 240 €. In the end the final social benefits are 31 €, in accordance to the WTP found in the social survey presented.

The previous formula will then be used for the evaluation of social benefits under the following suppositions: any reduction in noise level “on the source” acts directly on the pre-barrier equivalent noise level L_1 and the attenuation due to the introduction of a certain barrier “on the sound propagation path” will be computed into the term ΔL.

Costs of different attenuation measures are, on the other hand, estimated from literature, normative and reasonable assumptions on materials and manpower costs.

5 Cost-benefit analysis

5.1 Introduction

Present plans in Europe foresee High Speed trains running at speeds up to 350 km/h to form a Trans-European High Speed Railway Network. Noise and vibrations from High Speed lines mostly operating during the day-time is one of the main technical and social issues, as previously debated. This kind of problem often arises at the planning stage of new High Speed lines or services when noise mitigation becomes a key requirement and it is frequently cause of neighbouring population complaints.

Looking at the France experience about TGV Atlantique line we can see that quite the same approach has been followed also in the Italian High Speed line between Milan and Turin. As a matter of fact, the railway track crosses low density population areas and most of the route runs parallel to the existing motorway in order to reduce the environmental drawbacks of the infrastructure. The implementation of traditional noise protection measures, such as noise barriers, associated with the preference for track on overpasses and embankments, mainly due to security reasons and easiness to cross existing roads and infrastructures, effortlessly permits to reduce noise in the vicinity of the most exposed dwellings.

As stated in the preceding paragraphs noise reduction can be achieved in general acting directly on the vehicles, on the tracks or in the sound propagation path. With no doubt the latter type of measure with the use of acoustic barriers is the simplest one to cover the multiple situations found during the design phase and to comply with different national noise regulations, as implemented in the AV/AC case. Related costs to a such traditional approach are therefore obviously high and the general efficiency is quite low as well as the degree of innovation involved.

Investigations have illustrated the important contribution of measures at the source to cost-effective solutions [Vos96 & OWa96]. Therefore the principal instruments for railway noise abatement have to be assessed with respect to the enforcement or stimulation of this type of measures, and links for a common effective approach as well as instruments for the apportioning of responsibilities have to be developed. A Swiss study by Swiss Federal Railways [Oer00] found that an optimal cost distribution consists of spending 65% of the available resources on rolling stock improvement, 30% on acoustic barriers and 5% on insulated windows. This noise control strategy protects about 70% of the line-side population for 30% of the costs necessary to attain threshold levels for all inhabitants.

In the following paragraphs a brief introduction on the available traditional and innovative solutions regarding railway noise mitigation is presented in order to understand what would be the most efficient strategy to attenuate noise pollution and in the end our proposal is shown. Overall, we paid close attention to cost-benefit analysis and technical advantages and innovation of different solutions as well as the applicability in terms of time.

5.2 Noise and vibrations sources in high speed trains

The wayside and vibrations emitted by the railway system at high speed is known to be the combination of three main families of sources:

- The radiation of the vehicle and the track due to the excitation at the wheel/rail contact patch. This noise is generally called ‘‘rolling noise’’.
- The aero-acoustic sources generated by the turbulence around the vehicle structure (flow-obstacles interaction) so-called “aerodynamic noise”.
- The noise and the vibrations emitted by the sleepers and the ballast

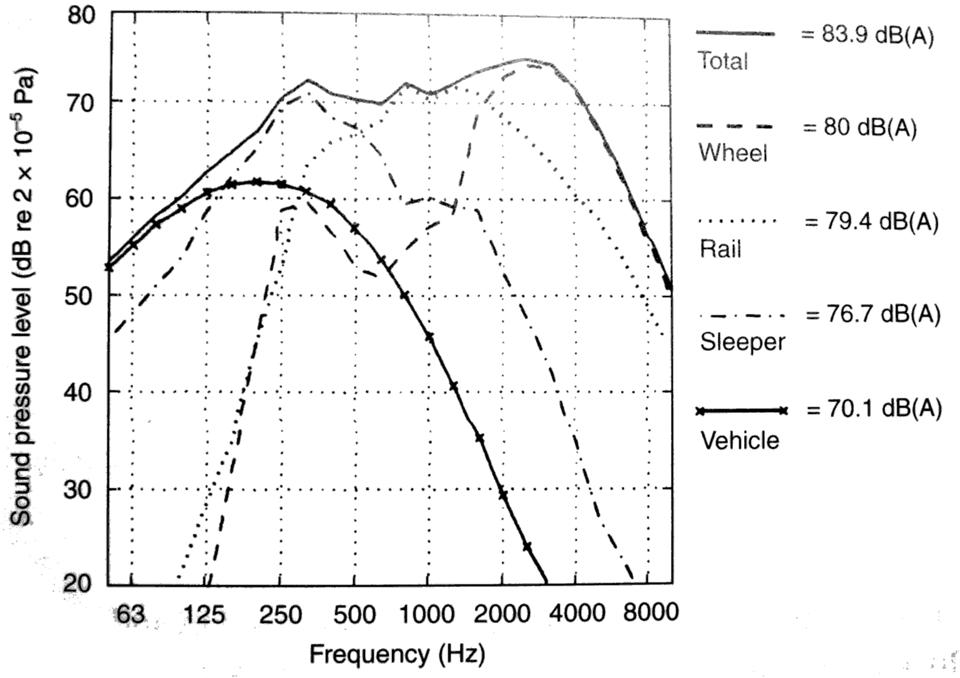

Fig. 5-1 Partial contribution of wheel, rail, sleeper and vehicle to the total pass-by noise

There is a need for a good knowledge and an accurate description of the main characteristics (position, strength, directivity, governing parameters, etc.) of these different sources as they are used as inputs in simulation tools (noise and vibration propagation codes, CFD simulations or wind tunnel tests) and guide the studies on mitigation measures.

For conventional speeds (up to 160–200 km/h), the phenomenon responsible for the wayside noise is mainly produced by only one kind of source, the rolling noise. But for speeds above 200 km/h, the contribution of the aero acoustic sources makes more complex the understanding of the pass-by noise mechanism. For these speeds, the quantification of each kind of source becomes a real problem.

For our study we obtained data on this subject from the SNFC, concerning the TGV and the TGV-Duplex ([MLP04] and [Lee01]), in our visit to the JR research centre, concerning the Japanese Shinkansen [Nag06] and from the German DB [SBD06] and from Bombardier [Let03]. Unfortunately no data were available from Trenitalia or Ansaldo on the ETR500.

A typical pass-by noise from an high speed train at 200 km/h registered by one microphone at 5m is shown as a spectrogram in Fig. 5-2. Wheel–rail noise dominates the pass-by noise in this case: the three dominant peaks in the plot are associated with passage of the 4 bogies. The ridge in the 1250 Hz band is due to rail radiation with propagating waves, which have a low rate of decay. It is interesting to note, however, that even at this low speed the pantograph contribution is evident in the 200 Hz band, as indicated by the arrow.

Vortex shedding around the contact strip of the pantograph head gives a speed dependent tone at $f = \frac{St \cdot V}{d}$, where f is the frequency, St the Strouhal number, V the velocity in m/s and d the typical dimension of the object producing the vortex. In this case the equation yields a frequency of approximately $f = \frac{0.19 \cdot 55}{0.05} = 209Hz$.

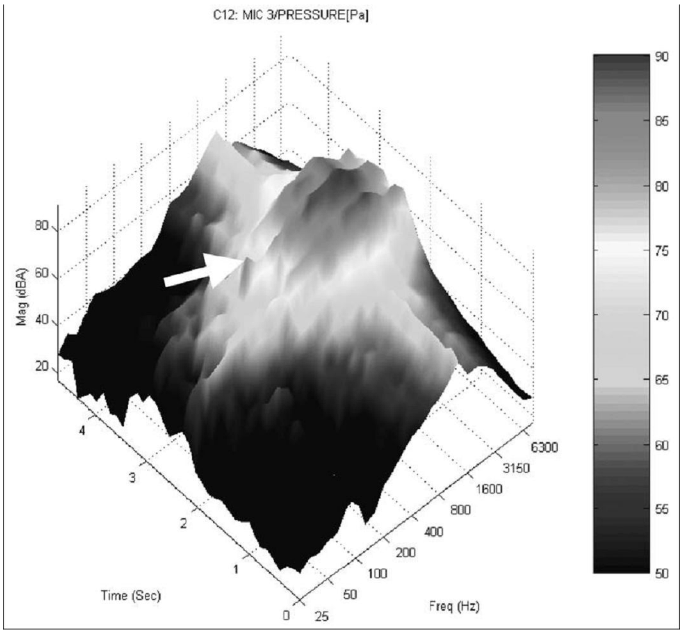

Fig. 5-2 Pass-by sound pressure level in dB(A) at 200 km/h, medium quality track.

In addition some experimental data are available on the TGV to highlight how these noise sources change with speed (Fig. 5-3). For high-speed trains the aerodynamic sources of noise has an intensity comparable with the rolling noise, the relevance of this phenomenon is that in high-speed trains noise is generated at an greater distance from ground (Fig. 5-4) and thus usually higher acoustic barriers are necessary.

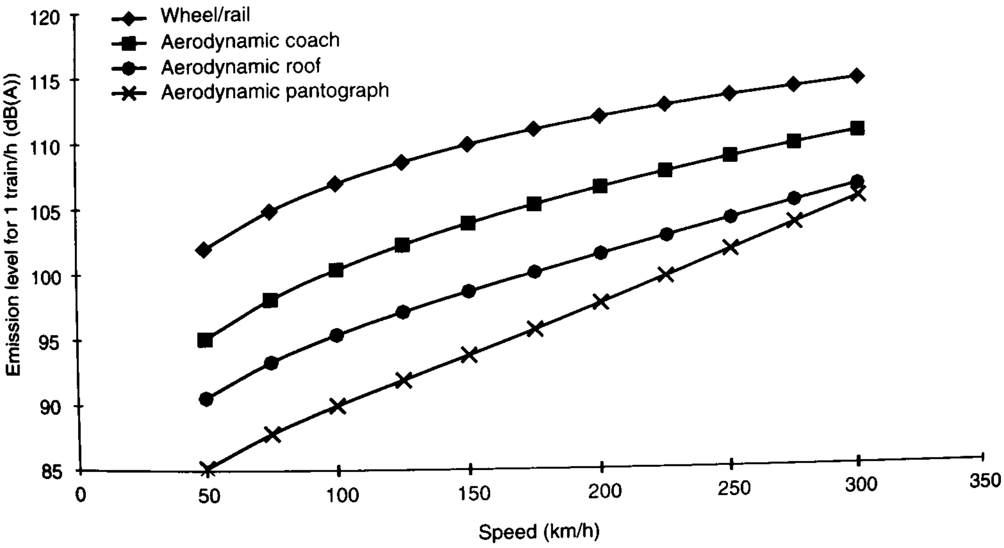

Fig. 5-3 Emission levels for a TGV consisting of two power cars and ten passenger cars.

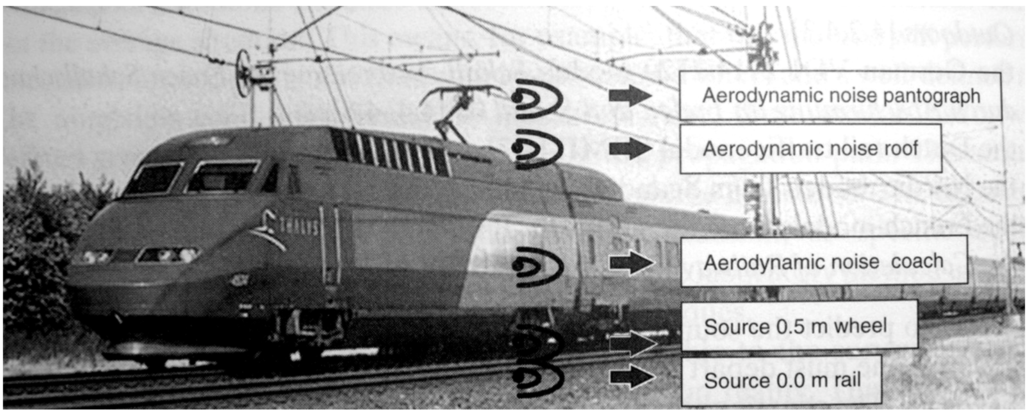

Fig. 5-4 Summary of all relevant noise sources of a TGV on motion

The image (Fig. 5-5) presents two colour maps of the sound pressure level as a function of the position on the forward power car and intermediate coaches of the TGV-Duplex. From the visualization of the different maps, the main sources present on the TGV-Duplex are identified.

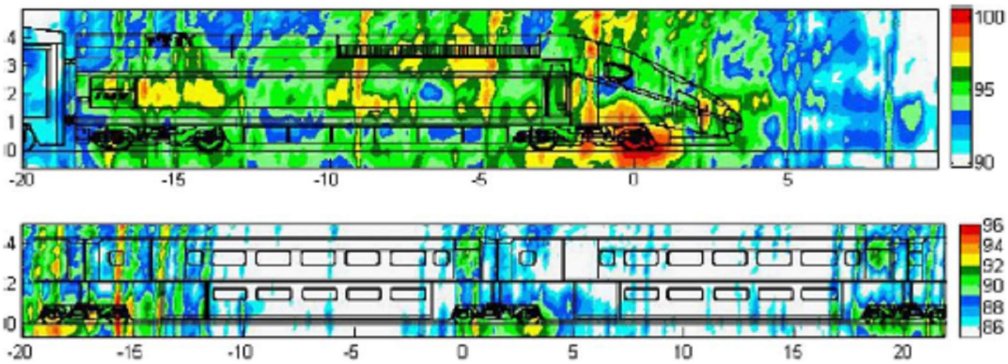

Fig. 5-5 Noise sources maps of the forward power car and second and third middle coaches of the TGV-Duplex at 300 km/h in the third octave band 1250 Hz.

Most of the densely populated areas in Pianura Padana are situated on deep deposits of clay and silt. Under such ground conditions low frequency vibrations are easily generated and propagated. For the softest deposits railway traffic may produce annoying vibration for people living and working in neighbouring buildings to a distance of more than 100 to 200 m from the tracks. Vibration is therefore one of the more important consequences to be considered when planning new lines and upgrading older ones. High speed trains and heavy freight tra.c pose the major problems. Models are therefore needed that can be used to predict the vibration with su.cient reliability and at an affordable cost for the different planning stages.

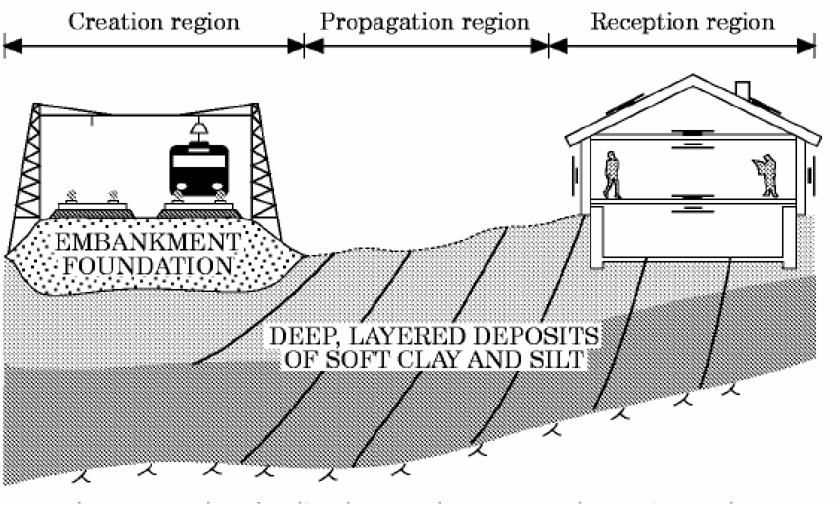

Fig. 5-6 Regions in vibration creation propagation and reception

Vibration measured on soft ground shows two distinct spectral peaks: one at low frequency with its maximum between 5 and 10 Hz and one at higher frequencies typically between 30 and 50 Hz. The softer the ground the more dominant the low frequency peak becomes. Vibrations at these low frequencies are those that attenuate least with distance and amplify most due to building resonances. They are therefore the main concern in connection with railways on soft ground. In the discussion of this type of ground-bornevibration it is beneficial to divide the problem into three regions as illustrated in figure 5-6: the creation region, the propagation region and the reception region.

Creation. The creation region comprises train, track, embankment, foundation and the soil in its vicinity. Here the vibration is generated and transferred into the ground. The mechanisms behind the generation of the low frequency vibration on soft ground are not fully understood. The model that we feel agrees best with measured data is based on the interaction between a moving static load and the layered system comprised of the track, embankment and the soil layers below. This leads to vibration that increases with increased axle load and train speed, decreases with the load!distributing ability of the rail and embankment and has a dominant frequency controlled by the dynamic properties of the embankment/soil system. This agrees well with vibration measured on soft ground, where the dominant low frequencies appear to be site specific rather than dependent on the train speed. The waves in the creation region are of the near field type and are dominated by the moving loads. No simple models can be applied for simulating such complex wave fields, and the present numerical models need further development before they can be relied upon quantitatively. Measurements show that railway vibrations are stochastic in nature. There are substantial variations among apparently similar train passages.

Propagation. The propagation region constitutes the soil profiles which transmits what was generated to free field vibration at the locations of neighbouring buildings. In this region the waves are of the far field type and are simpler to describe. For ground with mainly horizontal stratification most of the vibration energy is transmitted as Rayleigh like surface waves. These waves attenuate partly due to geometrical spreading and partly due to hysteretic energy absorption in the soil materials. Theoretically this leads to two separable attenuation laws for Rayleigh waves generated at a point source:

$$v/v_0 = \left[D/D_0\right]^{-0.5} e^{-\left(2\pi\xi_h f/C_R\right)(D-D_0)}$$

where the first term represents the geometrical and the second term the hysteretic damping. v is the vibration amplitude, D is the distance, ξ_h is the coefficient of hysteretic damping, f is the frequency and C_R is the Rayleigh wave speed. For most soil profiles C_R increases with decreasing frequency. Real soil profiles are laterally inhomogeneous with undulating surfaces and dipping layers. Equation can never be more than a rough indicator of the real attenuation. Numerical tools to simulate wave propagation in real soil profiles are available but their use requires substantial insight in numerical wave analyses and they are costly to use.

Another important question is whether a train is a point source or a line source. Measurements performed by NGI indicate that for the low frequencies the vibrations generated by a train are non-coherent if measured at a larger spacing than about 20 m along the track. This indicates that the train should be modelled as a series of statistically independent vibration sources each with the length on the order of 20 m: i.e., each car can roughly be considered as a statistically independent source. The variance of the vibration from the whole train should then be the sum of the variances from each car, making the train something between a point source and a line source.

Reception. A reception region is one neighbouring building its foundation and the soil in the immediate vicinity, which interacts with the foundation. To evaluate the annoyance of building occupants the vibration at the most unfavourable place where people regularly reside, usually at mid-floor spans must be predicted. Usually vibration is strongest in the top floor and increases with the number of floors in the building. At lower floor levels vertical vibration tend to dominate while horizontal vibration becomes stronger higher up. The propagated free field vibration in the ground is transferred to the building foundation through a dynamic soil:foundation interaction and is further transferred and usually amplified through the building structures. Important factors are the size of the foundation relative to the wavelength of the vibration the rigidity and mass of the foundation, and the natural frequencies and eigenmodes of the building. Methods based on approximate soil:foundation impedance functions and lumped mass-spring models of the building often apply for simpler buildings to simulate the transmission and amplification in the reception region. For more complex structures, more involved dynamic finite element or boundary element methods are needed.

As stated previously there are significant shortcomings in the ability of present numerical tools to predict the generation of low frequency vibration from railways on soft ground. Furthermore numerical tools to simulate vibration propagation and building response still are costly to use. The present numerical tools are deterministic and not suited for capturing the stochastic nature of railway vibration and the natural variability in ground conditions and dynamic properties of buildings of the same kind.

Models for vibration predictions in a planning process need to operate on groups of buildings, and coarse classifications of the ground conditions. The empirical prediction model presented here is therefore based on systematic treatment of measured vibration under various conditions. Numerical models can at present mainly serve as development tools to widen the understanding and to guide the development of empirical models.

5.2.1 Investigation on Dynamic Railway Sleeper / Ballast Interaction

There are two commercially available types of concrete sleepers: twin-block and monoblock sleepers, as shown in Appendix C. The former sleepers were originally developed in France and used in Europe, India, Brazil, and Mexico. The later ones first came from the UK and have been adopted in countries such as Australia, Canada, China, Japan, the UK, the USA, and the former USSR. Due to the nature of dynamic loadings on railway track, the vibration characteristics of concrete sleepers are essential in analysis and design procedures. Also, to develop and validate a numerical simulation of rail track, the free vibration characteristics of the sleepers in various conditions are needed. Archives of vibration response measurements and parameters of sleepers can help engineers to identify the vibration-based damage or remotely monitor the sleeper health, since it is clear that the sleeper damage occurs mostly at resonant frequencies of the sleepers. The resonant vibrations of sleepers affect not only the sleepers themselves, but also the wheel–rail interaction forces. Due to their wide use, the design and maintenance of prestressed concrete sleepers is a major concern to track engineers. There have been a number of studies related to the determination of dynamic properties of concrete sleepers. Modal analysis is one of the widely used techniques to examine the vibration characteristics of concrete sleepers. Ford performed modal analysis on a concrete sleeper in free-free condition using an electrodynamic shaker. Dahlberg and Nielsen developed an analytical model for analysing dynamic behaviour of concrete sleepers in both free-free and insitu conditions. Based on the experimental results, a two-dimensional dynamic modelling for vibration analysis of concrete sleepers was done by Grassie [4]. It was found that the Timoshenko beam element was the best approximation of the concrete sleepers, even though the elastic properties of prestressed concrete sleepers may not be precise. Recently, Gustavson [10] and Vincent [11] performed the three-dimensional finite element modelling and modal testing of concrete sleepers in free-free condition. The results were in good agreement between numerical and experimental data. In reality, however, the sleepers are placed on ballast/subgrade formation. A comprehensive sleeper-ballast dynamic interaction has rarely been studied. This paragraph presents results of an experimental modal analysis of prestressed concrete sleepers in both free-free and in-situ conditions. Four types of prestressed concrete sleepers were provided by theAustralianmanufacturers. The concrete sleepers were tested using an impact hammer excitation technique over the frequency range of interest: 0 to1600 Hz. Frequency response functions (FRFs) were measured using the Bruel&Kjaer PULSE dynamic analyser. The FRFs were processed using the STARModal analysis package to identify natural frequencies and the corresponding mode shapes for the sleepers. The conclusions are presented on the effect of boundary conditions on the dynamic properties of prestressed concrete sleepers and their use for predicting railway track dynamic responses. Vibration parameters of concrete sleepers are required for the development of a realistic dynamic model of railway track capable of predicting its responses to impact loads due to wheel burns, irregularities of the rail, so on.

Noise and vibration control on these sources can be applied in new design or redesign (retrofit) and has to be retained by maintenance of vehicles and tracks.

For rolling noise the following applies: smooth wheels and smooth tracks ensure minimal noise generation; this implies the use of braking systems that maintain smooth wheel running surface such as disc or drum brakes or composite-block brakes for block-braked vehicles, and appropriate maintenance of the tracks and the wheels; compact, massive design incorporating vibration isolation and high damping wheel-mounted, bogie-mounted or vehicle-mounted shrouds; low noise barriers close to the rail.

For high-speed trains the aerodynamic noise has be shown to be a predominant noise source at speeds above 250 km/h, with contributions from various heights. Noise barriers lower than 4m have insufficient effect on sources located at the top of the vehicle such as the pantographs and their recesses.

Aerodynamic noise can be reduced by:

- streamlined covers for the bogies;
- avoiding extruding parts or cavities along the train;
- streamlining and covering of the pantograph and its recess area;
- streamlined front of the vehicle.

5.3 Noise and vibrations reduction on the cars

5.3.1 Rolling-noise devices

Here some innovative devices for rolling noise reduction are presented.

Resilient wheels serve to reduce rolling noise, but only slightly. A typical reduction is 2 decibels on tangent track. This treatment is more effective in eliminating wheel squeal on tight turns and vibrations; reductions of 10 to 20 decibels for high-frequency squeal noise are typical. The costs for resilient wheels are approximately € 3000 per wheel or roughly € 200000 per train, in comparison to about € 700 for standard steel wheels. In general, there should be no extra yearly costs incurred with the use of resilient wheels relative to solid steel wheels.

Low-noise wheel shapes have been developed by the DB in order to understand the variation in noise emission of the different wheel shapes was compared with the standard wheel BA 04. Systematic analysis with the commercial finite element code ANSYS led to the low-noise wheel shape. In Fig. 5-6 the geometry and dimension of the low-noise prototype wagon wheel for block-braked operation is shown. Contrary to a stationary wheel, the work of the excitation force of a rolling wheel is only non-zero for a wheel resonance where the wheel vibration mode is identical with a harmonic of the stimulation roughness of wheel and rail running surface. Moreover, vibration amplitudes of axial wheel modes are significantly larger than radial and tangential vibration modes. These two concepts were used in the optimisation of the wheel shape. This leads to the result that the axial modes had to be shifted into a frequency area where no excitation is possible. In fact the most disturbing mode was shifted from 1717 Hz (normal wheel BA 14) to 3454 Hz by stiffening the wheel structure in the axial and radial directions by a specific tangential and radial ‘‘waviness’’ of the wheel disc.

(a) (b) (c)

Fig. 5-6 Low-noise prototype freight wagon wheel for block-braked operation ((a) side view and (b) horizontal cut through the wheel and (c) full wheel set ready for assembly).

The field measurements for the confirmation of the noise reduction properties led to several new insights concerning the relationship between the shape dynamics of the wheel and the noise emission. The measured noise reduction of a further 2 dB is a promising value with and additional cost of € 300 for each wheel, thus € 20000 for each train.

Damped wheels, like resilient wheels, serve to reduce rolling noise, but only slightly. A typical reduction is 2 decibels on tangent track. This treatment involves attaching vibration absorbers to standard steel wheels. Damping is effective in eliminating wheel squeal on tight turns and vibrations; reductions of 5 to 15 decibels for high-frequency squeal noise are typical. The costs for damped wheels add approximately € 500 to € 1000 to the normal € 700 for each steel wheel, thus roughly € 50000 per train. There is no significant maintenance cost, though there may be a cost associated with removal of the absorbers from condemned wheels and remounting on new wheels.

Spin-slide control systems, similar to anti-locking brake systems (ABS) on automobiles, reduce the incidence of wheel flats, a major contributor of impact noise. Trains with smooth wheel treads can be up to 10 decibels quieter than those with wheel flats. To be effective, the anti-locking feature should be in operation during all braking phases, including emergency braking. Wheel flats are more likely to occur during emergency braking than during dynamic braking. The cost of slip-slide control may be incorporated in the new vehicle costs, but may be between € 5,000 and € 10,000 per vehicle, thus roughly € 60000 per train.

Skirts have other attractive properties as well, such as controlling aero-acoustic noise generation, reducing drag and presenting an attractive. Skirt shields can reduce wheel-radiated noise by 4 dB [Fir03] with a cost of approximately of € 500 for wheel-set. The cost of retrofitting a train with two full-length skirts and under car absorption is about roughly € 15000. There are no maintenance costs associated with skirts, though there may be an increased cost associated with removal of the skirt for maintenance of the vehicle.

5.3.2 Aero-acoustic noise devices

Considering the aerodynamic, the pantograph is the easiest noise source to limit and also one of the most important noise source at high speeds. This is particularly true for Electric Multiple Unit (EMU) trains, which can include up to 6 pantographs on a 200 m train due to requirements on redundancy and multiple-system versions to fulfil standards and constraints in different European countries. On good tracks, with the addition of 2 metres noise barriers, pantographs may dominate the total noise level down to speeds as low as 200 km/h. Therefore, it is of great importance to implement low-noise pantographs on future high-speed interoperable EMU trains.

Development work on a new low-noise pantograph, ASP (Active Single arm Pantograph), is being carried out in a co-operative program between DB and Bombardier Transportation. Testing on a first prototype of the ASP was carried out in an anechoic wind tunnel in Ingolstadt. The ASP was compared with the DSA 50 pantograph that is currently used on the standards German high speed trains.

On the first ASP prototype, the pantograph head and knee were of a modified design but the foot region was unchanged. The foot region then dominated the noise emission, as clearly seen in the results from the array measurements in Fig. 5-8. Noise generated around the foot would be somewhat lower on an actual EMU train than in the wind tunnel, due to the reduction in relative air velocity associated with growth of the boundary layer along the train.

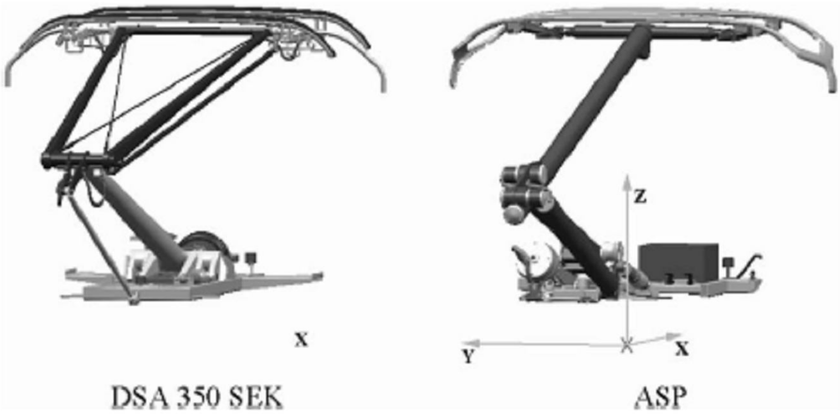

Fig. 5-7 New low-noise pantograph (ASP) compared with the DSA 350 pantograph

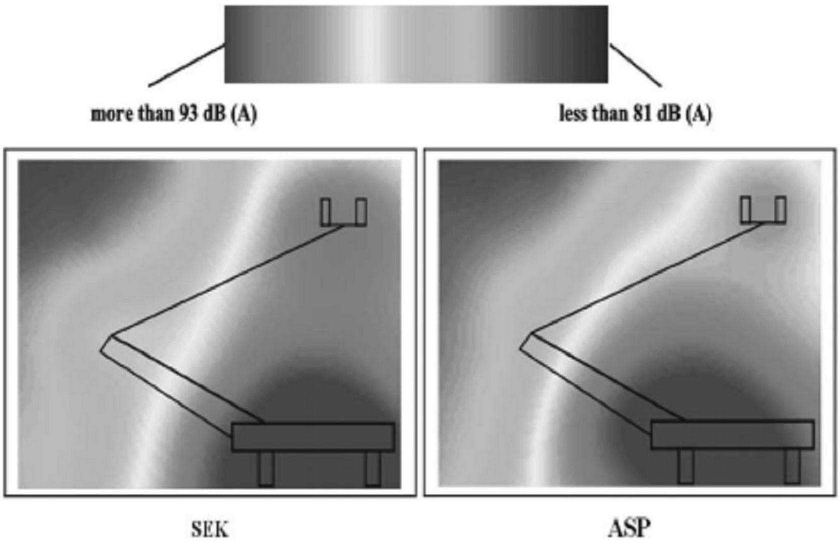

Fig. 5-8 Noise emission of the DSA 350 SEK and the ASP at 300 km / h [BOB00]

However, this area of the pantograph does, none-the-less, require noise control. Test results from single microphone recordings at 4m distance in the wind tunnel, shown in Fig. 5-9, indicate that a further reduction of about 8 dB(A) is realizable if modifications to the foot region are included, compared to the current DSA 350 SEK pantograph. In addition, it was found that the speed noise increment of the ASP much lower, with a speed exponent of 6.1, compared to a value of 7.2 for the DSA 350.

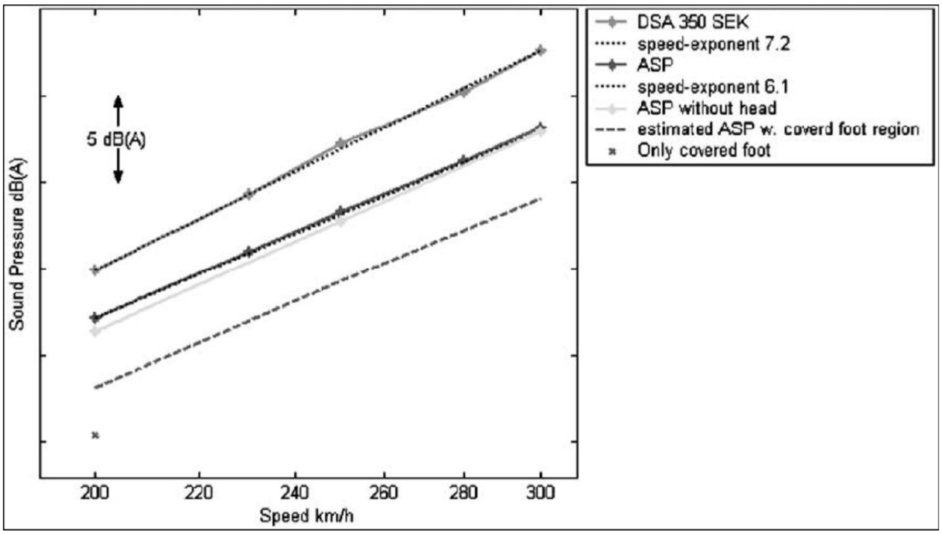

Fig. 5-9 A-weighted levels at different speeds for different pantograph configurations measured at 4m distance in an anechoic wind tunnel.

This new silent pantograph are already tested and available in a short time. The substitution of the present pantograph with the new model could be carried out in about 5 years. The additional cost of this kind of this device could be estimated as € 2000 for each pantograph; the total cost per train should amount at € 8000.

5.3.3 The long life of railway vehicles

In comparison to road vehicles, rail bound vehicles have a much longer life (about 40 years) with benefits in terms of resource consumption, but also much difficult in renew in a short time the rolling stock. As regulations are normally only applied to new vehicles, product solutions or procedures must be found to accelerate the implementation of noise reductions for vehicles already in use.

The Fig. 5-10 shows the slow pace of reduction of average levels if old vehicles are replaced with a constant rate of 2.5% per year by new wagons with a noise emission reduction of 10 dB(A). After 20 years the levels will be reduced by only 2.6 dB(A). This shows the need of retrofitting the present rolling stock in order to reduce noise and vibrations in short time and also suggest that the advantages of reducing emitted noise probably will be perceived in a medium term (10-12 years). In conclusion, in mean time some short-term solutions (mainly noise barriers) has to be adopted.

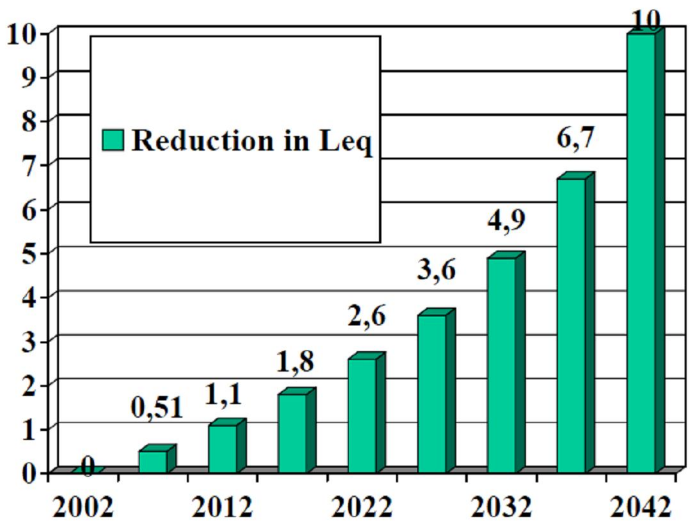

Fig. 5-10 Reduction of average levels due to new vehicles with ΔL = 10 dB(A) (linear substitution of old vehicles, assumed life time 40 years)

5.4 Noise and vibrations reduction on the track work

Track work treatments include sound absorption at the track level, perhaps between the rails, rail vibration absorbers, low height barriers between tracks and any other measure for which the track maintenance department (RFI) would be responsible.

Track bed absorption is effective for direct fixation track with concrete inverts or slabs, such as at concrete aerial structures. Noise levels at ballast-and-tie track are normally 4 to 5 dB lower than at aerial structure and concrete slab track with direct fixation fasteners, ostensibly because of the sound absorption provided by the ballast.

Additional track bed sound absorption would be ineffective at ballast-and-tie track. There may be substantial maintenance problems associated with sound absorption treatments positioned beneath the train in exposed situations. Such problems may involve the ability to inspect and maintain track components. Debris may accumulate beneath the absorption, making cleaning of the invert difficult. The treatment would be effective for station platform areas and areas where debris would not accumulate. The absorption must be protected from tunnel washing machines and other maintenance equipment which might otherwise damage the treatment. Candidate treatments include Tedlar-encased glass fibre board of density, protected by perforated sheet metal or fibre reinforced panels; spray-on cementitious sound absorption; and ballast.

Rail vibration absorbers are an intriguing noise reduction treatment. Vibration absorbers are spring-mass systems with damping incorporated into the spring to absorb and dissipate vibration energy. They are attached to the rail with clamps, without contacting the invert or ballast. Vibration absorbers may be tuned by the absorber manufacturer to optimize dissipation of rail vibration energy into heat over a particular range of frequencies and may be particularly desirable at locations where a sound barrier would be impractical and the needed noise reduction is on the order of a few decibels. The unit cost for rail vibration absorbers is expected to be on the order of € 50 to € 100 per absorber. Assuming that one absorber is applied in every space between fasteners at both rails, and that the fastener spacing is 80 centimetres., the cost per track meter would be on the order of € 240 to € 480. The rail vibration absorber may be particularly effective in reducing the pinned-pinned mode response of the rail associated with fastener pitch.

Resilient fasteners are not normally considered a treatment for wheel/rail noise. They are designed to reduce low-frequency ground-borne or structure-borne noise above about 30 Hz and can be effective in reducing wayside noise radiated from steel elevated structures and aerial structures with steel box girders. Resilient fasteners with elastomer springs have been proposed for reducing wheel/rail noise radiation by using the damping properties of the elastomer. Further, adding bonded resilient fasteners to wood tie elevated structures may reduce secondary impact noise radiation caused by an otherwise loose system consisting of tie plates and cut-spikes. The resilient fasteners provide rail support without looseness and, therefore, may reduce noise related to impact between the rail and tie plate. However, the damping provided by the elastomer may be the principal noise reducing agent, because the tight rail support with damping would be effective in reducing vibration transmission along the rail which otherwise might be free to vibrate. Systems that use concrete ties with spring clips may not benefit from the use of resilient fasteners, because the spring clips already eliminate any looseness between the rail and tie.

5.5 Noise reduction in the wayside

5.5.1 Acoustic barriers

Wayside treatments for normal rolling noise include sound barriers, absorptive sound barriers, and receiver sound insulation. These are the most effective treatments available for reducing normal rolling noise at wayside receivers. Although not listed, shifting the alignment is always a possibility, though this option is possible primarily for new construction in which such an option can be exercised at the design stage. Alignment shifting is not considered an option for existing systems because of the severe cost and disruption of service. Also included are station and subway treatments for controlling noise received by the transit patron and ventilation and fan shaft treatments for controlling noise radiated to nearby residences.

Sound barrier walls are the most effective treatment for controlling normal rolling noise in wayside areas. Sound barrier walls may be treated with sound absorbing materials to enhance their effectiveness, though at considerable cost. The site-specific limitations of sound barriers include lack of sufficient access for wayside maintenance vehicles at at-grade track, lack of sufficient distance from track centre to guarantee safety of individuals that might be trapped between the track and wall, source and receiver elevations that may not be appropriate for achieving effective noise reduction for a practical barrier height, high sound barriers that may be unattractive or undesirable in terms of aesthetics first.

The cost of a typical sound barrier wall is about € 300 to € 350 per square meter. Thus, a typical 3 meters high sound barrier wall could cost about € 1000 per lineal meter of track and gives a noise reduction of about 8 dB(A), not screening from the aerodynamic noise radiating from the higher part of the train (mainly the pantograph). There may be also additional costs for landscaping, maintenance, and additional architectural features. For higher barriers up to 6 meters the cost is about € 1750 per meter of track. Therefore barrier costs may vary considerably from one locale to another and may be driven by aesthetic considerations and topography; hence, barrier costs could increase up to € 400 per square meter when landscaping and drainage are included. Nevertheless, sound barriers can provide a visual as well as physical separation between a wayside residential community and a transit corridor, which may be highly desirable to the community. However, the mean noise reduction obtained by this barriers is approximately of 12-14 dB(A).

The track side of sound barrier walls may be treated with sound absorbing materials to improve barrier performance and reduce or eliminate reflections. Absorptive sound barriers are most effective at concrete invert track with direct fixation; the noise reduction obtained at ballast-and-tie track may be limited by the existing absorption provided by the ballast if the barrier is close to the vehicle. There are two conditions to consider: a barrier at a large distance from the track or a barrier very close to the track. In the first case, sound absorption is expected to improve the insertion loss of simple barriers, though the improvement may be limited to 2 to 3 dB. In the second case, multiple reflections between the barrier face and vehicle body will degrade barrier insertion loss. Sound absorbing material applied to the face of the barrier facing the train will reduce or eliminate multiple reflections and improve barrier performance. Absorptive barriers may be useful in situations in which high barriers are needed on either side of the track and where there is a need to reduce the reflection of sound from the more distant barrier. Sound absorption applied to the face of the barrier would cost about € 200 per square meter, which is added to the initial cost for the barrier. Savings can be obtained for absorptive barriers constructed of sheet metal and glass fibre, powder coated to provide an attractive finish and protection against the weather and oxidation. A variant of this approach is the addition of an absorptive crown to the barrier, which would increase barrier height, though less than that required for a non absorptive barrier. Examples of this last approach have been used in Japan.

5.5.2 The adopted barriers and our proposal

On the High Speed railway line between Milan and Turin some acoustic barriers are already present. These barriers are designed to reduce the noise generated by the passing trains both in the urban centres, where the train has a lower speed and in those parts of the line in which the train has his highest speed. In this view the barrier has to apt to different needs of noise reduction and the project has been developed in this way. As can be seen from the images, the barriers are non absorptive, are positioned quite distant the vehicle and can reach the height of over 7 meter by means of additional panels that can be joined if necessary. The shape of the barriers is on the other hand quite simple, linear and leaned towards the train (Fig. 5-11). All the noise reduction is mainly due to the height of the barriers.

The strength of this design is without any doubt the simplicity and the modularity, these barriers are relatively easy to be produced and can apt to the different need of different contexts of the High Speed railway line. This simplicity ends in a reasonably low mean cost of € 1500 per meter of track for an estimated sound absorption of 12 dB(A).

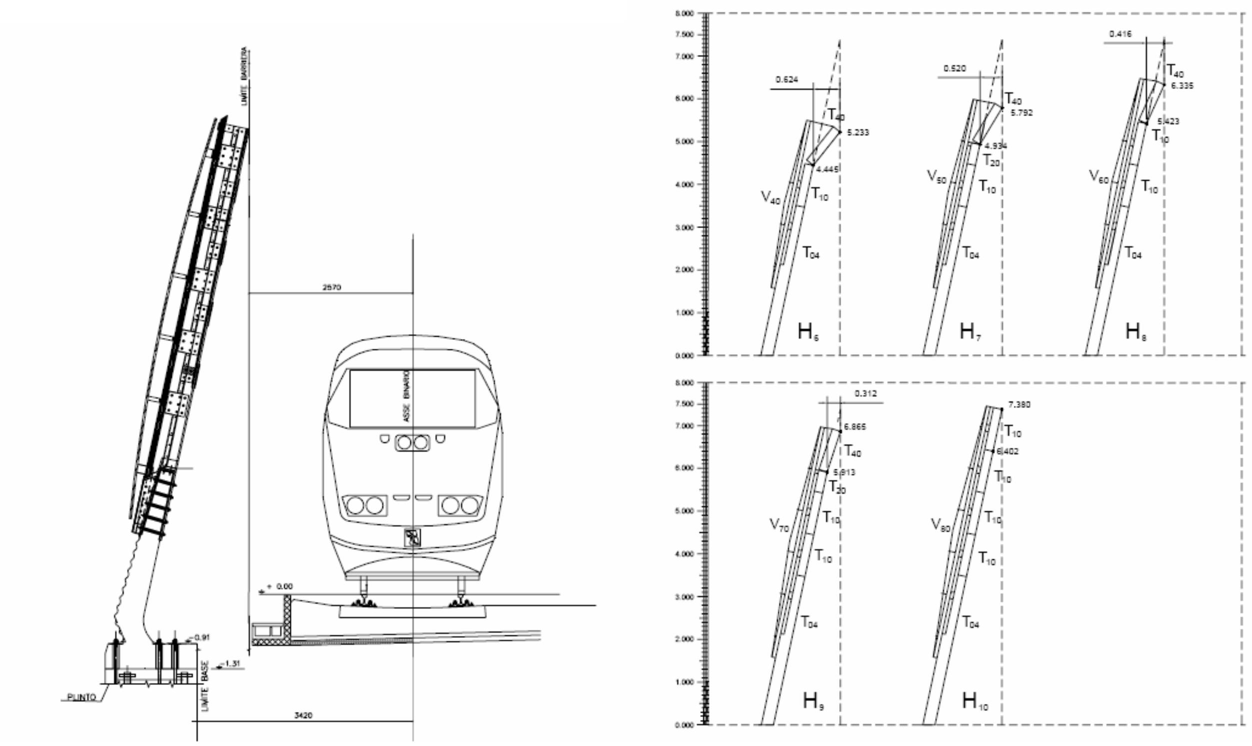

Fig. 5-11 – Drawings on the actual acoustic barriers on the high speed rail line and on their modularity

The drawbacks come directly from their points of strength. A barrier that is designed to fit different needs can't be appropriate for all these needs, thus a more complex and less adaptable design can bring a greater noise reduction and thus greater benefits for population and society. After a deeper analysis the most important lack of these barriers must be highlighted: they are designed to reduce noise only with their height and without specific features to reduce the different kinds of noise generated by the passing-by trains. The result is a great impact on the landscape with a 7 meter high wall, a reduced effectiveness on the aero-acoustic low frequencies, which are not efficiently damped only by the height of the barriers, and, as reported by RFI, some structural problems in the long term due to the pressure wave generated by the front power car.

On the basis of different research results our goal was to improve acoustic barriers in order to comply with national regulations and population complaints so as to obtain more benefits for the entire society.

A study has been carried out in order to compensate the drawbacks of the actual barriers, thus a barrier design focused on the analysis of the position, the frequency and the intensity of the noise generated is here proposed preserving the modularity feature of the old barriers and improving the landscape impact, the accessibility to the track and the structural strength.

The guidelines have been:

- Reduce the high frequency rolling noise that is dominant at low speed.
- Limit the low frequency main aerodynamic noise generated by the coach over 250 km/h.
- Reduce the structural problem induced by the front power car pressure wave
- Preserve the modularity
- Improve accessibility

Considering the rolling noise, his typical feature is the source position very close to the ground and this characteristic can be exploited to obtain a strong noise reduction. The principle is quite simple and uses simple physical phenomena as reflection, diffusion and sound absorption: an adequately shaped kneeled barrier can reflect the sound generated by the wheel/rail interaction, the reflected sound is then absorbed or diffused (and so reduced in intensity) by the ground and the ballast. The experimental data collected on reduced scale barriers in Van Der Toorn studies [Too01] show that a noise reduction up to 7 dB(A) higher can be obtain with a kneeled with respect to a linear one.

With respect to the aerodynamic noise, this is basely at low frequencies. This frequency is better absorbed by thick barriers that have on the other side inconvenient due to weight and cost. A way to avoid this inconvenient is to have two surfaces whit a gap in the middle. Exactly as happens in the double glasses of our windows, noise is greatly reduced in this way. In addition it has been shown [Too01] that a perforated metal panel as first layer can help in reduce of 2 dB(A) low frequency noise. This feature perfectly fits also the needs for modularity and reduction of pressure stresses.

The idea is then a one grade of freedom perforated kneeled metal panel added to the pre-existent barriers. This panel is free to rotate on the longitudinal axes, a damping effect on this movement is given by a damper in the constrain and by the pressure losses in the holes. This panel is modular and fits the goal of reducing noise by feature specific for his different natures. In addition the degree of freedom is such that the main stresses of the power cars pressure wave are absorbed by the dampers in the constrains and by the pressure losses in the holes.

A final important remark is made on the possibility of posing the barriers not all in a row, but in a spine way in order to obtain a greater structural strength and let the passenger have a little view of the landscape through the gaps between the barriers, provided with transparent panes. Providing these shorter sections with doors the general accessibility to the infrastructure will also be improved both for maintenance works and emergency situations. This sort of approach can be obviously done only for the barrier not already posed in order to not corrupt the modularity of the project.

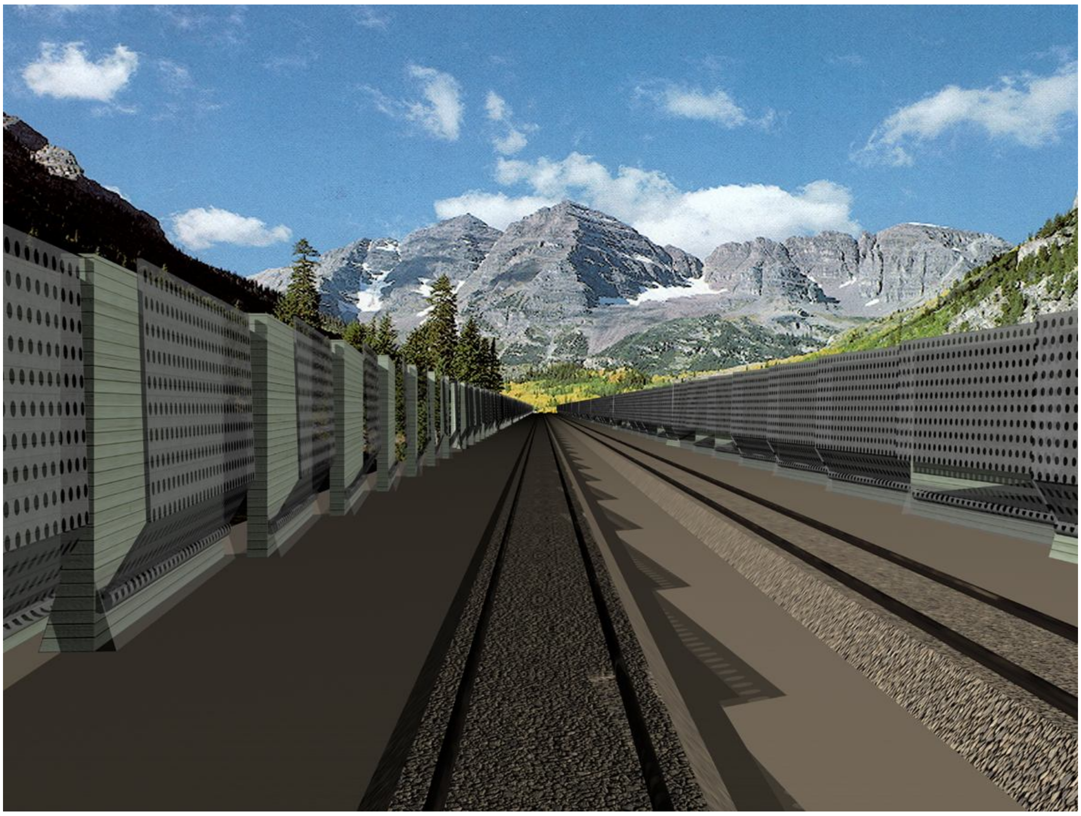

Fig. 5-12 – Three dimensional rendering of the proposed acoustic barriers

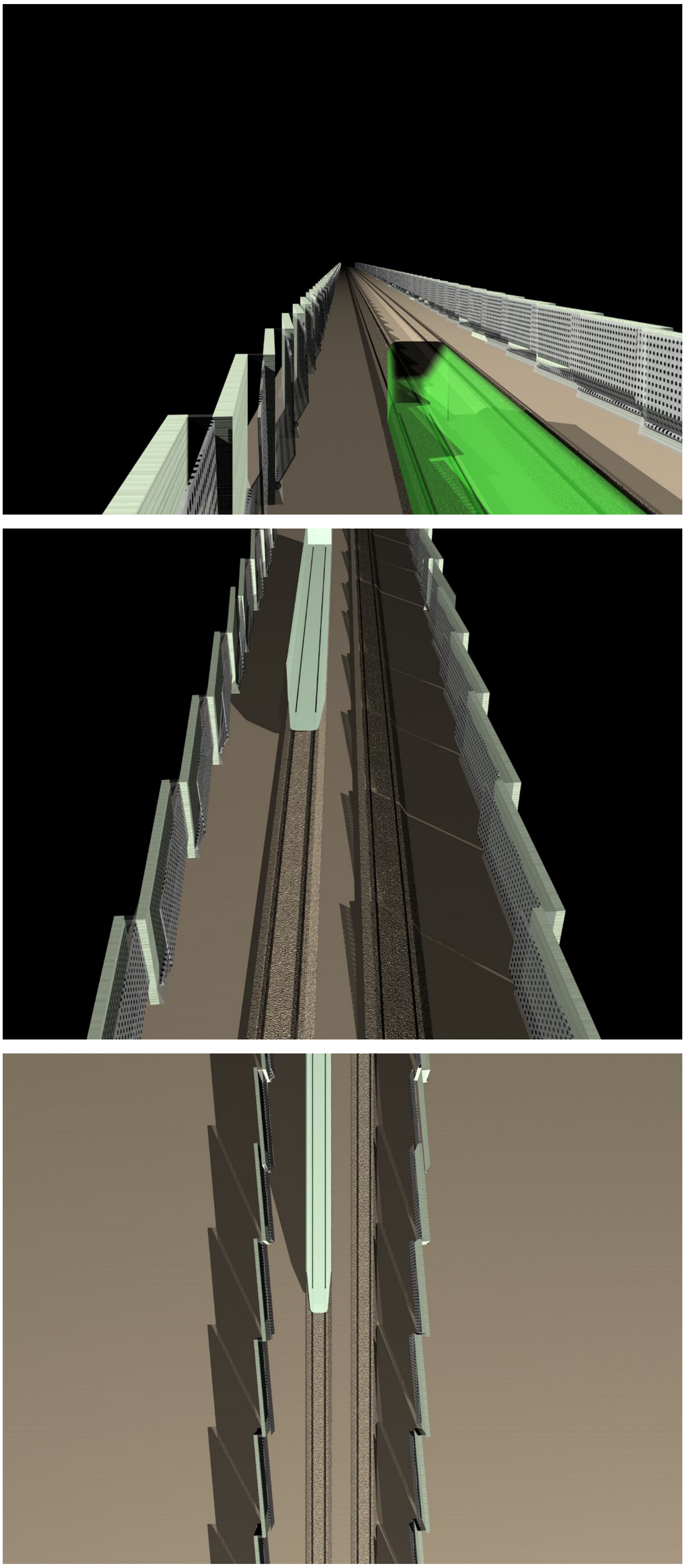

Fig. 5-13 – Aerial views of the proposed acoustic barriers

The experimental data show a global improvement up to 9 dB(A), but a quite high cost. A first esteem says that the cost for meter of track is about € 2750. This increment is mainly due to the double layer of the barrier and to the use of complex devices such the dumpers, but further economical analysis taking into account the technological experience and innovation will certainly reduce these unpleasant drawback.

5.6 Esteem of the interested population

In order to evaluate the problem concerning the Milan-Turin High Speed railway line it is useful to understand how many inhabitants are afflicted by the noise and vibrations problem and how many kilometres of noise barriers has to be built to protect this population.

The hypothesis that has been made to evaluate the afflicted population are here presented. Only the railway line between the gate-station of Rho and Settimo Torinese has been considered in order to avoid more complex evaluations in those urban areas where the travelling speed will be reduced. The High Speed railway line has been divided in 5 major parts with peculiar demographic characteristic. Among these parts, which are shown in Tab. 5-1, there are two rural areas in the neighbourhoods of Chivasso and Santhià, where the line mainly cross open field and as a consequence the number of persons interested by the noise and vibration pollution is low, while near Magenta many tows are crossed by the rail line and thus there are many more people interested. On the other side the area near the three main city crossed by the railway line (Milan (Rho), Novara and Turin (Settimo Torinese)) the noise and vibration problem afflicts an higher number of inhabitants. The number of this inhabitants has been esteemed considering an area of 250 meters on each side of the rail line, according to the national noise normative, and multiplying this area for the local population density. The results are in Tab. 5-1.

	Density [Inhab/km^2]	**Length [km]**	**Interasted area [km^2]**	**Population interested by HS noise**
Rho	2277.8	7.3	3.65	4156
Magenta	1078.5	14.2	7.1	3828
Novara	1000.1	30.6	15.3	3060
Santhià	179.7	32.4	16.2	291
Chiasso	506.8	21.3	10.65	1079
Settimo Torinese	1359.2	6.39	3.195	2171
Total		112.19	56.095	14590

Tab. 5-1 Population esteem in Milan-Turin High Speed railway line

Dealing with the barriers length a similar esteem has been made. It has been made the hypothesis of building noise barriers only in those part where the railway line crosses urbanised areas. These parts have been localized on the map and similarly to what has been done for the population esteem the number of persons interested by the noise barriers absorption has been computed. In Tab. 5-2 this esteem is reported.

	Installed barriers	**Barriers length [km]**	**Interasted area [km^2]**	**Population interested by barriers**
Rho				
	Pregnana Milanese	2.74	1.37	1560
	Sedriano - Vittuone	3.15	1.575	1793

Magenta				
	Corbetta	1.35	0.675	363
	Magenta	1.1	0.55	296
Novara				
	Romentino-Galliate	1.28	0.64	128
	Novara	2.3	1.15	230
Santhià				
Chivasso				
	Rondissone	0.81	0.405	41
	Chiasso	2.52	1.26	127
Settimo Torinese				
	Brandizzo	2.33	1.165	791
	Settimo Torinese	3.39	1.695	1151
Total		20.97	56.095	6488

Tab. 5-2 Noise barriers esteem in Milan-Turin High Speed rail line

5.7 Cost-benefit analysis resume

All the esteemed data on costs and benefits of noise and vibrations reduction devices can be now resumed. Some hypothesis has to be clarified first.

For the emitted noise, the cost of the single noise attenuating device on the source was previously given per train, while in Tab. 5-3 the total cost for the whole Trenitalia ETR500 fleet of 59 trains is reported, since it is expected that quite all the trains will run on the track considered. Benefits are estimated starting from the effective dB(A) noise reduction and applying the expression presented in the previous paragraph 4.4.2 where the starting noise level L_1 is modified. According to paragraph 4.4.3 every B-index point is evaluated as € 35 per person interested by the noise reduction. For noise emissions reduction on the rolling stock all the persons in on the rail line are considered.

$$\Delta B(€) = 35 \cdot 0,063 \cdot \Delta L_1$$

For the noise barriers the cost was given per meter, while in Tab. 5-3 the total cost for the whole 20.97 km length of the noise barriers on the Milan-Turin High Speed railway line is shown. Benefit are again estimated starting from the expression in paragraph 4.4.2, where barrier reduction is computed in the term ΔL, and considering the social cost of 30 € per unit increase in height. As usual, every B-index point is evaluated as € 35 per person interested by the noise reduction. For acoustic barriers only the persons interested by the noise barriers reduction are obviously considered.

$$\Delta B(€) = 35 \cdot 0,566 \cdot \Delta L - 30 \cdot H$$

To complete the analysis we can create different scenarios mixing different solutions and applying the cited formula starting from an hypothetical initial noise level of about 75 dB(A) to obtain so the real cost-benefit ratio of the solution considered.

The actual solution with 6 m noise barriers leads to a total benefit of

$$B(€) = 35 \cdot (5,281 - 0,063 \cdot 75) \cdot 9.730 + 564.340 = 753.686\ €$$

and then a cost-benefit ratio of 41,7.

Applying just our new acoustic barriers the total benefit will be

$$B(€) = 35 \cdot (5,281 - 0,063 \cdot 75) \cdot 9.730 + 2.296.280 = 2.485.626 \text{ €}$$

with a cost-benefit ratio of about 23,2.

Acting just on the rolling stock with skirts and ASP pantograph for a total reduction of about 12 dB(A) we have a social benefit of

$$B(€) = 35 \cdot (5,281 - 0,063 \cdot 75) \cdot 14.590 + 131.310 + 255.325 = 670.556 \text{ €}$$

and a cost-benefit ratio of 2,0.

In order to achieve quite the same reduction of new acoustic barriers but acting at the source with skirts, ASP pantograph and spin-slide control the total benefits are

$$B(€) = 35 \cdot (5,281 - 0,063 \cdot 75) \cdot 14.590 + 131.310 + 255.325 + 320.980 = 991.536 \text{ €}$$

and the cost-benefit ratio is 4,9.

In the future a combing solution with a reduction of 33 dB(A) would be expected and so, using new designed barriers, skirts and ASP pantograph, the social benefits will be

$$B(€) = 35 \cdot (5,281 - 0,063 \cdot 75) \cdot 14.590 + 131.310 + 255.325 + 2.296.280 = 2.966.834 \text{ €}$$

with a cost-benefit ratio of about 19,9.

The obtained results are not surprising. As well known in literature and as it has been shown in deeper analysis in Switzerland [Owa96] and Netherlands [Vos96] the noise emission limiting strategy is far more convenient, mainly for three reasons:

- Lower costs of the devices, which are far less expensive that noise barriers
- More persons who can appreciate the advantages in noise reduction. Noise is reduced on the source so that anyone on the rail line can take advantage from this reduction
- Greater economic effect on the population. As shown people values more the noise reduction on sources mainly because it has no effect on the landscape and is less intrusive.

Dealing with noise barriers it has been shown that our new design is far more effective and technologically innovative than the traditional barriers and it is even economically convenient, without considering in the economical analysis other original features such the staggered disposition. Furthermore, this measure could be useful in part of the rail line where stronger noise reduction is needed (up to 20 dB(A)) and cannot be achieved with traditional barriers which have already been posed or in those part where less high new barriers would be sufficient. In short term of time the disposal of the new type of barrier would be a sure goal but for the future an improvement in the rolling stock is required in order to reduce significantly the cost-benefit ratio.

Device	Mean noise benefit on tangent tracks [dB(A)]	Benefit variation for single resident [€]	Cost per train [€]	Cost per meter [€/m]	Population interested	Total Cost [€]	Total Benefit variation [€]	Cost-Benefit variation ratio
Resilient wheels	2	4,5	150.000		14.590	8.850.000	65.655	134,8
Silent wheels	2	4,5	20.000		14.590	1.180.000	65.655	18,0
Dumped wheels	2	4,5	50.000		14.590	2.950.000	65.655	44,9
Spin-slide control	10	22	60.000		14.590	3.540.000	320.980	11,0
Skirts	4	9	15.000		14.590	885.000	131.310	6,7
ASP pantograph	8	17,5	8.000		14.590	472.000	255.325	1,8
Low barriers (3 m)	8	68,5		1.000	9.730	20.970.000	68.500	306,1
Actual HS noise barriers (6 m)	12	58		1.500	9.730	31.455.000	564.340	55,7
New design noise barriers (6 m)	21	236		2.750	9.730	57.667.500	2.296.280	25,1

Tab. 5-3 Cost-Benefit analysis data resume

6 Conclusions

The evaluation of the socio-economical impact of the *AV/AC* high speed railway line shows how the realization of this infrastructure, and the consequent improvement of the whole transportation network, provides a great opportunity for the involved territories for developing a short and long-time advance, opening up to the European high-speed fast-mobility corridors.

The reduction of travel times of about 30% and increase of line capacity, that reduces the average waiting time, permit to have a very fast transportation vector between the Milan-Turin bipole. The availability of an efficient mean of transport yields an enlargement of the railway catchment area. Furthermore, as train-travellers will grow, the transportation by road and by air will gain efficiency, leading to a global equilibrium of the transportation network. As Turin and Milan represent one of the most Italian (and European) technologically advanced poles, the enhancement of mobility network is a necessary support for further internal development. Moreover, considering long spans, high speed lines permit to dramatically cut down travel times, offering a valuable alternative to air transportation.

While Lombardia and Piemonte are the most industrialized and populated regions, and their competitiveness on national, European and worldwide market is high, fast transportation for both people and goods is a fundamental requisite for maintaining a valuable position on the market. The insertion of *AV/AC* on the European *Corridor V* represents a good opportunity for improving the efficiency of Italian industry.

From the environmental point of view, as documented in our investigation, several possibilities to reduce noise emissions are available, depending on the quality and properties of rolling stock, anti-vibrations sleepers, and fixed installations such as noise barriers. Our cost-benefit analysis clearly shows that the employment of the top-quality noise barriers that we have designed, that exhibit excellent performances in terms of noise reduction and minimize aesthetic impact, is the best way to achieve the project's goal. Even though these components have higher costs than the standard barriers, they are particularly suitable for our proposal, because these barriers yield such a strong noise-reduction that they don't need further interventions on the other elements of the railway infrastructure, permitting to reduce the overall cost. Advantaging the development and application of fixed components, that usually require less maintenance and adaptation costs and can be flexibly employed, allows the avoidance of interventions on rolling stock and on the tracks, that are more difficult to be applied and require long-time operations. Moreover, this intervention strategy is based on the development of a high technological component, and follows the road of innovation and high-quality that the realization of *AV/AC* should undertake.

However, this analysis is based on the actual legislation about environmental impact. It is predictable that future developments will produce modification also on European normative, and therefore noise emission limits will be further reduced. As the building of such a complex infrastructure is really time-consuming and requires an extremely weighty economic investment, its project must be based not only on actual legislation, but has to take into consideration also the future normative; in practice, the noise emission limits must be designed in order to be lower than the ones foreseeable in the future. As a consequence, in a preliminary approach, the constraint of noise emissions must be lowered in order to make *AV/AC* insensitive to future modifications of environmental normative. In this way, the project of adequate countermeasures gets much more complex, and it is necessary to design a very flexible infrastructure that can be modified without explosion of costs. In particular, while our project relies on the installation of noise barriers as the only needed intervention, in the future it is unpredictable that this countermeasure, by itself, could produce such noise attenuation to undergo future noise limits. Hence, the long-time prediction is to integrate noise barriers with interventions on the rolling stock, in order to directly attenuate the noise sources, such as aerodynamic or wheeling noise. In this way, achieving a complete cost-benefit analysis of the environmental impact of the whole railway line is a good starting point for individuating the future principles of operation; the design should include flexible structures, suitable for dynamic implementations of structural adaptation to eventual future issues.

Appendix A: The Electromagnetic Compatibility

While the main part of the project activity deals with the socio-economical and "physical" impact of the *AV/AC* railway line, also the problem of studying and evaluating the electromagnetic impact of the Italian High-Speed Railway Line has been developed. The electromagnetic compatibility (*EMC*) is very difficult to be analyzed, because it is not possible to take into consideration only the radiated fields, but it's also necessary to preserve the whole *interoperability* of the high speed railway line with all the other rolling stock; hence, a widespread analysis of the whole railway system must be carried out.

Firstly, the European normative, which constitutes the limit bound for electromagnetic interference (*EMI*), is presented; starting from the maximum electromagnetic emission values, the guidelines for designing the railway compatibility can be found, translating the regulation system into a set of specifications for the whole components of the railway infrastructure. Hence, a full analysis of the electromagnetic compatibility is performed, focusing on some specific aspects that assume a particular relevance in the high speed railway framework; this investigation is outlined into three main fields:

- unwanted radiated fields due to sliding contacts [LMZ00], pantograph-catenaries interactions [LMM98] or other intrinsic side-effects ;
- electric traction of the train, which is a powerful source of electromagnetic interference and at the same time is affected by external fields [H6p97, H7p97];
- fixed installations, such as electrical substations (*ESS*), strictly connected to the railway line [MP04], which are very important because of the high power requirements.

The adoption of a dual traction system ($25KV_{ac}$ and $3KV_{dc}$) complicates the study of electromagnetic compatibility, because also the effect of the high voltage 25KV 50 Hz line on standard 3 KV lines must be taken into account. For this reason, the analysis takes into consideration only the particular features related to the *AV/AC* railway infrastructure.

A.1 Human exposure and interoperability specifications for limiting EMI

Human exposure to EMF

The dangerous effects of human exposure to electromagnetic fields are studied by international commissions, such as *IRPA* (*International Radiation Protection Association*) and *ICNIRP* (*International Commission on Non-Ionizing Radiation Protection*), with the aim to determining criteria for limiting the radiated fields. The reference unit of measurement of human exposure to EMF is the *Specific Absorption Rate* (*SAR*), defined as $SAR = 4.166\ \varrho C\ \Delta T/\ \Delta t$, where ϱ is the live tissue density [gr/cm^3], C is the specific heat constant [cal/°C], ΔT is the increase on the cell's temperature [°C] and Δt is the radiation time [s]. For every frequency, it is defined the maximum SAR acceptable for human safety; then, the SAR limits are translated into electric and magnetic fields limits, which are more oriented to the applications, such as devices or infrastructures.

For European Community, the reference standards for the exposure of people to electromagnetic fields (in the range 0 – 300 GHz), are:

- *Council Recommendations of 12 July 1999*, which provide the limits for exposure of general population to EMF;
- *Directive 2004/40/EC 29 April 2004*, which provide the limits for exposure of working population to EMF.

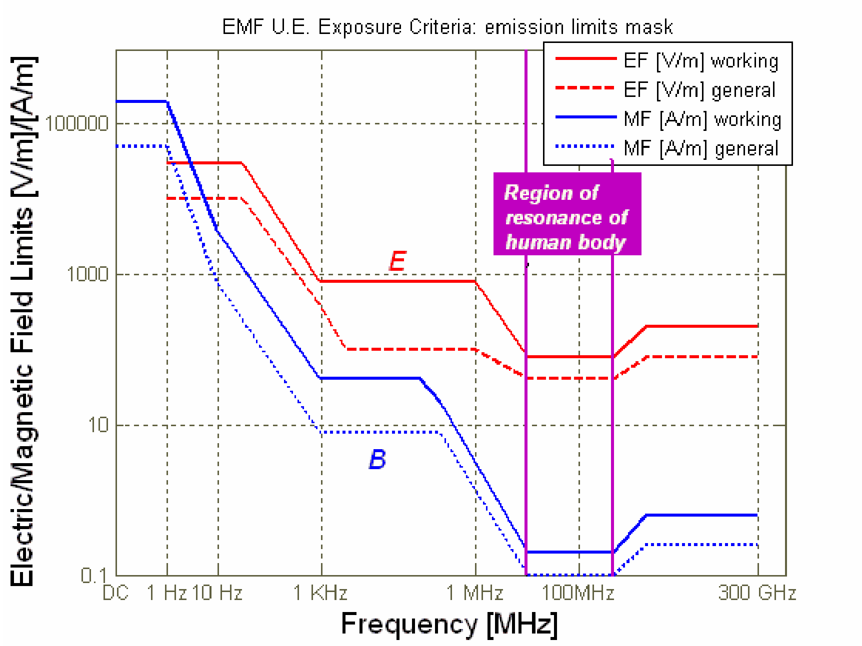

Fig. A-1 – E.U. Electromagnetic Interference limits for general and working population (Council Recommendations of 12 July 1999 and Directive 2004/40/EC 29 April 2004).

Frequency f [MHz]	Working Population			General Population		
	Effective Field Intensity		Power Density [mW/cm^2]	Effective Field Intensity		Power Density [mW/cm^2]
	Electric Field [V/m]	Magnetic Field [A/m]		Electric Field [V/m]	Magnetic Field [A/m]	
0.1 – 1	614	1.6 / f	-	87	0.23 / $f^{1/2}$	-
1 – 10	614 / f	1.6 / f	-	87 / $f^{1/2}$	0.23 / $f^{1/2}$	-
10 – 400	61	0.16	1	27.5	0.073	0.2
400 – 2000	3 $f^{1/2}$	0.008 $f^{1/2}$	f / 400	1.375 $f^{1/2}$	0.0037 $f^{1/2}$	f / 2000
2000 – 3 10^6	137	0.36	5	61	0.16	1

Tab. A-1 – IRPA exposure criteria for working and general population.

Fig. A-1 and Tab A-1 show the emission limits mask for both general and working population, expressed in terms of both electric field [V/m] and magnetic field [A/m]. As previously stated, the minimum of the emission mask corresponds to the region of resonance, in which the EMF harmful effects are enhanced by the high receptivity oh the human body.

Preserving the whole interoperability: the electromagnetic compatibility normative

In addition to the normative that regulates the EMF limitations, also a complete interoperability between all the railway subsystems must be assured, in order to preserve the complete functionality of all the parts. Consequently, it is required an adequate bound to the electromagnetic fields, in order to assure that the interference generated by a device or a side-effect does not affect in a relevant way the reliability of another device.

The electromagnetic compatibility of railway lines is defined by specific regulations: the European normative individuates all the needed requirements in order to preserve the whole interoperability; starting from the E.U. specifics, the *Technical Specifications of Interoperability* (*TSI*), the set of specifics on the different subsystems of the railway systems, are determined. Then, the essential requirements on the components are derived from the TSI. At present, the *EN 50121* standard [ENS00] is the main reference for electromagnetic compatibility, and defines the railway emission limits and the conditions in which they should be evaluated; this standard assures the whole interoperability between different railway lines.

EN 50121 Part	Issue
Part 1	General
Part 2	Emission of the whole railway system to the outside world
Part 3-1	Rolling stock – train and complete vehicle
Part 3-2	Rolling stock - apparatus
Part 4	Emission and immunity of signalling and telecommunications apparatus
Part 5	Emission and immunity of fixed power supply installations

Tab. A-2 – EN 50121 standards for railway applications.

The *EN 50121* standard is divided into 5 parts, as shown in table A-2, each one concerning a specific segment of the whole railway infrastructure; nevertheless, the EMC limitations are chosen by taking into consideration even the cross-actions between different interfering effects (e.g. the interference induced on the traction system by the signalling apparatus), and assuring that the respect of the emission limits does not compromise in any way the whole reliability.

A.2 Catenary-pantograph interactions and related EMI generation

The first analysis performed to evaluate the electromagnetic interference generated by the *AV/AC* railway lines is about the pantograph and its interaction between the catenary, evaluating strength of the contact between the pantograph and the contact line and the EMI generated by the detachment of pantograph from the overhead line. This study is based on the ATR95 pantograph, used by Italian high speed and illustrated in fig. 5.4.

The problem of evaluating the electromagnetic emissions of a high speed train is very complex, because it is required an accurate model of the catenary and the pantograph, in order to have an adequate definition of the mechanical contact strengths and, consequently, the contact wire shifts occurring when the train is passing. The first result of this analysis is shown in fig. A-2, which represents the interaction between the catenary and the pantograph as a function of the train speed: it is immediate to see how the contact force F_m is very high for ≈ 300 Km/h speeds.

Fig. A-2 – The ATR95 pantograph

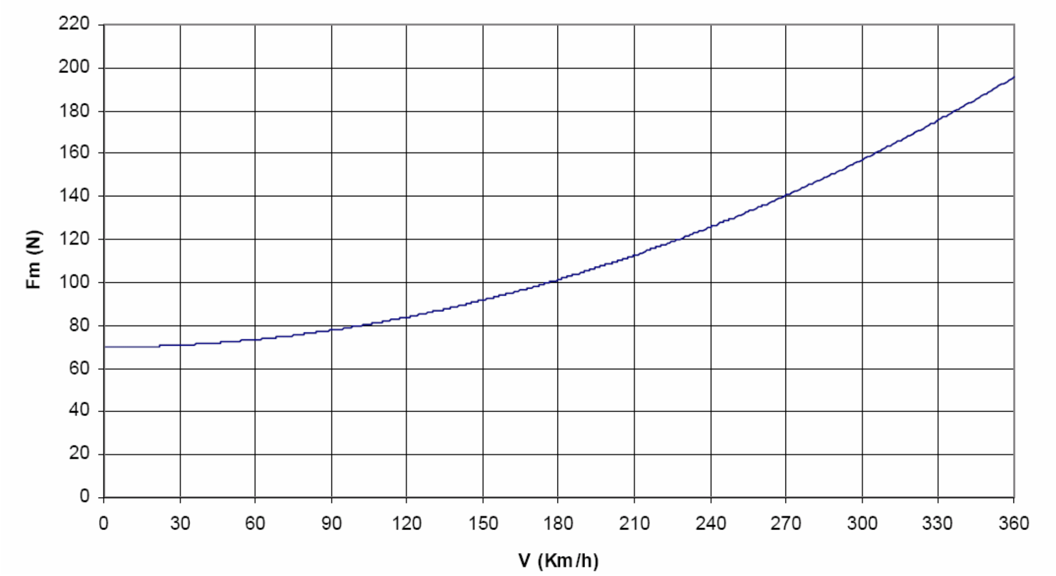

Fig. A-3 – Catenary – pantograph interaction strength as a function of train speed

Fig. A-4 shows the electric model of catenary-pantograph interactions, where the two resistances $R_1(t)$ and $R_2(t)$ are a function of the contact strength illustrated in fig. A-3. The higher is F_m, the deeper are the oscillations of the RLC filters, and the more powerful is the electromagnetic interference.

Starting from this preliminary analysis, it is possible to evaluate the electromagnetic interference induced by the catenary-pantograph interaction. However, this estimation is very difficult both to be modelled and to be measured, because of the fast transitory of the electric field. The measurements of EMI related to the pantograph interactions have been carried out in appropriate shielded rooms, trying to reproduce the line-pantograph real interaction. A possible solution for measuring fast electric fields due to high speed trains is the adoption of optic sensors.

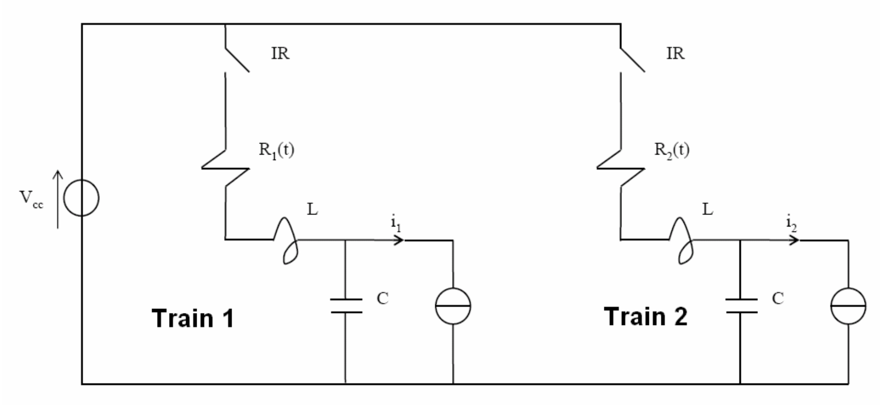

Fig. A-4 – Electric model of catenary – pantograph interaction

A.3 Electromagnetic compatibility between $25KV_{ac}$ and $3KV_{dc}$ railway lines

From the electrical point of view, the main feature of the *AV/AC* railway line is the adoption of a dual traction system: each high speed train is able to use both $25KV_{ac}$ and $3KV_{dc}$ power lines, permitting both to reach higher speeds, using the higher voltage line, and to reduce the electromagnetic emission near the critical points, mainly the railway stations, using the standard dc line (for v < 250 km/h).

This coexistence of two different kinds of power lines tends to compromise the electromagnetic compatibility of the whole railway system, because it is necessary to assure that the EMI and the disturbs produced by the 25KV ac power lines don't interfere in a strong way with the "old" 3KV line. Hence, a wide analysis of the interferences phenomena is needed, in order to be able to redesign the EMC system of the whole Italian railway lines, disposing the eventual countermeasures to reduce the harmful effects. Only with a careful and accurate project the whole interoperability is assured.

At a first sight, the main troubles produced by the dual tractions are three, as reported in [EMC04]:

- The new 25KV ac system can produce electromagnetic interference that affects the standard signalling and telecommunications apparatus.
- Induced and conduced currents can have negative effects on automatic control equipments operating at 50 Hz frequency.
- The 3KV dc return currents can produce perturbations that affect the AV line.

The analysis performed by *RFI* covered all the possible sources of electromagnetic interference. Firstly, mathematical models and theory have been studied, evaluating from a formal point of view all the possible effects. Then, a measurement campaign has been carried out with the purpose of validating the numerical models. The site chosen for experimental tests for the *AV/AC* line is *Castiglione del Lago*, in which coexist a complex system of electric substations which provide the feed power for both low and high voltage lines.. An accurate measurement session has permitted to assess the intensity of the various EMI phenomena, classifying their effectiveness, and then determining the most affecting ones. For this reason, this site, in which are located power generators for low (150V ac), standard (3KV dc) and high (25KV ac) voltages perfectly fits the requirements for the measurement campaign.

During the project activities, the main focus was about the *inductive* and *conductive* phenomena due to the electromagnetic interference between different power lines [WC98], as illustrated in fig. A-5. When two 3KC and 25KV railway lines are close, the currents flowing into the catenary, into the railway track or due to other conductors of the 25KV power system generate an inducing electromagnetic field, which affect the other railway line (fig. A-5a). The induced current flowing in the 3KV track is both common-mode and differential-mode, and therefore affects both the on-board apparatus and the fixed installations; moreover, this inductive coupling generates also longitudinal modes voltages over all the conductors into the induced electromagnetic field, causing possible disturbs for the equipment linked to them. Conductive coupling, instead, occurs in correspondence of electric boundaries between the two different kinds of traction (i.e. interconnections, input/output circuits, etc.), when the 50Hz traction current interferes with a near power track of the standard 3KV railway line (fig. A-5b). The key parameters, that definitively determine the strength of this kind of electromagnetic interference, are:

- distance between 3KV and 25KV railway lines, that determines the attenuation of the incident electromagnetic fields;
- dispersion conductance, that determines the value of the interfering conduced current;
- longitudinal resistance of the railway track;
- asymmetry and unbalancements of the voltage generators.

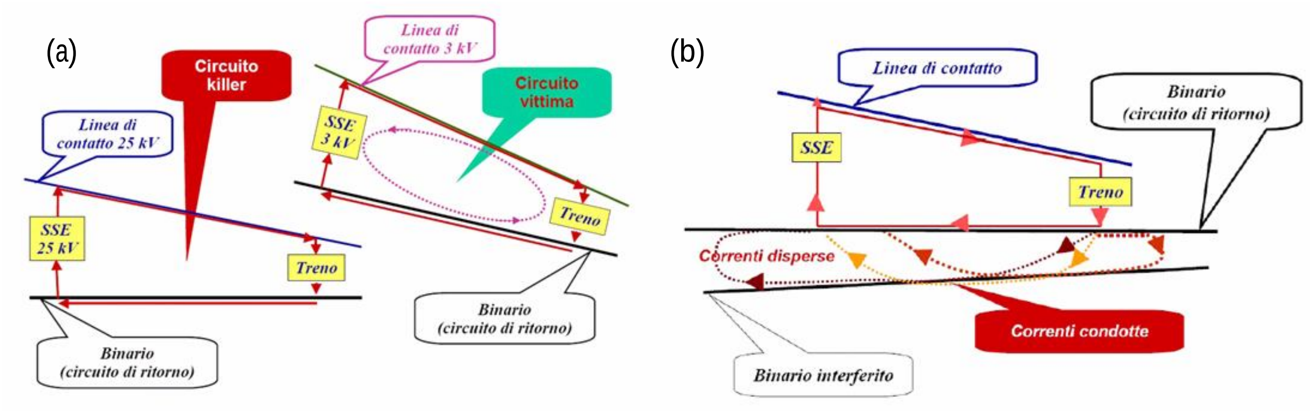

Fig. A-5 – Induction and conduction phenomena and their EMI effect.

(a) Inductive coupling between currents generated in a 25KV track circuit and a 3KV track circuit, depending on the distance between the lines.

(b) 25KV electric power line generates unwanted conducted currents in a near track.

In particular, the distance between the lines needs is determined through an optimization problem: the higher is this distance, the higher is the attenuation of the electromagnetic fields, and consequently the more reduced is the impact of EMI. Assuming a threshold value for the electromagnetic incident field (i.e. the maximum acceptable value, that assures a non-destructive impact), the task is to find the minimum possible distance between the line. This evaluation is very important, because gives an information about how near can be placed two different power lines avoiding damaging EMI effects, and is part of the interoperability assessment, essential for the *AV/AC* feasibility.

As the impact of inductive and conductive effects is very high, and affects in particular the devices related to the 3KV dc line working at 50Hz, it's necessary to find the appropriate countermeasures to protect the interested devices and to reduce the effectiveness of the interferences. For the DC power system, it has been found out that the best solution for limiting the EMI was to change the operative frequency from the standard 50 Hz to 83.3 Hz, by substituting the existent power generators with new ones operating at 83.3 Hz and replacing the selective components, such as filters or voltage rectifiers. In addition, a phase modulation is applied to the voltage. In this way, the track circuit is fed with an 83.3 Hz voltage, avoiding the isofrequential interference with the 50Hz *AV/AC* railway line, and the phase modulation periodically changes the voltage phase. This solution permits to modify only few devices, without recabling the power lines. Moreover, electromagnetic interference can be reduced applying filters that reject the 50Hz frequency and then make the devices less sensitive to the external fields. These interventions are needed when the distance between the 3KV and 25KV lines is too short.

Furthermore, to reduce the return conducted currents in the 3KV railway lines, the measurement campaign at *Castiglione del Lago* and the analysis of the reliability of the components proved that the best solution is to apply a separator transformer at the 25KV side, together with notch filters at the 3KV side, as shown in fig. 5.14. This solution has proven to be the best one, because it minimizes the influence of the required interventions, permitting to reuse the larger amount of devices already employed.

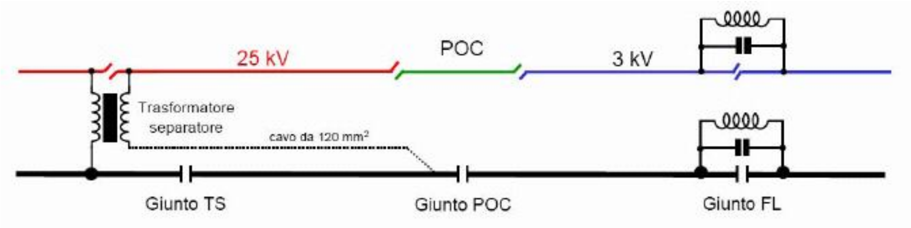

Fig. A-6 – solution applied for the reduction of the impact of conducted currents.

A.4 Electromagnetic emissions of electrical substations

In the previous section was described the electromagnetic interference between the whole 25KV ac line and the standard 3KV dc line, with the aim of investigating the interoperability of the *AV/AC* railway line. Furthermore, it is essential to evaluate the electromagnetic compatibility of the only electrical substations (*ESS*), used by the high speed lines, by themselves, because of the requirement of low electromagnetic impact imposed by EMC and EMF normative. This characterization is based on a measurement campaign, documented in [MP04], carried out in a DC power supply substation along a trunk of the Italian High Speed Railway Line. Hence, in this section a very brief detail of EMI generated by an ESS will be presented.

The basic structure of a DC substation used for Italian High Speed Line is shown in fig. A-7. The energy-conversion process in dc railway substations involves the operation of high-power rectifiers with consequent generation of harmonic currents associated to the rectifier configuration and broadband disturbances associated with the commutation of diodes. Any conductor of significant length carrying these currents produces magnetic fields with considerable levels even at long distances. Such fields should be quantified in order to investigate the electromagnetic environment where the substation equipment operates.

In fig. A-8 are reported the values of the magnetic field near rectifiers. The first figure plots the spectral response of the magnetic field in the low-frequency range: as the line voltage is 50 Hz ac, the fundamental frequency is 50 Hz. The higher order harmonics don't present a fast decrease, but, looking at the second figure, their decrease is very slow (about 2 orders of magnitude). Fig A-9 shows, instead, the magnetic interference in the medium-frequency range (10 KHz – 200 KHz). The field radiated in this range is much lower than the one in low-frequency, but is more critical because of the more restrictive values of EMF and EMC normative, discussed in section 5.1. In particular, it is immediate to note the presence of a large amount of harmonics that produce a strong electromagnetic interference at medium-high frequency. However, the recommended test levels are three to ten times larger than the measured ones, and this assures the respect of interoperability. The analysis is completed by the evaluation of the measured levels with respect to recommended levels for human exposure [Rec99]; it is shown that there are safety margins as high as two orders of magnitude over the considered frequency range. Nevertheless, adequate countermeasures for reducing the impact of harmonics have been studied and are can be found in literature [Br095, OKH97].

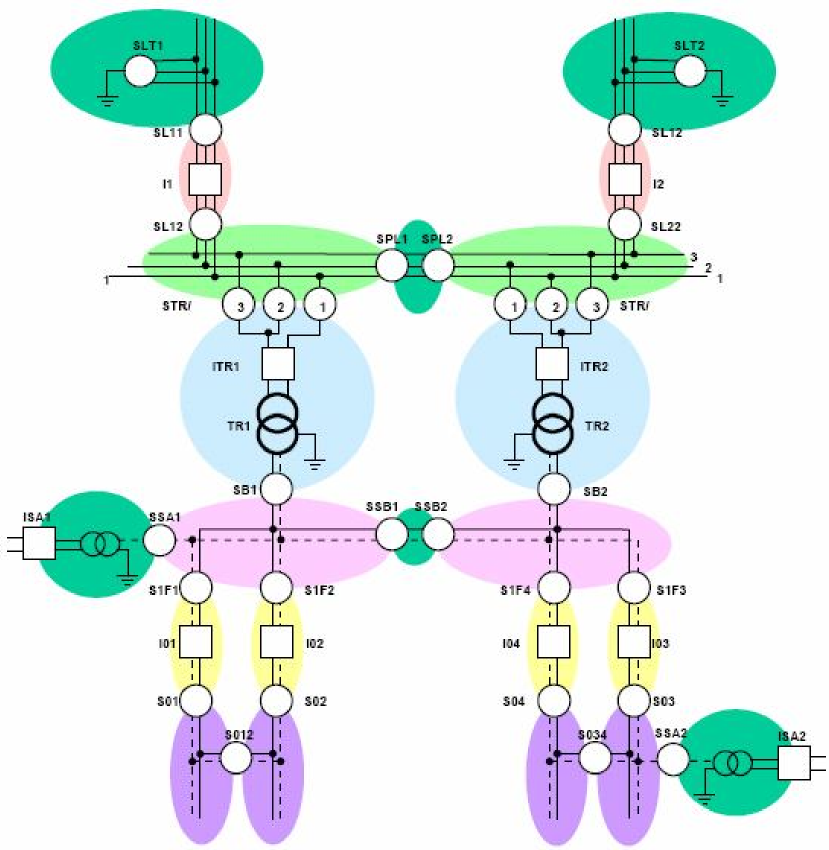

Fig. A-7 – Italian High Speed ESS schematic.

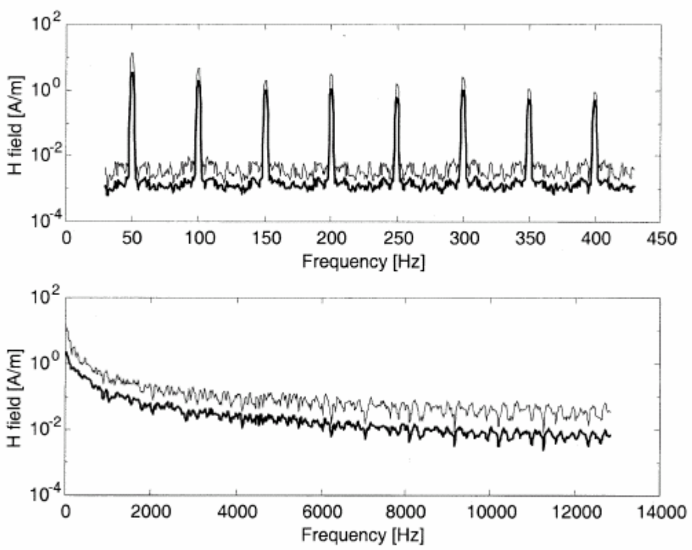

Fig. A-8 – Low-frequency magnetic field measured near rectifiers (average field in heavy black, maximum field in grey).

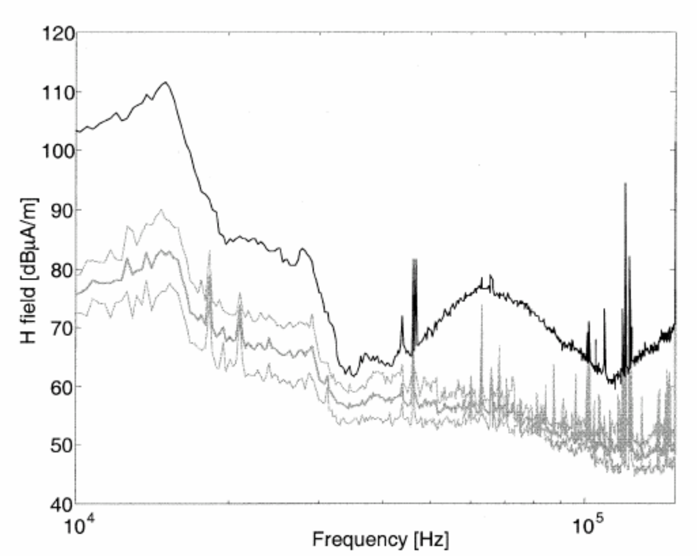

Fig. A-9 – Medium-frequency magnetic field measured near rectifiers (maximum field in heavy black).

A.5 EMI measurement through fibre optic sensors

The evaluation of electromagnetic compatibility requires accurate measures of external electric and magnetic fields. The standard measurement equipment is adequate for evaluation of "static" field or for the estimation of the total level of electromagnetic interference, such as the EMI generated by electrical substations, but is not much appropriate for the detection of fast-moving electromagnetic fields, e.g. the ones received by a high speed train; moreover, it's unfit to isolate the fields produced by a single effect, for example the field radiated by sliding contact, when immersed in the whole electromagnetic interference of all the devices.

In the last years, the development of the research on fibre optic sensors (*FOS*) has led to the realization of a lot of sensors [Udd91], based on the optical fibre technology, that have progressively replaced standard measurement equipments. In particular, a class of fibre optic sensors used for external electromagnetic fields detection has been developed. Even though commercial products are few, the research on this field is very active, and many solutions have been investigated. Obviously, these sensors can be excellent instruments for the measurement of electromagnetic interference in railway systems, and therefore the interest in this research area is high. In the next part of the section, some alternatives for electromagnetic field detection using fibre optic sensors will be briefly presented, describing how external fields are transduced into optical signals; the discussion is limited to three examples, that use different principles, but the possibilities investigated are a lot.

Electro-Optic modulators

An electro-optic modulator (EOM) is a device that returns an optic signal which power depends on the voltage applied to the modulator [ST91]. A typical realization of an EOM is called *Mach-Zender Modulator* (*MZM*), and uses a Mach-Zender interferometer and a phase modulator; a schematic of this device is shown in fig. A-10.

The device is based on an unbalanced Mach-Zender interferometer: the input optic signal E_{IN}, guided into an optical waveguide, is equally split into the two branches of the interferometer. On both the channels of the interferometer, a voltage (V_A, V_B) is applied; two phase modulators (the blue blocks in fig. A-10) convert the voltage into a phase shift applied to the waveguide channels: $\phi_A = K_A V_A$,

$\phi_B = K_B V_B$. The second Y-junction recombines the signals from the two channels: the output power, consequently, depends on the voltage applied to the MZM.

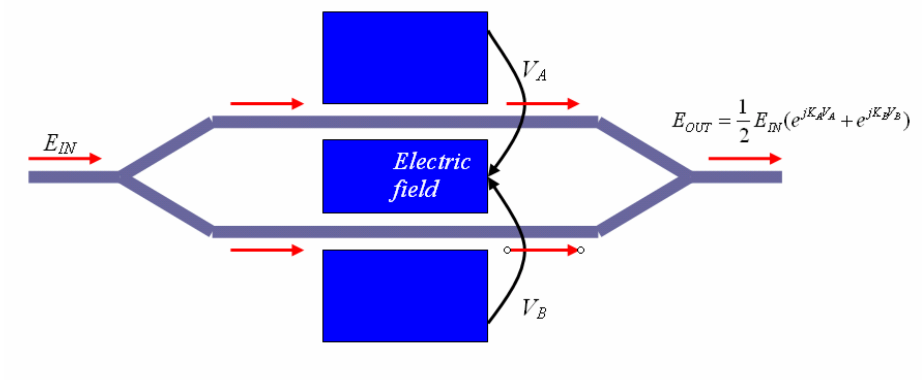

Fig. A-10 – Mach-Zender electro-optic modulator.

A typical application of Mach-Zender modulators is for external modulation of laser used for optical communications. However, it's immediate to notice how this device can be used for detecting external electric fields: the phase modulators are controlled by the electric field, and so the output power depends on the field intensity.

Several solutions based on electro-optic modulators have been characterized; the main design principle is to realize a modulator that returns an optic power proportional to the external field intensity [KTK92, ZR04].

Long-Period Gratings

A Long-Period Grating (*LPG*) is a periodical or quasi-periodical longitudinal modulation of the refractive index of an optical fibre (fig. A-11). Light incident on a LPG interacts on the diffraction planes of the grating, and their modes couple each other. In particular, the most important interaction is between the zero-order mode guided into the core of the fibre and the first-order mode guided into the cladding (see [OK99] for the complete LPG theory). The spectrum of a long-period grating has a peak around the resonance wavelength that depends on the index modulation period and on the refractive index of the core and the cladding.

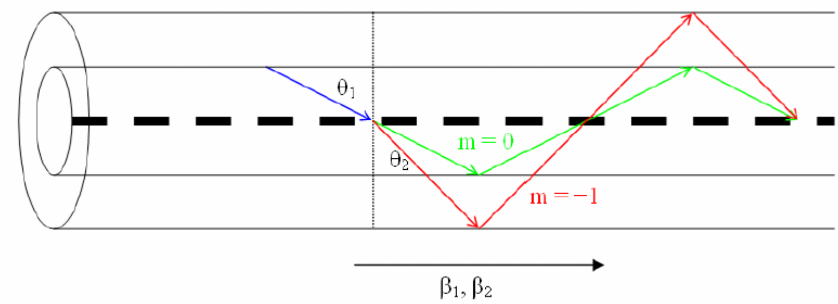

Fig. A-11 – A Long-Period Grating. Light couples between modes guided in the core and modes guided in the cladding.

As cladding modes are guided in the external part of the fibre, they are subject to external fields; hence, the characteristics of a LPG depend on the intensity of the EM field. As a consequence, it's possible to design LPG interrogation techniques that detect the intensity of electromagnetic fields that perturb the fibre cladding [Udd91].

Photonics crystal fibres

Photonics crystal fibres (*PCF*) [BBB01] are a new class of fibres based on typical photonic crystal properties. In general, such fibers have a cross-section (normally uniform along the fiber length) micro structured from two or more materials, most commonly arranged periodically over much of the cross-section, usually as a cladding surrounding a core (or several cores) where light is confined. Fig. A-12 shows a typical section of a PCF, characterized by its particular shape.

Recent studies [WSE06] demonstrated the strong relationship between external electromagnetic fields perturbing the fibre cladding and the propagation properties of the fibre: this leads to the realization of external fields in-fibre sensor, in which light is guided into crystal fibres.

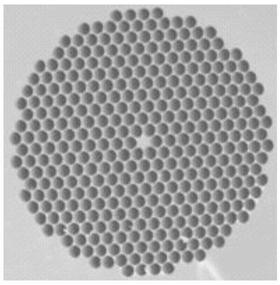

Fig. A.12 – A PCF typical section.

Appendix B: *AV/AC* future scenario

While in the first section of the project report we analyzed on a global scale the impact of *AV/AC* on the social background, here we report a more detailed investigation, that predicts the future scenario in terms of tourism, services, accessibility and other aspects that the high speed line is expected to create.

B.1 General

The new High Speed railway infrastructure relevantly modifies the distances between Milan and Turin and also between different cities within Lombardia itself, thank to the empowerment of the traditional line. As a consequence, the first-rate economical fields would take great advantage of the new situation whereas those fields more subjected to new competitors could have some problems.

The general idea is that the travelling time is influenced both by the infrastructure level and the traffic intensity. An empowerment of the infrastructure tends to reduce the travelling time and then increases the general accessibility of an area. The consequently increase in the number of firms, workers and goods that use the empowered transportation network would cause the congestion of the infrastructure rising again the travelling time.

The evaluation of the effect of such infrastructure is with no doubt a troublesome exercise, starting from the actual difficulty in getting all the information needed, which quite often are themselves in contrast. The complexity of such phenomena is certainly high and also with appropriate models and study techniques there are intrinsic limits related to hypothesis and measurements. Comparing the available studies found in literature 4 different economical fields have been briefly studied focusing in particular on the area around Milan: tourism, people services, labour market and real estate market.

B.2 Tourism

One of the principal effects related to the realization of the AV/AC railway line is the increase in the tourist accessibility of the area around Milan. The reduction of the generalised cost of transportation in comparison with the present offer could rapidly increase the number of travellers that would accord preference to train transportation instead of using road and air transportation for tourist reasons, including in the meaning of *tourist* all those people that travel because of cultural and general business events, shopping and fairs.

The first point is the individuation of the areas that would benefit most by the increased territory accessibility. These are pre-eminently those cities with a new AV/AC station that could be considered as poles capable to empower all the accessibility of the surroundings connected to them. In such scenario it has to be also considered the possibility that the so-called business tourism that now converges to Milan to attend congresses and fairs might then prefer Bologna, Florence and also Rome due to the reduction in travelling time to these destinations.

The dynamics involved are fundamentally of a competitive nature. Every area interested by the construction of a new AV/AC station would compete with the others to attract the maximum part of this enlarged market. There is then just an opportunity that is the individuation of the best offer of a certain area and there act in order to empower all the related services to increase the attractiveness of the territory itself.

The interconnection between the AV/AC line and the local transportation network is therefore of fundamental importance to redistribute the new tourist demand all over the area around Milan. The efficiency of the *Passante*, with the links with the AV/AC line, and all the local mobility services is then the key to make such an offer really attractive and comfortable.

The reduction in travelling time could also cause a significant change in the habits of travellers and in the time spent in the area around Milan. The possibility to reach the city in a shorter time could permit people on the one hand to spend there just a day with no overnight stay, with a decrease in the demand of hotel facilities, but on the other hand would increase the number of people that were previously prevented from reaching Milan due to these extra costs.

Different cases can be in the end outlined. All the places that are now connected to Milan in less than 3 hours – reckoned as the maximum travelling time acceptable to go back home in a day without overnight stay –, such as Florence, would decrease significantly their distance under the half day travelling time. In such case there would be a diminishment in the demand of general facilities during the day, such as restaurants, but on the other hand there would be an increase in the number of possible travellers attracted by the increased closeness of Milan. Those cities that are now far from Milan more than 3 hours, such as Rome, involving an overnight stay and that would be in the future available in just a day would reveal the best market on which concentrate the attention to improve the attractiveness of the territory accessibility around the city. Finally, all those areas that would be connected to Milan in more than 3 hours even after the AV/AC line opening could however register an increase in people travelling but with necessity of spending at least a night in the city.

B.3 People services

The general expression *people services* includes museums, art institutes, hospitals, universities and research centres. The reduction in travelling time significantly influences these kinds of activity since citizens tend to be attracted most by those structures that are more comfortable to be reached and, in other words, are closer to their own homes.

It has also been demonstrated that better hospital accessibility is an essential element for a better richness redistribution and an efficient transport infrastructure can increase the general educational level and then the analysis focuses on these two main variables.

The number of universities in *Provincia di Milano* is the greatest of the entire Lombardia: seven universities are located right in the area of *Provincia di Milano* and the number of students is about the 74% of the total amount. The total number of people that attend courses in this Region is more than 156.700 that is about 16% of the total number of students in Italy.

Students in universities 2003-2004

Bergamo - Università degli Studi	9.213	5,9%
Brescia - Univeristà degli Studi	9.011	5,7%
Castellanza (VA) - Università "Carlo Cattaneo"	1.314	0,8%
Milano - IULM	5.505	3,5%
Milano - Politecnico	23.174	14,8%
Milano - Università Cattolica "S.Cuore"	23.234	14,8%
Milano - Università Commerciale "Luigi Bocconi"	7.382	4,7%
Milano - Università degli Studi	37.975	24,2%
Milano - Università Vita-Salute "S. Raffaele"	1.120	0,7%
Milano - Università degli Studi Bicocca	18.488	11,8%
Pavia - Università degli Studi	14.344	9,2%
Varese - Università dell'Insubria	5.981	3,8%
Total	**156.741**	**100,0%**

Source: Personal elaboration

In order to evaluate the real attractiveness of universities located in Lombardia it is more useful to study the number of enrolments in universities, comparing different Regions.

Matriculations 2004

Piemonte	23.290	5,5%
Valle D'Aosta	185	0,0%
Lombardia	69.252	16,4%
Trentino - Alto Adige	4.608	1,1%
Veneto	26.967	6,4%
Friuli Venezia Giulia	8.683	2,1%
Liguria	7.863	1,9%
Emilia Romagna	33.653	8,0%
Toscana	27.960	6,6%
Umbria	7.363	1,7%
Marche	11.587	2,7%
Lazio	56.976	13,5%
Abruzzo	14.818	3,5%
Molise	2.491	0,6%
Campania	41.809	9,9%
Puglia	24.682	5,8%
Basilicata	1.692	0,4%
Calabria	10.552	2,5%
Sicilia	37.738	8,9%
Sardegna	10.723	2,5%
Totale	**422.892**	**100,0%**

Source: MIUR

In the table above the number of matriculations in every Region are shown. Lombardia stands in first place due to also the high population density and the excellence of its universities. Again, it can be noted that 16,4% of students in 2004 accorded preference to Lombardia.

The study of the impact of the AV/AC line on the universities in Lombardia focuses most on Piemonte and Emilia-Romagna. As a matter of fact the travel between Turin and Milan would take 50 minutes and between Bologna and Milan just an hour. The relative closeness between these areas would encourage the collaboration and the competitivity between different universities after the opening of the AV/AC service.

It has been found that in 2004 quite 3.000 students from Piemonte and 1.500 students from Emilia-Romagna started to attend courses held in different universities in Lombardia, that is the 6,5% of the total number of matriculations in the same year. On the other hand, the number of students that enrolled in 2004 in a university either in Piemonte or Emilia-Romagna coming from Lombardia was about 2.400 people.

In the end the actual total amount of new students that would be potential users of the new AV/AC railway line is about 7.000 people, but that evaluation would certainly increase. Considering the total amount of students, professors and researchers the number of potential clients rises to 350.000 people. Looking at different estimations made by researchers it can be said in the end that the new High Speed line would cause an increase of about 30% due to the improved attractiveness of universities in Lombardia.

The sanitary structures located in Lombardia are about 200. Among these 84 are private institutes and 116 are public institutes. 34,5% of the total amount of hospitals is located in *Provincia di Milano* and every year thousands of people coming from other Regions are treated in important structures such as *Policlinico*, *Niguarda*, *Sacco*, *S. Paolo*, *S. Carlo*. It has been found that just 5,4% of the total amount of patients was admitted to hospitals because of serious and complex treatments and the majority went to different sanitary structures for routine controls and ordinary treatments.

On these basis the advantage of road transportation is considerable just for special treatments and urgencies in general, but the possibility to have a High Speed railway service is deemed to be significant since permits more comfortable and rapid travels with minor stress and waiting times for 94,6% of the patients.

The actual catchment area is composed of about 7,5 million people whereas after the opening of the AV/AC lines there would be an increase of 3,2 million people that is about 40% of the present value.

B.4 Labour market

In 2004 employed people in Lombardia were about 4,2 million among which 1,7 million worked within *Provincia di Milano*, representing about 41% of the total.

Employed in Lombardia - Year 2004 *(thousand)*

Varese	385	9,3%
Como	246	5,9%
Sondrio	75	1,8%
Milano	1.713	41,2%
Bergamo	445	10,7%
Brescia	510	12,3%
Pavia	220	5,3%
Cremona	148	3,6%
Mantova	177	4,3%
Lecco	141	3,4%
Lodi	93	2,2%
Total	**4.153**	**100,0%**

Source:ISTAT

Agriculture employees about 2% of people, industry 40% and tertiary 58%. The development and the empowerment of transport infrastructures create lots of benefits principally in the tertiary field in terms of occupational indexes.

The direct impact of the AV/AC line is related to the construction of the new line. At the end of 2005 3.074 people were working along the railway section between Turin and Milan and 3.600 people were employed between Milan and Bologna. The most noteworthy effects are, however, related to the opening of the High Speed service, estimated at the beginning of 2009 for the track between Milan and Turin.

The most important result is the enlargement of the catchment area of Milan. The reduction in travelling time for both the connections with Turin and Bologna will permit people living in these two cities to reach Milan in less than an hour, reckoned as the maximum time to commute. At the moment commuters that work in *Provincia di Milano* are about 4 million but after 2009 also Novara, Vercelli, Turin and Bologna will be part of the same catchment area, which will increase of nearly 1,6 million people, that is 40% of the present situation.

However, there should be a more detailed analysis regarding the effective distribution of people and incomes in the new catchment area in order to properly evaluate the attractiveness of the High Speed service that would be much more expansive than the traditional service on the existing line.

B.5 Real estate market

It has been proved that the presence of transport infrastructures is a valid incentive for real estate market. In the last five years Lombardia closed about 20% of the total national transactions in terms of residential buildings and 27% concerning commercial buildings. In *Provincia di Milano* there have been registered 42% of all the residential building transactions, 54% of all the office sales, 52% of the commercial spaces sales and 32% of productive real estates sales, considering the entire Lombardia.

However, in the last few years a negative trend has been noted due to the relevant increase of the market-price of real estates in general: the average growth rate was greater than 7% per year for residential buildings, 6,5% for shops, 5% for storehouses and 3% for offices that is an average increase of about 5.200 €/m^2 in the most expansive areas.

Comparing foreign experiences it can be said that the areas more influenced by the construction of the AV/AC line are those right around the stations, also as a consequence of the considerable re-qualification of the stations themselves – projects *Grandi Stazioni* and *Cento Stazioni* – in order to facilitate and promote a global urban renovation of those spaces in the neighbourhoods, at the moment really degrading. The areas that would register the most significant effects are therefore *Milano Certosa*, Rho, Novara and also *Milano Centrale*.

The area around Rho represent an important example because of the presence of the AV/AC stop, the underground line, local transportation services, road connections and the new fair that altogether contribute to the creation of a stimulating environment for real estate market. Nevertheless, because of the presence of different new infrastructures it is quite difficult to estimate which are the effects directly related to the High Speed railway line.

Looking at different statistics it can be noted that from 2001 to 2005 there was a significant increase in residential buildings values but the trend is more evident for offices and shops, which both showed a rise of about 28%, greater than the average registered within *Comune di Milano*. Similar statistics can be also found regarding all the Northwest area around Milan even if not directly related to the construction of the AV/AC line, underlining again the complexity of the phenomenon. As a matter of fact, it has to be reminded that the opening of *Passante* and the suburban lines certainly represented an incentive for families to live in the neighbourhoods of Milan where life quality is much more appreciable.

In the end, the general economical impact evaluated on the market-price of different real estates can be estimated in an extra rise of the growth rate of about 2%, considering all together the construction of the new Milan Fair with the related road connections, the construction of the AV/AC stop and the opening of the underground service that evidently increases the attractiveness and the accessibility of the entire territory.

Appendix C: The structural problem of the sleepers

C.1 Introduction

From a structural point of view the realization of the High Speed Railway Line is a very interesting problem. The closer problem to the structural aspect is vibration pollution: to understand and solve it, it occurs to explain the different parts of track structure. First of all we treat the question of sleepers from an historical point of view. At the beginning of railway technology the preferred sleeper material was wood and it continued to be so for the next 50 years. Wood is susceptible to weathering and other external influences. This and the intense steel production in the last quarter of the 19^{th} century finally led to the change over to steel sleepers. These were used for more than 50 years in many parts of the world including Europe. However, increased axle loads and train speeds soon required heavier sleepers. The first concrete sleepers were introduced at the end of the 19^{th} century. Nowadays the introduction of heavy pre-stressed concrete sleepers was essential to enable the use of long welded tracks. Therefore, different innovative solutions have been evaluated for Italian AV/AC infrastructure. With a comparison between the solutions we take in account all the factors that determine the advantages of a particular type of concrete sleepers compared to the others. To better understand technical aspects of the design, we have made a study of sleepers both with a theoretic approach and in practical terms with an inspection in a precast plant.

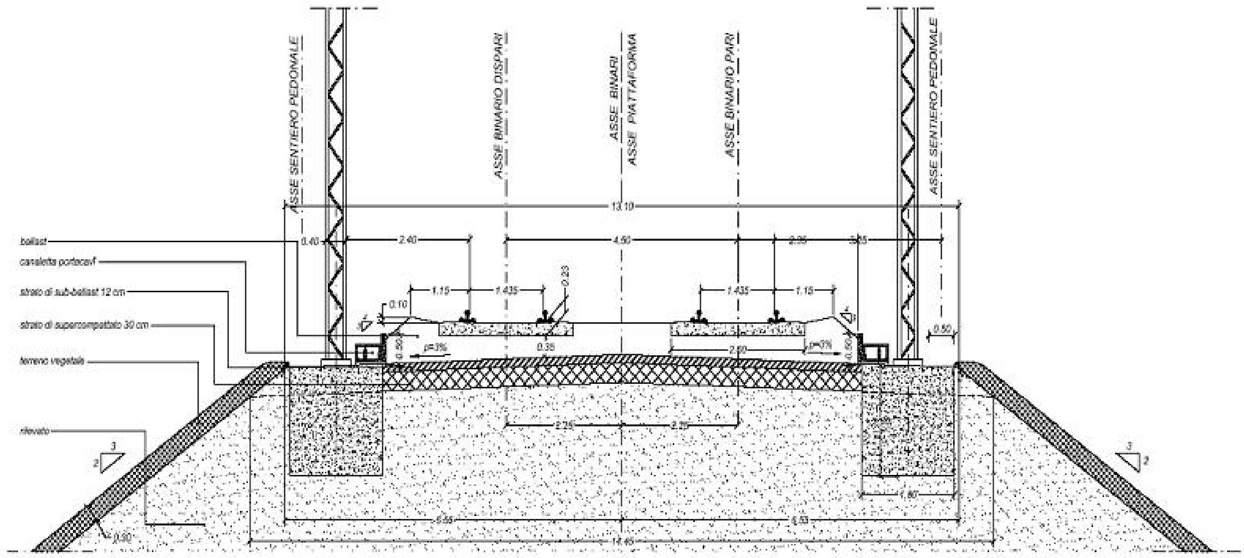

Fig. C-1 – Section type for Italian High-speed Railway (v = 300 km/h)

The classical railway track basically consists of a flat framework made up of rails and sleepers which is supported on ballast. The ballast bed rests on a sub-ballast layer which forms the transition layer to the formation. The rails and sleepers are connected by fastenings. These components and other structures such as switches and crossing are all considered ad part of the track.

Since the beginning of the railways, the principle of the ballasted track structure has not changed substantially. Important developments after the Second World War include: introduction of continuous welded rail, use of concrete sleepers, heavier rail-profiles, innovative elastic fastening, mechanisation of maintenance, and introduction of advanced measuring equipment and maintenance management systems. As a result, the traditional ballasted superstructure can still satisfy the high demands, as demonstrated by the TGV-tracks in France.

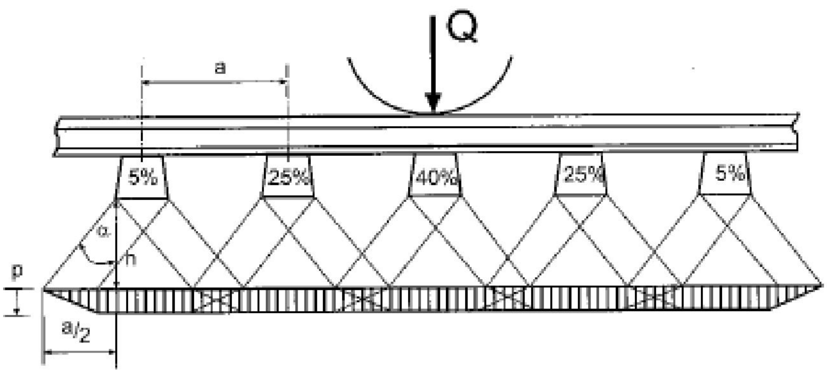

Fig. C-2 – Schematic representation for the calculation of the optimum ballast bed thickness.

In ballasted track the rails rest on sleepers and together form the built-up portion of the superstructure. At the beginning of railway technology the preferred sleeper material was wood and it continued to be so for the next 50 years. Wood is susceptible to weathering and other external influences. This and the intense steel production in the last quarter of the 19th century finally led to the change over to steel sleepers. These were used for more than 50 years in many parts of the world including Europe. However, increased axle loads and train speeds soon required heavier sleepers. The first concrete sleepers were introduced at the end of the 19th century. The French gardener Moniér designed the first reinforced concrete sleeper before the turn of the century and applied for a patent. In 1906 the first experiment with a conventionally reinforced concrete sleeper was made in Germany on the line Nümberg-Bamberg. During World War II the concrete sleeper production was extended and in 1939 the production of steel sleepers was discontinued. In general two different basic types of concrete sleepers were developed:

- the twin-block concrete sleeper where two pre-stressed concrete blocks are connected via a steel rod or a steel beam, and
- the mono-block concrete sleeper which consists of one pre-stressed concrete beam.

The introduction of heavy pre-stressed concrete sleepers was essential to enable the use of long welded tracks. High-speed traffic with speeds of 200-350 km/h led to the development of different types of ballastless track. At the same time new systems of concrete sleepers, such as the broad sleeper, the frame sleeper and the ladder sleeper were developed and presented.

Nowadays classic steel sleepers are hardly used. The only exception is a special form of steel sleeper, the so-called Y steel sleeper which is used under special conditions due to its small overall height and width.

A total number of approximately 3 billion sleepers are used all over the world. Only 20% of them are concrete sleepers. About 5%of the sleepers are replaced annually. The total production of concrete sleepers all over the world amounts to about 20 million.

C.2 Function of sleepers

The general functions and requirements of sleepers are:

- to provide support and fixing possibilities for the rail foot and fastenings;
- to sustain rail forces and transfer them as uniformly as possibly to the ballast bed;
- to preserve track gauge and rail inclination;
- to provide adequate electrical insulation between both rails;
- to be resistant to mechanical influences and weathering over a long time period.

To ensure stability, it is desirable that the sleeper is only supported in the areas beneath the rails. In the case of prismatic sleepers such as the timber sleeper and the mono-block concrete sleeper, this is achieved by only packing this area and leaving the centre portion free.

Furthermore, it must be ensured that the sleeper does not rotate under the rails as a result of the vertical load, for this can cause gauge to become narrower or to widen and it changes rail inclination. This happen if the sleeper is supported too close to the inside or outside as a result of incorrect lamping.

To ensure that the available ballast resistance in both longitudinal and lateral directions is put to optimal use, the ends and sides of the sleeper must be fully embedded in the ballast. The distance between sleeper centres is usually 60 cm. In lightly loaded CWR track, this value may be increased to 75 cm.

C.3 Wooden sleepers

The draft of the CEN sleeper standard EN13145, wooden sleepers, describes the approval and acceptance tests for these sleepers, the species of wood, the defect and the qualitative particularities of the individual species of wood, their permissible shape, dimension and tolerances. Wooden track sleepers have to have rectangular cross sections, their side surfaces being bevelled at an angle of 45°.

The wooden sleeper may bend or twist due to drying and impregnation process of wood. The reason for warped sleepers is usually the growth of the tree, whereas bent sleepers are the consequence of tension or shrinkage of the wood. The shrinkage of the wood in the longitudinal direction is negligible as opposed to its radial and tangential shrinkage. Bent sleepers usually cause narrowing of the track gauge; therefore the vertical twist of wooden sleepers should not exceed 5 mm of versine.

The third of the sleeper projecting from the ballast is subject to the full influence of climatic changes. A sleeper usually contains approximately 30-50% of water. Newly impregnated sleepers show a retarded water absorption. Therefore, it takes about 1-3 years, before a wooden sleeper has adapted to the prevailing humidity of the ballast bed.

During long dry periods in summer the upper parts of wood dry up significantly, which can lead to the development of cracks. The sleeper may even bend additionally. Large differences in humidity within the sleeper inevitably lead to the occurrence of tensile stress on the sleeper surface. The consequence is a narrowing of the track gauge due to the sleeper ends pulling up.

The standard timber species used in Europe today is beech. Pine sleepers are no longer used, as their mechanical strength properties do not withstand the stress that has been steadily increasing. Oak sleepers are too expensive. Both latter species of timber are – compared to the impregnated beech – inferior concerning their resistance to decay. Beech sleepers, except for their red heart which is limited due to supply conditions, can be easily impregnated by coal tar oil, while the heart, the share of which is much higher in the sleeper when using pine or oak, cannot be impregnated and does not have the same durability as tar impregnated wood. Sleepers made from tropical woods are not viable, as they are too expensive compared to beech sleepers. The situation is different for switch sleepers, as they have much higher shape requirements. Here the standard timber species is oak.

Beech sleepers are no longer secured from cracking by bandaging, but by securing devices which are pressed into the ends of the new sleeper in the sleeper manufacturing plant. All sleepers are secured in this way.

Comparison between wooden and concrete sleepers

Timber and concrete sleepers, and to a limited extent steel sleepers, are used. The principal advantage of the concrete sleeper is that climatic influences have little effect. Its service life is expected, under certain conditions, to be significantly higher than in the case of timber sleepers. These conditions entail that formation and ballast bed are of good quality as are also the rail and weld geometry. Concrete sleepers are susceptible to impact loads, especially in the 25-300 Hz frequency range.

The advantages of concrete sleepers compared to wooden sleepers are the following:

- longer life cycle and service life;
- less expensive than hardwood sleepers;
- lower maintenance of the fastenings;
- higher resistance to lateral displacement due to higher weight.

On the other hand concrete sleepers have the following disadvantages:

- susceptible to shock and impact (especially in the 25-300 Hz frequency range);
- difficult handling due to greater weight, and
- maintenance of longitudinal level is somewhat more difficult because of the higher moment of inertia and the lower elasticity.

The treatment of wooden sleepers

The raw sleepers are air-dried for 1-2 years, after which they are impregnated under pressure by hot tar oil (Creosote). During this procedure the impregnating substance penetrates only in the direction of the fibres (along the sleeper). It is important to ensure that a maximum inner surface is moistened.

Full impregnation means that up to 500 kg of tar oil/cubic m of wood is absorbed. At first, a vacuum has to be produced, then impregnation is performed at an oil pressure of 10 bar.

For economic impregnation (the Rüping method) up to 150 kg of tar oil/cubic m of wood is absorbed. First an atmospheric pressure of 3 bar is produced, then oil pressure of up to 10 bar and then vacuum treatment is carried out. The interior pressure causes part of the oil to be pressed back.

The life cycle of wooden sleepers is 20-40 years (depending on the type of impregnation and stress).

C.4 Reinforced concrete sleepers

The operation stress of concrete sleepers is characterized by frequent changes in temperature and by the permanent traffic load. This stress requires high tensile strength of the sleeper concrete and favourable deformation properties.

Sleepers approval tests

The draft of the CEN standard on sleeper, EN13230-1-5, concrete sleepers, describes the approval and acceptance tests for these sleepers, the requirements concerning durability of concrete, the requirements of building materials, of dimensions (tolerances) and minimum overlaps and also stipulations and approvals by the client, as well as certificates to be given by the manufacturer.

Requirements to be met by concrete

It is advisable to use only type 1 Portland cement. Its minimum strength should meet the requirements of class 42.5, and its compressive strength – depending on the client's requirements – C45/55 Mpa or C5/60 Mpa class. The water-cement ratio must be below 0.45. The minimum content of cement should be 300 kg/m^3. The weight of the individual components of concrete must not deviate by more than 3% from the calculated weight. Cement with an alkali content of less than 0.6% should be used. The total mass of reactive alkalis should never exceed 3.5kg/m^3.

The following characteristics must be indicated on every concrete sleeper:

- year of production;
- boarding number;
- sign of the manufacturing plant;
- furthermore, date of manufacturing and serial number should be indicated on every concrete sleeper.

Fig. C-3 – Production step in a manufacturing plant of concrete sleepers.

Static bending test

Concrete sleepers are loaded and tested statically in accordance with the expected operational loads.

Dynamic bending test

For dynamic testing a vibrating and increasing load is applied to the concrete sleeper to simulate the impact load on the track. This determines, on the one hand, the test load at which, after load relief, a permanent crack of 0.05 mm width has developed, and, on the other hand, the breaking load, at which after load relief a crack of 0.5 mm width has developed.

Fatigue test

The fatigue test simulates the loaded condition of rolling stock in motion.

Electric sleeper resistance

The electric sleeper resistance is measured between two short rail sections fastened on one single sleeper. For measurement purposes the sleeper is sprinkled with water. Measurement has to be continued for 10 minutes after sprinkling. The electric resistance of concrete sleepers should be less than 5 kOhm. This corresponds to a minimum ballast bed resistance of 3 kOhm/km.

Further tests

Wear resistance, freeze-thaw resistance and porosity of concrete may be measured and the stability of the fastening system also has to be checked.

Twin-block sleepers

Various types of twin-block sleepers exist and can be easily adapted to different load and speed conditions. Their service life is about 50 years and they are mainly used in France, Belgium, Spain, Portugal, Greece, Mexico, Brazil, Algeria, India and Tunisia.

Two conventionally reinforced concrete blocks ($30 \times 70 \times 25$ cm^3) are connected to each other by a rigid steel beam. This conception of connecting sleepers by a non-prestressed reinforcement has been carried out particularly in France, in connection with twin-block sleepers. The reasons are on the one hand certainly tradition (Moniér), and on the other hand the fact that the twin-block sleeper already in the twenties was able (due to its non-rigid connecting rod which guarantees that the central part is free of bearing stress) to hold the negative bending moment in the centre of sleeper, which increases when the sleeper length decreases, at a very low level. The anchorage of the steel beam in the concrete block is of particular importance. Other types of sleepers do not show any of the problems connected with this question.

Advantages:

- high resistance to lateral displacement,
- elastic behaviour – no centre-bound sleepers,
- low weight (easier to handle), and
- the sleeper has been successfully tested on TGV tracks.

Disadvantages:

- sagging of the sleepers during handling, manual tamping or tamping with heavy-duty tamping machines,
- defects due to corrosion or fatigue of the steel beam and related track gauge defects.

Sleepers of staggered permanent way are a type where concrete blocks are connected to each other diagonally and the connecting tubes glued in. This type of design is no longer in use as it has proven in practice.

Mono-block concrete sleepers

Mono-block concrete sleepers are suitable for use at high speed and at high axle loads. Their service life amounts to 50 years. They are used in Germany, Austria, Canada, Australia, the USA, China, England, Japan, Sweden, India, South Africa, Switzerland, Russia, Italy and many other countries.

Fig. C-4 – Mono-block concrete sleeper.

Manufacturing

Concrete is cast in troughs in long pre-stressing with a large number (20-40) of pre-stressed wires and is pre- or post-stressed. The value of pre- or post-stress is chosen as high as necessary to avoid the development of bending cracks. The compressive strength of concrete is very high, around 6 kN/cm^3, the bending tensile strength is only 0.065 kN/cm^2.

Bending tensile strength has to be at least 5.5 N/mm^2 for concrete sleepers delivered to the DB AG. The average value of the static modulus of elasticity is about 42000 N/mm^2. The coefficient of thermal elongation amounts to approximately 10×10^{-6} [1/K°]. When the pre-stressed force is applied, the cube compressive strength must be 45 N/mm^2. The target value of pre-stress must be 320 kN for sleepers where the formwork is immediately removed and 325 kN for sleepers where the formwork is removed later. The aim is to reach a planned final priestess value of 260 kN in the area of the rail support, which is achieved in most cases.

Two methods are used mainly:

- immediate removal of the formwork, subsequent tensioning against the hardening concrete, and
- later removal with previous tensioning of the steel against the mould.

Advantages:

- large number of these sleepers have been tested and laid. Setbacks occurred only when unsuitable cement was used.

Disadvantages:

- no reinforcement against shearing and torsional forces, therefore, on poor subsoil, danger or development of longitudinal cracks.
- mono-block sleepers are also used in switches and laid by machines. Concrete sleepers hardly require any maintenance.

Following table shows an overview of the multitude of mono-block sleepers used.

Overview of some typical, internationally used, sleeper dimensions

country	track gauge	sleeper length	dimensions [mm]					
			shim			centre of the sleeper		
	[mm]	[mm]	height	width	depth	height	width	depth
Australia	1435	2500	212	250	200	165	250	200
Canada	1435	2542	203	254	216	159	264	226
China	1435	2500	203	280	170	203	250	161
Germany	1435	2600	214	300	170	175	220	150
UK	1432	2515	203	264	216	165	264	230
Italy	1435	2300	172	284	222	150	240	190
Japan	1435	2400	220	310	190	195	236	180
Sweden	1435	2500	220	294	164	185	230	150
USA	1435	2592	241	279	241	178	279	250
South Africa	1065	2057	221	245	140	197	203	140
India	1673	2750	210	250	var.	180	220	var.
Russia	1520	2700	193	274	177	135	245	182

Fastening systems

The term "fastening systems" or in short "fastenings" is considered to include all the components which together form the structural connection between rail and sleeper. All over the world a great variety of fastening exists to which new types are regularly added in order to keep up with changes in requirements and opinions or due to the availability of new material. The choice of fastening also greatly depends on the properties and structure of the sleeper.

Fig. C-5 – Fastening system for Italian AV (Pandrol).

The general functions and requirements of fastenings are:

- to absorb the rail forces elastically and transfer them to the sleeper. The vertical clamping force of the rail on the sleeper must be sufficient in all load situations, even in case of wear, in order to provide the necessary longitudinal resistance to limit the breathing length in CWR rail, to limit gaps in the case of rail fractures, and to resist creep;
- to damp vibrations and impacts caused by traffic as much as possible;
- to retain the track gauge and rail inclination within certain tolerances;
- to provide electrical insulation between the rails and sleepers, especially in the case of concrete and steel sleepers.

C.5 Improvements in ballasted tracks

New development have fund their way into the design of traditional ballasted super-structures. Ballast spreads the load from underneath the sleepers to the foundation. This loading causes pressure between the contact-points of the grains which causes the ballast roadbed to deteriorate: the grains wear and wander, the ballast becomes polluted causing a diminished drainage-function, and the track quality decreases. Maintenance work is necessary at a regularly basis, depending on the amount of tonnage which has passed.

There is a direct link between the level of pressure and the deterioration of the track. Decreasing the average pressures on the ballast will lead to a lower rate of deterioration. To achieve this, one can use heavier rail-profile which spreads the load over more sleepers, decrease the distance between the sleepers, or increase the bearing surface of the sleepers themselves by making them longer or broader. Several attempts have been made with broader sleepers and slab sleepers, but these were not successful.

Wide sleepers

Currently, in German the “wide sleeper” has been developed as a sequel to these former attempts. The main problem then was the inability to provide specific tamping-techniques. This has now been solved. This wide sleeper is 2.40 m long and 57 cm wide. The distance between them is 60 cm leaving a 3 cm gap which is covered with a rubber cover.

In the case of the wide sleeper, the sleeper-weight is doubled to 560 kg, but with an axle load of 22.5 tonnes this results in an average surface pressure of 2 kg/cm^2 compared to approximately 3.7 kg/m^{2}in the case of traditional sleepers. The track-bed remains free of rain and vegetation as a result of which the rate of pollution is reduced.

Because the track can now be considered as a continuous slab of discrete elements, tamping can only take place at the end of the sleepers or the edge of the "slab". The tamping device must be turned 90 degrees.

Frame sleepers

The frame-sleeper intends to replace the load transmitting structure of a traditional ballast track, i.e. cross sleepers in a regular distance, by a girder-grid, thus combining a continuous longitudinal beam with cross members. The "longitudinal beam" is formed by sections in the frames which are connected and held in place by the rail and the fastening which are situated at either end of the frame-sleeper. Hence, the running wheel-load is transmitted in a continuous manner onto the ballast bed reducing the pressure under the sleepers substantially and avoiding most of the stress gradients.

It is not only suitable for high-speed lines, but also for difficult track conditions, such as narrow curves. Due to its high resistance to lateral displacement (> 60 kN at a displacement of 1 mm) it is also ideally suitable for laying long welded track in very narrow curves. This fact has been proven on the Semmering, where such sleepers were laid in a curve with R = 176 m.

The idea of the frame sleeper is to imagine the traditional cross-sleeper track as a bearing system transformed to a bearing grid consisting of frame sleepers arranged one after the other. The longitudinal support is divided into individual sections connected to each other by the rail. This connection is resistant to slide, but elastic to bending. The four rails fastening at the corners of the frame lead a very high rigidity of the frame and a high resistance of the track grid to lateral displacement.

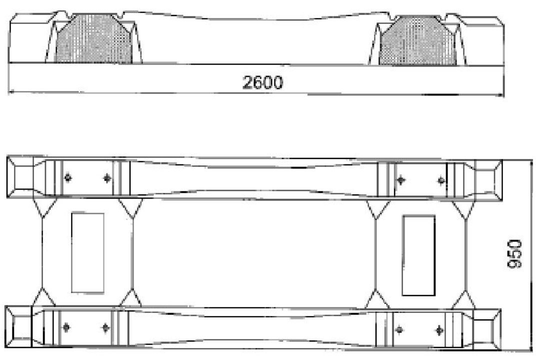

Fig. C-6 – Geometric data of the frame sleeper.

The double H-shaped concrete sleeper was tested in Austria. These elements can be considered as two sleepers which are connected at the fastening systems with "bridges". The same principal as with the wide sleeper is used to increase the bearing surface of the sleeper and, thus, decrease the pressure of the ballast. The elements are 2.4 m long and 0.95 m wide with two sets of rail fastenings per element. Between the fastening systems, the rail itself is supported by the concrete bridge which provides a quasi-continuous rail support. Underneath the sleeper elements a 12 mm thick polymer layer will provide a better spreading of the loading and additional damping. Test results showed a reduction in settlements of two-thirds compared to a normal sleeper.

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