Economic Evaluations using Genetic Algorithms to Determine the Territorial Impact Caused by High Speed Railways

Gianluigi De Mare, Tony Leopoldo Luigi Lenza, and Rino Conte

Abstract**—**The evolution of technology and construction techniques has enabled the upgrading of transport networks. In particular, the high-speed rail networks allow convoys to peak at above 300 km/h. These structures, however, often significantly impact the surrounding environment. Among the effects of greater importance are the ones provoked by the soundwave connected to train transit. The wave propagation affects the quality of life in areas surrounding the tracks, often for several hundred metres.

There are substantial damages to properties (buildings and land), in terms of market depreciation.

The present study, integrating expertise in acoustics, computering and evaluation fields, outlines a useful model to select project paths so as to minimize the noise impact and reduce the causes of possible litigation. It also facilitates the rational selection of initiatives to contain the environmental damage to the already existing railway tracks. The research is developed with reference to the Italian regulatory framework (usually more stringent than European and international standards) and refers to a case study concerning the high speed network in Italy.

Keywords**—**Impact, compensation for financial loss, depreciation of property, railway network design, genetic algorithms.

I. Introduction

RAILWAY networks, and in particular high speed networks, are a synergic set of different systems subjected to specific technical regulations that allow the traffic of convoys to have a cruise speed greater than a minimum value set by the regulations[1].

Over the years these networks have undergone a progressive development, determined by the technical innovation of transport. In the 70's networks were designed for traffic at 200km/h; today there are networks which sustain a traffic with a speed greater than 300[2] km/h (Turin-Florence and Rome-Salerno).

This has involved an increase in safety standards, raising the costs of construction, adjustment and maintenance of the infrastructure.

Such an impacting infrastructure changes the territory it runs across in terms of environmental and human balance. The effects generated by networks on the crossed land are numerous and various: they may condition vehicle and pedestrian traffic, the possibility to build new buildings, the way of using land and houses, the impact on ecosystems and quality of life.

Among the various effects, very important are those on the housing market, as buildings and land heavily suffer in terms of value for the proximity to railway networks. On the other hand, it is undeniable that in some cases the reverberations due to the proximity to a railway network may be an improvement in the market value (as in the case of suburban areas intended to accommodate future modal interchange nodes).

One of the most significant negative impacts is the sound wave the convoys in transit transmit to the environment. When the threshold of allowed noise is exceeded, noise contamination becomes harmful for humans and places. On humans it causes biological damages with strong psychological connotations; on real estate it results in a conspicuous damage due to the depreciation induced by the lower marketability of buildings and areas. This latter component, until now rarely considered in the feasibility analysis of railways, is taking increasing importance, triggering legal disputes with important consequences on the financial sustainability of investments in transport networks.

This study sets out to quantify the conditioning to the definition of paths arising from claims for damages invoked by the owners of properties near the networks. The information framework thus creates disthenused for economic evaluations useful in the design phase and during the review of the structures which have already been completed. Indeed, on existing networks there is a problem in selecting the most efficient ways for bringing down the noise threshold (active or passive remedies or compensation).

The suggested model consists of two operational moments. In the first one it searches the regulations[3] and bibliography [1] to define the noise impact function on the environment surrounding the tracks. The identified functional form correlates the input on the receptors and the distance between

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[1] See EU Directive 2008/57/EC on the interoperability of the Community rail system, July 2008, Implementation of Directive 2008/57/EC and Directive 2009/131/CE, Italian Republic November 2010.

[2] See International Union of Railways in www.uic.org/spip.php?article971; technical data of Ansaldo Breda's carriers (ETR 300 and 500) in www.ansaldobreda.it.

[3] Decree of the Minister of the Environment of the Italian Republic of 16.03.98; and above all see ANPA Model - National Agency for Environmental Protection in Italy.

the receptors and the emission source. This brings about a proportional depreciation of real estate. In the second part the model computes the ideal path minimizing the function which sums up the construction expense and the cost of claims for damages (or environmental remediation). The protocol reaches this result using an Operational Research technique of a stochastic type named *Genetic Algorithms* [2], capable to optimize the objective function (*Fitness*) through a self evolutionary process similar to the Darwinian natural selection of the species.

II. Regulatory Framework

Domestically, the relevant legislation in the field of noise pollution is represented by Law 26 October 1995, n. 447 called *Framework Law on Noise Pollution*[4]. It is integrated, of course, by its implementing regulations. Article 2 introduces the following definition of noise: “the introduction of noise in housing areas or outdoor environment that is annoying or disturbing to rest and to human activities, dangerous for human health, ecosystem deterioration, material goods, monuments, housing or external environment or such as to interfere with the legitimate functions of the environment itself”.

Of particular relevance to this research is the DPR 18th November 1998 n. 459, concerning the *Regulations for the implementation of Article 11 of Law 26th October 1995 relating to noise pollution caused by rail traffic*. The document laid down the rules for the prevention and containment of noise pollution having its origin from railway infrastructures and underground lines when above ground, with the exception of trams and funiculars. Article 3, paragraph 1, letter a) of the Decree identifies territorial areas of relevance 250 meters wide for existing infrastructures and their variants, the newly built alongside existing ones, and the infrastructures of new construction with a planned speed of not more than 200 km/h. The regulations define limit values of noise impact for the territorial areas.

A territorial area is divided into two sections: the first, which is closer to the infrastructure, is 100 meters wide and is called area A; the second, more distant from the infrastructure, is 150 meters wide and is called area B.

The absolute limit values of noise pollution produced by the infrastructure are as follows, expressed in equivalent noise level (L_{Aeq})[5]:

TABLE I
Absolute Limit Values of Noise Pollution Produced by the Railway Infrastructure (DPR 18.11.1998, N. 459)

Land use classification	Buffer zone	Outside limits	
		Day LAeq	Night LAeq
Schools, hospitals, nursing homes and clinics	A+B (250 m)	50	40
Other	A (100 m)	70	60
Other	B (150 m)	65	55

Reference values for infrastructures with planned speed of ≤ 200km/h.

TABLE II
Absolute Limit Values of Noise Pollution Produced by the Railway Infrastructure (DPR 18.11.1998, N. 459)

Land use classification	Buffer zone	Outside limits	
		Day LAeq	Night LAeq
Schools, hospitals, nursing homes and clinics	A+B (250 m, also up to 500 m)	50	40
Other	A+B (250 m)	65	55

Reference values for infrastructures with planned speed of > 200km/h.

For areas outside the areas of relevance the values reported in Table C established by the DPCM 14/11/97 are applied. Article 4 paragraph 5 of Presidential Decree 459/98 provides that when thresholds in the areas of relevance or in areas defined in Table C are not technically achievable, or if according to technical, economic or environmental evaluations there is evidence of the advisability of direct action on the receptors, it must be ensured that the following limits are respected:

1) 35 dB night LAeq for hospitals, clinics and nursing homes,
2) 40 dB night LAeq for all other receptors,
3) 45 dB day LAeq for schools.

As it can be noticed, outside the areas of relevance limits of noise pollution are much stricter when concerning sensitive buildings; in this case the managing authority of the network must ensure widespread interventions on the same (for example, noise barriers) or specific protections for individual receptors impacted. Beyond these areas, therefore, the general normative reference (that is, valid for urban areas) is derived from the provisions of the Municipal Plans of Acoustic Zoning (PZA[6]). Table III shows the limit values of noise pollution defined by the DPCM 14/11/97 - Table C in Annex to the Decree. It is, therefore, desirable that in proximity to railway areas municipalities place areas of Class III or higher. If then in proximity of railway areas there are sensitive buildings, the more stringent limits imposed by Presidential Decree 459/98 will have to be ensured.

TABLE III
Absolute Limit Values of Noise Pollution Produced by the Railway Infrastructure (DPR 18.11.1998, N. 459)

Classes	Land use classification	Reference times	
		Day	Night
I	Specially protected areas	50	40
II	Predominantly residential areas	65	55
III	Areas of mixed type	60	50
IV	Areas of intense human activity	65	55
V	Mainly industrial areas	70	60
VI	Exclusively industrial areas	70	70

[6] The PZA is an instrument by which the municipality aims to protect people from environmental noise pollution, both outside and inside housing, while ensuring respect for the values established in DPCM 14/11/97.

It must also be said that the Legislative Decree 19 August 2005 n. 194 imposed on the companies and the managing authorities of public transport services or related infrastructures to process and transmit, by 30th June 2007, to the region or autonomous province authority and, in the case of infrastructures concerning more regions, also to the Ministry of the Environment, the noise mapping and data required in Annex 6 of the same decree, relating to the previous calendar year, for major railways which have more than 60,000 train passages per year.

For such railways action plans were processed and transmitted by 18th July 2008[7]. These plans implemented and updated the plans for containment and abatement of noise produced by public transport services, adopted according to article 3, paragraph 1, letter i) of Act 26th October 1995 n. 447.

In the case of key infrastructures within agglomerations (urban areas consisting of one or more villages, in accordance with article 3 Legislative decree 30th April 1992 n. 285, adjacent to each other) with more than 250,000 inhabitants, acoustic mapping[8] and action plans were sent to the regions respectively by 31st December 2006 and by 18th January 2008.

Similar deadlines have been set for the main railways which have more than 30,000 train passages per year[9]. Having less impact than the previous ones, the deadlines for the information reports are less critical: noise mapping and action plans must be processed and transmitted respectively by 30th June 2012 and by 18th July 2013; for railways in agglomerations with more than 100,000 inhabitants noise mapping has already been sent by 31st December 2011 and action plans will be sent by 18th January 2013.

III. Protection of the Environment from Noise Impact and Efficient Design

The assessment of acoustic compatibility of works of major importance, such as a railway line, requires a precise analysis of the objectives of protection of environment and population. First, we need to clearly identify the parameters and limit values laid down by the regulations. As shown in the previous section, national legislation defines the maximum allowed noise values within the territorial area of a railway infrastructure (250 m wide area on each side of transit platform); areas beyond are subject to the limits laid down by the Municipal acoustic zoning.

In order to design properly, within the context in which the work will be included, it is necessary to have information and analysis for the assessment of noise impact, to use in preliminary design and final design. These investigations are aimed to determine the noise level before works. The information framework built determines choices of cost-efficient routes, particularly with respect to expense required for silencing long stretches of the network or to reduce impact on particularly sensitive punctual receptors.

Equally important are the assessments of the operational phase, for which it is not possible to influence the choice of route, but it is always possible to discriminate between the technical alternatives to reduce noise impact, fighting the onset of lawsuits.

While verification occurs with field measurements (except frequent cases in which the costs of the survey campaigns become unsustainable), the determination of noise level *before works* proceeds according to a census phase and a modeling phase. The first is the identification and characterization of the receptors located within the study area. This is followed by the determination of the local noise level.

The census of receptors is supported by their definition given in the DPR 459/98. A receptor is "*. . . any building used for living including the related outside areas, or for work or recreation; protected natural areas, public parks and outdoor areas used for recreational and social activities of the community; buildable territorial areas already identified by existing general plans and their general variants, in force at the time of submission of the rough drafts*". It is clear that the effects of noise impact should be recorded with respect to both buildings and areas.

After the census noise level predictions are carried out through the use of specific forecasting models. These are calibrated to instrumental recordings made during the operation of similar infrastructures, then adapted to the design characteristics of the network to be built. Their reliability is closely related to the precision of the input data (acoustic and geometric), therefore for particularly complex scenarios, mistakes made in the estimation can take on not negligible values. Indeed, the orography of the area, the design of the network and the receptors, the sources of possible echo induce considerable disturbance to the output values of forecasting algorithms.

A. Forecasting Models of Noise Level

The models [3]–[7] based on algorithms for the calculation of the sound propagation allows to predict the level of audible noise in one or more points (receptors) due to emission from n sources. The functional form depends on the characteristics of the sources, the nature of places (usually presence of artifacts, orography, etc.) and the relative position between each receptor and source. The accuracy and reliability of the results are related to the quality and consistency of the input data as well as to the peculiarity of the algorithm.

Decisive influences may derive from the direction and the speed of the wind or the particular atmospheric stratification. These factors can determine, even for relevant distances relevant (over 500 m), variations of sound levels up to 10 dB; in a valley context such effects can be potentially amplified by the particular orography of the area.

[7] See Directive 2002/49/CE, Art. 4, in Italy Law 194/05.
[8] See Directive 2002/49/CE, Art. 3.
[9] See Noise mapping of major railways, RFI (Italian Railway Network) internal work.

In the present case the basic assumptions for the selection of the model of sound wave production and propagation are the following[10].

Referring to a linear source (typical railway) and assuming as input:

v = velocity (speed) of the train;
l = length of the convoy;
d = distance of the receptor from the railway;
having defined the following parameters
L_{max25} = equivalent level associated to the transit of a convoy measured at a distance of 25 meters;
L_{max} = maximum noise value;
L_{Ax} = maximum level associated to the transit of a single convoy;
the Equivalent level (L_{Aeq}) at a distance d can be determined
through the following model:

$$L_{Aeq} = L_{Ax} - 35,5$$

$$L_{Ax} = L_{max} + \left(3.6 \cdot \frac{1}{v}\frac{6 \cdot d}{100}\right)$$

$$L_{max} = L_{max25} - K \cdot \frac{d}{25}$$

With K = 12 for long trains and K = 17 for short trains and assuming

$$L_{max25} = 30 \_ \log v + 28$$

In addition, taking into account the number of transits per hour (N), it is possible to determine the hourly equivalent level using the following equation:

$$L_{Aeq(N)} = L_{Aeq} + 10 \_ \log N$$

B. Effects of noise level on track design

As said, the design of a stretch of high speed railway network depends on a large number of factors. The orography of the crossed land, the type of train (passenger, freight, etc.), the volume of traffic that the network will have to accommodate, the average speed of transit, the number of stations, etc. [8]–[11].

Due to the continuous increase in running speed, today the problem of noise emissions is increasingly felt. Particularly in an area such as that of the South of Italy, where the population density causes widespread situations of interference between the network and the artifacts in neighboring areas.

Therefore for the managing authority it is essential to have a useful tool in the design phase, but also in the verification phase, to implement efficient choices of environmental preservation and remediation.

The model presented in this study allows, in the design phase, to take into account the noise reverberation on real estate by making adjustments to the suggested route. In verifying existing paths, it uses the above formulations to estimate the noise impact on neighboring properties without excessive expenses connected to a survey campaign.

After determining the noise level, and depending on the ratio between the input levels expected and permitted by law, the model quantifies the resulting depreciation on property, appreciating the potential expenses which the managing authority shall bear to compensate the owners of the assets. After establishing the total compensation, the algorithm compares it with the cost of the protections which can be installed along the tracks to contain the noise emissions, providing information on the cheaper option.

The assumptions underlying the protocol tested in this study are obviously simplified in comparison with the actual operations. However, the power of the stochastic solver used allows the possibility of a wide implementation of the model.

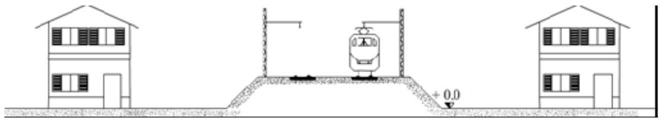

Fig. 1 Schematic example of a work hypothesis for the development of the model of noise emission and propagation

The assumptions concern the orographic conditions, the absence of any interference between the emission source (the track) and receptors (buildings). As far as orography is concerned, it is necessary to have a completely flat landscape, whose texture is thick enough not to require soil strengthening works. This leads to a track that extends without tunnels, viaducts or trenches. Furthermore, between the emission source and properties there is supposed to be no interference. This means that we are in the condition illustrated in Fig. 1.

IV. Genetic Algorithms

For the resolution of a complex problem like that of the optimization of a railway line between two points identified in an area, so that the sum of the cost of construction of the line and the depreciation caused by the noise impact on existing structures is the lowest possible, an Operations Research tool[11] known as Genetic Algorithms has been adopted.

The technique introduced by J. H. Holland in the 70s and spread also to Italy in the early 90's [2], [19], is inspired by the principles of Darwin's natural selection, according to which nature is able to cross its various and changing solutions to the problems caused by the environment, by combining them in evolutionary prototypes which are more powerful than the original elements. The chances of survival of the species are entrusted to the ability of individuals to adapt to the surrounding environment; such ability is in turn connected with the possibility to change their genetic pool by combining the existing profiles or introducing new ones.

In computer science this performance function is called fitness; it evaluates the goodness of processed solutions and decides the future trends by combining them. So an

[10] The adaptation of the quoted models was carried out by the authors by making the simplifications useful in this case. It is obviously possible to adopt more complex algorithms where necessary.

[11] See applications there upon in [12]–[18]

evolutionary algorithm is all the more suitable to the needs to be met as the fitness is consistent with the specific problem to be solved [20], [21].

To simplify, the algorithm generates a family of initial solutions which then it combines genetically in relation to the score of these solutions compared to the fitness. The combination occurs through a process called crossover which brings about an exchange of genes between the best solutions in order to increase their effectiveness. The crossover can be of different types (*one point, standard order*) depending on how the combinations of genes are generated.

The ameliorative mechanism is exponentially enhanced by a further possibility of evolution connected with the process of *mutation*. This determines the modification of the genes depending on stochastic factors.

The process stops after a certain number of processes (also depending on the power of the computer, if the problem is highly complex), when the solution is stabilized, by passing an acceptability limit imposed a priori or proving substantially asymptotic compared to a target value.

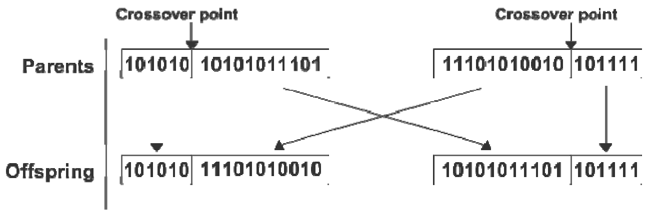

Fig. 2 Example of single point crossover (from Holland, 1992)

Any software (see for example Momentum V9 in the financial field or model Sciddica in the geotechnical field) which develops the logic of solution algorithms is based on a solver, that is the part of the code that simulates the path just described, and on a suitable fitness for the problem to be solved.

In the present study we have adopted the solver OptiGen library Genetic Software, proposed by NeuroDimension Inc (Florida corporation), whose license has been purchased, and the fitness submain structured as follows[12]:

```
Sub Main()
Lettura File dati()
Proiezione Edificio su Tracciato()
Dim Fitness As Double = Double.MaxValue
Dim Costi As Double = Costo Costruzione()
Deprezzamento = Danno Deprezzamento()
Fitness = Costi + Deprezzamento
Dim Raggio Curvatura verificata As Boolean
Raggio Curvatura verificata = Verifica Raggio Minimo()
Verifica Abbattimento Edifici()
If Raggio Curvatura verificata = False Then
Fitness = Fitness + 1.0E+31
EndIf
Dim File As New StreamWriter("fit.dat")
File.WriteLine(Fitness)
File.Close()
Dim File2 As New StreamWriter("DatiOutput.dat", True)
File2.WriteLine("Costototale ="& vbTab &
Fitness.ToString("f0"))
File2.WriteLine("Sviluppo lineare ="& vbTab &
LunghezzaTracciatoOutput)
File2.WriteLine("Costo costruzione ="& vbTab & Costi)
File2.WriteLine("Numero edifici deprezzati ="& vbTab &
NumeroEdificiDeprezzatiOutput)
File2.WriteLine("Deprezzamento ="& vbTab &
Deprezzamento.
ToString("f0"))
File2.WriteLine("Percentuale (deprezzamento/costo
costruzione) ="& vbTab & (Deprezzamento /
Costi).ToString("f4"))
File2.WriteLine(" ")
File2.Close()
Dim File3 As New StreamWriter("Deprezzati.dat", True)
For i = 0 To ListaDeprezzati.Count - 1
File3.WriteLine(ListaDeprezzati.Item(i).ToString)
```

[12] The development of the fitness has been carried out by the authors.

V. Application of the Model to a Hypothetical Case

A first verification of the proposed model is carried out with reference to a hypothetical case, represented by a portion of land of extension equal to 10,000 m x 5,000 m. We have to define the ideal track to join the midpoints of the short sides of the rectangle, considering the onerous impact due to the length of the track and the reduced value of the properties on the area. It is assumed that there are 80 residential properties with the following economic characteristics:

Commercial area per floor m^2 100
Number of floors 3
Market value per unit €/m2 1.500
Total market value €450.000

The buildings are distributed randomly along the long median of the rectangle.

Applying the model described in section III-A and on the basis of a typical traffic plan for the AV (high speed) network in southern Italy, a L_{Aeq} = 93 dB[13] along the track is obtained.

The function of sound wave propagation in space is derived on the basis of the following considerations.

Assuming free field (absence of reflective surfaces and/or obstacles which may interfere with the propagation of the wavefront and the presence of highly absorbent surfaces), a condition which is obtainable in external environment away from any surface that is not wholly absorbent, for the study of propagation it is necessary to firstly define the type of source that generates the acoustic field.

In this case, namely that of a railway train, we refer to a linear source.

A linear source in a free field produces cylindrical waves; whereas a tract of unitary length W, for the linear source the sound intensity I in a normal direction at a distance d is given by the sound power emitted by the source in the unitary

[13] This value is supported by instrumental measurements performed in the study [22]

portion W divided by the cylindrical surface of unitary length S of the wavefront. The pressure level, taking into account the attenuation factor ΔL, is [1], [23]:

$$L = L_W - 10 \log d - 8 - \Delta L$$

In general, the factors that contribute to the attenuation of sound during its propagation in the external environment can be identified as dissipative phenomena, more or less complex, related to the effects of wind, the temperature gradient, the absorption of sound energy by air and surfaces lapped by the pressure wave (soil, vegetation, etc.). Neglecting, in this first hypothesis, the attenuation factor (ΔL = 0), we have [24]–[32]:

$$L = L_W - 10 \log d - 8$$

The punctual level is a function of the source emissions and of the attenuations due to the source-receiver distance (*d*), assuming LW = 93 dB (that is, as already said, the assumable value to the considered traffic plan).

After finding the dissipation function of noise depending on the distance from the track, we have to define the function of depreciation of the buildings [33]–[39].

First we should highlight the adopted assumption of simplification of the market, reduced in this case to its residential component. This approximates the ordinariness of the most widespread real situation and facilitates the retrieval of the market values of the property, borrowed from the indications given by the OMI[14] of Land Agency.

As to the functional form suitable to identify the decrease in value due to the noise of trains in transit, we can refer to the circular letter of the CIPE (Interministerial Committee for Economic Planning) prot. 16754 of 10.10.1990, according to which the maximum depreciation of a manufactured building, impacted by the proximity of a rail network, is equal to 30% of its original value[15]. It is assumed then that the maximum depreciation is registered in correspondence of the track, and then decreases proportionally with the increase of the distance from this. Depreciation cancels at a sound level of 55 dB, which is the average threshold deemed acceptable in the regulations for residential buildings.

The results obtained are shown in Table IV.

TABLE IV
RESULTS OF THE OPTIMIZATION OF THE PATH CARRIED OUT BY THE MODEL

		Case 0	Case 1	Case2
A	Minimum radius of curvature (m)	∞	500	2500
B	Length of path (m)	10.000	10.150	10.163
C	Construction cost (€)	9.000.000	9.135.388	9.146.470
D	Number of depreciated buildings	40	6	10
E	Depreciation cost (€)	81.310	166.179	495.354
F	Accomplishment cost (€) [C+E]	9.495.354	9.216.698	9.312.649
G	Depreciation /construction cost ratio [E/C]	0,055	0,009	0,018

The first column of Table IV describes the characteristics of the most logical track to implement (Case 0), coinciding with the long median of the rectangle (see Fig. 3).

It is a straight path, therefore it has a radius of curvature equal to infinity.

It should be remembered that the radius of curvature affects the maximum speed allowed, due to the centrifugal force responsible for the consumption of some mechanical parts of the vehicle and for the transmission of unpleasant sensations to passengers. These reduce traveling comfort [40], [41].

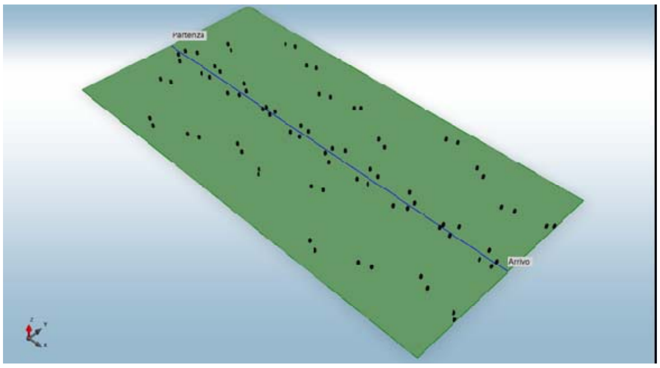

Fig. 3 Representation of the simulation grid adopted for the refinement of the model and the path of immediate design (blue)

The equation adopted to connect speed and radius of curvature is of the type

$$V = \sqrt{6{,}07 \cdot R}$$

valid for modern high speed convoys [41], [42].

Again in Case 0 we have an extension of the track equal to 10.000 m, with a construction cost obtained by multiplying the indicated extension by a unit cost averagely assumed in 900 €/m[16] (obviously for tracks on flat land).

40 buildings are impacted by the sound wave, and therefore

[14] It is a database (Observatory of the real estate market), with integrated webgis, with free access available online on the website of the governmental agency.

[15] The circular refers to a multiplicity of further negative effects, compared to only noise impact, that the proximity of a network can induce on an artifact (vibrations, decrease of sunshine, atmospheric pollution and psychological security).

[16] see Manuale di progettazione, Metodologia di valutazione tecnico economica dei progetti preliminari Legge Obiettivo 443/01 - Allegato 1, RFI internal documentation.

subject to a sound level greater than or equal to 55 dB. The total depreciation is 495.354 €[17], which affects more than 5% of the construction cost of the network.

The second column gives an account of the implementation of the model on a path (Case 1) which involves a minimum radius of curvature of 500 m, corresponding to a maximum speed of about 140 km/h.

The model defines a solution that drastically reduces the impact of the depreciation of real estate (from 5% to less than 1%), though increasing the length of the track of 150 m.

The buildings that fall within the sound wave disturbance are reduced to only 6.

The third column describes Case 2, with a minimum radius of 2,500 m and a maximum speed of 270 km/h.

The percentage of depreciation goes back up to a value of 2%, as the number of conditioned buildings becomes equal to 10.

The track increases its size to 10.163 m.

The testing carried out with a limited building density, less than two buildings per square kilometer, shows the effectiveness of the suggested algorithm. In particular, Case 2 is representative of a design solution that ensures very high speed (over 270 km/h), decreasing with respect to Case 0 (maximum speeds) the overall construction cost of the network
section.

The model also provides the amount of depreciation, allowing the designer to choose between the construction of 4-meter-high noise barriers (with a linear cost of around 1,000 €/m) and the compensation to be paid to legal claimants. For example in Case 2 10 buildings are impacted, for a front on the track of about 120 m. This value is obtained by multiplying the front attributable to each building (10 m) by the number of buildings (10) and by an amplifying safety coefficient of 1.20. Building barriers for 120 m would cost €120,000 (= €1,000 x 120 m), which would represent clear savings compared with the potential cost of compensation (€166,179). This is certainly a good choice if you also take into account the delays of probable lawsuits and the uncertainty of decisions.

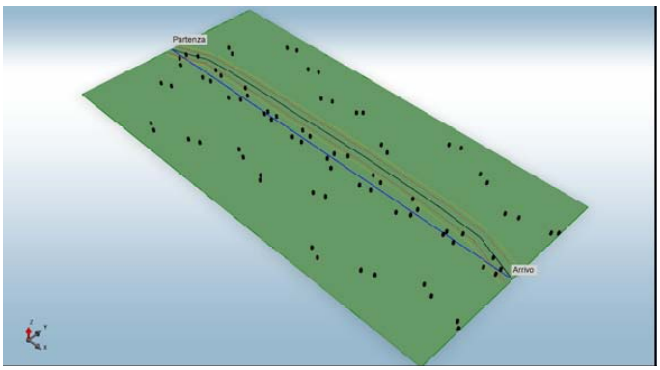

Fig. 4 Representation of the path (between red stripes) that allows the optimization of the rail route

VI. Application of the Model to a Case Study: the High-Speed Railway Stretch Salerno - Naples

The model has been applied to the high speed railway stretch between the cities of Salerno and Naples. The path, which extends north-east of the Vesuvius, has a total length of about 50 km. However about 17 km are in a gallery between Salerno and Nocera Superiore, therefore they are excluded from the analysis.

The path crosses the lands of several Vesuvian towns, such as Pomigliano d'Arco, Somma Vesuviana, Ottaviano, San Gennaro Vesuviano, Nola, Poggio Marino, Striano, Palma Campania, San Valentino, Nocera Inferiore and Superiore and Pagani. The analysis permitted to draw the path on to satellite photo (see Fig. 5).

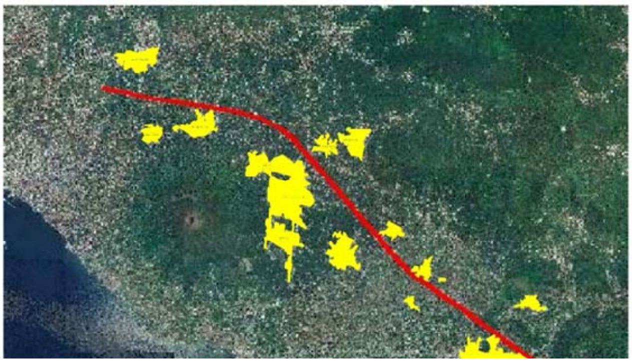

Fig. 5 Path of the high speed stretch between Salerno and Naples. In yellow the constraints in the presence of settlements

Then all the buildings (approximately 7,100) sited within a buffer zone of 2.5 km on each side of the track were georeferenced[18] with a Cartesian axial system. In this case the building density is 43 properties per square kilometer. In Fig. 5 the borders of the above mentioned towns are drawn in yellow.

Starting from this representation, the study protocol was implemented.

The fitness was the same as in Case 0. However, property values were borrowed, for each municipality crossed, from the Real Estate Market Observatory established by the Land Agency. The dimensional characteristics of the building population are the same of the previous section.

Some constraints have been imposed to the algorithm. The first concerns the possibility of diversification of the existing track, which cannot compromise the space limits of towns (in yellow in Fig. 5). The second constraint is the minimum radius of curvature, assumed to be equal to 1,000 m. It allows a maximum speed of 200 km=h, consistent with the real local situation.

Finally, the basic rule prevents the algorithm from generating solutions that include the removal of existing structures to enable the development of the network. The summary data table is shown below.

[17] obtained by applying a depreciation of 30% on the market value of OMI data.

[18] The process was carried out vectorizing the satellite images available on the web and giving each building on them a local cad origin coordinate.

As seen, the solution obtained by the optimization process would have allowed a reduction in the cost of construction of the path of approximately 10%.

This result would have been possible due to the reduction of the depreciation cost, despite an increase of the length of the path.

Indeed, the algorithm can reduce by 30% the number of noised buildings, so the expected compensation for damages decreases from 11.5 million euro to 6.8 million euro.

In Fig. 6 the existing and optimized path is shown.

With reference to the strategic choice to be made for environmental remediation, according to the arguments expressed in the previous section we have a front to be reclaimed of 11,592 m (966 x 10 m x 1.2) at a cost of approximately 11.592 million euro, in comparison with 11.496 million euro estimated damage compensation. The managing authority must evaluate the risks of possible litigations for the final decision.

TABLE V
RESULTS OF THE OPTIMIZATION OF THE PATH CARRIED OUT BY THE MODEL ON THE HIGH SPEED STRETCH SA-NA

		Real Case	Case 3
A	Minimum radius of curvature (m)	1.000	1.000
B	Length of path (m)	33.333	33.333
C	Construction cost (€)	30.678.696	30.678.696
D	Number of depreciated buildings	966	676
E	Depreciation cost (€)	6.795.219	11.496.938
F	Accomplishment cost (€) [C+E]	41.496.455	37.473.916
G	Depreciation /construction cost ratio [E/C]	0,380	0,220

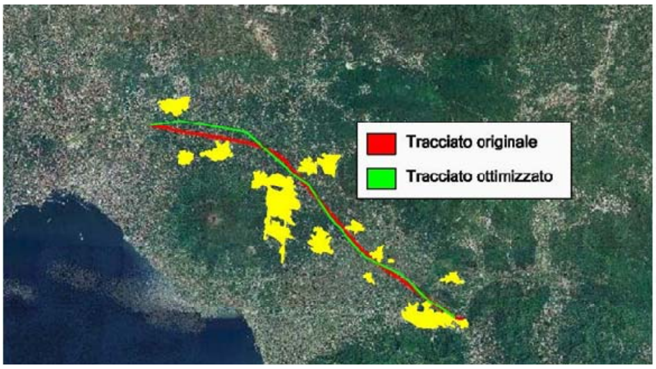

Fig. 6 Path of the high speed stretch between Salerno and Naples. In yellow the constraints in the presence of settlements

VII. CONCLUSION

The recent controversy over the implementation of the TAV (High Speed Trains) in the alpine section brought to public attention the issues and concerns of the impact that such infrastructures can induce on the crossed territory.

The determined by the noise of the vehicles are becoming increasingly important. This is due to the increase of the speed of transit and therefore of the noise.

The effects of loud noise are evident on the health of people living in proximity of the platforms and in particular on their psychological balance. But they are equally important for properties close to the network, both areas and buildings.

Both suffer a capital write-down due to the conditioning to their functions.

Litigations raised by the owners of properties located near the railways are increasingly frequent. They move into judicial offices technical and estimation issues of no small importance for the judicial bodies and their auxiliaries.

In this context the present paper has been developed, which aims to offer a complex tool capable of predicting the noise impact generated by railway traffic, obviating expensive survey campaigns often not accessible to private citizens. The model also has high potential to support the managing authority of the network in the verification of the noise along the path and in the choice of the most efficient technical solutions for environmental remediation, comparing their cost with the probable expenses for compensation of damages.

The presented protocol, however, expresses its full potential in the design phase of the railway network. Therein the implementation of the methodology based on Genetic Algorithms allows to select the path that minimizes the risk of litigation.

In addition, it rationalizes the choice of the best path and allows considerable evidence that is representative of the alternatives, so that the decisions of non-technical stakeholders
is significantly simplified.

Finally, the model is easily implemented with further variables which influence the design choice, becoming a professional tool which can also be distributed with appropriate software.

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