MODELS FOR DETERMINATION OF NOISE LEVEL FROM RAILWAY TRANSPORTATION SYSTEMS

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ABSTRACT

Railway and road traffic noise has become an important problem in all developed and developing countries. Fourteen percent of the population in Germany feel very or continuously annoyed by train and road traffic noise. In recent years methods for evaluating the noise of railway transport systems were developed. In contrast, international methods to estimate railway noise do not exist. This paper introduces new models for estimating the mean noise level produced from Egyptian railway transportation systems considering the background environmental noise, and other factors that affect railway noise . Noise measurements for different railway systems had been performed. The German model had been evaluated and calibrated to adapt the Egyptian transportation circumstances. Sources of railway noise and factors affecting it were analyzed. Finally, measures to reduce the impact of railway noise are presented.

***Keywords**:* Transportation Engineering, Railway, Noise, Prediction Models.

INTRODUCTION

Although the development of transport systems (railway and road systems) has produced both economic and social benefits, transport can also pollute the environment in which it is constrained the quality of human life. Noise emission penetrates the work environment, causing disturbance and interruption in concentration. It disturbs at home and during the leisure periods. Its presence may reduce the quality of sleep.

The influence of all kinds of noise on our daily life increases, and is still growing. It is due to the steady growth of traffic, and railway transport systems. For the traffic and train noise, alone the European countries comprised about 130 million people exposed to mean daily level of noise of more than 65 db(A)[1].

Each transportation system has its own noise spectra, and particular environmental problems. The characteristics of noise emission at any site is usually defined as a sound level based on an extended observation period. This can be the mean level during the day time (6.00 to 22.00 hours). But usually there are differences between successive days, and between weekdays and weekends.

The objectives of this paper are to analyze factors affecting the railway noise, develop new models to estimate the railway noise, which adapt the Egyptian transportation circumstances, and introduce measures to reduce the railway noise impacts.

EFFECT OF NOISE ON HUMAN HEALTH

The effects of noise on human health are various and often interrelated. There are also interrelationships between the general state of health of individuals and the various effects of noise. Stress may be introduced by the presence of noise, and stress may then induce physiological changes in the body and a general decline in health. The various effects of noise on human can be considered in three categories:

- Health effects,

- Activity effects, including sleep disturbance, and
- Annoyance.

Long term exposure to high noise levels can result in a permanent hearing loss. It is generally accepted that permanent deafness will occur if the ear is exposed to 90 dB(A), Decibel (A), as equivalent noise level, for 8 hours per day over more than 20 years [2]. Noise can also induce a range of physiological response reaction such as increases in blood pressure, heart rate, and breathing.

Studies have shown that noise can affect sleep in a number of ways [2]. It may shorten the length of the sleeping period and increase the number of frequency of awakenings, and it may affect the duration of the various stages of sleep. Sleep deprivation may at the same time produce another indirect effects such as reducing the performance during the day and creating a feeling of annoyance.

Sources of Railway Noise

Train noise can be classified into wayside and interior noise. The wayside noise is the noise radiated from train operation and track structures. Generally, wayside noise constitute the major noise sources from a railway transport system. The interior noise is the noise inside the train cars. Table 1 gives a summary of typical maximum wayside noise level taken from main line freight and passenger train operations at a distance of 25 m from track center line. The interior noise levels in passenger cars for operation in ballast and tie track range from about 55 to 80 dB(A).

Noise sources from a railway transport system can be classified into:

- Noise sources independent of train movement,
- Noise sources dependent on train movement, and
- Other railway noise sources.

Table 1 Typical maximum wayside noise levels from main line (25 m from track center-line, [2]).

Condition	Speed km/h	Noise Level in dB(A)
Idling 2000 hp loc.	0	61-66
Idling 3000 hp loc.	0	65-68
Passenger train		
Electric loc.	132	90
Cars		84-88
Freight train		
Diesel loc.	108	95
Cars		82-90

The locomotive usually represents the most common noticeable noise source of the first type. The engine operation produces noise, and this noise is a function of engine type and power. Electric locomotive is much quieter than diesel locomotive. Other noise sources of the engine is related to vibration radiated from the engine block and the whole locomotive body. Engine cooling, air compressors, and exhaust are another sources of noise from a locomotive.

Noise sources dependent on train movement can be categorized into:

- Rail/wheel noise sources,
- Brakes noise,
- Concrete structure noise sources,
- Gear noise, and
- Aerodynamic noise,

Rail/wheel noise is the main source of noise dependent on train movement. It is considered the major element of rail and vehicle suspension system noise which caused by the interaction of the steel wheels and the steel rails. This noise is significant in frequencies 500 to 2000 Hz. The roughness of the contact surfaces between the rail and the wheel (flat wheel or rail corrugation) is almost an only factor which influences the magnitude of rail/wheel noise. The rail/wheel reaction generates sound by the vibration of wheels, rails, and vehicle structure, track support system and ground.

The following vibration generating mechanisms may be considered to occur as a result of rail/wheel interaction:

- The impact of the wheel on a rail joint, a mechanism that is not present in the case of continuously welded rail,
- The impact of wheel flanges against the rail,
- The motions caused by track and wheel irregularities, and
- Vibration of the supporting structure.

The noise radiated from the vibration of concrete structure is another noise source dependent of train movement (specially for the high speed railway system). It has rather lower frequency than rail/wheel noise.

When a train in power running, definite gear noise is generated at frequency equal to the number of gearing in unite time. The dependence of gear noise level on train velocity is rather intense ($V^{4\text{-}5}$law), so it overcomes the rail/wheel noise for high speed rail systems (at speed higher than 270 km/hr) [3].

Various aerodynamic noises are generated from the variances of surface configuration of the railway cars. They are noticeable at high speed systems, and can be classified into:

- Aerodynamic noise from pantographs (for electric locomotives),
- Aerodynamic noise from the nose shape of the leading car,
- Aerodynamic noise from windows, doors, and gap of neighboring cars, and
- Aerodynamic noise from the equipment of air conditioner.

Generally, all aerodynamic noises are generated from the unsteady air flows induced by the various shaped parts, cavities and roughness of the train cars and equipment.

Other railway noise sources include railway maintenance machinery such as ballastcleaner, and tamping machines, and bridge noise (steel and concrete bridge noises).

Factor Affecting Railway Noise

Factors affecting railway noise (wayside and interior noise) can be summarized as:

(1) Factors affecting the generation of railway noise such as:

- The interaction of the wheels and rails,
- The condition of the wheels and rails (flat wheel or corrugation),
- The car or locomotive propulsion system,
- Train speed,
- Train length,
- Train and locomotive types,
- Type of brakes,
- Track and tie types,

(2) Factors affecting the propagation of railway noise such as:

- Geometrical conditions of railway network (alignment, land topography, land use, reflection effects from building and other surfaces),
- Distance between track and buildings
- Atmospheric conditions (wind speed, air temperature),
- Existence of vegetation between track and noise receiver, and
- Planning conditions (subway, at grade, embankment, cutting).

PREDICTION OF RAILWAY NOISE

Methods used to estimate railway noise are either empirical or semi-empirical. According to the German railway specification, the mean noise level can be determined from the following model [4]:

$$Lm,e = 10\log\left\{\sum_i 10^{0.1(C+D_v+D_b+D_l+D_s)}\right\} + D_t + D_{br} + D_{cr} + D_{cu} \quad (1)$$

where:

$L_{m,e}$: mean noise level of the running trains with different types (i), and for a railway track (j), in dB(A), measured at a distance of 25m from the track centerline, and at a height of 3.5m above the rail level at a certain time period, C : constant, equal to 51 according to the German specification.

D_v : effect of type of vehicle (locomotive or cars), Table 2,

D_b : effect of type of brake, model (2),

D_s : effect of running speed, model (3),

D_l : effect of number of trains and train lengths, model (4),

D_t : correction due to type of track, Table 3

D_{br} : correction due to existence of bridge, Table 3

D_{cr} : correction due to road crossing, Table 3

D_{cu} : correction due to existence of curves, Table 3.

Table 2 Effect of vehicle type on train noise [4]

Type of Vehicle	D_v (dB(A))
Vehicles with wheel absorption or screening wall	-4
Vehicles with wheel disk brakes	-2
Vehicles and locomotive with wheel disk brakes	-3
Other vehicle types	0

Train noise depends also on the portion of cars provided with brakes, this effect can be determined from the following model {4}:

$$D_b = 10 \log (5 - 0.04 P_b) \qquad (2)$$

where:

P_b : the percentage of vehicles provided with disc brakes,

For high speed passenger trains P_b=30%; for freight trains P_b = 0%; for short distance passenger local trains P_b=20%; other trains P_b=100%.

Train speed effect can be calculated as:

$$Ds = 10 \log (0.1\ V) \qquad (3)$$

where V is the permissible train speed in km/hr.

Train noise is affected with the train lengths according to the following equation:

$$D_l = 10 \log (0.01\ l) \qquad (4)$$

where l is the sum of lengths of all trains class (i) running at one hour.

Table 3 shows the different corrections due to track type, bridges, road crossing, and curves.

Table 3 Different corrections of train noise due to track condition [4].

Condition	Correction in dB(A)
ballast track with wooden sleeper, D_t...,	0
ballast track with concrete sleeper, D_t...,	2
slab track, D_t ....,	5
existence of bridges, D_{br}.................,	3
existence of road crossing, D_{cr}.......,	5
existence of track curves (D_{cu}):	
r < 300 m ....,	8
300 < r < 500 m ....,	3
r 500 m ....,	0

MODEL EVALUATION AND CALIBRATION

In order to calibrate and evaluate the previous model to adapt the Egyptian railway transportation circumstances considering the background environmental noise, the lifetime of trains, track and tie types, and the type of the railway transport system (inter-city or transit), the railway noise produced from RAML TRAM, ABO-KIR railway line (as railway transit systems in Alexandria city), and the railway main line ALEXANDRIA-CAIRO (as inter-city transport system), were measured by using CEL-282 LUCAS environmental noise level analyzer. These measurements were recorded at 7.5 m and 25 m from the track centerline (according to the German specifications and the ISO standard for the acoustic measurement of noise emitted by railway transportation system under urban and rural conditions). While recording the railway noise level, train speed, and the characteristics of the track were also recorded. The background environmental noise, maximum noise level, and mean noise level were measured. For the RAML TRAM, the mean noise level from neighboring traffic roads were also recorded. The field measurements for the RAML TRAM were performed at three sections, at grade (between EL-Shobban EL-Moslemin and EL-Shatby stations), cutting (between EL-Shatby and EL-Gamaa stations), and embankment sections (between EL-Ibrahimya and EL-Ryada EL-Soghra stations). While the measurements for the ABO-KIR railway line were recorded at half-cutting section (between EL-Hadra and Alexandria main stations), and at grade section (between Sidi-Gaber and EL-Dahrya stations). The measurements for the main railway line ALEXANDRIA-CAIRO were recorded by Abis station for the four types of passenger trains running on this line, namely, Turbine, Spanish, French, and traditional train.

These measurements were conducted for two weeks from November, 25 to December 9, 1998

Based on this data, the railway noise level for the three transport systems were computed. In order to quantify the value of the constant C in model (1), a comparison had been made between the noise levels recorded and the calculated values.

The results of the measurements and the calculations proved that the value of the constant C in Equation 1 depends on the background environmental noise, the type of railway system (rural, urban), the type of train, type of tractive unit or locomotive and the lifetime of the trains. Table 4 shows the background environmental noise measured for the case studies and the related derived constant C.

The German model does not consider the effect of the track geometric design (at grade, cutting, or embankment section), therefore this correction will be considered in the new models according to P.M. Nelson [2].

NEW MODELS FOR DETERMINATION OF NOISE LEVEL FROM RAILWAY TRANSPORTATION SYSTEMS

Substituting the value of constant C from Table 4 into Equation 1, and considering the effect of the track geometric design, the mean noise level produced from Egyptian railway transportation systems can be determined from the following model :

For RAML TRAM:

$$Lm,e = 10\log\left\{\sum_i 10^{0.1(60+D_v+D_b+D_l+D_s)}\right\} + D_t + D_{br} + D_{cr} + D_{cu} + D_{e,c} \quad (5)$$

Table 4 Background environmental noise and the related derived constant C for the case studies.

Case study	Environmental background noise (dB(A))	Constant C
RAML TRAM Urban system, (electric, old units),	58	60.0
ABO-KIR LINE urban system, (diesel, old units),	62	70.0
Main Line ALEXANDRIA-CAIRO, rural (intercity) system, (diesel):	60	65.0
• Turbine (new units)		69
• Spanish and French (new units)		67.5
• Traditional train (old units)		69.5

For ABO-KIR railway line:

$$Lm,e = 10\,\text{leg}\left\{\sum_i 10^{0.1(70+D_v+D_b+D_l+D_s)}\right\} + D_t + D_{br} + D_{cr} + D_{cu} + D_{e,c} \quad (6)$$

For main line Alexandria-Cairo:

Turbine train:

$$Lm,e = 10\,\text{leg}\left\{\sum_i 10^{0.1(69+D_v+D_b+D_l+D_s)}\right\} + D_t + D_{br} + D_{cr} + D_{cu} + D_{e,c} \quad (7)$$

For Spanish and French trains:

$$Lm,e = 10\,\text{leg}\left\{\sum_i 10^{0.1(67.5+D_v+D_b+D_l+D_s)}\right\} + D_t + D_{br} + D_{cr} + D_{cu} + D_{e,c} \quad (8)$$

For traditional trains:

$$Lm,e = 10\ \text{leg}\left\{\sum_i 10^{0.1(69.5+D_v+D_b+D_l+D_s)}\right\} \quad (9)$$
$$+ D_t + D_{br} + D_{cr} + D_{cu} + D_{c,c}$$

Where: $D_{e,c}$ is the correction due to type of track geometric design, according to Reference 2; D_e (embankment)= 4dB(A); D_c(cutting) = -5 dB(A) for 3m cutting depth and it equals -10 dB(A) for 7m cutting depth.

Figure 1 illustrates a comparison between the field measurements, the German model results, and the new proposed models result for the three case studies. This Figure indicates the congruence of the field measurements values with the values calculated from the new proposed models.

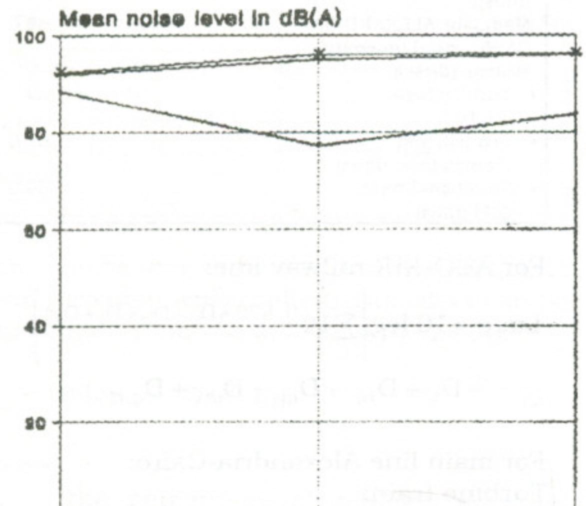

Figure 1 A comparison of the field measurements and models results.

A continuous noise trace level had been performed over the RAML TRAM line (section Shobban El-Moslemin to El-Ryada El-Kobra), Figure 2, to compare the new model results with the field measurements, and to recognize the noise level produced from this type of urban transport system which exists in a dense land use area. This method is also suitable for assessing changes in the characteristics of the track. The noise trace indicates not only the congruence of the field measurements values with the values calculated from the new proposed models but also the effect of the track geometric design on the mean noise level in the RAML TRAM system.

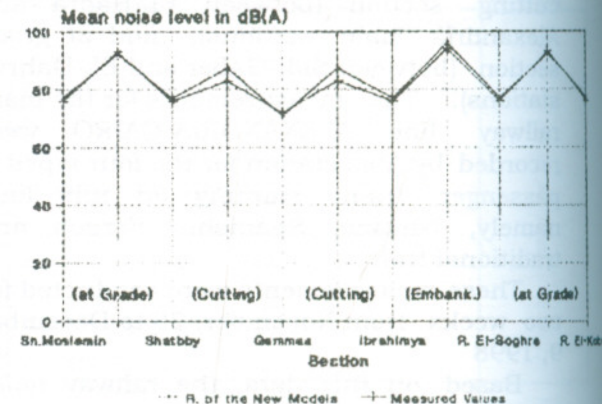

Figure2 Noise Trace over RAML TRAM, Field measurements and new models results.

The analysis of the results of the field measurements indicates that the train type, speed, and the locomotive horse power (hp) affect the mean noise level. A comparison between the mean noise level produced from the four passenger train types running on the main railway line Alexandria - Cairo is shown in Figure 3. This figure shows that the Turbine passenger train with hp equal to 3200, and speed of 100 km/h at the observation point, has the maximum noise level (hp for traditional train = 2475, hp for Spanish and French trains = 1650 and a power unit for the air conditioning and lightning).

The analysis of the results attained from the field measurement showed that, the mean noise levels produced from the urban railway system RAML TRAM and ABO-KIR railway line, in Alexandria city, as well as the intercity railway system (Alexandria - Cairo main line) exceed the international permissible noise limits. This value reaches 92 dB(A) for the RAML TRAM, 95 dB(A) for ABO-KIR line, and 100 dB(A) for the

intercity railway systems. That means, urgent countermeasures must be performed to reduce the railway noise. Table 5 shows a guideline for permissible noise levels for highway and railway territory [5].
Using train horn in the Egyptian railway systems (due to unsafe railway crossing) can increase the noise level by 23%.

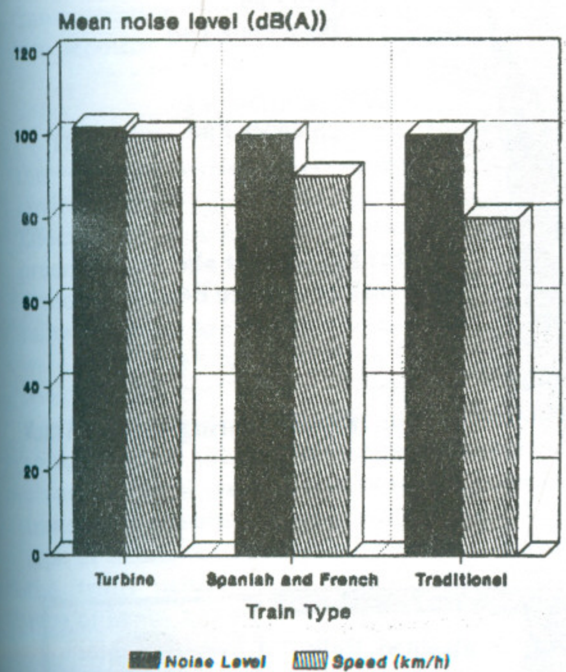

Figure 3 Comparison of the mean noise level produced from different types of trains

Table 5 Guideline of permissible noise levels for highway and railway territory [5].

Noise Emission Place	Permissible Noise Level in dB(A) day	night
Residential district	59	49
Hospitals, schools, universities	57	47
Commercial district	69	59

SUGGESTED COUNTERMEASURES TO REDUCE THE NOISE LEVEL PRODUCED FROM EGYPTIAN RAILWAY SYSTEMS

The suggested railway noise control measures are classified into three categories:

- Noise control at the source,
- Noise control at the transmission path, and
- Noise control at the receivers.

Control of noise at the source in a railway system can be achieved using silencers equipment within the locomotives or by isolating the engine of the locomotive from its surroundings using appropriate engine mounts. Electric locomotives are more quieter than diesel locomotives.
Methods to control the rail/wheel noise may follow seven directions:

- Reduce or control the roughness (corrugation) both of wheels and rails and reduce the formation of the wheel flats and rail corrugation.
- Using damping material such as rubber in producing train wheels to provide vibration isolation.
- Using damping material between track elements, such as rubber, as rail bad, base plate pad, sleeper pad, and ballast mat.
- Using resilient rail fasteners to aid damping in the rail.
- Using embedded rails.
- Employment of rail isolation technique.
- The use of ballast mats on bridge decks to limit vibration coupling through the ballast to the bridge structure.
- Reducing the number of wheels per unit length of the train.
- Reducing the number of rail joints by using the continuous welded rail.

Figure 4 illustrates different recent techniques used to control the railway noise at the transmission path.
Noise impact control can be also achieved by appropriate management of the adjoining land use of the railway system. This technique includes:

- Placing enough distance between the noise source and the noise sensitive activity.
- Placing noise - compatible activities such as parking bays, open spaces and commercial facilities between the noise source and the sensitive areas.

- Using plantings as barriers to screen sensitive areas.

Methods to control noise at the receivers may include:

- Isolation of buildings using noise protective measures, and
- Using rail-side noise barriers.

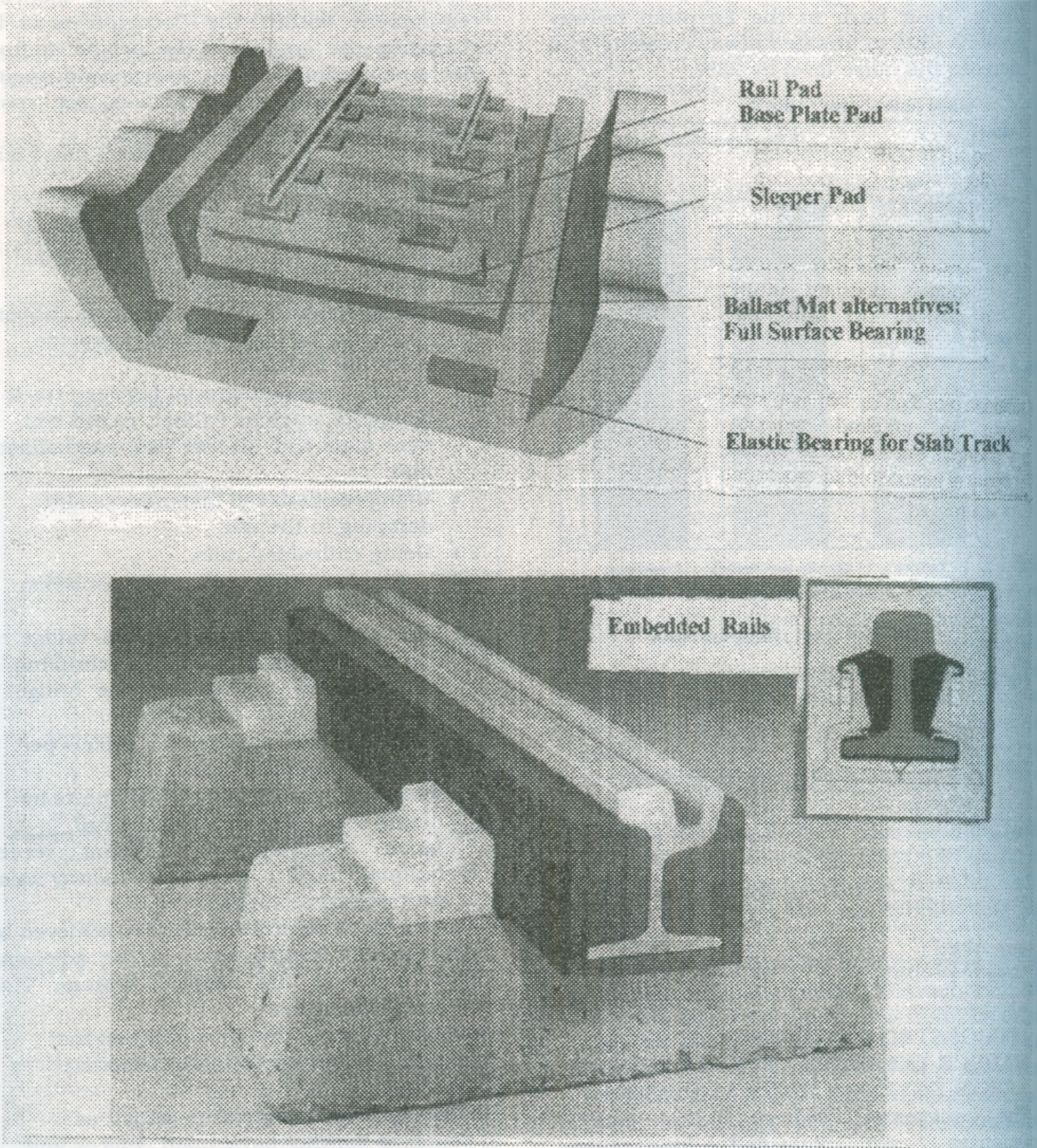

Figure 4 Different recent techniques used to control noise at transmission path.

Because of the separate noise sources combine logarithmically to produce the overall transportation system noise, it is important that all main sources are reduced together since little or no noticeable improvement is made if only one or two sources of noises are reduced. Consequently, any workable program of transportation noise reduction has to take into account every important noise.

CONCLUSIONS

This paper has focused on the impact of the railway transport systems on the environment, acoustic pollution impact. Effects of noise on human health are presented. Main sources of railway noise are demonstrated. Different factors that affect railway noise are also analyzed. New models were developed to determine the mean noise level produced from Egyptian railway transport systems. Significant factors were considered, such as the background environmental noise, the type of the railway transport system (transit or intercity), the type of trains and locomotives, the lifetime of the train units, train speed, train length, type of brakes, and track and tie types.

Field measurements (using CEL-282 LUCAS environmental noise level analyzer) for the three case studies on the railway transit system and the railway intercity systems agree the calculated values from the new derived models. This demonstrates that the logic leading to the new models is reasonable.

The mean noise levels produced from the urban railway system RAML TRAM and ABO-KIR railway line, in Alexandria city, as well as the intercity railway system (Alexandria-Cairo main line) exceed the international permissible noise limits. Aggressive intervention will be needed to reduce the noise impact produced from the Egyptian railway transport systems. Such intervention, in the form of employment of rail isolation technique, using silencers equipment within the locomotives, control rail corrugations and wheel flats, using resilient rail fasteners, placing noise compatible activities between the railways and the sensitive areas, and using plantings as barrier to screen sensitive areas, could reduce the noise impact of the railway systems.

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نماذج تحديد قيم الضوضاء من أنظمة النقل بالسكك الحديدية

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ملخص البحث

لقد أصبحت الضوضاء الناتجة عن قطاعات النقل على السكك الحديدية والطرق من أهم المشاكل فى الدول المتقدمه والدول النامية على حد السواء. فلقد أثبتت الإحصائيات أن ٤٠% من المواطنين فى جمهورية ألمانيا الإتحاديه يشعرون بالإزعاج المستمر نتيجة هذه الضوضاء. وفى السنوات الحديثة طورت العديد من النماذج الرياضية لتقدير الضوضاء الناتجة عن الحركة على السكك الحديدية، وبالرغم من ذلك وإلى الآن لا يوجد نموذج عالمي يطبق لتحديد هذه الضوضاء فى جميع الدول. ولذلك فإن هذا البحث يهدف بصوره أساسيه إلى بناء نماذج رياضية جديدة لتحديد القيمة المتوسطة للضوضاء الناتجة عن أنظمة النقل بالسكك الحديدية المصرية ، متخذا فى الاعتبار قيمة background environmental noise ، وعوامل أخرى مثل العناصر التصميميه للسكه والتخطيط الهندسي لها . وللوصول إلي هذا الهدف تم عمل قياسات حقلية للضوضاء الناتجة عن هذه الأنظمة. وعن طريق هذه القياسات تم تقييم النموذج الألماني ومعايرته بغرض مناسبته لظروف النقل فى جمهورية مصر العربية. ولقد تم أيضا فى هذا البحث تحليل منابع الضوضاء في أنظمة النقل بالسكك الحديدية والعوامل المؤثرة فيها. وأخيرا تم عرض وسائل تخفيض الضوضاء الناتجة عن الحركة على السكك الحديدي.