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RAILROAD NOISE IMPACT STUDY

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

RAILROAD NOISE IMPACT STUDY

Abstract

This paper reviews the current approaches to the prediction and assessment of railroad noise impact. Methods for the evaluation of railroad line and railyard noise impact are discussed as well as outlines of the Railroad Line Noise Impact Model (RLNIM) and the Railyard Noise Impact Model (RYINM). This report also describes a common analytical model which is the Railroad Noise Impact Model (RNIM).The RNIM consist of three general sub-models: noise generation model, noise propagation model and noise impact model. This model can be used in many situations and different countries.

Section 1 Introduction

The high energy acoustical noise and vibration generated by major transportation modes, such as rail, highway and airline, are a source not only of annoyance and discomfort in humans, but also of fatigue and possible structural problems in machinery and vehicles. A great deal of guidance on dealing with noise and vibration has been published by governments at all levels for a number of different reasons: to carry out public law mandates to protect public health and welfare; provide for environmental enhancement; or to integrate the consideration of noise in the overall comprehensive planning and coordination process. All of the policies address, in varying degrees, transportation noise problems. The policies concentrate on this noise source because transportation systems are a major source of environmental noise.

At the present time the EPA evaluates the noise portion of each Environmental Impact Statement (EIS) in isolation. It would be useful to have a comprehensive study report, which describes the railroad line and the railyard noise prediction and impact models, in order to estimate the influence of railroad noise nation-wide.

Section 2 Railroad Noise Impact Model (RNIM)

2.1 General

The railroad noise impact model generally comprises two major components: one is prediction of the radiated sound energy caused by all moving and stationary noise sources in the railroad transportation system, and the other is evaluation of the community noise exposure and the Noise Impact due to railroad operations. These two components are considered two specific models: the Railroad Line Noise Impact Model (RLNIM) and the Railyard Noise Impact Model (RYNIM).

The common model RNIM for both the RLNIM and the RYNIM includes the following:

1. Determination of the reference sound level and associated sound exposure level (SEL) for equipment and facilities, e.g., locomotive, car (passenger or freight) and railroad and railyard facilities.

2. Calculation of the Day-Night Sound Level(L_{dn}) based on the traffic flow and the operating times of the railroad facilities during the full 24-hour day.

3. Prediction of the noise exposure in the community areas affected by railroad noise. Correction factors are included for: distance attenuation, sound barrier insertion loss, shielding effect of buildings, ground and air absorption, etc.

4. Quantication of the areas affected by the railroad noise and the population density in these areas.

5. Computation of the Equivalent Noise Impact (ENI) in different L_{dn} areas and determine the composite effect for all affected areas.

6. Evaluate the effects of possible mitigating actions such as muffler retrofit on locomotives, installation of noise barriers at various locations, etc.

2.2 Basic Computing Formulas

A number of key parameters are needed in setting up the Railroad Noise Impact Model. The primary parameter is the noise data measured in the field, processed to obtain statistical average results. These data are used as inputs to the theoretical formulas which based on general acoustical principles. The railroad noise impact model incorporates empirical formulas which represent modifications, based on field measurements, of the theoretical formulas. Some of the basic computing formulas for the Railroad Line Noise Impact Model and the Railyard Noise Impact Model are discussed below.

2.2.1 Maximum A-weighted reference sound level (L_{max})

The maximum A-weighted reference sound level (L_{max}) is defined as the greatest A-weighted sound level in decibels, measured during a designated time interval or during an event, e.g., passage of a locomotive or rail car, or operation of a facility or equipment.

The measurement method is described below:

The microphone shall be positioned four feet above the ground, and on a line perpendicular to the track at a point 100 feet (30m) from the track center line. The sound level meter (SLM) shall be used with the "fast" meter response characteristic [1].

The L_{max} is one of the most basic parameters. Usually, we take the average value of several measurements of the greatest A-weighted sound level for a railway noise source, as the L_{max} for that equipment or event. The tables 2-1[2] and 2-2[3] show the L_{max} values of different types of locomotives and the major railyard noise sources respectively. Figure 2-1 shows the L_{max} range and distribution for locomotives as they pass the point of measurement. These data cover a wide range of maximum sound levels at a distance of 100 feet (30m); L_{max} ranges between 77 dB and 96 dB [4].

Equation 2.1 [5] is the formula for calculating L_{max} of the passenger cars and freight cars, based on field measurements.

For passenger car:

$$L_{max} = 74 + 30 \text{ Log } v/v_0 \pm 6\text{dB} \qquad 2 - 1$$

where

L_{max} = maximum A-weighted sound level at 100 ft. (30m)

v = railcar speed in km/h (or mph), and

TABLE 2-1

SUMMARY OF STATIONARY LOCOMOTIVE NOISE LEVELS

Locomotive Mfr/Model	Load Device	Noise Level at 100 Ft			Source
		Ambient	Idle	Throttle 8	
GM/GP-9	Load Cell	-	67[1] dBA	89 dBA[1]	Appendix D
GM/GP-38-2	Self Load	-	66.5 dBA[3]	92 dBA[1]	Appendix C
GM/GP-9	Load Cell	-	69 dBA[1]	89 dBA[1]	Appendix C
MLW/M-420[2]	Load Cell	-	65 dBA[1]	87 dBA[1]	Appendix D
GE/U36C Road No. 3322 Rated 3600 hp	Self Load	57 dBA	68 dBA	87 dBA	State of New Jersey
GE/U36C Road No. 3322 Rated 3600 hp, Actual 3564 hp	Load Cell	55 dBA	68 dBA	90 dBA	State of New Jersey
GE/U34CH Road No. 3358 Rated 3435 hp, Actual 3497 hp	Load Cell	57 dBA	70 dBA[1]	87 dBA	State of New Jersey
GM/SD45-2 Road No. 3680 Rated 3600 hp, Actual 3840 hp	Load Cell	60 dBA	66 dBA	91 dBA	State of New Jersey
GE/U25B Road No. 2502 Rated 2500 hp, Actual 2375 hp	Load Cell	64 dBA	70 dBA	92 dBA	State of New Jersey
Alco/C424 Road No. 2406 Rated 2400 hp, Actual 1760-2297 hp (surging)	Load Cell	65 dBA	72 dBA	89 dBA[4]	State of New Jersey
GE/U33C Road No. 3314 Rated 3300 hp, Actual 3278 hp	Load Cell	60 dBA	69 dBA	90 dBA	State of New Jersey
GM/GP-9 Road No. 1262 Rated 1750 hp, Actual 1878 hp	Load Cell	61 dBA	68 dBA	92 dBA	State of New Jersey
GM/GP-35 Road No. 2556 Rated 2500 hp, Actual 2424 hp	Load Cell	59 dBA	69 dBA	86 dBA	State of New Jersey

[1] Nonideal test site, usually because of sound-reflecting objects within 100 ft of locomotive or microphone.

[2] The Montreal Locomotive Works M-420 model is very similar to the Alco C-420 series.

[3] At 450 rpm. This locomotive can have three idling conditions depending on the electrical requirements (heating, lights, etc.) of the passenger cars.

[4] This test considered not representative since the engine was not developing full power.

Table 2-2 SOURCE NOISE LEVEL* SUMMARY

(dBA)

Noise source	Number of Measurements	L_{max}	Leq (Work cycle)	$\bar{L}_s$** or [Leq(1)]
Master Retarder: Group, Track and Intermediate MR	410	111	-	100
Inert Retarder IR	96	93	-	90
Flat Yard Switch Engine	Ref. 17	90	77	94 (4 MPH)
Hump Switch Engine, (Constant Speed)	Ref. 18	90	78	95 (4 MPH)
In-or-Out-bound Locomotive	Ref. 18	90	78	95 (4 MPH)
Idling Locomotive IL	27 55	65 67	(<2500 HP) (>2500 HP)	[66]
Car Impact CI	104	99		94
Refrigerator Car RC	23	73	67	[67]
Load Test (High Throttle) LT	59	90	87	[87]
Crane Lift	Ref. 19	83	79	106.5
Hostler truck	Ref. 19	82	65	94.5
Railcar Coupling (Impact)	31, (61000 for car coupling speed)	98.8		94
"		97.3		92.0 [6 MPH]
		91.7		85.8 [4 MPH]
TOFC/COFC Yard***	Ref. 19			
Crane-lift		83	79 (9 min.)	106.5
Goat Truck		82	65 (15 min.)	94.5

* A-weighted Average at 100 ft.

** $\bar{L}_s$ = Average Single Event Level or Single-Event Noise Exposure Level (SENEL), $\bar{L}_s = L_{max} + 10 \log \Delta t_{eff}$, ($\Delta t_{eff} = 0.5$ sec.)

*** TOFC = Trailers-On-Flat-Car, COFC = Container-On-Flat-Car

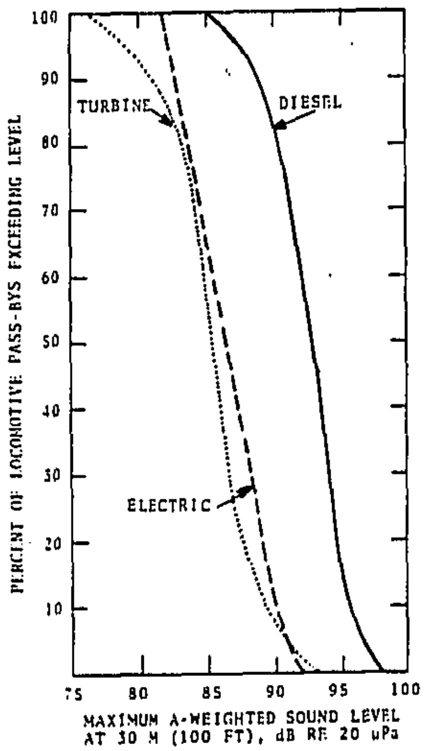


Fig. 2-1 Distribution of A-weighted sound level for three types of locomotives

TABLE 2-1–*Correction factor (C_{WR}) to account for effects of type and condition of wheels and rails on wayside noise–tangent (straight) track* [9].[a]

Wheel or Rail Condition	C_{WR}[b] Typical Value (Range) dBA
Rough welded rail	4 (3 to 6)
Rough wheels	5 (3 to 6)
Corrugated rail	10 (5 to 15)
Wheels with flats	12 (7 to 15)
Jointed rail	
Passenger cars	7 (4 to 10)
Freight, mainline track	1 (0 to 3)
Freight, low speed track	6 (4 to 8)
Switch	6 (5 to 8)
Wheels with damping treatment	–1 (0 to –2)
Wheels with resiliently mounted rims	–2 (0 to –3)

[a] These corrections are applicable when wheel-rail noise is the dominant source of wayside noise.

[b] To be added to levels for railcars with trued ordinary steel wheels traveling on smooth continuous welded rail.

V_0 = reference speed in 60 km/h (or 37 mph).

The data used in obtaining Eq. 2-1 are based on more than 50 measurements including both unpowered and electric self-propelled passenger cars at more than 20 sites. Ninety percent of the data lie within the range defined by Eq. 2-1. The passenger cars travel on at-grade tie and ballast track with continuous welded rail.

For freight cars:

$$L_{max} = 81 + 30 \text{ Log } V/V_0 \quad \pm \; 6 \text{ dB} \qquad 2 - 2$$

The running conditions are the same as Eq. 2-1.

The running conditions in Eqs. 2-1 and 2-2 were on at-grade tie and ballast track with continuous welded rail. If the railcars run on curved track or a transit car rans with flatted wheels and on rough welded rail, then the sound levels will be higher. In this situation, we use Table 2-3 to correct the wayside noise. The maximum pass-by noise level decreases with distance from the track, in the absence of obstacles such as noise barriers, buildings, etc., this decrease is due to spreading of sound energy, attenuation of the sound energy along the ground surface and absorption in the air. Each of these correction factors is added to the maximum A-weighted pass-by level at 100 feet (30m). We will discuss these correction factors in later sections.

2.2.2 Sound Exposure Level (SEL)

The sound exposure level (SEL) is often used as the basis for computing various noise exposure indexes such as L_{eq}, L_{dn} and CNEL. It reflects the total sound energy received from a single event such as a train pass-by.

The SEL of a group of locomotives (n_L)passing by a fixed observer at perpendicular distance (r_0)from a track is approximately:

$$(SEL)_L = L_{max} + 10 \text{ Log } r_0 n_L / v \qquad 2 - 3$$

where

L_{max} = the value for a single locomotive

v = locomotive speed in ft/sec, and

n_l = number of locomotives

In EPA's view,[2] experience with actual pass-by measurements indicates that 10 log ($r_0/2v$)gives a better approximation to the data. So the Eq. 2-3 should be:

$$(SEL)_L = L_{max} + 10 \text{ Log } r_0 n_0 / 2v \qquad 2 - 4$$

The SEL for railcars is expressed as:

$$(SEL)_C = L_{max} + 10 \text{ Log } T_{EC} \qquad 2 - 5$$

where

T_{EC} = effective duration of the train pass-by

A relationship for T_{ec} which agrees well with available theory and data is:

$$T_{EC} = l/v (1 + 1.2 d/l) \qquad 2 - 6$$

where

d = distance from the track , m (ft)

l = train length , m (ft), and

v = train speed , m/s (ft/s).

The EPA proposes calculating SEL of freight cars as [2]:

$$(SEL)_C = 72 + 30 \text{ Log } v/20 + 10 \text{ Log } t \qquad 2 - 7$$

where

v = train speed (mph)

t = train passing time (s)

The results computed by Eqs. 2-5, 2-6 and 2-7, are in reasonably close agreement.

The total $(SEL)_T$ for a train is the energy sum of the locomotive and railcar generated noise exposure levels, SEL_l and SEL_L, respectively. The total $(SEL)_T$ is expressed as:

$$(SET)_T = 10 \text{ Log } [\text{ Log}^{-1}(SEL_L/10) + \text{Log}^{-1}(SEL_C)] \qquad 2 - 8$$

2.2.3 Day-Night Average Sound Level, L_{dn}

The day-night average sound level (L_{dn}) is the basic noise metric used by EPA. L_{dn} means the 24-hour time-of-day-weighted equivalent sound level, for any continuous 24-hour period, obtained after addition of 10 dB to sound levels produced during the hours from 10 p.m. to 7:00 a.m. For any given type of train operation L_{dn} may be computed from equation 2.9:

$$L_{dn} = SEL_T + 10 \text{ Log } N - 49.4 \qquad 2 - 9$$

where

$$N = N_d + 10\, N_n$$

N_d, N_n are the number of operations of the train type during the day (7:00 a.m. - 7:00 p.m.) and night (10 p.m.-7:00 a.m.), respectively.

We can also compute the equivalent sound level (L_{eq}) and community noise equivalent level (CNEL) with Eq. 2-9, but the term N is as follows:

$$N = \begin{cases} N_d + N_n \\ N_d + 3\, N_e + 10\, N_n, \text{ for computing CNEL} \end{cases}$$

where

N_e = number of operations of the train type during the evening (7:00 p.m. - 10 p.m.)

2.2.4 Corrections for Sound Propagation Loss

We take into account the different attenuation effects on noise propagation from the sound source to the receiver in assessing the railroad noise impact. These sound attenuations are included: geometrical spreading effect (sound intensity decreasing with increasing distance), attenuation due to obstacles, such as walls, berms, sound barriers and buildings, ground and air absorption, etc.

a. Geometrical Spreading for Railcar/Locomotive Noise

The sound intensity decreases with increasing distance. The rule of geometrical spreading relates the source sound level to the distance between source and receiver. If the sound source is a point source relative to the receiver at large distance, the sound level decreases 6dB per doubling of distance from the source. If sound source is a line source relative to the receiver, then the sound level decreases 3 dB per doubling of distance from the source. It also can be expressed as:

$$C_s = -10 \text{ Log } (r/r_0)^n \qquad 2 - 10$$

where

C_s = geometrical spreading correction (dB)

r = distance to the track centerline, and

r_0 = reference distance of 30m (100 ft.)

$n = 1$, for a line source

$n = 2$, for a point source

Figure 2-2 gives the difference, due to geometrical spreading only, between the maximum A-weighted sound level from a train of specified length at any prescribed distance, and that from an infinitely long train at 30m (100 feet). It is based on a model of the train as a continuous line of incoherent point sources, each with dipole directivity. This model has been shown to be in good agreement with measured data for distances on the order of a car length or more from the track[6] A simple, but close, approximation to the geometrical spreading represented in Fig. 2-2 is a 3 dB decrease in noise level per doubling of distance for distances less than $2/\pi$ times the train length, and 6 dB decrease per double distance at larger distances.

For a single locomotive, the sound level decreases 6 dB per doubling of distance from the source for distances greater than 7.5 m (25 feet)[7].

In assessing railroad line noise impact, the model for train noise propagation into communities is based on the model developed for urban highway noise by Kugler, Commins, and Galloway.[8] The theory on which that model is based shows the noise falloff with distance from track (or highway) to be 4.5 dB per double distance.

this can be expressed as:

$$C_S = 15 \text{ Log } r/r_0 \qquad 2 - 11$$

In evaluating railyard noise impact, the railyard noise source can be divided into two kinds: stationary source and moving source. The stationary source is treated as a point source and the moving source as a line source.[9] Eq. 2-9 is applicable.

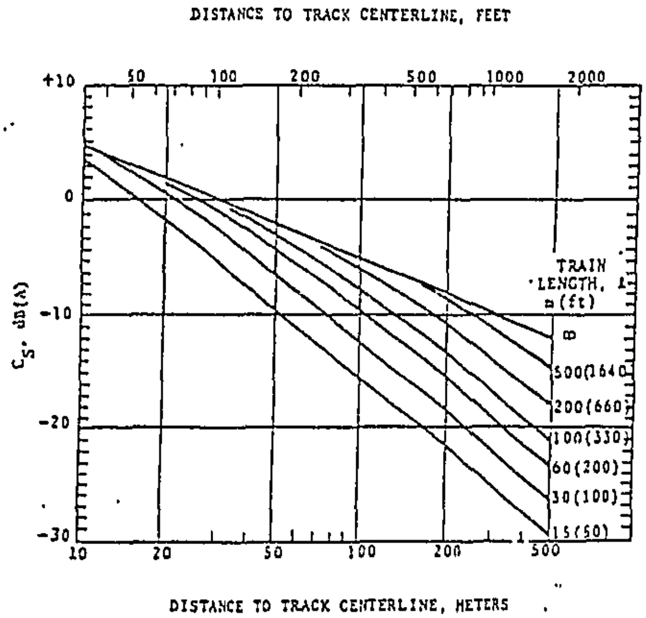
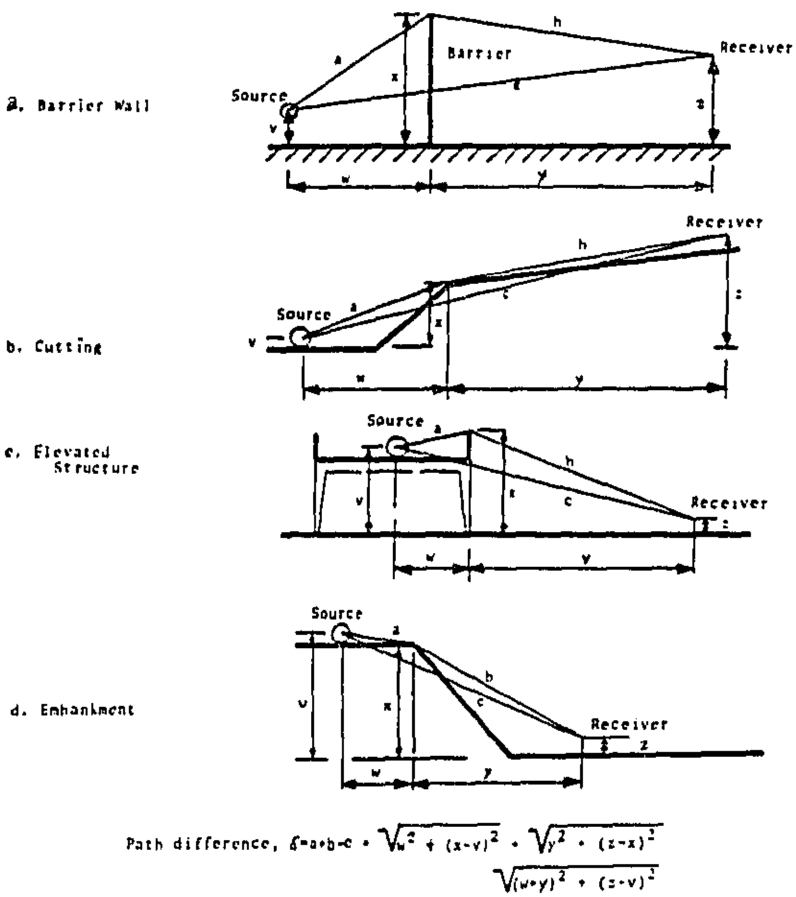


FIG.2-2-*Correction factor for geometrical spreading, C_S. This figure gives the difference, due to geometrical spreading only, between the maximum A-weighted sound level from a train of specified length at any prescribed distance, and that from an infinitely long train at 30 m (100 ft).*



Path difference, $\delta = a + b - c = \sqrt{w^2 + (x-v)^2} + \sqrt{y^2 + (z-x)^2} - \sqrt{(w+y)^2 + (z-v)^2}$

Fig. 2-3 Defining of path differences for various barrier configurations

b. Corrections for Obstacles

Barriers include such items as berms, walls, large buildings, hills, etc., that affect sound propagation by interrupting the propagating path and creating an "acoustic shadow zone." The sound level is lower in the shadow zone than in the corresponding free field.

Barrier corrections can be used to estimate the sound attenuation for a train traveling behind walls and hills, through cuts, and in some cases on embankments and elevated structures. Figure 2-3 defines the path difference for various configurations.[10] The effective source location can be approximated as the axle height on the track centerline for wheel-rail dominated noise, and on top of the locomotive (4.9 m above the rail surface) for diesel locomotive (exhaust-dominated) noise.

Using the theoretical solution for the barrier attenuation of sound from a long incoherent line source, the A-weighted barrier correction term, C_b, was determined as a function of path difference for the average of the railcar noise spectra. For the barrier attenuation of locomotive noise, the theoretical solution for a point source was applied to a typical diesel locomotive noise spectrum. The resulting barrier attenuation curves are shown in Figure 2-4. Note that the resulting insertion loss for a given path difference is greater for diesel locomotives than for railcars. However, because the effective source height for diesel locomotives is typically 4.4 m (14.5 ft.) higher than that for railcars, diesel locomotives require a substandially higher barrier to achieve the same path difference.

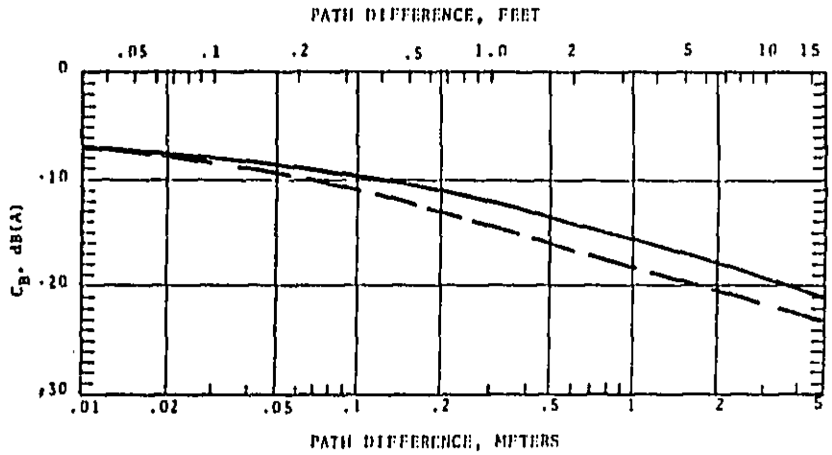


Fig. 2-4 Barrier correction, C_B, as a function of path difference

We also can compute the sound attenuation due to barriers. For most practical situations the reduction in sound level (attenuation) provided by a barrier may be expressed as a function of a single variable called the Fresnel number. The Fresnel number, N, is defined by:

$$N \doteq 2\,\delta/\lambda \qquad 2 - 12$$

where δ is the path difference, δ = a+b-c, and λ is the wavelength of sound radiated by the source.

Assuming a point source located behind on infinitely long barrier, the attenuation, Δ, is given in terms of the Fresnel number, N , by:

$$\Delta = \begin{cases} 0 & N < -0.1916 - 0.0635\epsilon \\ 5(1+0.6\ )+20\ \text{Log}\sqrt{2\pi|N|}\Big/\tan\sqrt{2\pi|N|} & (-0.1916-0.0635\epsilon) \leq N < 0 \\ 5(1+0.6\ )+20\ \text{Log}\sqrt{2\pi|N|}\Big/\tanh\sqrt{2\pi|N|} & 0 < N < 5.03 \\ 20\ (1+0.5\epsilon\ ) & N > 5.03 \end{cases} \qquad 2 - 13$$

where

$\epsilon = 0$, for a wall

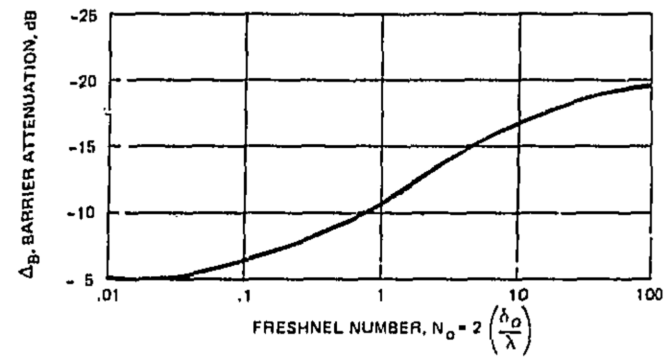
$\epsilon = 1$, for a berm

For a wall, Eq. 2-13 can simply be expressed as:

$$\Delta = \begin{cases} 0 & N < -0.1916 \\ 5 + 20 \operatorname{Log} \sqrt{2\pi|N|} / \tan \sqrt{2\pi|N|} & -0.1916 \leq N < 0 \\ 5 + 20 \operatorname{Log} \sqrt{2\pi N} / \tanh \sqrt{2\pi N} & 0 < N \leq 5.03 \\ 20 & N > 5.03 \end{cases} \qquad 2 - 14$$

We can roughly estimate, when the wall is not high enough to interrupt the line-of-sight between the source and the receiver, the attenuation is zero and when the wall height is just high enough to break the line-of-sight, Δ =5dB.

Figure 2-5 shows the barrier attenuation vs. Fresnel number.



a. Barrier Attenuation vs Fresnel Number, N_o, for Infinitely Long Barriers.

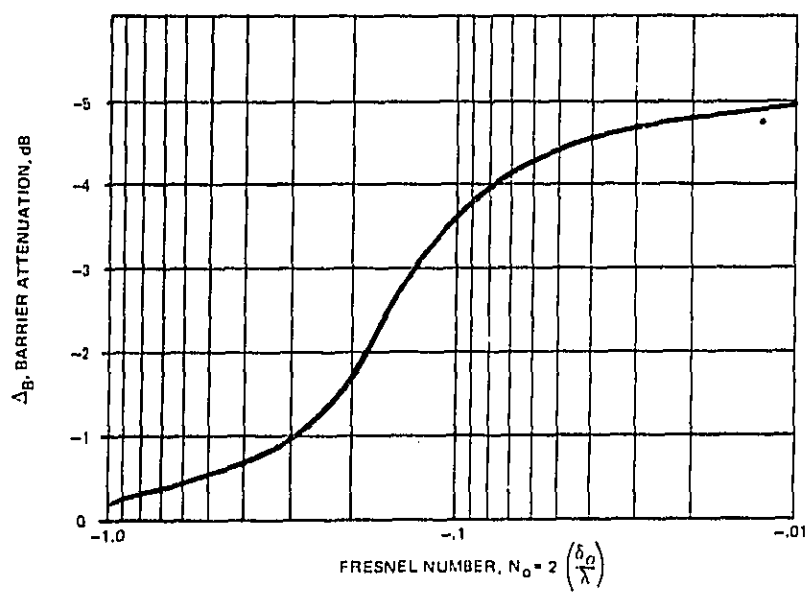


Fig. 2-5 b. Barrier Attenuation vs Negative Fresnel Number, N_o, for Infinitely Long Barriers

For detailed computation of barrier attenuation, refer to Figure 2-6. flow chart for barrier attenuations calculations

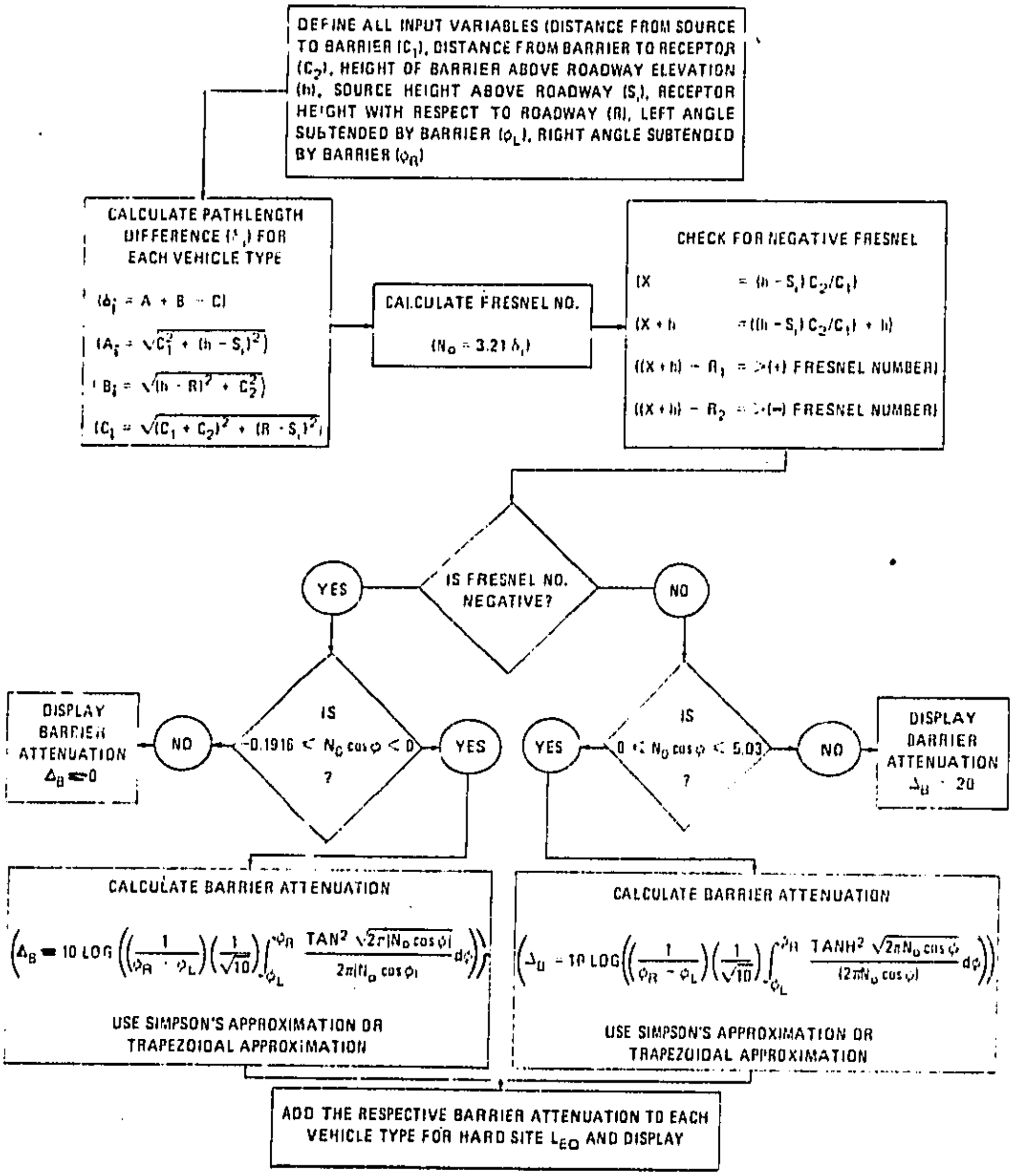


Figure 2-6 Flow Chart for Barrier Attenuation Calculations

c. Shielding Attenuation

Attenuation due to shielding of buildings is also an important mechanism by which railroad sound levels are lowered. Shielding occurs when the observer's view of a railroad is obstructed or partially obstructed by an object or objects which significantly interfere with the propagation of sound waves. The amount of attenuation provided by rows of buildings depends upon the actual length of the row occupied by the buildings. An attenuation of 3 dB is provided by the first row and 5 dB when the buildings occupy 65 to 90 percent of the length of the row. No attenuation is allowed for rows of houses that occupy less than 40 percent of the length of the row and 1.5 dB additional attenuation is provided by each successive row until a total attenuation of 10 dBA for all rows is obtained[11].

HMMH Inc. has performed the measurement of the shielding of freight train noise by a row of house.[12] Two portable sound level meters were used, one positioned in front of the houses 100 feet from tracks, the second positioned 200 feet from the tracks behind the first row of houses. After normalizing the measurements to the 100-ft position, they found a reduction of 4.6 dBA for the locomotive noise and 4.7 dB for the freight car noise.

These results are consistent with the common assumption of 5 dBA attenuation for the first row of houses and 1.5 dB for each successive row.

Table 2-4 summarizes the noise attenuation due to buildings.

Table 2-4 Noise Attenuation Due to Buildings*

	building occupy percent of length of row (%)			local average population density (people/sq.mi.)			industrial buildings source characteristics		
rqnge	<40	40-65	65-90	<2000	2000-8000	>8000	moving	stationary	M.&S.
atte.	0	3	5	0	4	8	5	10	7

* The common assumption of 5 dBA attenuation for first row of houses and 1.5 dBA for each successive row.

d. Ground and Air Attenuation

Numerous factors affect the attenuation of sound propagation over flat ground. These include type and condition of soil (as it influences the ground surface impedance), presence of vegetation (foilage and stems), temperature and wind gradients, atmospheric turbulence, and height of source and receiver above the ground. In addition, absorption of sound energy by the air depends upon temperature and humidity as well as frequency and distance. Nominal expressions for ground attenuation developed by DOT, for an average day (60°F and 65% relative humidity) are:

$$C_G = \begin{cases} 10 \text{ Log}(fd/4\times10^5), & \text{for } fd > 4\times10^5 \\ 0 & \text{for } fd \leq 4\times10^5 \end{cases} \qquad 2 - 15$$

$$C_A = 2fd/10^6 \qquad 2 - 16$$

where

C_G, C_A = ground and air attenuation, dB

f = sound frequency, Hz, and

d = distance from source, ft

However, since the noise model must compute L_{dn} values, and since the L_{dn} noise rating scale is based on A-weighted sound levels, it is more convenient to use a combined air and ground attenuation factor representing the attenuation of the A-weighted noise levels with distance. For each type of source the ground and air attenuation was calculated for 100 to 2,000 feet (30 to 610 m) distance using the center frequency of each octave band for the f value in the equations given above. The A-weighted level at each distance was then computed from correspondingly attenuated octave band noise levels, and the differences between the levels at the selected distances were used to determine the average extra attenuation (C_{G+A}) in dB attributable to ground and air absorption. The resulting combined air and ground absorption coefficients are shown for each noise source type in Table 2-5 [9].

In general, the noise impact results from groups of either stationary or moving sources. The average absorption coefficients assumed for mixed stationary and moving sources are shown in Table 2-6.

Figure 2-7 gives ground attenuation at a receiver height (above flat ground) of 1.5 m for various source (axle) heights, or at various receiver heights for a source height of 1.5 m vs.distance from the track.

Table 2-5 COMBINED AIR AND GROUND ABSORPTION FOR MAJOR RAILYARD NOISE SOURCES

Noise Source	Combined Air and Ground Absorption Coefficients, ALPHAG (dB/ft)*	
Retarder	0.01 (dB/ft)	0.033(dB/m)
Switch Engine	0.001	0.0033
Car Impact	0.005	.0164
Idling Locomotive	0.0025	.0082
Locomotive Load Test	0.002	.0066
Refrigeration Car	0.0035	.0115
Road-Haul Locomotive	0.002	.0066
Crane-lift	0.002	.0066
Hostler Truck	0.002	.0066

*Based on A-weighted SPL

Table 2-6 Average Propagation Attenuation Coefficient for Grouped Sources

Group Type	GALPHAG (dB/ft.)
Moving Source Group	0.002
Stationary Source Group	0.005

Figure 2-8 [13] presents the air absorption correction factor C^A for the average relative spectra and for temperatures and humidifiers satisfying the relation $4{,}000 < (1.8T + 32)H < 8{,}000$, where T is temperature in °C (note that the expression in parentheses is simply the temperature in °F), and H is relative humidity in percent.

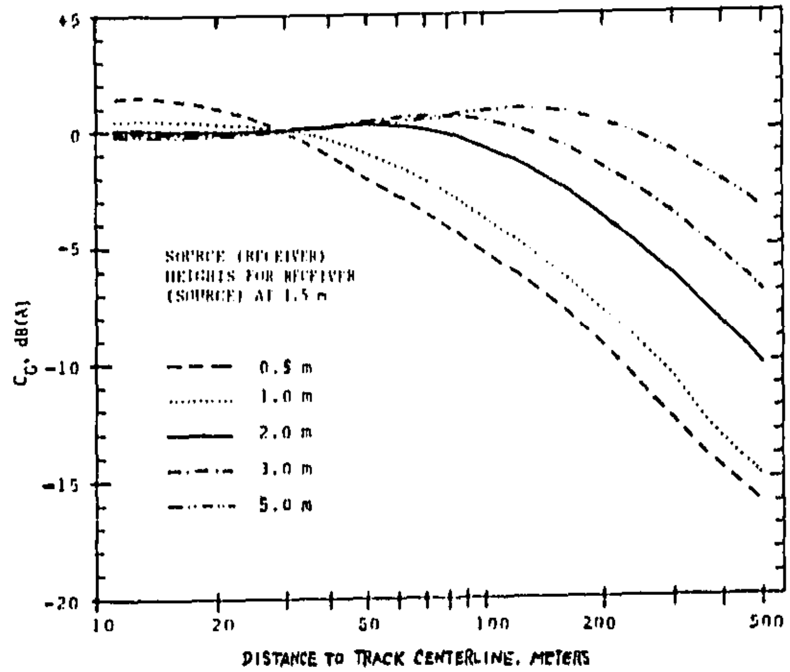


FIG.2-7-*Correction factor C_G, for railcar noise due to ground effects relative to attenuation at 30 m (100 ft) for same source and receiver heights. For propagation over flat grass-covered ground in the absence of wind and temperature gradients.*

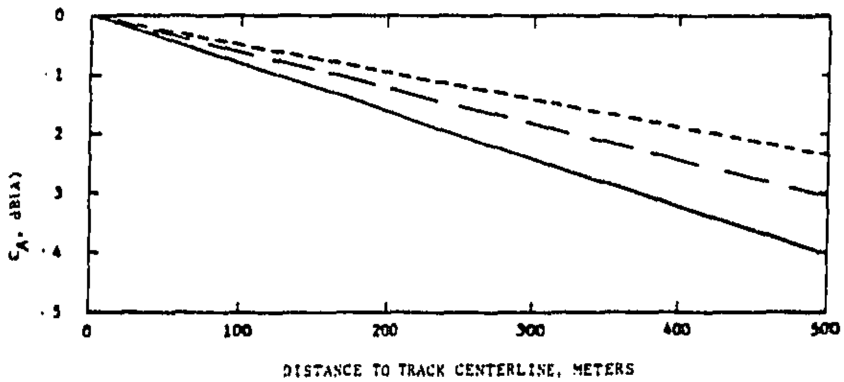


FIG.2-8-*Correction factor due to air absorption, C_A. The attenuation values are for combinations of temperature (T in °C) and relative humidity (H in percent) which fall in the range 4000 < H (1.8T + 32) < 8000. Note: ——— = railcars (passenger, freight, transit) and electric locomotives; — — — = diesel locomotives and U.S. transit elevated structures; and ·········· = railroad bridges.*

2.3 Methods of Evaluating Noise Impact

2.3.1 Fractional Impact

An environmental noise assessment usually entails analysis, evaluation and comparison of many different planning alternatives. Obviously, creating multiple arrays of population impact information is quite cumbersome, and subsequent comparisons between complex data tabulations generally tend to become somewhat subjective. Clearly, what is required is a single value which both interprets the environmental noise impact and incorporates attributes of both extensity and intensity of impact. Accordingly, the National Academy of Sciences, Committee on Bioacoustics and Biomechanics (CHABA)[14] has recommended a procedure for assessing environmental noise impact which mathematically takes into account both extensity and intensity of impact. This procedure, the fractional impact method, computes total noise impact by simply counting the number of people exposed to noise at different levels and statistically weighting each person by the intensity of noise impact. The result is a single number value which represents the overall magnitude of the impact.

The purpose of the fractional impact analysis methods is to quantitatively define the impact of noise upon the population exposed. To accomplish an objective comparative environmental analysis, the fractional impact method defines a series of "partial noise impacts" within a number of neighborhoods or groups, each of which is exposed to a different level of noise. The partial noise impact of each neighborhood is determined by multiplying the number of people residing within the neighborhood by the "fractional impact" of that neighborhood, i.e., the statistical probability or magnitude of an anticipated response as functionally derived from relevant noise effects criteria. The total community impact is then determined by simply summing the partial impacts of all neighborhoods.

The function for weighting the intensity of noise impact with respect to general adverse reaction (annoyance) is displayed in Figure 2-9.

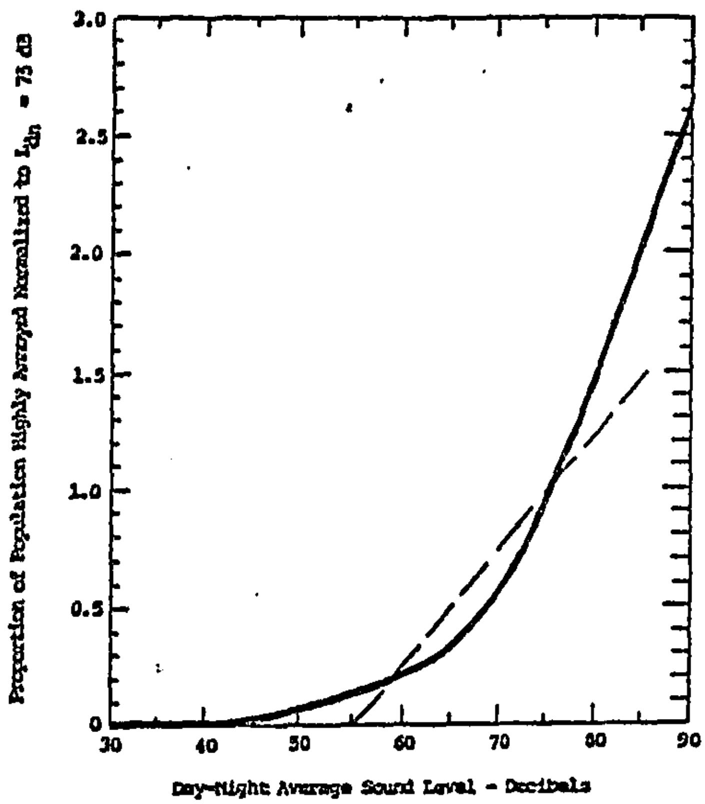


Fig. 2-9 Weighting Function for Assesing the General Adverse Response to Noise

The nonlinear (curvilinear) weighting function is arbitrary normalized to unity at L_{dn} = 75 dB. For convenience of calculation, the weighting function may be expressed as representing percentages of impact in accordance with the following equation:

$$FI = (3.364\ 10^{-6} \times 10^{0.103L_n})/(0.2\ 10^{0.03L_n} + 1.43 \times 10^{-4} \times 10^{0.08L_n}) \qquad 2 - 17$$

A simpler linear approximation that can be used with reasonable accuracy in cases where day-night average levels range between 55 and 80 dBA is shown as the dashed line in Figure 2-9, and is defined as:

$$FI = \begin{cases} 0.05(L_{dn} - 55) & \text{for } L_{dn} > 55 \\ 0 & \text{for } L_{dn} \leqslant 55 \end{cases} \qquad 2 - 18$$

2.3.2 Equivalent Noise Impact (ENI)

Using the fractional impact concept, an index referred to as the Equivalent Noise Impact (ENI) may be derived by multiplying the number of people exposed to a given level of noise by the fractional or weighted impact associated with that level as follows:

$$ENI_i = FI_i \cdot P_i \qquad 2 - 19$$

where

ENI_i = magnitude of the impact on the population exposed at L_{dni}

FI_i = fractional weighting associated with a noise exposure L_{dni}, and

P_i = number of people exposed to L_{dni}.

The total impact may be computed by determining the partial impact at each level and summing over each of the levels. This may be expressed as:

$$ENI = \sum_i ENI_i = \sum_i FI_i \cdot P_i \qquad 2\text{-}20$$

2.3.3 Noise Impact Index (NII)

The average severity of impact over the entire population may be derived from the Noise Impact Index (NII) as following:

$$NII = ENI/P \qquad 2\text{-}21$$

2.3.4 Relative Change in Impact (RCI)

In order to compare the relative difference between two alternatives, we can use the Relative Change in Impact (RCI). This concept takes the form expressed as a percent change in impact.

$$RCI = (ENI_i - ENI_j)/ENI_i$$

where ENI_i and ENI_i are the calculated impact under two different conditions.

We usually use terms such as Equivalent Population (P_{eq}) and Level-Weighted Population (LWP) alternatively to ENI.

An example of the fractional impact calculation procedure is presented in Table 2-7.

Table 2-7

EXAMPLE OF FRACTIONAL IMPACT CALCULATION FOR GENERAL ADVERSE RESPONSE

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Exposure Range (L_{dn})	Exposure Range (L_{dn})	P_i	FI (Curvilinear)	FI (Linear approx)	ENI_i (Curvilinear) (Column (3) x (4))	ENI_i (Linear) (Column (3) x (5))
55-60	57.5	1,200,000	0.173	0.125	207,600	150,000
60-65	62.5	900,000	0.314	0.375	282,600	337,500
65-70	67.5	200,000	0.528	0.625	105,600	125,000
70-75	72.5	50,000	0.822	0.875	41,100	43,750
75-80	77.5	10,000	1.202	1.125	12,020	11,250
		2,360,000			648,920	667,500

ENI (Curvilinear) = 648,920

ENI (Linear) = 667,500

NII (Curvilinear) = 648,920 ÷ 2,360,000 = 0.27

NII (Linear) = 667,500 ÷ 2,360,000 = 0.28

Similarly, using relevant criteria, the fractional impact procedure may be utilized to calculate relative changes in hearing damage, risk, sleep disruption and speech interference.

2.4 Railroad Noise Impact Model (RNIM)

We now can use the above-discussed basic formulas to set up a common model -- the Railroad Noise Impact Model (RNIM). In its simplest form, the railroad noise impact model consists of three general sub-models: noise generation model, noise propagation model and noise impact model. These sub-models consist of the of following:

° Noise Generation Model

$$L_{max}\text{, (for each noise source) (at 100 feet)} \left\{ \begin{array}{ll} \text{Locomotive:} & \text{Fig. 2-1} \\ \text{Passenger car:} & \text{Eq. 2-1} \\ \text{Freight car:} & \text{Eq. 2-2} \end{array} \right.$$

$$\text{SEL} \left\{ \begin{array}{ll} \text{Locomotives:} & \text{Eq. 2-5} \\ \text{Railcars:} & \text{Eq. 2-6, 2-7 or Eq. 2-3} \end{array} \right. \quad \text{(for the train, combine two, using Eq. 2-8)}$$

$$L_{dn} \left\{ \begin{array}{l} \text{Train: Eq. 2-9} \\ \text{Railyard Equipment: Table 2-1, 2-2} \end{array} \right.$$

° Noise Propagation Model

$$\text{Attenuation of } L_{dn} \text{ with distance (between source \& receiver)} \left\{ \begin{array}{l} \text{Train: Eq. 2-11 or Fig. 2-2} \\ \text{Railyard: Eq. 2-10} \left\{ \begin{array}{l} n = 2 \text{ for moving source} \\ n = 1 \text{ for stationary source} \end{array} \right. \end{array} \right.$$

Insertion loss due to barrier: Eq. 2-13 (Fig. 2-4) or Fig. 5

Insertion loss due to buildings: Table 2-4

$$\text{Attenuation of ground and air} \left\{ \begin{array}{l} \text{ground attenuation: Eq. 2-15 or Fig. 2-7} \\ \text{air attenuation: Eq. 2-16 or Fig. 2-8} \end{array} \right.$$

For composite attenuation, use Tables 2-5, 2-6.

- Noise Impact Model

  Fractional impact: Eq. 2-17 or Eq. 2-18

  Equivalent noise impact: Eq. 2-9 and Eq. 2-20

  Relative change in impact: Eq. 2-21

Section 3 Railroad Line Noise Impact Model (RLNIM)

How does one use the RNIM as discussed above to evaluate the railroad line noise impact? The general method is as following: investigate the present situation for railcars operating in areas of interest; compute the noise level of railcars; survey the present distribution of residential areas; and calculate the Equivalent Noise Impact (ENI) value. We can judge the acoustic-environmental quality of the residential areas according to the various noise criteria, and we can predict the future railroad noise impact. This in turn can lead to land use recommendations and analysis of the benefit of noise control measures adopted.

3.1 Train Operations

To assess railroad line noise impact, we need first accurate data on train operations in the areas of interest.

The following data are needed:

- Based on timetable information, the average number of trains operating per day, characterized as daytime operations (7:00 a.m. - 10 p.m.) and nighttime operations (10 p.m. - 7:00 a.m.), respectively.
- Average running speed of trains
- Average number of locomotive and cars, and length of train

3.2 Computed Noise Level of Train

° Computed L_{dn} at r feet from the track centerline

Figure 3-1 shows the procedure for computing the L_{dn} at r feet distance from track centerline:

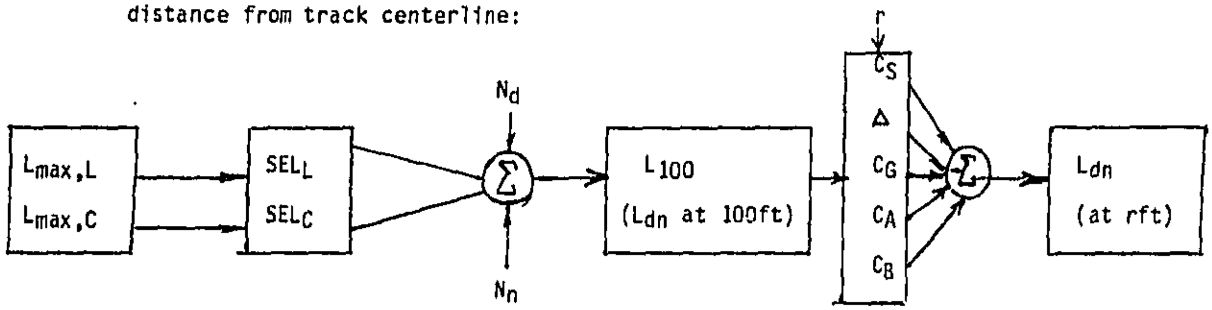


Fig. 3-1 L_{dn} at r ft computing chart flow

° Calculate the Affected Width (r) of Strip Under L_{dn}.

Sometimes we are concerned with identifying the areas exposed to a specified noise level [$L_{dn}(r)$]. For this purpose, the following formula is used:

$$r = 100\text{ft}\times 10^{[L_{dn}(100)-L_{dn}(r)]} \qquad 3 - 1$$

where

r = distance at the specified L_{dn} without any propagation attenuation $L_{dn}(100)$ = L_{dn} at 100 feet from track centerline

The (impacted region width) distance to the region at which $L_{dn} = L_{dn}(i)$ is:

After computing as above, we can estimate the noise propagation loss (L) due to increased distance (r). Finally, we use Eq. 3-1 again to obtain the real width of strip under corrected L_{dn}. The formula can be expressed as:

$$r = 100\text{ft}\times 10^{[L_{dn}(100)-L_{dn}(r)- L]/20} \qquad 3 - 3$$

° Draw the Noise Distribution Map (L_{dn} Contours)

3.3 Computing the ENI

° Population Density Statistic

Determine the number of persons within each L_{dn} region.

° Calculate the ENI Value

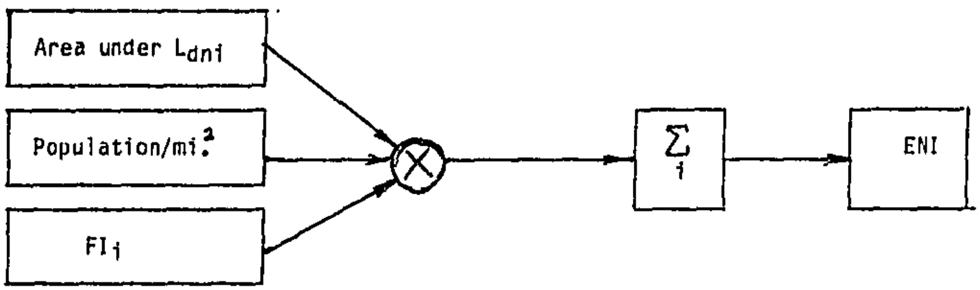


Fig. 3-2 Flow Chart for ENI Calculation

3.4 Evaluation of Railroad Noise Impact

3.4.1 Result of Ten-City Studies

In 1975 the EPA evaluated the railroad line noise impact Nation-wide. At first, we took 10 typical cities to assess railroad line noise impact. These 10 cities with widely varying populations were selected to provide a detailed breakdown of train traffic and population densities near railroad tracks, and the type of land use adjacent to tracks. Such comparisons provide a basis for determining how many people are exposed to railroad noise, how often they are exposed, and what activity they are engaged in at the time.

Table 3-1 summarizes the results of the 10 case studies:

TABLE 3-1
TRAIN TRAFFIC AND COMMUNITY CHARACTERISTICS NEAR TYPICAL RAILROAD LINES

CITY & STATE	POPULATION	NUMBER OF FREIGHT TRAINS		MAXIMUM FREIGHT SPEED (mph)	NUMBER OF PASSENGER TRAINS		MAXIMUM PASSENGER SPEED (mph)	LAND USE (%)			NO. OF PEOPLE PER SQUARE MI. WITHIN 500 FT	MILEAGE STUDIED	
		DAY	NIGHT		DAY	NIGHT		RESIDENTIAL	BUSINESS	OTHER		LAND USE	POPULATION
Akron, Ohio	542,775	22	18	55	0	0	—	40	23	37	1,662	25	31
Altoona, Pa.	81,795	7	5	50	2	2	70	16	18	65	3,090	6	12
Boston, Mass.	961,071	0	8	40	0	0	—	59	9	32	20,660	7	7
Cheyenne, Wyo.	40,914	?	?	?	2	0	?	9	11	79	1,471	15	9
Columbus, Ind.	27,141	1	1	50	0	0	—	?	?	?	730	—	20
Denver, Colo.	1,047,311	24	10	60	4	0	?	12	3	85	3,027	51	26
Durham, N.C.	100,764	11	1	65	0	0	—	?	?	?	1,780	—	31
Michigan City, Ind.	39,369	5	2	50	2	0	50	29	15	56	608	17	43
Newton, Mass.	91,066	7	1	50	0	0	—	75	21	4	5,320	6	6
Valparaiso, Ind.	20,020	19	10	60	0	0	—	43	8	49	1,528	9	9

and Figure 3-3 shows some L_{dn} profiles that were calculated by applying the prediction techniques to actual operation on a specific railroad line. The profiles shown in Figure 3-3 were calculated from the following data supplied by Penn Central:

Night Operations (10 p.m. - 7:00 a.m.)

Six freight trains, each 14 loaded cars and 10 empty cars and

Day Operations (7:00 a.m. - 10 p.m.)

Thirty-six passenger trains, each 40 mph

Pasenger trains with eight cars correspond to the national average passenger loading of cars.

3.4.2 Results of Nation-Wide Studies

EPA investigated the railroad line noise impact Nation-wide through a more wide-ranging survey; the following basic parameters have been determined:

- Average train-flow per day

  Table 3-2 shows the result of average train flow per day.

- Miles of railroad track

  According to a survey of 106 cities,[15] the percentage of the land in central cities presently devoted to railroads averages 1.7 percent in cities of 100,000 or more people and 2.4 percent in cities of 250,000 or more. The total land area of central cities having populations greater than 100,000 is approximately 9.84×10^3 sq. mi. If it is assumed that half of the land used by railroad is right-of-way (the remainder occupied by yards and terminals) and that the typical right-of-way is 100 feet wide, the following calculation results:

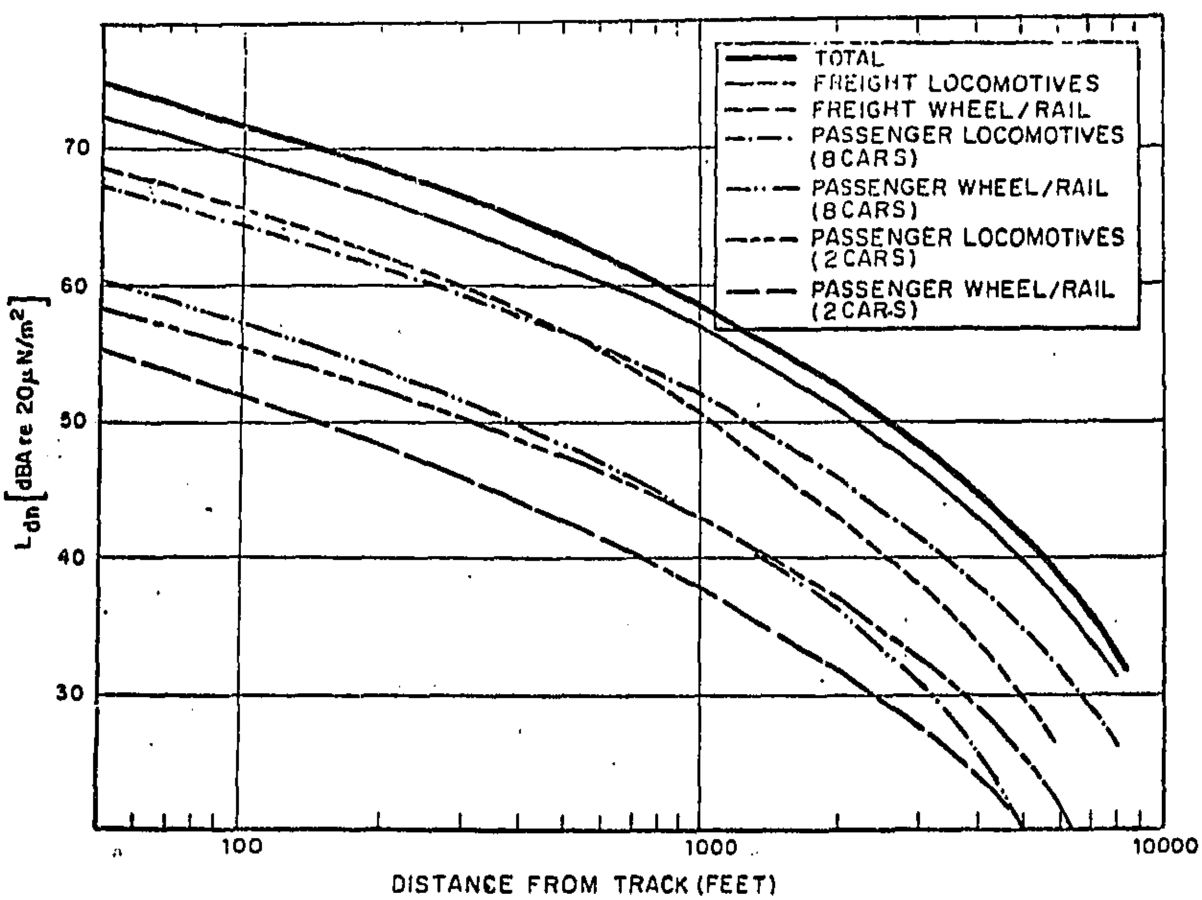


Figure 3-3 L_{dn} vs Distance From the Track for the Dorchester Branch of Penn Central

Therefore, it is estimated that there are approximately 4,000 miles of right-of-way in central cities.

Table 3-2 Average train-flow per day*

train type	Urban areas		Nonurban areas		Locom./train	cars/train	speed	weight
	tra./day 7am 10pm	tra./nigh. 10pm 7am	tra./day	tra./nigh.				
Fright	4	2	3	2	3.0	66.8 72.6**	33	3800
Passe.	2	0	0	0	1.4	5.6 5.2**		

*source: ICC,1971; **source:ICC,1985.

° Population density

Hoyt [16] gives 58.6 million as the total population of central cities having populations of 100,000 or more. Dividing that figure by the total area of $9.84 \times 10^3 mi^2$ gives an average density of people/sq.mi. Census maps of land in the vicinity of central-city railroad line indicate that the population density near rail lines is slightly less than half the local average. We therefore estimate that the population density near central city rail lines is approximately 2,500 people per sq. mi.

° People exposed

Table 3-3 shows the computation procedure for L_{dn} due to freight trains. In order to determine the distribution of people by L_{dn} interval, in steps of 5 dB, we should use Eq. 3-1 and Eq. 3-2. Table 3-4 shows the distribution of people in different L_{dn} regions in the noise level range from 55 dB to 70 dB in steps of 5 dB. Results are shown for the "baseline"

Table 3-3 EPA's Noise General Model

No.	Input date	Calculation formula	Result	Note
1	$L_{maxL} = 90$ dBA			
2	$L_{maxc} = 72$ dBA*			
3	$v = 33$ mph	$SEL_L = L_{maxL} + 10 \log \frac{\pi r_0 n_L}{v}$ Eq. 3	100.1 dBA	using data 1, 3, 4 (at 100 ft)
4	$n_L = 3$ Loco./train			
5	Cars = 70 cars/train			
6	$l_{car} = 50$ ft/car	$t = 70$ cars/train $\times 50$ car $\div v$	72 sec.	using data 3, 4, 6
7	$t = 72$ sec.	$SEL_c = 72 + 30 \log \frac{v}{20} + 10 \log t$ Eq. 6	97.3 dBA **	using data 2, 3, 7
8	$SEL_L = 100.1$ dBA, $SEL_c = 97.3$ dBA	$SEL_T = 10 \log [\log^{-1}(\frac{SEL_L}{10}) + \log^{-1}(\frac{SEL_c}{10})]$ Eq. 8	101.9 dBA	using data 8.
9	$N_d = 4$ trains/day, $N_n = 2$ trains/day	$L_{dn} = SEL_T + 10 \log N - 49.4$ $(N = N_d + N_n)$ Eq. 9	66.3 dBA	using data 9, 8

* using Eq. 2, $L_{max} = 81 + 30 \log \frac{v}{v_0} = 79.5$ dBA ($v = 33$ mph)

** using Eq. 5, $SEL_c = L_{maxc} + 10 \log T_{EC} = 98.3$ dBA ($T_{EC} = 75$ sec.)

Table 3-4 Distribution of People by L_{dn} Interval and ENI

L_{dn} Interval (dBA)	Distances of Strip Boundaries from Track (ft)		Width of Strip (ft)		Aggregated Area of Strips in U.S. (sq. mi.)		People Within Strip (million)		Fractional Impact (F I)	Equivalent Noise Impact million	
	Baseline	Post-Reg.	Baseline	Post-Reg.	Baseline	Post-Reg.	Baseline	Post-Reg.		Baseline	Post-Reg.
65 – 70	65 – 116	51 – 90	51	39	155	118	0.387	0.295	0.625	0.242	0.184
60 – 65	116 – 207	90 – 160	91	70	276	212	0.690	0.530	0.375	0.259	0.199
55 – 60	207 – 367	160 – 285	160	125	485	379	1.213	0.948	0.125	0.152	0.119
									Total ENI =	0.653	0.502

conditions, i.e., the existing situation (based on 1971 data) and for a post-regulation condition which assumes that all locomotives are in compliance with the regulatory standard of 87 dB. It is assumed that the "typical" compliant locomotive will emit an average sound level of 86 dB, one dB below the regulatory limit, and 2.2 dB below the baseline average level. The corresponding L_{dn} values at 100 feet are 66.3 dB for the baseline condition and 64.1 dB for the post-regulation condition.

The overall impact of railroad noise may be judged by computing the Equivalent Noise Impact (ENI), using Eqs. 2-18, 2-19, 2-20, which shows, from the figures in the last column of Table 3-4, the equivalent number of people exposed to levels 20 dB above the criterion level. For residential areas, the criterion level is $L_{dn} = 55$ dB.

The population figures in Table 3-4 show that a muffler retrofit program, which would provide 2.2 dBA average reduction in locomotive. noise, would reduce the Equivalent Noise Impact by 151,000 or 23 percent.

Section 4 Railyard Noise Impact Model (RYNIM)

4.1 Railyard Noise Impact Model Flow Chart

The Railyard Noise Impact Model (RYNEM) is designed to quantify the health/welfare impact due to railyard generated noise. The principle of the RYNIM is based on the common model described in Section 2. The RYNIM also consists of a noise generation model, a noise propagation model and a noise impact model -- three general sub-models. The basic logic for the model is indicated in Figure 4-1, for a given railyard type, types of noise sources operating, railyard traffic rate, and impact area. The noise generation model first computes the L_{dn} value for each source at a reference distance of 100 feet, and then computes the L_{dn} for each source at DN, the distance to the near side of the impact area. The composite L_{dn}

is determined for the source group, and combined with the background noise level. In the baseline case (no barrier wall) the composite noise level is then propagated across the impact area, integrating the L_{dn} vs. distance relationship with the impact weighting factors and population density in 1 dB increments to obtain the PE and LWP values. This procedure is followed for all impact areas and sources (groups) at the railyard, and the resulting PE and LWP values are summed to obtain the total impact.

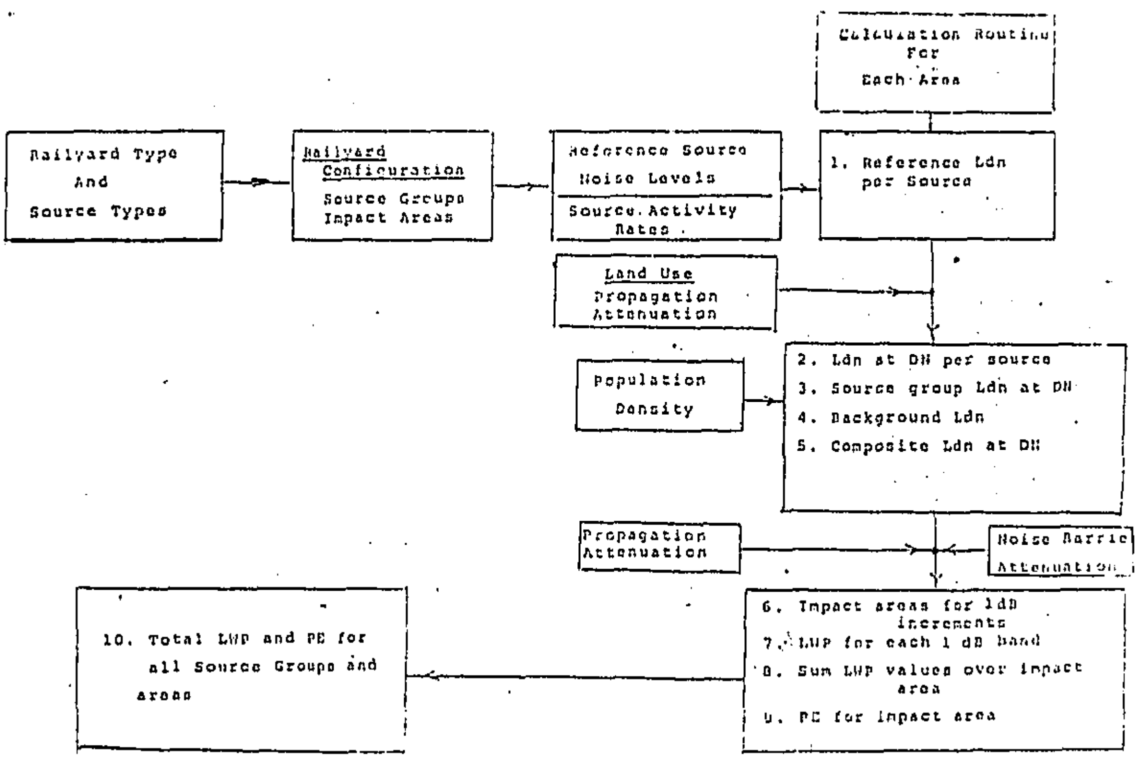


Figure 4-1 Model Schematic for Railyard Noise Impact

Table 4-1 RAILYARD DISTRIBUTION BY YARD TYPE, PLACE SIZE AND TRAFFIC RATE CATEGORY

NUMBER OF RAILYARDS

Yard Type	Place Size (Population)												Total/Yard Type
	Less Than 50,000				50,000 to 250,000				Greater Than 250,000				
	Traffic Rate				Traffic Rate				Traffic Rate				
	Low	Med	High	Total	Low	Med	High	Total	Low	Med	High	Total	
I Hump Classification	19	19	14	52	14	12	8	34	13	16	9	38	124
II Flat Classification	321	204	104	629	135	83	44	262	115	70	37	222	1113
*III Industrial				849				239				293	1381
*IV Small Industrial				1262				133				156	1551
Total/Place size				2792				668				709	Grand Total: 4169

*Industrial and small industrial yards were not categorized by traffic rate.

For each of the alternative noise limits at the receiving properties, the various heights for a wall at the railyard boundary necessary to reduce the baseline L_{dn} value to the desired values at the receiving properties are computed. The LWP and PE values are then calculated as discussed above.

4.2 Railyard Type, Source and Configuration

4.2.1 Railyard Type

As a result of the identification and classification study of railyards, the four major basic railyard categories used in the impact model are:

- Hump classification yards
- Flat classification yards
- Flat industrial yards
- Small flat industrial yards

The railyard types and locations are also grouped by the average level of activity (traffic rate) and the population size of the urban area in which the yard is located.

A summary of the railyard data is shown in Table 4-1 by type of yard, place size (population), and traffic rate (activity).

4.2.2 Railyard Noise Sources

In general there are 11 types of sources in hump yards, eight types in flat classification yards and four types in the other yards. These noise sources are listed in Table 4-2.

Table 4-1 RAILYARD DISTRIBUTION BY YARD TYPE, PLACE SIZE AND TRAFFIC RATE CATEGORY

NUMBER OF RAILYARDS													
	Place Size (Population)												
	Less Than 50,000				50,000 to 250,000				Greater Than 250,000				
Yard Type	Traffic Rate Low	Med	High	Total	Traffic Rate Low	Med	High	Total	Traffic Rate Low	Med	High	Total	Total/Yard Type
I Hump Classification	19	19	14	52	14	12	8	34	13	16	9	38	124
II Flat Classification	321	204	104	629	135	83	44	262	115	70	37	222	1113
*III Industrial				849				239				293	1381
*IV Small Industrial				1262				133				156	1551
Total/Place size				2792				668				709	Grand Total: 4169

*Industrial and small industrial yards were not categorized by traffic rate.

Table 4-2 RAILYARD NOISE SOURCES

HUMP YARD - NOISE SOURCES:

- Mr - Master Retarders (Includes Group, Intermediate, and Track)
- HS - Hump Lead Switchers
- IR - Inert Retarders
- MS - Makeup Switchers
- CI - Car Impacts
- IL - Idling Locomotives
- LT - Locomotive Load Test
- RC - Refrigerator Cars
- IS - Industrial and Other Switchers
- OB - Outbound Trains (Road-Haul plus Local)
- IB - Inbound Trains

FLAT CLASSIFICATION YARD - NOISE SOURCES

- CSE - Classification Switchers, East End of Yard
- CSW - Classification Switchers, West End of Yard
- CI - Car Impacts
- IB - Inbound Trains
- OB - Outbound Trains (Road-Haul plus Local)
- IL - Idling Locomotives
- LT - Load Tests
- RC - Refrigerator Cars

FLAT INDUSTRIAL YARD - NOISE SOURCES:

- SE - Switch Engines
- CI - Car Impacts
- IB - Inbound Trains (Road-Haul plus Local)

4.3 Running the Model

4.3.1 Reference L_{dn} for each source

The reference average noise levels for each source were determined by field measurements. The measured source noise levels are summarized in Table 2-2. In computing the railyard noise impact, the fixed data shown in Table 4-3 can be used. These fixed input data remain constant for all yards unless new data become available or new assumptions are made. In that case, the values of the input parameters can be changed accordingly.

4.3.2 Reference L_{dn} at DO (DO = 100 feet)

- For repeated single noise events all sources except IL, RC, AND LT, use Eq. 2-9 to compute L_{dn} value. The term (10 log N) should be adjusted to $N=(N_d+10N_n)(N_L/N_v)$ in Eq.2-9. The additional term (N_L/N_V)represents the number of locomotives at each virtual source (e.g., if there are three virtual sources and six locomotives, then the effective number of locomotives at each virtual source is: 6/3=2)
- For quasi -- continuous noise events (IL, RC, and LT) use the one-hour L_{eq} equation:

$$L_{dn} = SEL_T + 10 \text{ Log } N - 13.8 \qquad 4 - 1$$

where

$SEL_T = L_{eq}(1)$, the 1-hour equivalent(continuous) noise level,

and $N = N_O + 10N_n$

* DO = reference distance, equal to 100 ft, between the source and the reciever

TABLE 4-3 Fixed Input Data for Railyard Noise Impact Model
Noise Source Data

INPUT DATA PARAMETER										
NOISE SOURCE	LMAX* (dBA)	$\bar{L}S$* (dBA)	NP	NL	N	NV	NES	EP	ALPHAG** (dB/FT)	DO (FT)
HS	90	95	2	1	1	1	1	1	.001	100
MS	90	94	2	2	1	1	1	1	.001	
IS	90	94	2	1	1	1	1	1	.001	
CS	90	94	2	1	1	1	1	1	.001	
IB	90	95	1	3 (1)	1	1	1	1	.002	
OB1	90	95	1	3 (2)	1	1	1	1	.002	
OB2	90	95	1	1	1	1	1	1	.002	
MR	111	108	1	1	2	1	2	0.50	.010	
IR	93	90	1	1	2	1	1	0.85	.010	
CI	99	94	1	1	2	2 (3)	1	0.50	.005	
IL	66	66	NA	NA	2	NA	NA	NA	.0025	
RC	73	67	NA	NA	2	NA	NA	NA	.0035	
LT	90 (4)	87 (4)	NA	NA	2	NA	NA	NA	.0020	
GT	82	94.5	1	1	2	1	2	1	.0020	
CT	83	106.5	1	1	2	1	4	1	.0020	
Moving Source Group									.002	
Stationary Source Group									.005	

* Reference (at 100 ft.)

(1) 1 for Industrial and Small Industrial Yards

(2) 1 for Small Industrial Yards

(3) 4 for Flat Classification Yards

(4) These values are reduced by 12 dB in the model when it is assumed that the source standard for load test cells requires a noise absorbing barrier to be used at the test cell site.

NP — Number of pass-bys , NL — Number of Locomotives , N

NV — Number of virtual Sources , NES — Number of Noise Events.

EP — Noise Event probability NA — Number of Areas in the yard

** ALPHAG — Combined Air and Ground Absorption for Major Railyard Noise Source

4.3.3 L_{dn} at DN for each source

The L_{dn} at the receiving property should be corrected by the noise propagation attenuation, including geometrical spreading correction (Eq. 2-10), ground and air attenuation coefficient (as ALPHAG in Table 4-3, or calculated by Eqs. 2-15, 2-16), noise barrier attenuation coefficient (Eq. 2-14), insertion loss due to buildings (Table 2-4), etc.

4.3.4 Source Group L_{dn} at DN

The source group L_{dn} at DN is the summation of L_{dn} values for each noise source, expressed as:

$$L_{dn} = 10 \, \text{Log}[\sum_j 10^{L_{dnj}/10}] \qquad 4 - 2$$

where

L_{dnj} = L_{dn} value for the jth source

4.3.5 Background L_{dn}

The background (or ambient) noise level, due to other than railyard noise sources is determined from the site-specific level based on average population density values for each place size and density range class according to the formula:

$$L_{BG} = 22 + 10 \, \text{Log}\rho \qquad 4 - 3$$

where

L_{BG} = background(non-railroad source), dB

ρ = local average population density (people/sq.mi.)

when:

$\rho \geqslant 1585$, $\quad L_{BG} = 54$ dB

4.3.6 Composite L_{dn} at DN

To combine the source group L_{dn} with the background L_{dn} one uses the formula:

$$L_c = 10 \text{ Log } (10^{L_G/10} + 10^{L_{BG}/10}) \qquad 4 - 4$$

where

L_c = composite L_{dn}, dB

4.3.7 Impact Areas for 1 dB Increments

The basic noise impact relationship is given by Eq. 2-20 (ENI = FI.A.P), where the area (A) is a function of source type, either moving or stationary, and population density (P) is a function of place size and population density range. The general equations for computing A were developed on the basis of eliminating the area inside the yard boundary in the determination of noise impact areas. The area expressions for the two different types of sources are for either segments of circles (for stationary sources) or rectangular strips (for moving sources).

$$A = \begin{cases} L_0(D - D_0) & \text{for moving source} \\ D^2 \cos^{-1}(D_0/D) - D_0\sqrt{D^2 - D_0^2}, & \text{for stationary sources} \end{cases}$$

where

L_0 = Characteristic path length for moving sources

D = Distance from source to receiving location

D_0 = Distance from source to railyard boundary

The characteristic path length for the switch engines and locomotives was determined on the basis of the 120 yard samples evaluated. The resulting L_0 values ranged from 790 to 2,070 meters, depending on type of yard and traffic rate (see Fig. 4-2).

Yard Type	Representative Railyard Dimension (m)							
I. Hump Classification:	d_1	d_2	d_3	d_4	l_1	l_2	d	l
Traffic Rate:								
Low	43	137	64	192	1556	1129		
Medium	43	146	95	192	1952	1312		
High	55	171	113	229	1952	1739		
II. Flat Classification:								
Traffic Rate:								
Low	31	107	34	107	793	854		
Medium	31	137	34	128	976	1312		
High	92	183	92	214	1251	2074		
III. Industrial							70	1312
IV. Small Industrial							52	1009

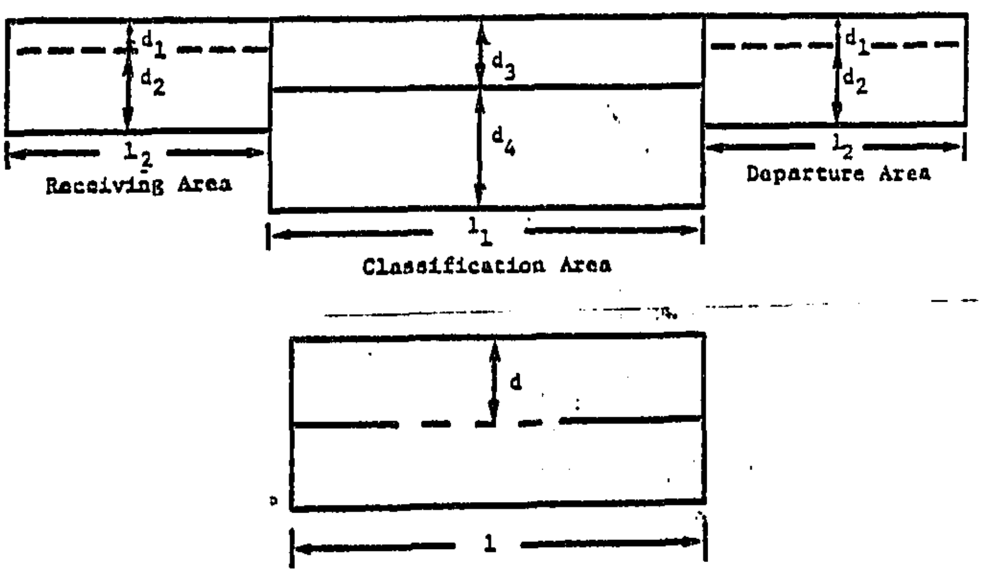


Fig 4-2 Representative Configuration for Railyard

According to Eq. 4-5, the incremental areas (A_i) are computed by:

$$A_i = D^2_{i+1} \cdot \cos^{-1}(DN/D_{i+1}) - DN\sqrt{D^2_{i+1} - DN^2} - \left[D_i^2 \cdot \cos^{-1}(DN/D_i) - DN\sqrt{D_i^2 - DN^2}\right] \quad \text{for stationary sources}$$

$$A_i = L_0(D_{i+1} - D_i) \quad \text{for moving source} \qquad 4 - 6$$

where

A_i = incremental areas

D_i = distance from source to near side of area increment,

D_{i+1} = distance from source to far side of area increment.

In practice, we often want to know the value of (D_{i+1} - D_i) for each 1 dB decrement. Then we can use Eqs. 2-22, 2-24:

$$D = 100\text{ft} \times 10^{[L_{dn}(100) - L_{dn}(i)]} \, (10^{1/10} - 1) \qquad 4 - 7$$

where

D = distance increment.

In other words, the distance increment is 12.2% for each per 1 dB decrement.

4.3.8 ENI for Each 1 dB Band and Sum of ENI Over Impact Area

At first, we use Eq. 2-18 to calculate the Fractional Impact (FI) in each 1 dB decrement band. Average L_c for each incremental area in computing ENI_i:

$$\overline{L_{ci}} = L_{ci} - 0.5 \text{ dB} \qquad 4 - 8$$

therefore:

$$FI_i = 0.05\,(L_{ci} - 55.5) \qquad 4 - 9$$

where L_{ci} is the composite L_{dn}, in the ith band

For each 1 dB band, the ENI_i is expressed as:

$$ENI_i = FI_i \times \rho_i = FI_i \times A_i \times \rho \qquad 4 - 10$$

And the total ENI_i can be summarized by $\sum_i ENI_i$.

Thus, starting at DN and continuing across the receiving property, increments of area are defined (D_i is computed) such that L_{ci} decreases 1 dB for each successive area increment until either the far side of the property is reached or L_c decreases to 55 dBA, which is the criteron level. FI_i and ENI_i are computed for each area increment, and the ENI_i values are summed to obtain the total ENI value. Also, the total area to L_{dn} = 55 dBA is multiplied by A to obtain the Population Exposed (PE) value.

4.4 Total National Impact

When the ENI values have been computed for a sample of railyards for one of each of the four types of railyards, the ENI associated with all the railyards of that type Nationally is estimated by:

$$ENI_s = \sum_i ENI_i, \text{ and} \qquad 9 - 11$$

$$ENI_t = ENI_s \cdot (N_t/N_s) \qquad 9 - 12$$

where

ENI_s = total ENI for the sample railyards (of a particular type)

N_s = number of railyards in the sample, and

N = estimated number of railyards nation-wide of that type.

4.5 Baseline Impact

A model run using data based on the estimated current conditions (as of 1971) for the identified sources at all the railyards established the baseline case. The baseline ENI and PE results are segregated in Table 4-4 which presents the computed ENI and PE values for each source type, and categorized yard type. The sensitivity to the assumptions regarding the treatment of external ambient noise levels is indicated by the range of computed values of baseline population exposed (6.5 to 10.2 million) and baseline ENI (1.74 to 1.94 million). The dominant contributors to the noise impact are switch engines, since these sources operate in all 4,169 yards and generally outnumber each of the other source types.

Table 4-4 BASELINE CASE
CONTRIBUTION TO TOTAL ENI AND PE FOR ALL YARD TYPES BY TYPE OF SOURCE

Source Type	ENI	PE
Inbound and Outbound Trains	201,180 - 214,200	1,082,100 - 2,311,500
Switcher Operations	1,243,300 - 1,400,100	4,274,800 - 5,957,000
Idling Locomotives	88,580 - 98,900	346,600 - 561,900
Retarders (Master, Group, Inert)	26,720 - 28,900	65,700 - 98,830
Refrigerator Cars	92,110 - 102,700	342,700 - 545,200
Car Impacts	50,400 - 55,400	256,500 - 509,920
Load Test Operations	39,930 - 44,300	141,200 - 208,900
	1,740,600 - 1,944,500	6,509,600 - 10,182,000

Ranges of values are due to different methods for handling the external ambient noise level. Any inconsistencies in numerical values are attributable to round off. See text for further explanation.

The detailed listing of noise impact (ENI) by noise source and yard type is presented in Table 4-5.

Table 4-5
BASELINE CASE

CONTRIBUTION TO TOTAL ENI BY TYPE OF SOURCE AND TYPE OF YARD

Yard Type (No. of Yards)	Source Type	ENI	% ENI for Yard Type	% of Total ENI all Yards
Hump: (124)	Inbound and Outbound Trains	65,200	23.8	3.5
	Switchers (Hump, Industrial, Make-up)	154,100	66.2	8
	Idling Locomotives	7,000	2.6	
	Master Retarder Group	27,000	9.8	
	Inert Retarder Group	1,900	0.7	
	Refrigerator Cars	8,900	3.2	
	Car Impacts	4,200	1.5	
	Load Tests	5,900	2.2	
	Subtotal	274,200	100	14
Flat Classification: (1113)	Inbound and Outbound Trains	126,700	13.4	6.5
	Switchers	564,000	59.9	29
	Idling Locomotives	91,900	9.8	
	Refrigerator Cars	93,800	10.0	
	Car Impacts	27,400	2.9	
	Load Tests	38,400	4.1	
	Subtotal	942,200	100	48.5
Industrial and Small Industrial (2932)	Inbound and Outbound Trains	22,300	3.1	
	Switchers	682,000	93.7	35
	Car Impacts	23,800	3.2	
	Subtotal	728,100	100	37.5
	TOTAL	1,944,500		

4.6 Summary

A flow diagram for the model elements and ENI computing procedure is shown in Figure 4-3. A computerized model for the rail yard noise impact assessment, programmed according to the relationships detailed above, was exercised using baseline noise level data and activity parameters to obtain the total baseline ENI for all the railyards. Because the typical configuration of the hump and flat classification yards is asymmetrical, the near side and far side ENI values were computed separately and added to obtain the total baseline ENI.

The calculation procedure may be summarized as follows:

For yard noise impact, compute the ENI for each source for each yard cetegory according to the following sequence:

- Select yard type, traffic rate, place site and source.
- Find L_{dn} from yard/source matrix.
- Compute L_{dn} per D for each 1 dB interval, using appropriate N, K_1 and K_2 values relative to source and population density range.
- Compute FI for each successive strip area using the L_{dn} average relative to the strip boundaries.
- Compute strip area (A_i) between successive D values (in accordance with the type of source). Continue out to boundary of noise impact area.
- Compute ENI_i for each strip area using the appropriate population density value for the place size.
- Sum the ENI_i values to obtain the ENI for each density range for the selected conditions. Multiply the ENI value by the number of railyards in the particular yard category selected.

- Repeat the procedure and sum the ENI values for all the sources, all the population density ranges, all the place size classes and all the railyards for the selected yard type and activity level.
- Repeat the procedure for each of the yard types and obtain the grand total ENI for all sources, yard types, activity levels, etc.

Acknowledgements

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* Office of Noise Abatement and Control

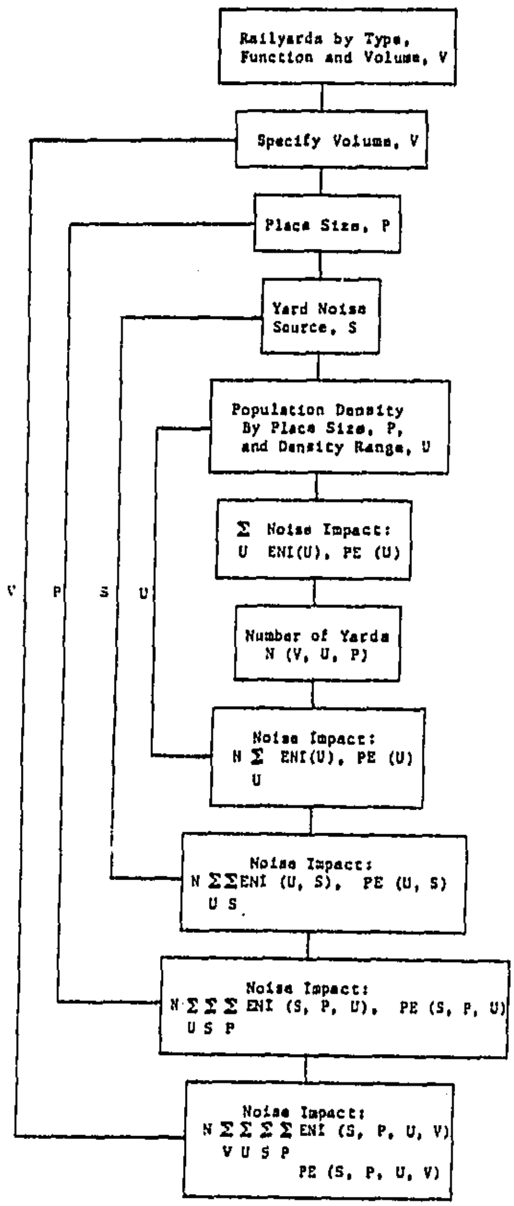

FIGURE 4-3. RAILYARD NOISE IMPACT MODEL

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