REPORT NO. FRA/ORD-80/91

PB 81 154 395

Thomas

ASSESSMENT OF LOCOMOTIVE CREW IN-CAB OCCUPATIONAL NOISE EXPOSURE

ROGER D. KILMER

NATIONAL BUREAU OF STANDARDS
NATIONAL ENGINEERING LABORATORY
WASHINGTON, DC 20234

DECEMBER 1980
FINAL REPORT

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22161.

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington, D.C. 20590

NOTICE

NOTICE

Technical Report Documentation Page

1. Report No. FRA/ORD-80/91	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ASSESSMENT OF LOCOMOTIVE CREW IN-CAB OCCUPATIONAL NOISE EXPOSURE		5. Report Date December 1980
		6. Performing Organization Code
7. Author(s) Roger D. Kilmer		8. Performing Organization Report No.
9. Performing Organization Name and Address National Bureau of Standards National Engineering Laboratory Washington, DC 20234		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Rail Safety Research Washington, DC 20590		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The railroad industry, unlike most other U.S. industries, is not subject to the safety regulations of the Occupational Safety and Health Administration. Instead, railroad workers are covered by the safety regulations of the Federal Railroad Administration (FRA). This report documents an extensive study designed to assess the noise environment in locomotive cabs. Operational duty cycle and in-cab sound level data are presented for 18 test runs made on 16 different locomotives used in wide range of operational modes (e.g., through freight and local transfer freights), varied terrains (mountainous, undulating and flat) and varied trip lengths (6 to 12 hours). The general conclusion of this study is that there does not appear to be a widespread problem of overexposure to noise based on the same type of evaluation as currently used by OSHA (only 1 out of 18 test runs exceeded the criteria). The noise exposure is within acceptable limits because the operational duty cycle is such that the sources which generate high sound levels (horn and brake) are operating only for short periods of time and because the locomotive spends a great deal of time in idle (diesel engine sound levels below 90 dB). However, there was one test run for which an overexposure to noise was measured. To pinpoint such cases where overexposure to noise may occur, a simplified testing procedure is developed. This test consists of making in-cab sound level measurements of engine notch 8 (no load), horn sounding and brake application with the locomotive stationary. With these three sound level measurements and an estimate of the time that the locomotive is operating on-line, the in-service noise dose can be estimated and a pass/fail assessment made of whether the noise exposure might exceed acceptable limits.

17. Key Words locomotive crew, simplified testing, in-cab sound level	18. Distribution Statement Document is available to the U. S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

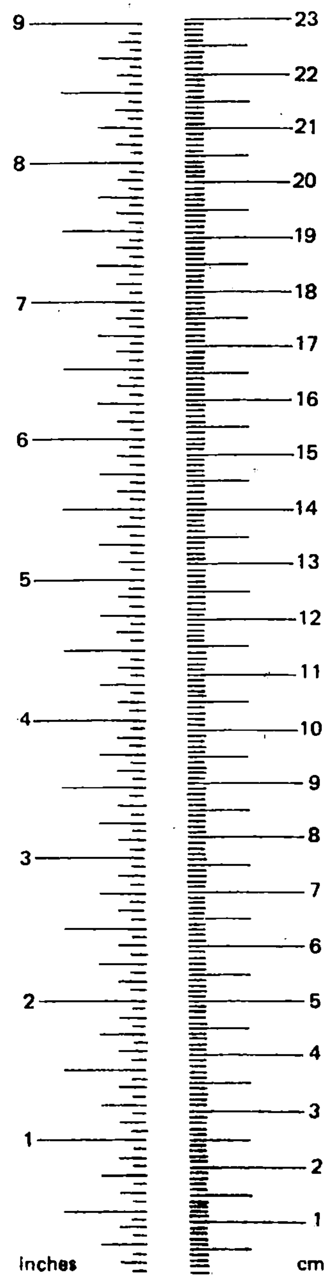
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

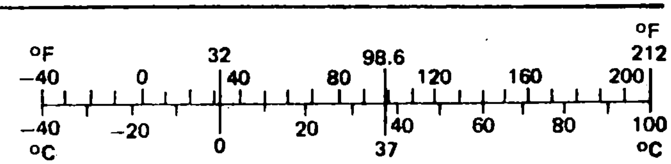


TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

LIST OF TABLES CONT.

LIST OF TABLES CONT.

LIST OF TABLES CONT.

Conversion Table to SI Units

This publication uses customary English units for the convenience of engineers and others who use them habitually. The table below is for the reader interested in conversion to SI units. For additional information see:

(1) NBS LC1056, November, 1977, "NBS Guidelines for Use of the Metric System."

(2) NBS SP330, August, 1977, "The International System of Units (SI)."

Quantity	To convert from	To	Multiply by
Length	inch	m (meter)	2.540×10^{-2}
	foot	m	3.048×10^{-1}
	mile	m	1.609×10^{3}
Area	in^2	m^2	6.452×10^{-4}
	ft^2	m^2	9.290×10^{-2}
Volume	in^3	m^3	1.639×10^{-5}
	ft^3	m^3	2.832×10^{-2}
	gallon	m^3	3.785×10^{-3}
Temperature	°F	°C	$t_{°C} = (t_{°F} - 32)/1.8$
T. difference	$\Delta t_{°F}$	K	$\Delta T_K = \Delta t_{°F}/1.8$
Mass	pound	kg	4.536×10^{-1}
	ounce	kg	2.835×10^{-2}
Pressure	psi	Pa	6.895×10^{3}
	in H_2O	Pa	2.488×10^{2}
	in Hg	Pa	3.386×10^{3}
	mmHg	Pa	1.333×10^{2}
Energy	Btu	J	1.055×10^{3}
	MBtu	J	1.055×10^{9}
	kWh	J	3.600×10^{6}
	ft • lbf	J	1.356×10^{0}
	kilocalorie	J	4.187×10^{3}
Power	Btu/h	W	2.931×10^{-1}
	hp	W	7.457×10^{2}
Flow	gal/min	m^3/s	6.309×10^{-5}
	ft^3/min	m^3/s	4.719×10^{-4}
Density	lb/ft^3	kg/m^3	1.602×10^{1}
	lb/gal	kg/m^3	1.198×10^{2}
Heat Capacity	Btu/(lb • °F)	J/(kg • K)	4.187×10^{3}
	Btu/(ft^3 • °F)	J/(m^3 • K)	6.707×10^{4}

EXECUTIVE SUMMARY

This report documents an extensive study designed to investigate and assess typical in-cab diesel locomotive noise environments in terms of crew noise exposure. In addition, the effects of different locomotive operations and terrain features on the in-cab noise environment were determined. A field test program was conducted to provide the necessary information. Eighteen test runs (16 locomotives, two of which had two crews) were made. These 16 locomotives covered a range of locomotive models representing over 80 percent of the types found in the current U. S. locomotive fleet population. The 18 test runs covered a wide range of operational conditions (high speed through-freights, slow speed drag-freights, local transfer movements, etc.), varied terrains (mountainous, flat, undulating,), and varied trip lengths (6 to 12 hours). The data obtained from the program consisted of operational duty cycle information and in-cab sound level data. These were used to evaluate the crew noise exposure in terms of the OSHA noise dose (and other alternative criteria) and to determine which locomotive operations and/or terrain features significantly affected the noise exposure. To pinpoint cases where overexposure to noise may occur, a simplified testing procedure was developed. This procedure, based on in-cab sound level measurements with the locomotive stationary, provides an estimate of the in-service crew noise dose which can be used to make a pass/fail assessment of whether the noise exposure might exceed acceptable limits.

The major results of the investigation and evaluation are:

- The operational duty cycle varies widely from run to run, and even from day to day over the same route depending upon the type of train, the train weight, the amount of traffic on the route and whether there are any cars to be picked up or set off or unscheduled stops because of mechanical problems.

- While the train is underway, approximately 40 percent of the time is spent in notch 8, 25 percent at idle/notch 1, and the remaining 35 percent distributed about equally among notches 2 through 7.

- Inclusion of the time that the train is standing and not operating online increases the average time spent at idle/notch 1 to almost 62 percent and reduces the average notch 8 time to 20 percent with the remaining 18 percent in notches 2 to 7. Thus, during a good portion of the time the crew is in the cab, the locomotive is being operated such that the engine noise levels are likely to be below 90 dB.

- In general, the sound levels are not a significant function of spatial location inside the locomotive cab. The sound generated by venting the brake pipe is the one exception to this. The highest sound levels for the brake occur at the engineer left-side microphone location which is nearest to the brake pipe vent.

- The three principal sources of in-cab locomotive noise are the diesel engine, horn and brake. The radio is also important, but the sound levels it generates vary as a function of both the in-cab sound levels due to the diesel engine and the personal listening preference of each engineer. Other sources, such as the bell, warning alarms, and dynamic brake, either have little influence on the in-cab sound levels or occur very infrequently.

- Both the stationary and in-service data show that the in-cab sound levels increase with notch setting. Based on linear regression analysis of the mean values for the 16 test locomotives, the sound level increases approximately 1.5 dB per notch setting for stationary conditions (windows open or closed), and 0.6 dB per notch setting for in-service conditions.

- The in-cab sound levels are more greatly influenced by window position for sources which are located outside the cab. This is particularly true for the horn (a range of 0.5 to 13.1 dB reduction with the windows closed) and to a lesser extent the diesel engine (0.9 to 2.2 dB decrease with the windows closed). Window position and quality of sealing are especially important for locomotive operations in tunnels.

- In general, terrain features, such as grades and cuts, do not have much effect on the in-cab sound levels. Tunnels, on the other hand, can lead to significant increases. For Test Runs 10, 11 and 12, which had a relatively large number of tunnels, the in-service equivalent sound levels for tunnels are approximately 4 to 7 dB higher than the equivalent sound levels for the overall trip.

- Based on the group of locomotives tested, it does not appear that overexposure to noise is a widespread problem for locomotive crews under the current OSHA standard. Of the 18 test runs, only the locomotive on Test Run 2 (which was being used in an atypical situation) failed the OSHA criteria.

- For a criterion value of 90 dB at 8 hours there is only one case of overexposure (Test Run 2) regardless of the threshold level (90, 87 or 85 dB). If the criterion value is reduced to 85 dB at 8 hours, the locomotives on Test Runs 2 and 7 would exceed the allowable limits for an 85 dB threshold level. For a threshold level of 80 or 82 dB, the locomotives on Test Runs 14 and 15 would also exceed the allowable limits.

- The crew noise doses calculated from the lapel microphone recordings are generally higher than the noise doses for the fixed microphones. This difference is due primarily to the fact that the lapel microphones are located closer to the crew members' mouths so that the sound levels due to conversation are higher than at the fixed microphones. This results in the noise dose also being higher.

- The two principal locomotive operations contributing to the crew noise dose are engine notch 8 and horn soundings, with some smaller contribution from the brake and engine notch 1.

- Of the various terrain features examined, only tunnels are found to have a significant affect on the crew noise dose. For features such as upgrades, downgrades and cuts, the noise dose is a function of duration and not the terrain.

- A simplified testing procedure based on in-cab sound level measurements of engine notch 8 (no load), horn sounding and brake application with the locomotive stationary appears to be a reasonable approach to making a pass/fail assessment of locomotive crew noise exposure. However, additional data are necessary to improve the statistical confidence of the stationary screening test prediction.

Based on these results, there does not appear to be a widespread problem of overexposure to noise for locomotive crews under current FRA regulations. However, as was seen for the locomotive on Test Run 2, there can be cases where overexposure to noise can occur when certain locomotives are used on certain runs. These cases, where overexposure to noise might occur, can be pinpointed using a stationary screening test procedure. If alternative hearing conservation criteria, such as that proposed by NIOSH, are adopted, the number of cases of overexposure to noise would increase and the stationary screening test procedures would have to be reexamined to determine their applicability.

1.0 INTRODUCTION

Noise has long been recognized as a contributing factor in hearing damage [1][1]. As such, the prospect of workers incurring hearing damage as the result of occupational exposure to noise is recognized in American industry as a potential safety and health hazard. In order to minimize this risk potential, the Occupational Safety and Health Administration (OSHA), acting under the authority of the Occupational Safety and Health Act of 1970, has established regulations for maximum allowable occupational noise exposure [2]. These regulations are applicable to all workers not otherwise subject to safety and health related regulations issued by other Federal agencies. In the railroad industry, operating employees fall under this latter class of potentially exempted workers since they are subject to the safety regulations of the Federal Railroad Administration (FRA) as outlined in the Federal Railroad Safety Act of 1970 [3].

On March 7, 1975, the FRA published an Advance Notice of Proposed Rule Making titled "Railroad Occupational Safety Standards" [4] in which it proposed to adopt many of the OSHA Occupational Safety and Health Standards including 29 CFR 1910.95 "Occupational noise exposure." Because of an interest in locomotive crew noise exposure, the FRA decided that a study of railroad noise environments should be conducted to determine the extent of railroad worker noise exposure and to obtain the

[1]Numbers in brackets refer to references listed in Section 8.0 of this report.

information necessary to provide railroad workers with hearing conservation protection.

As a first step, the FRA decided to investigate railroad locomotive crew noise exposure. Through an Interagency Agreement, the FRA arranged for the National Bureau of Standards (NBS) to conduct a cooperative study with the Association of American Railroads (AAR) and four operating railroads--Consolidated Rail Corporation, Seaboard Coast Line Railroad Company, Southern Pacific Transportation Company and Southern Railway System--to assess the noise environment in locomotive cabs. The objectives of this study were to determine the characteristic noise levels in locomotive cabs for various operational duty cycles and to investigate simplified testing procedures which might be used to assess crew noise exposure for actual over-the-road runs. This report presents a description of the measurement methodology and instrumentation system used to collect the necessary data base, an evaluation of the noise environment in locomotive cabs for actual over-the-road operations, and the development of test procedures for routinely assessing the occupational noise exposure of railroad locomotive crews.

On March 31, 1980, the FRA published the final rule titled, "Railroad Locomotive Safety Standards and Locomotive Inspections." This rule now defines the present noise regulations for the locomotive cab.

2.0 OCCUPATIONAL NOISE EXPOSURE

In developing this program, initial consideration was given to the question of which hearing conservation criteria should be used as a "benchmark" to assess the locomotive cab noise environment. This was necessary in order to design a measurement program and instrumentation system that would provide all of the required data to compare with the chosen hearing conservation criteria. A review of the literature on the subject indicates that, while many hearing conservation criteria exist, the OSHA Occupational Noise Exposure Standard [2] is most commonly used in the United States and therefore is probably most appropriate for this study.

The current OSHA noise regulation utilizes a time-weighted averaging scheme that takes into account the intensity and duration of the noise to which the worker is exposed. The time/intensity relationship utilized by OSHA is illustrated in Figure 1.[2] There are three important characteristics which describe this relationship:

Criterion Value - reference value for determining allowable noise exposure, usually defined as the maximum steady-state sound level permitted for 8 hours of exposure,

Tradeoff Rate - defines the relationship between the equivalent steady-state sound level and the allowable exposure time at that level, i.e., the slope of the line in Figure 1, and

[2]It should be noted that the OSHA Occupational Noise Exposure Standard specifies that the sound levels be measured using A-weighted, "slow" response as specified in ANSI S1.4-1971 [5]. All data presented in this report are A-weighted, "slow" response sound levels unless stated otherwise.

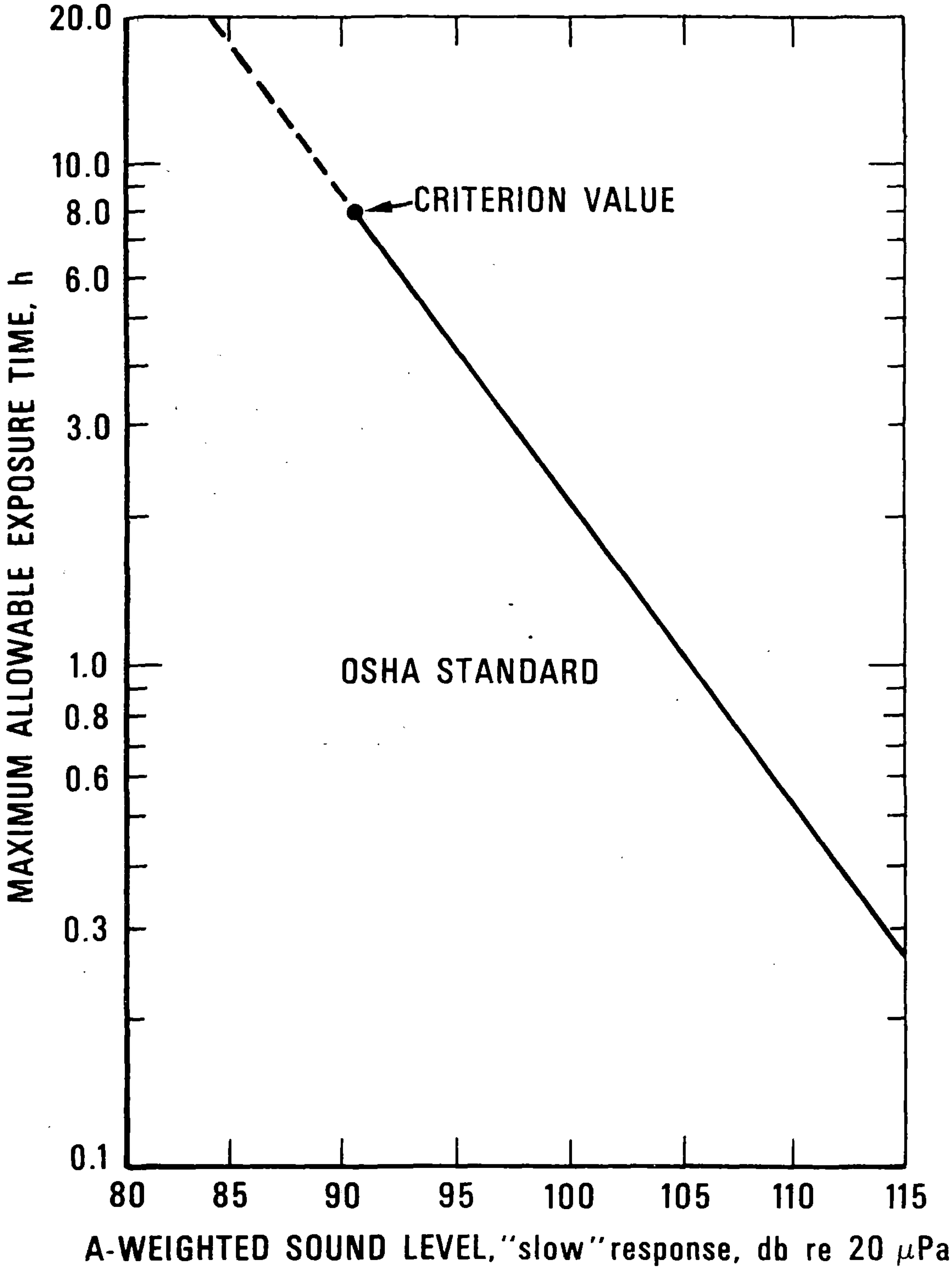


Figure 1. Time/intensity relationship for the current OSHA standard [2].

Threshold Level - steady-state sound level below which it is assumed that there is no contribution to potential hearing loss.

As shown in Figure 1, as the sound level increases the maximum allowable exposure time at that level decreases. The "trade-off" rate between level and duration is 5 dB for each doubling of duration, e.g., 8 hours of exposure is permitted for a sound level of 90 dB, but only 4 hours is permitted at 95 dB. In equation form, the maximum allowable time based on the OSHA standard is given by

$$T = 8x2^{\left[\frac{90-L}{5}\right]}, \qquad (1)$$

where T = maximum allowable time, hours, and

L = A-weighted, "slow" response sound level, dB.

The noise exposure or noise "dose" of the worker is determined by dividing the actual time exposed to a given sound level by the maximum allowable time at that sound level obtained from Figure 1. If the worker is exposed to several different sound levels, the dose is the sum of the ratios of the actual times divided by the maximum allowable times. Mathematically this can be expressed as:

$$\text{Noise Dose} = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \ldots + \frac{C_n}{T_n}, \qquad (2)$$

where, C_n = actual time exposed to a given sound level, hours

T_n = maximum allowable time at that given sound level, hours.

The criterion for allowable noise exposure requires that the noise dose be less than 1.0. A noise dose of 1.0 or greater indicates that the hearing conservation criterion has been exceeded and that there is a risk of potential hearing damage.

Two other items to note in Figure 1 are the upper sound level limit of 115 dB and the baseline or threshold level of 90 dB. Under the current OSHA standard, no exposure time is permitted for sound levels in excess of 115 dB. Thus, if a worker is exposed to levels above 115 dB, this automatically indicates that the OSHA criteria are exceeded.

The threshold level of 90 dB represents the baseline for determining a workers noise exposure. This means that any time spent in an environment where the sound level is less than 90 dB is not included in the noise exposure or "dose" calculation for the worker. This is demonstrated in the following example. Assume a machine shop worker does the following tasks in an 8 hour day:

lathe operation - 2 hours at 91 dB
stamping - 2 hours at 95 dB,
punch press - 0.25 hour at 97 dB, and
parts inspection - 3.75 hours at 83 dB.

The OSHA noise dose is then calculated by dividing the actual time by the maximum allowable times at each sound level above 90 dB and summing the results. The noise dose for this example is

$$\text{Noise Dose} = \frac{2}{7.0} + \frac{2}{4.0} + \frac{0.25}{3.0} = 0.87.$$

Since the noise dose is less than 1.0, the OSHA hearing conservation criterion is not exceeded. Note that in the above calculation the time spent inspecting parts is not included since the sound level is below the threshold of 90 dB.

The OSHA standard is based on an 8-hour work day. This is appropriate for most industrial situations, but the FRA hours of service rules permit railroad locomotive crews to work as long as 12 hours [6]. Hearing damage data for exposures greater than 8 hours are limited and no legally established procedures for dealing with such cases exist. One possibility might be to extend the threshold level to the sound level corresponding to 12 hours. From Figure 1 or Equation (1), this sound level is 87.1 dB for the OSHA standard.

Another approach proposed by OSHA, but not yet legally adopted, was to lower the threshold level to 85 dB [7]. The criterion value remains 90 dB for 8 hours but exposures to levels as low as 85 dB are included in the noise dose calculation. Referring to Figure 1, this corresponds to extending the solid line to the threshold level of 85 dB, which has a maximum permitted exposure of 16 hours. This same procedure has been proposed by FRA for regulating in-cab locomotive noise [8]. In this report, the noise dose is calculated using both the 85 and 87.1 dB threshold levels, in addition to the 90 dB value specified in the current OSHA standard. This is done to give some idea of the effect of possible future revisions of hearing conservation criteria on in-cab locomotive noise exposure.

Two other hearing conservation criteria which are being considered are the National Institute for Occupational Safety and Health (NIOSH) proposed 85 dB criterion value [9] and the equal-energy criteria [10]. The proposed NIOSH criteria are similar to the current OSHA standard with a time/intensity trade-off of 5 dB per doubling of duration. The difference is that the NIOSH proposal would reduce the criterion value to 85 dB at 8 hours with an 80 dB threshold level. The equal-energy criteria, on the other hand, assume that the hearing-damage risk is determined by the total amount of sound energy to which the worker is exposed, so that the trade-off is 3 dB per doubling of duration and there is no threshold level. These criteria are plotted along with the OSHA standard in Figure 2. (For sake of comparison, a criterion value of 90 dB at 8 hours is assumed for the equal-energy criteria.) As a further comparison of the differences between these criteria, if the example of the machine shop worker were repeated, the noise doses would be 2.09 for the NIOSH criteria and 1.36 for the equal-energy criteria. Both of these proposed criteria would be exceeded in this case.

The noise dose calculations in this report are based on the 90 dB at 8 hour criterion value with a 90 dB threshold level as specified in the OSHA standard (except where overall comparisons are made). The NIOSH and equal-energy hearing conservation criteria are mentioned only to demonstrate the effect on the noise dose calculation. If new regulations were adopted which used either of these criteria, the material presented in this report would have to be reexamined to determine its applicability.

The primary concept that should be remembered is that the noise dose is a function of both sound level and duration. Even though a worker is exposed to high sound levels (i.e., greater than 90 dB), the OSHA criteria may not be exceeded if the exposure times are sufficiently short (unless 115 dB is exceeded). Thus in examining railroad locomotive noise, not only must the characteristic sound levels of the different sources and operations be determined, but also the typical duration or operational cycle. This concept of sound level versus duration is also important in determining which

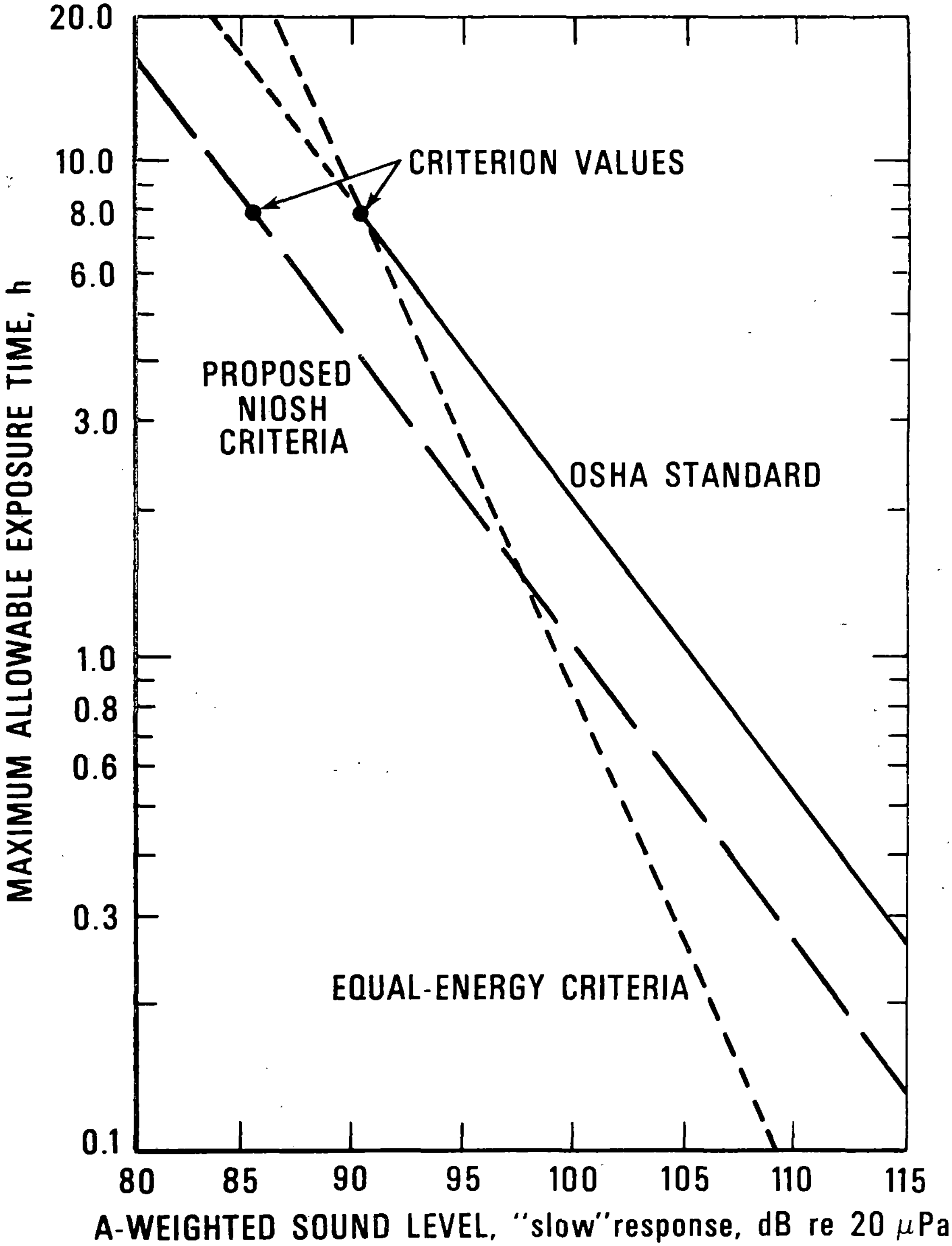


Figure 2. Comparison of the time/intensity relationships for the current OSHA standard [2], the proposed NIOSH criteria [9], and the equal-energy criteria [10].

types of railroad locomotive operations are most likely to have cases of overexposure to sound e.g., switching versus over-the-road freight. Because in-cab sound level and operational duty cycle data are extremely limited, only engineering estimates can be made regarding the various types of locomotive operations. Based on the available data and conversations with FRA and AAR staff, railroad locomotive operations are broken down into four general categories: switching, long division or drag freight, short division or passenger and electric commuter. The relative qualitative estimates of sound level and exposure time for these four categories are:

Operation	Sound Level	Exposure Time
switching	low	high
long division or drag freight	high	high
short division or passenger	high	low
electric commuter	low	low

This is illustrated in Figure 3. As shown here, locomotives operated in divisions which have long runs, or where slow drag freight movement is involved, are most likely to have problems with excessive noise exposure because of the high sound levels and long exposure times. On the other hand, switching operations, which have long exposure times but little notch 8 operations and thus low sound levels, and short division or passenger trains, which have high sound levels but short exposure times, are less likely to have situations where excessive noise exposure occurs.

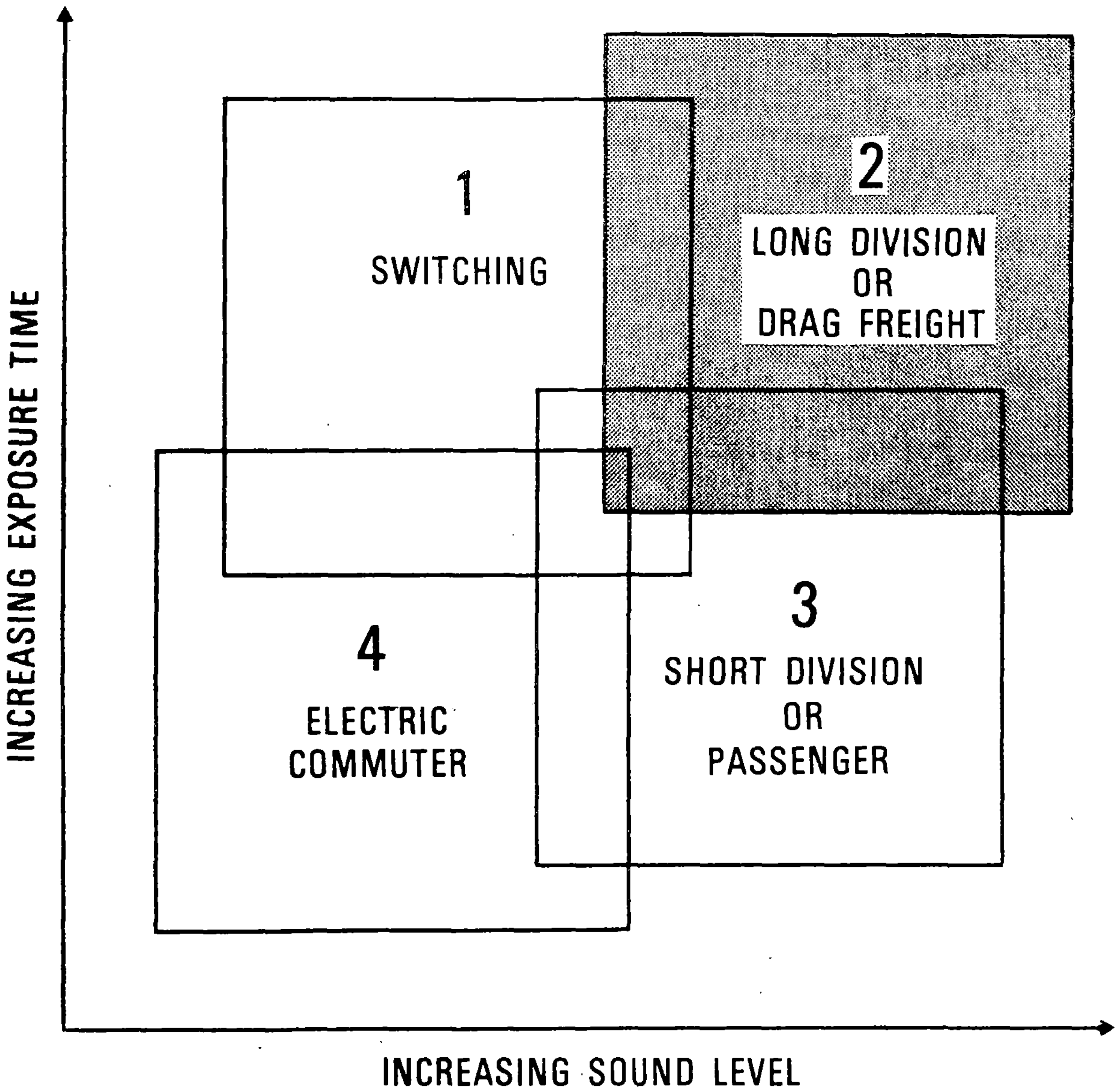


Figure 3. Approximate relationship between sound level and exposure time for various types of locomotive operations.

These, of course, are only qualitative estimates and are not intended to imply that there are not cases of overexposure to noise for these other operations. It merely means that the potential for overexposure to noise is greater for long division and drag freight operations. Thus, this initial study was limited to examination of long division and drag freight operations.

3.0 EXISTING LOCOMOTIVE DATA

In developing this program, initial efforts were directed at examining the available information on in-cab locomotive noise, typical locomotive operations, and the make-up of the current locomotive fleet. This information is useful in assessing the potential problem of in-cab locomotive noise and in determining what types of locomotives and locomotive operations are most prevalent. These data formed the basis for the development of the field measurement program.

A review of the literature showed that a breakdown of the U. S. locomotive fleet existed, but that data on in-cab locomotive noise and locomotive operations were limited. In no case had noise and duty cycle data been recorded simultaneously to permit evaluation of the noise dose. Thus, a survey of the current locomotive fleet was necessary to develop the required data base.

The remaining portion of this section is divided into three subsections dealing with in-cab locomotive noise, locomotive operations and the make-up of the locomotive fleet. Although limited, the data do indicate that cases of overexposure to noise could occur given the right combination of locomotive and trip length.

3.1 In-Cab Noise

The majority of data that are available on locomotive noise are for exterior measurements, primarily in regard to the EPA Interstate Rail Carrier Noise Emission Standards [11]. Although rank ordering of different types of locomotives according to these data is possible, the information necessary to infer in-cab noise levels from exterior noise measurements does not exist.

The data on in-cab noise that previously were available consisted primarily of maximum A-weighted sound levels for horn and brake applications and for the eight engine notch settings under load and no load conditions. Although this is useful information, without some knowledge of the operational duty cycle, e.g. the duration and number of horn applications and the amount of time spent in notch 1, notch 2, etc., assessment of crew noise exposure is not possible.

The data found in the literature are listed in Tables 1 and 2. These data are for either stationary or over-the-road operating conditions for five types of locomotives. The operating condition during the measurement, engine notch setting and measurement location in the cab, if specified in the original reference, are also listed in these tables. The following general conclusions can be made based on these data:

1) In-cab noise levels increase with engine notch setting.

2) Horn and brake applications generate noise levels greater than that generated by the engine, even at notch 8.

3) In most cases there is little difference in noise level between the engineer's position and the fireman's or brakeman's position in the cab.

4) At low notch settings there is practically no change in noise level due to opening or closing the cab windows. At notch 8, opening the windows increases the noise level in the cab by 2.5 to 4 dB.

These results are not surprising considering the physical construction and layout of most diesel electric locomotives. The general design consists of a diesel engine hard-mounted to the main frame rails and exhausted out of a stack through the top of the locomotive hood. The diesel engine drives an

Table 1. In-cab noise levels for various locomotives operating under stationary or over-the-road test conditions.

LOCOMOTIVE MODEL	OPERATING CONDITION DURING MEASUREMENT	LOCOMOTIVE NOISE SOURCE	ENGINE NOTCH SETTING	MEASUREMENT LOCATION IN CAB	A-WEIGHTED SOUND LEVEL, dB re 20 μPa	REFERENCE
EMD SD45	lead unit in consist with another SD45 operating on-line pulling 72 car, 4065 ton freight train a) light load, medium speed b) heavy load, low speed	engine (a)	unspecified	unspecified	92	12[1]
		" (b)	"	"	88	
		horn (a)	unspecified	unspecified	98	
ALCO AGP-20-MSC	operating on-line pulling 4 car passenger train medium load, medium speed	engine	unspecified	unspecified	90	12[1]
		horn	"	"	93	
		brake	"	"	105	
EMD F7A	stationary, connected to load cell a) windows closed b) windows open c) engine room door open	engine (a)	1	unspecified	75	13[2]
		"	2	"	78	
		"	3	"	81	
		"	4	"	85	
		"	5	"	88	
		"	6	"	89	
		"	7	"	90.5	
		"	8	"	90.5-92.5	
		engine (b)	8	fireman's position	91	
		engine (c)	8	"	105	
		horn (b)	8	"	103	
		brake (b)	8	unspecified	98	
		crossing bell (b)	8	"	91	
EMD GP9	stationary, connected to load cell a) windows closed b) windows open c) engine room door open	engine (a)	1	engineer's position	71	13[2]
		"	2	"	74	
		"	3	"	80	
		"	4	"	81	
		"	5	"	84	
		"	6	"	85	
		"	7	"	88	
		"	8	"	87	
		engine (b)	8	fireman's position	94	
		engine (c)	8	"	100	
		horn (b)	8	"	102	
EMD GP7	operating as switching engine pulling 25 loaded cars	engine	1	engineer's position	70	14[2]
		"	8	"	92-95	
		horn	1	"	93	
		brake	1	"	92-97	
		emergency brake	1	"	116-120	
	stationary, connected to load cell, window position unspecified	engine	8	engineer's position	95	15[1]
		horn	1	"	104	

[1] Measurements made using a sound level meter, meter response unspecified.

[2] Measurements made using a sound level meter, meter set for "fast" response.

Table 2. In-cab noise levels for an EMD SD40-2 locomotive operating by itself. Measurements were made at positions corresponding to 6 inches from the engineer's and brakeman's ears using a sound level meter set for A-weighting and "slow" meter response [16].

SPEED, mph	THROTTLE NOTCH SETTING	WINDOW POSITION	A-WEIGHTED SOUND LEVEL, dB re 20 μPa			
			SHORT HOOD FORWARD*		LONG HOOD FORWARD*	
			ENGINEER	BRAKEMAN	ENGINEER	BRAKEMAN
10	Idle	Closed	68	68	--	--
10	1	Closed	69.5	69.5	69	69
10	1	Open	71	71.5	69.5	70
20	Idle	Closed	68.5	69	--	--
20	1	Open	69.5	70.5	69.5	69.5
20	1	Closed	70.5	71	70.5	70.5
20	8	Closed	82.5	81.5	84	83.5
40	Idle	Closed	71	71	71	71.5
40	4	Closed	76	75.5	76.5	76.5
40	8	Closed	--	--	83	83
55	Idle	Closed	73.5	74	74	74
55	8	Closed	84	83.5	82	81.5
55	8	Open	--	--	84.5	85.5

*See Figure A-1 on page 154 for illustration of short hood and long hood ends of a locomotive.

electrical alternator which in turn drives electric traction motors on the axles. Since the cab is also hard-mounted to the same frame rails as the engine, a considerable portion of the in-cab noise is probably due to structure-borne noise propagated along the frame rails and radiated into the cab from the interior panels. Thus as the engine notch setting is increased, the engine speed and generated horsepower increase and as a result so do the in-cab noise levels.

The fact that the in-cab noise levels are affected by window position at notch 8 and not at low notch settings indicates that the principal sources of noise are most probably structure-borne engine noise at low notch settings and exhaust stack radiated noise at high notch settings. Although no data were reported, one would expect that window position would have an influence on in-cab levels due to horn operations, since the horn is located on the exterior of the cab, but not the levels due to brake applicatons since the brake pipe vent is inside the cab. Also, since the cab is a relatively hard, reverberant space, the noise levels would not be expected to vary significantly throughout the cab. This is verified by these data.

There are several specific items which should also be mentioned regarding these and other related data:

1) Opening the engine room door obviously has a significant effect on in-cab noise levels and must be considered when evaluating the crew noise exposure in locomotives [13].

2) The data from references [13] and [14] must be treated cautiously since measurements were made using "fast" rather than "slow" meter response as specified by OSHA. If relatively "steady-state" noise sources are being measured, such as engine noise, the difference between "slow" and "fast" response results may be small, but for transient events such as horn blasts or brake pipe ventings, this is not the case. For such events, a meter set for "slow"

response cannot respond fast enough. This results in a lower maximum sound level reading than if "fast" meter response were used. This is mentioned here because in Reference 14 the emergency brake application, which is a short duration, high intensity noise, generated levels greater than the 115 dB permitted by OSHA. If "slow" meter response had been used, these levels would probably have been lower than those reported and perhaps even less than 115 dB.

3) Locomotive diesel engine noise is composed primarily of low frequency components, with the largest component near 100 Hz. This is shown by the spectral data plotted in Figure 4 for conditions of engine only and engine with horn in use for an EMD SD45 locomotive [12]. For the particular horn used on this locomotive, the spectrum has a primary peak at 400 Hz and a secondary peak 7 dB down at 1000 Hz.

In general, these data indicate that noise levels in the locomotive cab can be greater than 90 dB (the threshold level for the current OSHA standard). If the duration is long enough, potential problems of overexposure to noise could occur. Although no crew noise dose measurements were found in the literature, engineering estimates of the dose have been made based on rough approximations of the locomotive duty cycle [12,17]. In both references, the authors concluded that the noise levels and duty cycles of typical locomotives could result in cases of potential overexposure to noise. Thus, a survey of different types of locomotives being used for various forms of train movement under a range of operational conditions is necessary to assess adequately railroad locomotive crew noise exposure.

3.2 Operational Duty Cycle

Characterization of the duty cycle for various types of train movements is essential because the noise levels in the cab, and thus the crew noise dose, are a function of how the locomotive is operated. Since there is such a wide range of possible operations, development of a standardized duty cycle with

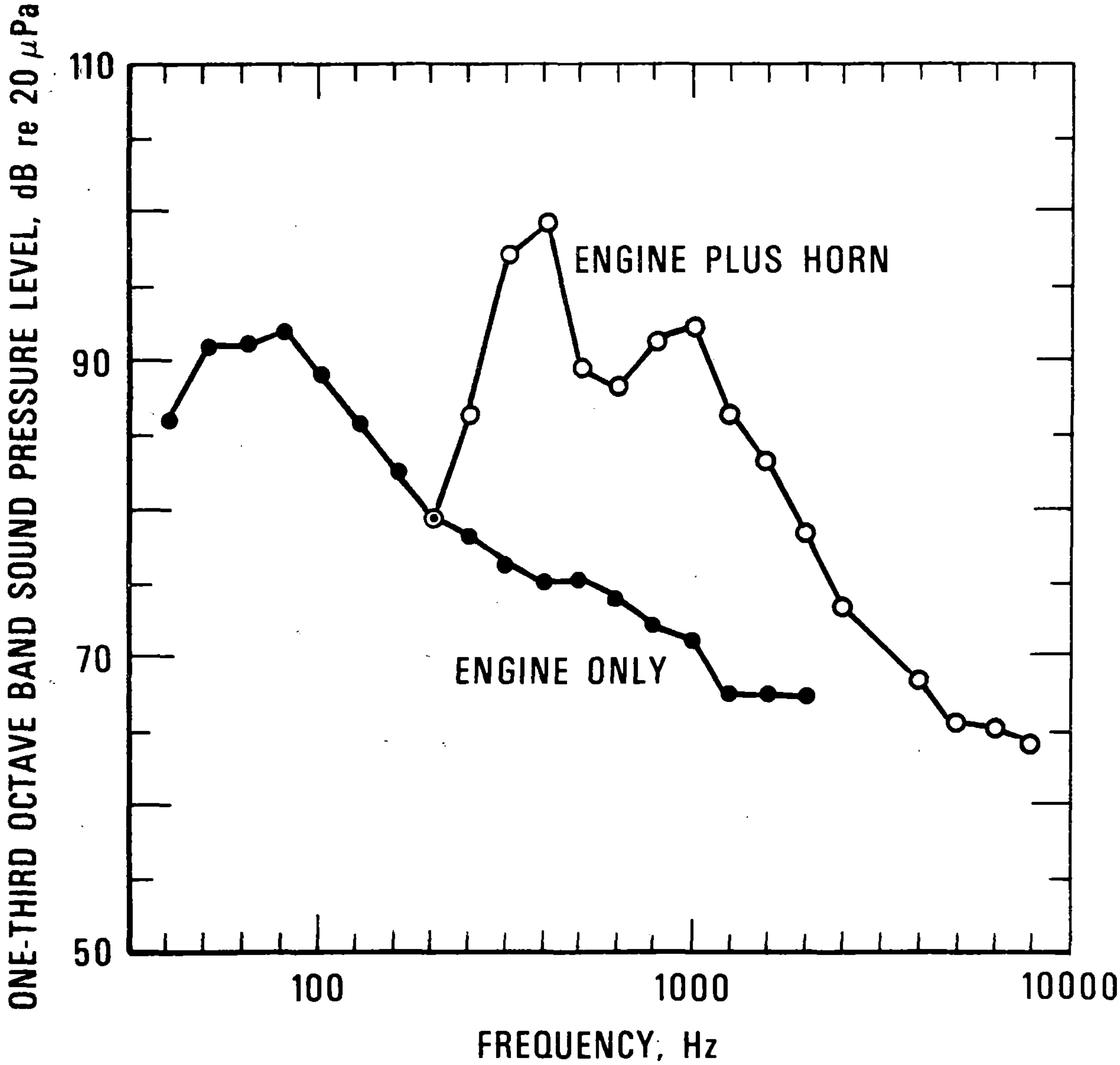


Figure 4. Sound level versus frequency for conditions of engine only (notch 8) and engine (notch 8) with horn in use for an EMD SD45 locomotive [12].

wide applicability may not be feasible. Examination of the available information in the literature shows that duty cycle data are available for locomotive diesel engine operations, but that only very sketchy information is available concerning horn and brake applications for different types of runs. The duty cycle data on locomotive diesel engine operations were obtained primarily for fuel economy and exhaust emissions studies and may not represent a broad enough range of locomotive operations to characterize adequately all types of locomotive operations in the United States.

3.2.1 Diesel Engine Operations

Locomotive diesel engines operate in a number of discrete throttle positions or "notches", each of which corresponds to a unique engine speed and power output. Many line-haul locomotives are also equipped with a dynamic brake mode which utilizes the traction motors to slow down the train. This is accomplished by using the traction motors as generators and passing the current that is produced through a bank of resistor grids where the power is dissipated as heat. In the dynamic brake mode the engine operates at a predetermined speed specified by the engine manufacturer.

The two primary manufacturers of diesel-electric locomotives in the United States are the Electro-Motive Division (EMD) of General Motors Corporation and the General Electric Company (GE). All EMD and most GE locomotives utilize eight engine speeds to obtain the eight power outputs or notch settings (plus an idle notch). However, late model GE units use just two engine speeds (plus a low idle speed) to produce the same eight power outputs. The nominal engine speeds and percent of rated brake horsepower for both types of GE locomotives and for EMD locomotives are given in Table 3 [18].

Table 3. Typical EMD and GE locomotive engine speeds and percent of rated brake horsepower for idle, the eight throttle positions and dynamic brake [18].

Throttle Position	EMD LOCOMOTIVES		GE LOCOMOTIVES		
	Nominal Engine Speed, rpm	% Nominal Rated BHp	Nominal Engine Speed, rpm 8-speed	Nominal Engine Speed, rpm 3-speed	% Nominal Rated BHP
Idle	315	1.0*	450	450	1.0*
1	315	5.0	450	790	4.0
2	395	12.0	535	790	10.0
3	480	23.0	620	790	20.0
4	560	35.0	705	1050	30.0
5	645	51.0	790	1050	48.0
6	730	66.0	880	1050	65.0
7	815	86.0	965	1050	82.0
8	900	100.0	1050	1050	100.0
Dynamic Brake	645	3.0*	1050	1050	6.0*

*Auxiliary Load Only

Several studies dealing with duty cycle in regard to exhaust emissions and fuel consumption have been conducted by cooperative efforts between the engine manufacturers and various railroads. The results of these studies, summarized in Reference 18, are presented in Table 4 along with a compromise schedule proposed by the Association of American Railroads (AAR). All but one of these cycles are for line-haul or road operations, with the exception of the cycle for switch engine service compiled by the Atchison, Topeka and Sante Fe Railway (ATSF). The duty cycle for the GE locomotives consist of the minimum and maximum values obtained in their study and two average schedules presumably derived by differentiating between different types of train movements. The two EMD cycles and ATSF cycles represent upper (or "High") and an average (or "Medium") amount of notch 8 utilization. The

Table 4. Locomotive diesel engine duty cycle data [18].

THROTTLE POSITION	DUTY CYCLE, PERCENT OF OPERATING TIME									
	GE				EMD		ATSF			AAR
	Min.	Max.	1st Avg.	2nd Avg.	High	Medium	High	Medium	Switcher	
Idle	59.0	40.0	54.0	53.0	41.0	46.0	46.0	59.0	77.0	43.0
1	6.5	2.5	5.0	5.1	3.0	4.0	5.0	5.0	10.0	3.0
2	6.5	2.5	2.5	3.9	3.0	4.0	3.0	4.0	5.0	3.0
3	6.5	2.5	2.0	3.4	3.0	4.0	3.0	3.0	4.0	3.0
4	6.5	2.1	5.0	3.3	3.0	4.0	3.0	2.0	2.0	3.0
5	2.9	1.7	2.0	2.8	3.0	4.0	2.0	2.0	1.0	3.0
6	2.9	1.7	2.0	3.4	3.0	4.0	3.0	2.0	1.0	3.0
7	2.5	1.8	2.5	2.6	3.0	4.0	2.0	1.0	---	3.0
8	5.2	38.0	21.0	17.0	30.0	17.0	24.0	20.0	---	28.0
Dynamic Brake	1.5	7.0	4.0	5.5	8.0	9.0	9.0	2.0	*	8.0

* Switch engine not equipped with dynamic braking.

AAR duty cycle is a compromise between the "High" EMD and the GE duty cycles and is not the result of an actual study.

These data show that for line-haul locomotive operations the major percentage of time is spent either in notch 8 or at idle with a much lower, and fairly even, distribution among the other notch settings. The switcher duty cycle is, as expected, primarily idle and low power notch settings.

There are differences among the nine duty cycles for line-haul locomotives, especially the percentages of time spent at idle and at notch 8. As reported in Reference 18, these differences may be due to the interpretation of "total" engine operating time, since locomotive engines are normally allowed to idle when not in use and are not shut off except for major maintenance and repair. If the total engine operating time is defined to include the time spent with the locomotive in idle awaiting routine maintenance or service such as fueling, loading with sand, etc., the percent time for the idle throttle position will be substantially higher. Based on these data, it is not possible to determine the locomotive engine duty cycle for in-service operations, since a portion of the total engine operating time may include times when the crew is not aboard. This difference can be noted by comparing the data from Table 4 with the data in Table 5 which gives the average percent time spent in each notch setting while the locomotive is operating online [19]. In this case, the majority of time is spent at notch 8, with no time at idle. While this may be a valid representation of the duty cycle for the total time that the locomotive is under way, it does not represent the duty cycle for the total time that the crew is aboard the locomotive. There are times spent with the locomotive at idle waiting to get into or out of yards or on a siding for another train to pass which should be included in the duty cycle.

Table 5. Locomotive diesel engine duty cycle based on the time that the locomotive is under way [19].

THROTTLE POSITION	DUTY CYCLE, average percent time
Idle	--
1	5
2	5
3	5
4	5
5	5
6	5
7	5
8	51
Dynamic Brake	14

The data presented in Tables 4 and 5 represent averages based on various types of operational runs. While this information is useful for examining the relative amounts of time spent in each notch setting, it does not provide any indication of the variability of this time for different types of operational runs.

Duty cycle data for individual runs were obtained in a fuel consumption test program conducted by FRA [20]. These data are for a unit coal train (both loaded and unloaded) and a unit "TOFC" (trailer-on-flat car) train. The data are presented for discrete test zones which were established to begin and end at crew change points. The operating conditions, train parameters and general terrain features for these trains are listed in Table 6. The duty cycle data in terms of percent time in motion versus notch setting are presented in Tables 7 and 8. As shown by the large standard deviations, there is a high degree of variability of percent time in each notch setting due to differences in terrain features and, perhaps to a lesser extent, different engineers. An interesting point to note is that based on the average values, there are only minor differences in the duty cycle (total trip time and percent time versus notch setting) for the loaded and unloaded coal trains. This may indicate that the engine duty cycle is more strongly influenced by terrain than by train load.

A comparison of the average values from Tables 7 and 8 with the duty cycles reported in Table 4 indicate a general agreement, except for idle. These values are significantly lower because the trip times in Tables 7 and 8 are based only on the time the trains were in motion.

3.2.2 Brake Applications

Braking duty cycle is strongly dependent on the train make-up (number of cars and trailing tonnage) and the terrain features for a particular run. Because of the trend in the past two decades towards the use of larger freight cars capable of carrying heavier loads, the braking duty cycle in flat and undulating terrain is now double to triple that in the early 1950's. It is expected that this trend will continue for at least the next decade [21].

The braking system on a train is pneumatically operated. A brake pipe system, pressurized to about 80 psi, runs the length of the train. This

Table 6. Operating conditions for trains used in FRA fuel consumption test program [20].

OPERATING CONDITIONS	UNIT COAL TRAIN		UNIT "TOFC" TRAIN	
	LOADED	UNLOADED	WESTBOUND	EASTBOUND
Type of Terrain	Predominantly level: 80% of run between 0 ± 0.49% grade		Mixed: level to mountainous	
Locomotives	EMD SD40 (4 units)		EMD DD40 (2 units) EMD SD40 (1 unit)	
Total Horsepower	12,000		16,200	
Total Number of Cars	110	110	35	47
i. loaded	110		34	46
ii. unloaded		110	1	1
Trailing Gross Tons	14,395	3,397	2,501	3,233
Miles Traveled	682.1	682.1	1,519	605
Total Time in Motion, hours	27.90	27.5	31.38	11.03
Average Speed, mph	24.4	24.8	48.8	55.3
Number of Crews	6	6	8	3
Number of Stops	31	32	8	3

Table 7. In-service locomotive diesel engine duty cycle information for a unit coal train (loaded and unloaded) [20]. The operating conditions are listed in Table 6.

	TEST ZONE	TRIP TIME, hr	STOPS	PERCENT OF TOTAL TRIP TIME IN EACH NOTCH SETTING								
				IDLE	1	2	3	4	5	6	7	8
LOADED	1	5.10	2	4.8	3.4	10.5	6.6	8.6	5.8	10.5	6.2	43.6
	2	3.52	2	4.7	9.0	11.1	19.9	15.1	4.7	5.1	1.7	28.7
	3	4.47	4	9.7	6.8	10.1	8.9	5.5	12.7	5.2	2.3	38.8
	4	2.99	4	15.6	8.7	23.2	14.8	6.5	10.7	5.1	4.8	10.5
	5	6.93	12	7.7	8.5	16.0	13.3	14.9	11.9	11.5	6.3	9.9
	6	4.89	7	5.8	9.6	12.7	10.9	13.8	14.6	7.7	4.3	20.6
MEAN		4.65	5	8.1	7.7	13.9	12.4	10.7	10.1	7.5	4.3	25.4
STANDARD DEVIATION		1.38	4	4.2	2.3	5.0	4.7	4.4	4.0	2.9	1.9	14.2

	TEST ZONE	TRIP TIME, hr	STOPS	PERCENT OF TOTAL TRIP TIME IN EACH NOTCH SETTING								
				IDLE	1	2	3	4	5	6	7	8
UNLOADED	1	(3.23)*	4*	9.3	10.5	12.7	7.0	5.0	6.9	9.7	8.9	30.0
	2	3.39	5	2.7	5.5	8.7	9.3	7.4	2.6	8.3	12.1	43.4
	3	(0.63)*	2	5.3	15.7	16.2	3.7	2.9	2.9	4.2	0.0	49.1
	4	(2.48)*	2	6.0	14.3	31.4	11.6	4.5	5.0	6.7	6.6	13.9
	5	6.98	10	10.9	19.2	29.0	12.7	16.1	7.7	2.4	0.6	1.4
	6	4.88	9	4.8	12.9	22.0	13.2	15.6	18.3	5.9	2.3	5.0
MEAN		5.08	8	6.1	12.5	19.9	11.7	13.0	9.5	5.5	5.0	16.3
STANDARD DEVIATION		1.80	3	4.3	6.9	10.3	2.1	4.9	8.0	3.0	6.2	23.6

* Less than trip time; percent times based on available throttle data. Data for these zones are not included in the mean and standard deviation calculations.

Table 8. In-service locomotive diesel engine duty cycle information for a unit "TOFC" train [20]. The operating conditions are listed in Table 6.

TEST ZONE		TRIP TIME, hr	PERCENT OF TOTAL TRIP TIME IN EACH NOTCH SETTING							
			C *	2	3	4	5	6	7	8
WEST	1	4.46	8.1	11.1	4.0	4.7	1.7	4.4	20.5	45.5
WEST	2	3.23	17.2	2.8	5.6	15.4	7.9	6.0	7.4	37.5
WEST	3	3.33	29.3	6.3	14.0	11.7	10.4	10.4	7.6	10.3
WEST	4	4.01	45.3	1.0	6.0	11.6	7.9	10.9	5.6	11.6
WEST	5	3.42	13.6	1.7	7.5	9.6	18.9	15.4	17.1	16.2
WEST	6	5.31	51.7	1.1	2.8	3.7	9.6	9.0	7.1	15.0
WEST	7	3.45	33.5	1.3	3.4	3.9	8.7	13.5	5.7	30.0
WEST	8	4.17	43.5	7.9	8.3	7.2	3.6	6.8	5.8	16.9
EAST	1	4.26	39.4	6.3	4.2	8.5	11.3	10.9	13.4	6.0
EAST	2	2.93	25.6	1.5	6.2	10.8	5.6	5.1	3.6	41.6
EAST	4	3.84	11.7	2.0	8.6	8.2	5.1	24.6	12.1	27.7
MEAN		3.86	29.0	3.9	6.4	8.7	8.2	10.6	9.6	23.5
STANDARD DEVIATION		0.68	15.0	3.4	3.2	3.7	4.6	5.8	5.4	13.6

* Combined idle-dynamic brake sequence.

brake pipe system is connected, through appropriate control valves on each car, to brake cylinders which are used to apply the brakes. In over-the-road operations, the brakes are applied by venting controlled amounts of air from the brake pipe system through the automatic brake valve in the lead unit of the locomotive consist. This pressure reduction ranges from 5 to 10 psi for a minimum reduction, to 23 to 26 psi for a full service system reduction [22]. The air released from the brake pipe system during this pressure reduction is vented directly from the automatic brake valve into the locomotive cab. This venting of air is the mechanism which generates the noise associated with a brake application. The duration and intensity of this venting process are functions of the brake pipe pressure reduction and the length (i.e., total air volume in the brake system) of the train. Should a situation occur which requires the train to be stopped immediately, the automatic brake valve can be placed in the "emergency" position. In this position the air from the brake pipe is vented at a much higher rate causing the train brakes to be quickly applied. In this case the duration of the air venting is shorter, but the sound level is much higher.

The locomotives in the consist also have a separate braking system from the train brakes. This system, referred to as the "independent" brake, is similar to the train brake system. The air venting for the independent brake is identical to the train brake pipe venting except that because the total volume is smaller, the duration is shorter.

Data on braking duty cycle are limited primarily to studies investigating brake equipment and brake shoe wear. Although a considerable amount of work has been done on braking to improve train handling, these studies have looked at the proper braking sequence for particular train make-ups and terrain features and not the total braking duty cycle for a complete run. Reference 21, cited above, gives an overview of past trends and future projections of braking duty cycle for freight train services in North America, as well as an example of braking duty cycle for a complete run. This example, given in Table 9, is for an in-service run in the southcentral portion of the United States. For this particular run, which is 136 miles long, there were 32 brake applications with an average brake pipe pressure reduction of 8.6 psi and an average duration of 67 seconds.

Based on information similar to this for runs over other types of terrain, the ranges of average braking duty cycle listed in Table 10 were determined [21]. Although the percentage of time spent braking is higher for long, heavy grade terrain, the majority of the braking that occurs takes place over general undulating terrain because of the large proportion of route miles which are this type of terrain. The braking technique commonly used is called power or "stretch" braking. Stretch braking involves working the power of the locomotive consist against the action of the brakes to hold the train speed steady or to make minor speed reductions on a downgrade while running over undulating terrain. Utilization of this braking technique results in frequent use of the air brake system, but provides for better train handling through closer control of train speed and slack.

3.2.3 Horn Soundings

There are very few data regarding horn duty cycle because the horn is used only intermittently and is not an integral part of the train handling or

Table 9. Example of braking duty cycle for an actual run in the southcentral portion of the United States [21].

Application Number	Length of Time Brakes Applied, Seconds	Speed Range, mph	Brake Pipe Reduction, psi
1	60	64-59	8
2	40	64	8
3	40	63-50	8
4	150	62-35	12
5	70	61	8
6	80	62	8
7	70	63-58	8
8	80	63-55	8
9	90	58-30	10
10	70	60	8
11	90	60-40	8
12	60	40-15	9
13	90	62-55	8
14	70	65-60	8
15	50	65-40	9
15A	40	40-25	15
16	30	30	*
17	60	30	8
18	70	40	8
19	60	45	8
20	70	62-55	8
21	60	60-57	8
22	75	60-55	8
23	60	45-40	8
24	120	45-40	8
25	60	60	8
26	40	64	8
27	60	62	10
28	60	62	8
29	60	62	8
30	50	63	8
31	60	60-0	To Full Service

Note: Distance traveled was 136 miles.

*No value reported in Reference [21].

Table 10. Average braking duty cycle on various types of terrains [21]. Braking duty cycle is percent of total run time that the brakes are applied.

Type of Railroad Profile	Grade	Braking Duty Cycle	Route Miles
Flat	±0.5% or less	2-5%	24,600
General Undulating	±0.5% up to approximately ±1.3%	8-20%	160,000
Significantly Long and/or Heavy Grade*	±1.3% up to approximately ±3% with a few ±4% to ±5% maximum	25-40%	61,400

*Long and heavy grade districts usually include considerable mileage of general undulating and some flat territory. Very few heavy grades are in the ±5% range.

performance. The horn is used primarily as a warning signal at grade crossings and to a lesser extent for alerting crew members and other railroad workmen that the train is about to move. The sequence for the horn application at a crossing is two long blasts as the lead locomotive approaches the crossing, one short blast immediately prior to the crossing, and finally, one long blast through the intersection. In Reference 17, engineering estimates of 3 seconds for the three long blasts and 1.5 seconds for the short blasts are used to compute noise exposure. However, the author of Reference 12 reported that for the two trains he examined the two engineers differed in horn blowing techniques. One used very short blasts, while the other sounded the horn considerably longer. Thus, the timing for the horn-blowing sequence and the duration of each blast is strongly influenced by the horn-blowing technique of each engineer.

Regardless of the horn-blowing technique of the engineer, the controlling factor for horn duty cycle is the number of grade crossings. This number is dependent on the particular operating territory, whether it be through populated areas with many crossings or through the mountains or desert with virtually no crossings. Because few data are available, further information on the number of crossings for various types of runs is needed to characterize typical horn duty cycles.

3.3 Fleet Population

The third element required to assess the extent of railroad crew noise exposure is the make-up of the current diesel locomotive fleet in the United States. This is necessary to determine which types of locomotives are most prevalent and thus more likely to have a larger percentage of on-board crew time than other less common types of locomotives.

The current U. S. locomotive fleet for Class I railroads[3] totaled 27,598 units as of April 1978 [24]. A breakdown of this fleet is given in Table 11. Based on these numbers, it is seen that 84 percent of the locomotive fleet is composed of road units with the remaining 16 percent being switchers. As noted in the caption to Table 11, the values for "switchers" includes only those units designed as switchers (mostly endcabs) and not road units assigned to switching. Thus, the number of locomotives utilized as road units will be somewhat less than the 84 percent shown here. Examination of the road units shows that 96 percent of such locomotives have been manufactured by EMD and GE, with EMD accounting for 83 percent. A similar

[3]Class I railroads are those having annual revenues of $5 million or more. They account for 99 percent of the national freight traffic [23].

Table 11. Breakdown of the United States locomotive fleet (as of April 1978) for Class I railroads [24]. "Switchers" are units designed as switchers (mostly endcabs) and don't include road units assigned to switching.

OPERATING RAILROAD	ROAD UNITS						TOTAL NUMBER OF ROAD UNITS	SWITCHERS		TOTAL NUMBER OF SWITCHERS	SLUGS	TOTAL NUMBER OF LOCOMOTIVES	TOTAL NUMBER OF ROUTE MILES
	EMD 4-axle	EMD 6-axle	GE 4-axle	GE 6-axle	ALCO & MLW 4-axle	ALCO & MLW 6-axle		EMD	ALCO & MLW				
CR	2,134	564	437	126	216	70	3,547	873	8	881	1	4,581(1)	20,677
SP	583	1,111	90	261	32	47	2,124	447	54	501	3	2,625	11,474
BN	811	797	61	370	44	10	2,093	396	2	398	3	2,491	22,988
FL	1,059	277	430	143	83	34	2,026	363	—	363	80	2,390(2)	16,576
CS	1,698	178	102	13	4	—	1,995	210	36	246	2	2,241	11,043
AT&SF	947	416	65	177	—	—	1,605	25	2	27	21	1,632	12,321
N&W	782	351	136	3	141	19	1,432	73	37	110	23	1,542	7,603
UP	473	634(6)	—	180	—	—	1,287	131	—	131	7	1,418	9,460
SR	742	331	70	15	—	—	1,158	192	—	192	27	1,350	10,200
MP	665	236	49	35	—	—	985	196	—	196	0	1,181	11,229
ICG	836	51	6	9	—	6	908	152	—	152	1	1,060	9,044
CNW	425	273	—	6	9	43	756	120	—	120	31	876	9,701
Milw	308	159	38	16	—	—	521	150	—	191(5)	5	712	10,074
RI	330	35	103	18	—	—	486	132	10	142	4	628	7,361
SL-SF	228	49	62	—	—	—	339	92	—	92	0	431	4,621
D&RGW	148	86	—	—	—	—	234	20	—	20	0	254	1,855
KCS	60	83	—	—	—	—	143	89	—	89	11	232	882
Soo	129	55	—	10	2	—	196	28	—	28	0	224	4,589
GTW	103	22	—	—	—	—	125	45	21	66	0	191	1,198
B&M	112	—	—	—	6	—	118	50	14	64	0	183(3)	1,574
D&H	52	3	15	21	65	22	178	—	—	—	0	178	1,400
MKT	128	—	3	—	—	—	131	36	—	36	1	167	2,223
WP	92	—	35	—	—	—	127	13	—	13	0	140	1,186
URR	—	12	—	—	—	—	12	112	4	116	0	128	268
EJ&E	5	31	—	—	—	—	36	63	—	63	5	99	200
B&LE	18	77	—	—	—	—	95	2	—	2	0	97	205
P&LE	8	—	22	—	—	—	30	65	—	65	0	95	273
DM&IR	—	75	—	—	—	—	75	—	—	—	0	75	461
DT&I	64	5	—	—	—	—	69	—	—	—	0	69	478
LI	28	—	—	—	8	—	36	31	—	31	0	69(4)	322
FEC	60	—	—	—	—	—	60	4	—	4	0	64	554
TOTALS	13,028	5,911	1,724	1,403	610	251	22,927	4,110	188	4,339	225	27,423	165,896

(1) Includes 153 electrics.
(2) Includes one GE 70-tonner.
(3) Includes one 44-tonner.
(4) Includes two GE 25-tonners.
(5) Includes 41 Fairbanks Morse switchers
(6) EMD 6-axle includes 88 EMD 8-axle.

comparison for switchers shows that nearly 95 percent of the locomotives of this type have been manufactured by EMD.

A more useful breakdown for the purposes of this study is by locomotive model and date of manufacture. Such a breakdown based on the fleet population as of January 1, 1977 for the 18 largest Class I railroads is given in Table 12. The values given in this table differ slightly from those in Table 11 because the totals are based on fewer railroads. The relative percentages of road units to switchers and the breakdown by manufacturer, however, are comparable for the two tables.

Looking at the breakdown by year shows that approximately 40 percent of the road units and 80 percent of the switchers were manufactured prior to 1963. For the years 1964 to 1976 the road unit population is evenly distributed with two to four percent of the total population manufactured per year. The switcher population, on the other hand, ranges between one to two percent for the years 1964 to 1973, with no units listed for 1974 to 1976. The reasons for this are that switchers have a longer useful life than road units because of the less severe use cycle and that older road units are often assigned to switching [23].

The breakdown by locomotive model shows that 12 or 13 different models comprise over 80 percent of the total road unit fleet. These 12 or 13 different models can be grouped into ten categories based on locomotive design and engine horsepower, as shown in Table 13. The locomotives in each of these categories have the same engine characteristics and in general, are the same age. Thus, locomotives within the same category can be expected to have similar noise generating characteristics and presumably similar in-cab noise environments.

Table 12. Breakdown of the United States locomotive fleet (as of January 1, 1977) by model and date of manufacture for the 18 largest Class I railroads [25,26].

LOCOMOTIVE MODEL	HORSEPOWER	PRIOR TO 1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	TOTAL
ROAD UNITS																
EMD (1)																
E7/8/9	1800-2400	187														187
F7/9	1500/1750	692														692
GP7/9	1500/1750	5,517														5,517
SD7/9	1500/1750	548														548
GP15	1500														60	60
MP15	1500												32	139	32	203
GP18	1800	302														302
SD18	1800	19														19
GP20	2000	236														236
SD24	2400	215					1									216
GP28	1800		15													15
SD28	1800						2									2
GP30	2250	885														885
GP35	2500	54	552	541												1,147
SD35	2500		77	282	16											375
SDP35	2500			14												14
GP38	2000				12	116	1	236	226	264	340	338	212	53	111	1,909
SD38	2000								35			6		15		56
GP39	2300							20					17	52		89
SD39	2300						18	25	8		5					56
GP40	3000			47	258	214	311	126	81	163	130	5	16	62		1,313
SD40	3000				362	68	54	59	89	173	194	219	339	203	135	1,895
SD45	3600				236	317	233	269	108	96	164	36	62	61		1,642
SDP40/45	3000/3600					10		14	12	20		40	110			206
F40PH	3000														30	30
F/FP45	3600					14	40									54
DD35	5000	27	18					24	10	12						91
GE (2)																
U18B	1800											56	49			105
U23B/C	2250							59	61	15	55	94	63	51	15	413
U25B/C	2500	147	177	206	12											542
U28B/C	2800			3	161	42										206
U30B	3000				12	124	10	5	50	35	15		10			261
U30C	3000				4	25	56	26	47	34	89	92	102	45	40	560
U33B	3300					4	109	20								133
U33C	3300						41	89	46	80	59	18	11	15		359
U36B	3600						4	8	30	57	21	10	3	5		138
U36C	3600									7	32	21	47	17		124
U50	5000	1	4	1				2	18	20						46
P30CH	3000													16	9	25
C30-7	3000														10	10
ALCO	1000-3600	552	53	174	103	50	26									958
BLW	1000-1800	24														24
ROAD UNIT TOTAL		9,406	896	1,268	1,176	984	806	982	821	976	1,104	995	1,073	734	442	21,663
SWITCHERS																
EMD	600-1500	2,660	40	88	87	56	80	72	71	83	159	59				3,455
ALCO	600-1500	293														293
BLW	660-1200	106														106
F-M	1000-1200	50														50
SWITCHER TOTAL		3,109	40	88	87	56	80	72	71	83	159	59				3,904
TOTALS		12,515	936	1,356	1,263	1,040	886	1,054	892	1,059	1,263	1,054	1,073	734	442	25,567

(1) EMD designations for hood-type locomotives:
GP -- General Purpose locomotive with four traction motors
SD -- Special Duty locomotive with six traction motors

(2) GE designations for Universal model hood-type locomotives:
B - four traction motors
C - six traction motors

Table 13. Breakdown of locomotive road unit population based on engine design and horsepower [27].

ENGINE MANUFACTURER	ENGINE DESIGN	ENGINE TYPE	NUMBER OF CYLINDERS	HORSEPOWER	LOCOMOTIVE MODEL	NUMBER OF UNITS	PERCENT OF ROAD FLEET
EMD	two-stroke naturally aspirated	567	16	1500-1800	GP & SD7 GP & SD9 GP & SD18	6,386	29.5
EMD	two-stroke turbocharged	567	16	2000-2500	GP20 SD24 GP30 GP & SD35	2,859	13.2
EMD	two-stroke naturally aspirated	645	16	2000	GP & SD38	1,965	9.1
EMD	two-stroke turbocharged	645	16	3000	GP & SD40	3,311*	15.3
EMD	two-stroke turbocharged	645	20	3600	SD45	1,745*	8.1
GE	four-stroke turbocharged	FDL-8	8	1800	U18B	105	0.5
GE	four-stroke turbocharged	FDL-12	12	2300	U23B & C	413	1.9
GE	four-stroke turbocharged	FDL-16	16	2500-2800	U25B & C U28B & C	748	3.5
GE	four-stroke turbocharged	FDL-16	16	3000	U30B & C	821	3.8
GE	four-stroke turbocharged	FDL-16	16	3300-3600	U33B & C U36B & C	754	3.5
					TOTAL	19,107	88.2

*Includes half of the SDP population of 206 from Table 11.

A comparison of Tables 12 and 13 shows two noticeable omissions in this latter table -- ALCO road units and all types of switchers. The ALCO road units were not included because the entire group of ALCO road units comprises only 4.4 percent (3.8 percent based on Table 11) of the total road unit population. Since the newest of the ALCO road units is ten years old, and over half are 15 years old or more, these units are being rapidly phased out of use.

Switchers are omitted from this table because of operational considerations. Since the duty cycle for switchers consists primarily of idle and notch 1 operations (approximately 87 percent from Table 4) and because the noise levels for such operations are typically less than 80 dB (based on the data in Section 3.1), the noise environment in the cab is not likely to result in cases where the noise dose is exceeded. For this reason, even though switchers comprise 15.3 percent of the total locomotive fleet, they are not included in this initial study.

For this current study, Table 13 served as the basic test matrix for the field test program. This program and the results that were obtained are described in the remaining sections of this report.

4.0 FIELD TEST PROGRAM

Based on the information presented in the previous sections, a field measurement program was developed to provide the data necessary to evaluate the noise exposure of locomotive crews. The program was also designed to provide a means of identifying individual component sources and specific locomotive operations, which might influence the noise levels in the cab, and to develop a procedure for estimating their relative contributions to the overall crew noise expsoure. The feasibility of developing a simplified measurement procedure, which would provide information that could be used to estimate the noise exposure for in-service operations, was also examined.

Determination of noise exposure or "dose" requires a knowledge of the time history of the noise levels to which the worker is exposed. In certain industrial settings the noise environment is essentially constant over a worker's shift, thereby minimizing the difficulty of determining the noise exposure and ascertaining whether the allowable hearing conservation criteria have been exceeded. In other settings, the noise environment may not be constant, thereby necessitating continuous noise exposure monitoring throughout the worker's shift.

In locomotive cabs the noise environment is characteristically highly variable in nature due to the wide variety of sources contributing to in-cab noise and to differences in operating conditions necessitated by the type of run and terrain features. The fact the the workplace is mobile makes the task of determining the individual crew member's noise exposure even more difficult.

The measurement program was designed to have the following features:

1. Continuous noise exposure monitoring inside the locomotive cab.

2. Capability of identifying and characterizing individual component noise sources.

3. Capability of identifying specific locomotive operations which might significantly contribute to the total noise dose.

4. Procedure for estimating relative contributions of individual component sources, or of specific locomotive operations, to the total noise dose.

5. Procedure for measuring and correlating noise levels for stationary operations to those for in-service operations.

With this list of required features, an appropriate measurement methodology and instrumentation system were developed. These are described briefly in the next section.

4.1 Instrumentation System

The instrumentation system that was developed by NBS for this program is shown schematically in Figure 5. This system is comprised of three basic subsystems: 1) the acoustic measurement equipment, 2) the operational parameters system, and 3) the signal conditioning and recording system. Acoustic measurements were made using six microphones -- three each for the engineer and brakeman. Two of the microphones were positioned approximately 6 inches from each ear when the crew member was seated. The remaining microphone was attached to the crew member's shirt lapel (on the side away from the window),

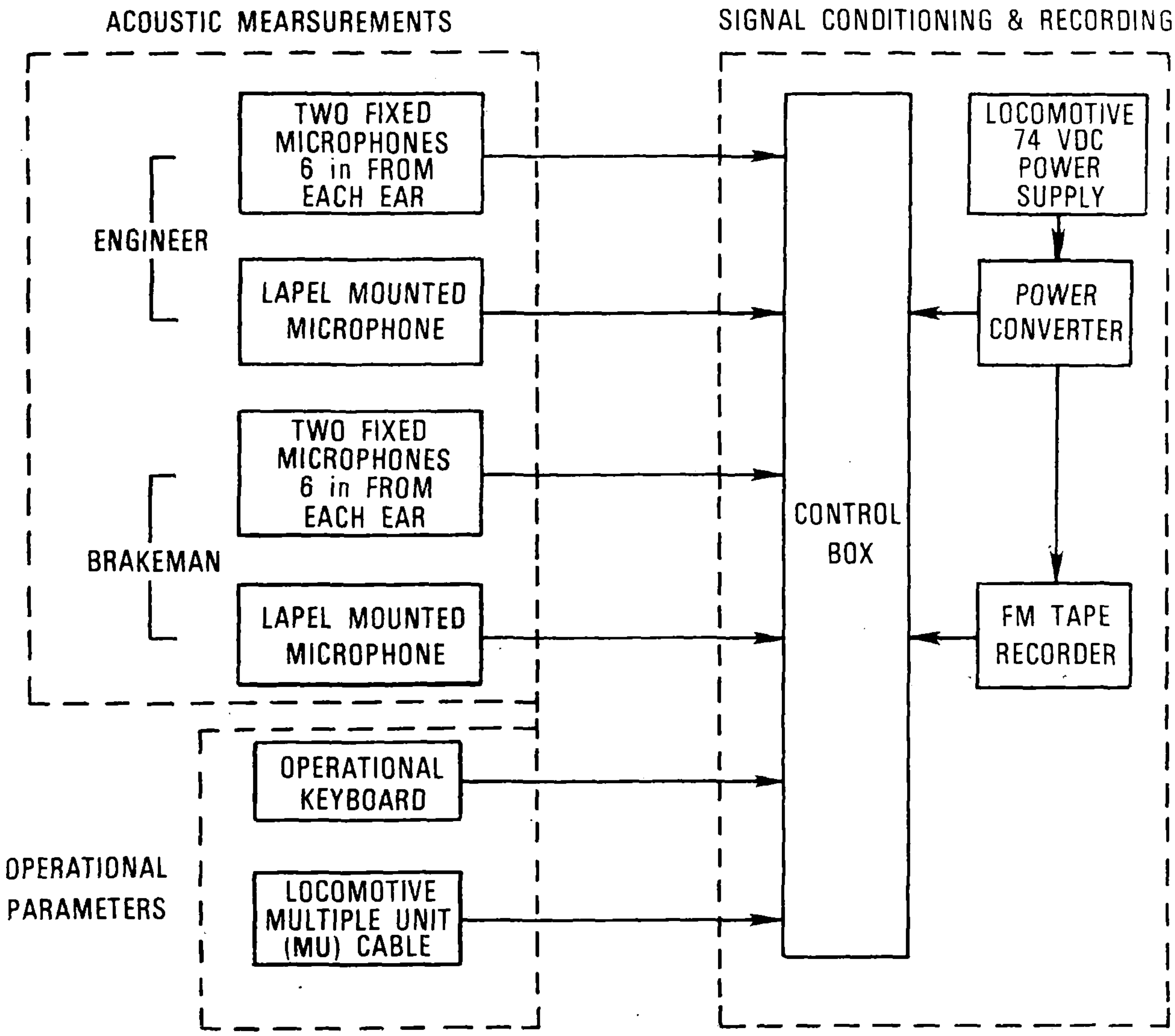


Figure 5. Schematic diagram of instrumentation system developed by NBS for evaluation of the noise exposure of locomotive crews.

similar to the location of the microphone for a noise dosimeter[4]. Figure 6 shows the locations of the three microphones near the engineer during one of the test runs. As seen in this figure, the two fixed microphones suspended from the ceiling are equipped with foam windscreens. The purpose of the windscreen was to minimize the extraneous noise generated by wind coming through the open window and blowing across the protective grid on the microphone. The lapel microphone was not equipped with a windscreen because it would have been bothersome to the engineer and brakeman. A windscreen was not essential in this location since the lapel microphone was shielded from the open window by the body of the crew member.

The operational parameters system was used to provide information on the locomotive operation and terrain features. This information came from two sources: the multiple-unit (MU) cable and an operational keyboard. The MU cable is used in multiple-unit locomotive consists to provide notch setting and dynamic brake signals to the trailing units so that they can operate synchronously with the lead locomotive. For this program, these signals, obtained by tapping into the MU cable socket on the front of the lead locomotive, were used to provide continuous monitoring of notch and dynamic brake settings of the locomotive.

[4]One of the common techniques of checking compliance with hearing conservation criteria is through the use of noise dosimeters. Noise dosimeters give a direct indication of the worker's noise exposure; however, no diagnostic data, which could be used to pinpoint problem areas, are provided. Simple measurement techniques for determining noise exposure, such as the use of noise dosimeters, are not adequate for identifying and characterizing individual component sources as required for this study. Instead, a system is required which provides a permanent record of the noise signatures that can be used for further analysis.

Figure 6. View inside the cab of one of the test locomotives showing the locations of the three microphones near the engineer.

The operational keyboard, shown in Figure 7, consisted of 15 switches (a 16th was reserved to indicate system calibration), each corresponding to a specific locomotive operation, such as a horn or brake application, or to a terrain feature, such as a cut, tunnel, upgrade or downgrade (see Table 14). During the run the keyboard was manually operated by NBS test personnel. As different operations occurred or the terrain changed, the appropriate switch was thrown. To record events that did not correspond to one of the 15 switches, a handwritten log was attached to the keyboard. When such events occurred, a note was made along with the time of day, which was displayed directly below the switches on the keyboard. This information was then used to help interpret the data when they were analyzed.

The output signals from the microphones, operational keyboard and MU cable were routed into the control box where signal conditioning and logic control were performed. The output of the control box was then recorded on magnetic tape using a 14-channel FM tape recorder.

The control box contained a variety of elements including: signal amplifiers, peak-hold detectors to sense amplifier overload, time-of-day clock (accurate to the nearest second), tape recorder start/stop controls and the digital logic system controls for recording the instrumentation and operational parameters. The information regarding the instrumentation and operational parameters was recorded on a separate digital channel of the FM tape recorder. Besides the operational parameters previously described, the information recorded on the digital channel also included run number, time of day, and amplifier gains and overload indicators. Each of the operational and instrumentation parameters, listed in Table 14, was sampled and recorded

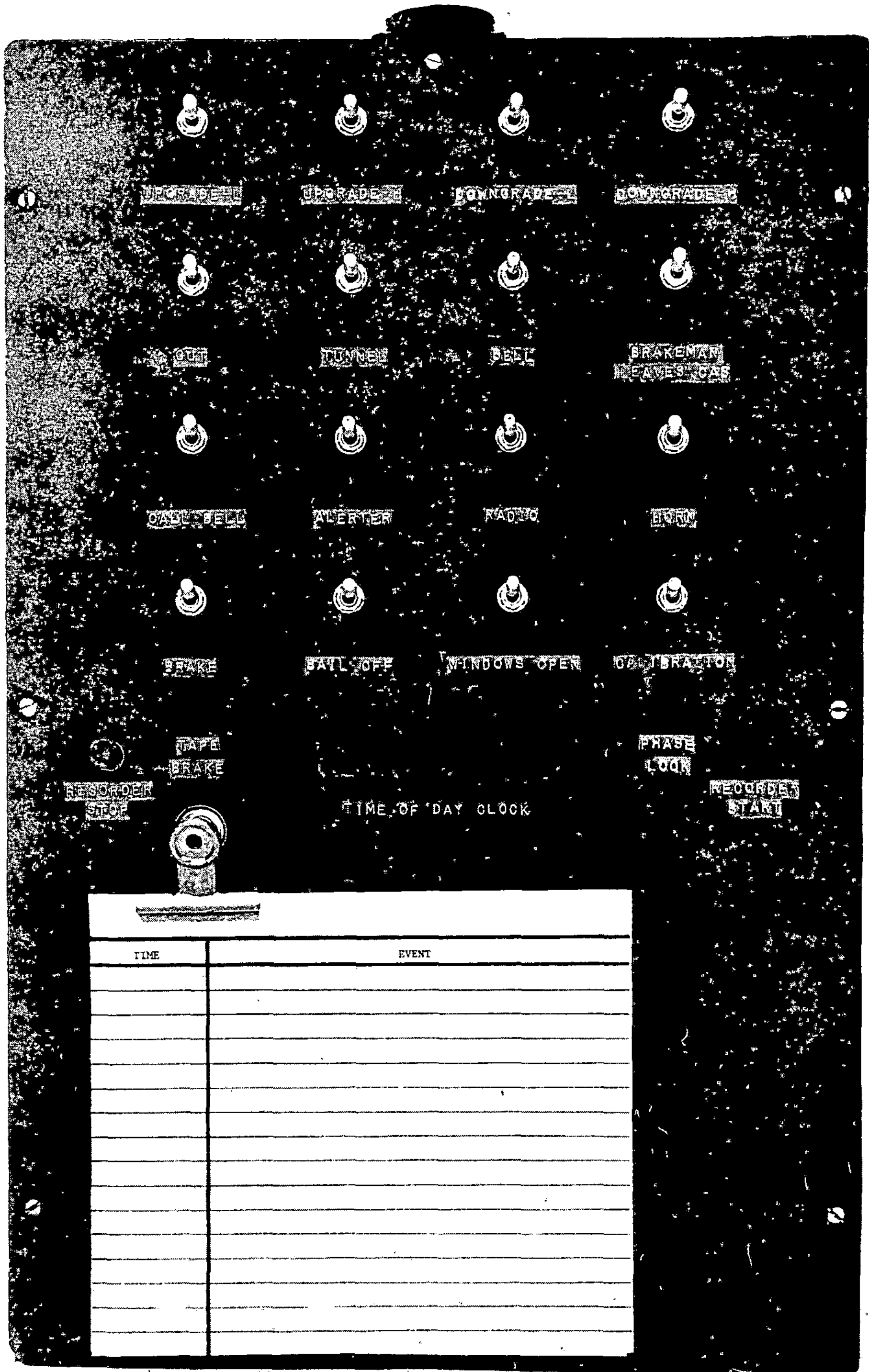


Figure 7. Operational keyboard used to record locomotive operations and terrain changes.

Table 14. List of operational parameters recorded for in-service tests.

SOURCE	OPERATIONAL CONDITION
Operational Keyboard	upgrade - light upgrade - heavy downgrade - light downgrade - heavy cut tunnel bell brakeman leaves cab call bell alerter radio (receiving only) horn brake bail-off * windows open/closed system calibration
MU Cable	engine notch settings 1-8 dynamic brake (on/off)
Control Box	run number time of day amplifier gain settings amplifier overload indication

*It was found to be very difficult to distinguish between bail-off of the independent brake and application of the train brake since they sound alike. To avoid confusing these two operations, all occurrences of air venting from the brake valves were recorded as "brake."

on tape once every second. This served in place of a detailed handwritten log, greatly simplifying data acquisition and permitting data reduction to be done automatically under computer control.

To be capable of handling the wide range of sound levels which could occur in locomotive cabs (typically 70 to 115 dB), the control box was designed to have two output channels with adjustable gains for each microphone input. With this configuration, the effective dynamic range of the system could be expanded by setting the gain on one of the output channels 20 dB (or whatever was appropriate to have the amplifer operating at its mid-range) higher than the other. The output from the channel with the higher gain was used for data analysis except when the sound level was too high and caused the input signal from the microphone to overload the amplifier. In this case an overload indicator was triggered and automatically recorded on the digital channel of the tape recorder. During the data analysis the computer read the overload indicator which told it to analyze the channel with the lower gain.

As mentioned above, all data were recorded on a 14-channel FM tape recorder -- 12 channels of acoustic data (two for each microphone) and one channel of digital information on the instrumentation and operational parameters. An FM recorder was used to obtain the low frequency response necessary to record locomotive noise which, as discussed in Section 3.1, has strong low frequency components. All recordings were made with flat frequency response, i.e., there was no frequency pre-weighting of the recorded signals. Utilizing this system continuous recordings were made for approximately one hour (4600 foot reel of tape at 15 ips) followed by a 5 minute break while a new tape was mounted on the recorder and calibration signals recorded. The previous data tape was not rewound until returning to the lab since this could take an additional 10 to 15 minutes.

The power for the control box and tape recorder was obtained from the locomotive DC power supply. A power converter was required to transform the locomotive power supply of nominal 74 volts DC to 24 volts DC and to eliminate sharp power supply peaks of over 2000 volts and one millisecond duration which occurred during throttle position changes. Using the available locomotive power supply eliminated the need for bulky battery supplies which would otherwise be required to operate the equipment.

4.2 Test Procedures

Field testing was carried out on locomotives used in actual over-the-road revenue runs. A typical test sequence began with the initial set-up and calibration of instrumentation on the locomotive[5]. Following this, but prior to the over-the-road run, a series of stationary tests was conducted on the locomotive. If feasible, for these tests the locomotive (or the entire consist) was moved to a site which did not have any large objects nearby such as buildings, freight cars or other locomotives. This was done to avoid unwanted sound reflections which could affect the measured sound levels. Depending upon the configuration of the track within the yard, schedule restrictions, and operational constraints, stationary data were recorded for as many of the operational conditions listed in Table 15 as was possible. These tests were conducted both with windows open and windows closed.

After the stationary tests were completed, the train was dispatched. Continuous sound level and operational event data were collected throughout the trip, with the exception of gaps which occurred when tapes were being changed and calibration signals recorded. Also, when the train was waiting to get into or out of a yard or waiting on a siding for another train to pass, only a short sample of the noise levels was recorded. Since there were no operational changes in the locomotive and the noise levels were

[5]After the initial instrumentation set-up and after each tape change, a calibration signal was recorded for each microphone. Field calibration was performed using a pistonphone which produced a 124-dB sound pressure level (re 20 μPa) at a frequency of 250 Hz.

Table 15. Locomotive operational conditions for stationary tests. Measurements made with windows open and closed.

OPERATIONAL CONDITION	COMMENT
Engine Notch Settings : 1 - 8	No load on engine
Automatic Brake Application	Independent brake application substituted if locomotive not coupled to consist or train
Emergency Brake Application	Obtained only for reference purposes
Horn Sounding	Sounded for sufficient length of time to be relatively steady-state
Bell	
Call Bell	Or similar warning device
Alerter	

essentially constant, this short sample was sufficient to characterize the noise environment for those periods of time (as long as several hours) when the locomotive was stationary.

Tests were conducted on a sample of 16 locomotives operating in various portions of the United States[6]. Because of crew changes, two runs were made on two of the locomotives, giving a total of 18 test runs. As discussed in Section 3.3, only road locomotives, as opposed to switching locomotives, were

[6]Access to in-service locomotives was arranged through the Association of American Railroads (AAR). Participating members in this program were Consolidated Rail Corporation (CONRAIL), Seaboard Coast Line Railroad Company, Southern Pacific Transportation Company, and the Southern Railway System.

tested. The choice of an individual locomotive for testing was based on its availability, but at least one locomotive from each of the categories in Table 13 was tested. Care was taken to select runs which had a wide mix of operational conditions (i.e., high speed through-freights, slow speed drag-freights, local transfer movements, etc.), varied terrains (mountainous, flat, rolling hills), and varied trip lengths (6 to 12 hours). In each case, the lead locomotive in the consist was instrumented since this was where the crew normally rode. Detailed descriptions of the locomotives and test runs are given in Appendix A.

Following each field trip, which typically involved making measurements on three different locomotives, the magnetic tape recordings were returned to NBS and analyzed. The results of these analyses are presented in Section 5 and form the basis for the stationary screening test discussed in Section 6.

5.0 TEST RESULTS AND CONCLUSIONS

The information obtained from the field test program consisted of acoustic data for six microphone locations and operational duty cycle data, in terms of the parameters listed in Table 14, for each of the 18 test runs. This section is divided into three parts dealing with the locomotive operational duty cycle, in-cab noise levels, and crew noise exposure or dose. Based on these results alternative approaches to dealing with in-cab locomotive noise are suggested and discussed.

5.1 Operational Duty Cycle

Operations for road locomotives can be broken down into two general groups. These groups refer to operations either when the locomotive and train are underway and operating on-line, or when the locomotive (i.e. locomotive consist) is uncoupled from the train or the train is stationary. This latter category includes operations such as the initial locomotive inspection by the crew at the terminal, train make-up and waiting to leave the yard, waiting on a siding for another train to pass, pick-up and set-off of cars (which may or may not be done by the lead consist), waiting to get into the yard, and final terminal drop-off of the locomotive consist. In general, for these operations the locomotive is operated in idle (when stationary) or very low notch setting (when moving between the terminal and the yard). Thus, the noise levels in the cab will normally be less than a 90 dB threshold level and will not influence the noise dose.

This was taken into consideration when conducting the field test program and, as discussed in Section 4, only a short sample of the noise levels was recorded for such operations. However, in order to document the time required to perform this portion of the duty cycle, a log was kept for each trip. A summary of the trip logs for the 18 test runs is shown in Table 16[7]. The three principal columns in this table are T_{O-B}, T_{dose} and $T_{notch\ 1}$. These three times are defined as follows:

T_{O-B} - on-board time, which is the time from the moment the crew gets on the locomotive until the time they get off at the final destination.

T_{dose} - effective crew "dose" time, which includes only the time that the train is underway. This is comprised of the tape recorded data plus a small increment of time required to change tapes and calibrate the microphones while underway.

$T_{notch\ 1}$ - total time the locomotive is not operating on line. This includes the times when the train is stationary (i.e. locomotive at idle) and when the consist is moving between the yard and terminal.

As might be expected because of the intentional choice of differing types of terrain and train make-up, the variability of times spent performing various operations is quite evident, as indicated by the large standard deviations relative to the mean values. The important thing to note is that even though the crew may be on-board for eight or more hours, the actual time that the locomotive is underway (and generating levels greater than 90 dB for extended periods of time) is significantly less. This will have an influence on the crew noise dose since the length of exposure time is an important factor. Additional operational duty cycle information in terms of terrain features, locomotive operations, and engine notch settings is given in Tables 17, 18 and 19, respectively.

Table 17 gives a breakdown on the terrain features in terms of the percent of the effective crew "dose" time and the number of occurrences. For

[7]It was mutually agreed in setting up this voluntary cooperative program that in the final report the locomotives would not be identified by operating railroad.

Table 16. Trip log (in hours) for the 18 test runs.

TEST RUN NUMBER	Time of Day: Crew On	Time of Day: Crew Off	Crew On-Board Time T_{O-B}	Initial Terminal Locomotive Inspection and Train Make-up A	Tape Recorder Operating B	Tape Changing and Calibration C	Waiting on Siding for Another Train to Pass D	Pick-up and/or Set-off of Cars E	Final Terminal Locomotive Drop-off F	Effective Crew "Dose" Time: T_{dose} = B + C	Effective Crew "Dose" Time: Percent of On-Board Time	Total Time Locomotive Not Operating On-Line: $T_{notch\ 1}$ = A+D+E+F	Total Time Locomotive Not Operating On-Line: Percent of On-Board Time
1	18:47	03:00	8.22	0.15	4.46	0.37	1.87	0	1.37	4.83	58.8	3.39	41.2
2	08:00	15:52	7.87	1.91	4.68	0.53	0.18	0.08	0.49	5.21	66.2	2.66	33.8
3a	20:18	01:03	4.75	0.98	2.87	0.34	0	0.41	0.15	3.21	67.6	1.54	32.4
3b	01:03	09:30	8.45	0.32	3.49	0.41	0	0	4.23	3.90	46.2	4.55	53.8
4	16:12	19:00	2.80	0.93	1.10	0.34	0	0.43	0	1.44	51.4	1.36	48.6
5	09:00	17:30	8.50	0.88	3.70	0.38	1.31	0	2.23	4.08	48.0	4.42	52.0
6	09:20	18:00	8.67	2.13	4.38	0.59	1.01	0	0.56	4.97	57.3	3.70	42.7
7	05:12	12:10	6.97	0.56	2.98	0.30	1.08	1.43	0.60	3.28	47.1	3.69	52.9
8	14:37	20:30	5.88	1.16	2.61	0.17	0	1.35	0.59	2.78	47.3	3.10	52.7
9	05:00	11:30	6.50	2.07	2.00	0.23	0.32	0	1.88	2.23	34.3	4.27	65.7
10	19:53	03:00	7.12	0.85	4.34	0.58	0	0.72	0.63	4.92	69.1	2.20	30.9
11	12:18	22:30	10.20	1.55	5.17	0.52	0.46	0.20	2.30	5.69	55.8	4.51	44.2
12	11:15	22:15	11.00	2.15	6.06	0.70	0.45	0.40	1.24	6.76	61.5	4.24	38.5
13	10:50	20:30	9.67	1.79	4.76	0.59	0.84	0.17	1.52	5.35	55.3	4.32	44.7
14a	14:13	20:01	5.80	0.62	3.91	0.53	0.74	0	0	4.44	76.6	1.36	23.4
14b	20:28	22:30	2.03	0.10	0.53	0	0	0	1.40	0.53	26.1	1.50	73.9
15	13:22	20:00	6.63	0.88	3.73	0.36	0	0.12	1.54	4.09	61.7	2.54	38.3
16	12:26	19:15	6.82	1.90	2.87	0.25	0	0	1.80	3.12	45.7	3.70	54.3
MEAN			7.10	1.16	3.54	0.40	0.46	0.32	1.25	3.94	54.2	3.17	45.8
STANDARD DEVIATION			2.34	0.70	1.41	0.18	0.56	0.46	1.04	1.56	12.5	1.17	12.5

Table 17. Breakdown of terrain features for the 18 test runs.

TEST RUN NUMBER	LEVEL	UPGRADE-LIGHT		UPGRADE-HEAVY		DOWNGRADE-LIGHT		DOWNGRADE-HEAVY		CUT		TUNNEL	
	Percent of T_{dose}	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences
1	57.3	36.0	14	0	0	6.7	6	0	0	2.3	10	0	0
2	40.9	40.4	7	0	1	18.3	5	0.4	1	3.4	22	0.1	4
3a	7.8	62.0	5	29.4	2	0.8	1	0	0	5.3	26	0.3	6
3b	22.6	34.4	10	31.4	5	11.6	4	0	0	20.6	65	2.2	9
4	82.4	5.2	1	12.4	2	.0	1	0	1	3.4	2	0	0
5	18.6	27.3	13	18.7	4	34.7	11	0.7	1	7.2	47	0.2	3
6	25.6	9.1	12	22.6	3	34.3	8	8.4	1	8.2	51	0.4	9
7	66.9	26.8	5	0	0	6.3	5	0	0	0	0	0.1	1
8	88.9	9.3	9	0	0	1.8	3	0	0	0.1	1	0	0
9	100.0	0	0	0	0	0	0	0	0	0	1	0	0
10	8.1	55.4	5	20.9	3	15.6	2	0	0	22.0	130	4.7	30
11	21.4	18.8	12	39.9	2	19.9	6	0	0	17.9	114	4.7	20
12	21.1	35.1	12	1.6	1	26.5	16	15.7	4	9.6	99	1.2	14
13	57.7	42.3	3	0	0	0	0	0	0	0	0	0.1	4
14a	48.9	48.9	5	0	0	2.2	1	0	0	2.6	14	0.1	4
14b	71.0	29.0	2	0	0	0	0	0	0	1.4	1	0	0
15	42.3	57.7	7	0	0	0	0	0	0	4.2	26	0	0
16	70.9	25.9	10	0	0	3.2	2	0	0	2.4	15	0	0

Table 18. Operational duty cycle data for various locomotive operations.

TEST RUN NUMBER	HORN		BRAKE **		RADIO		BELL		WARNING ALARMS		WINDOWS OPEN	
	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences	Percent of T_{dose}	Number of Occurrences
1	4.7	59	4.7	56	18.4	329	9.2	34	0	0	60.2	6
2	3.2	56	3.4	128	16.6	397	10.2	41	0	1	98.9	2
3a	3.9	35	4.6	20	6.9	139	9.8	19	0.1	14	94.2	2
3b	3.2	41	5.4	66	4.7	122	4.9	15	0.2	12	7.4	2
4	2.3	18	8.8	27	11.2	67	3.7	4	0	0	99.6	4
5	2.3	77	4.2	45	11.4	199	6.2	14	0	0	100.0	2
6	2.2	83	1.2	26	10.5	241	3.0	15	1.0	4	99.6	2
7	5.9	178	1.6	11	35.6	320	12.5	54	0	0	100.0	1
8	10.3	148	2.6	34	21.4	209	16.7	40	0.3	1	100.0	1
9	8.8	143	0.9	25	11.2	163	15.2	33	0	0	100.0	1
10	5.5	144	0.4	10	11.5	285	6.5	34	0	0	13.0	3
11	1.7	49	1.9	36	8.9	274	0.1	6	0	1	0.4	5
12	3.7	199	1.4	29	8.4	302	3.1	29	0.6	29	39.3	8
13	2.2	49	0.9	18	5.1	196	0 * ‡	0 * ‡	0	0	99.9	4
14a	8.8	237	8.4	8	5.8	181	12.1	49	0	0	99.6	2
14b	5.8	15	0 * †	0 * †	3.9	14	20.2	3	0	0	95.2	1
15	15.9	165	1.5	22	10.5	285	28.8	63	0	0	100.0	0
16	11.5	247	0 * †	0 * †	8.6	190	1.7	9	0	0	99.8	3
MEAN	5.7	108	3.2	35	11.7	217	9.6	28	0.1	3	78.2	3
STANDARD DEVIATION	3.9	75	2.6	29	7.6	97	7.5	18	0.3	8	36.6	2

* Not included in mean and standard deviation calculations.

** As discussed in the footnote to Table 14, "brake" includes both independent and train brake operations.

† Only major brake application occurred when stopping the train in the yard at the final destination, after the test equipment had been disassembled.

‡ Bell could hardly be heard in the cab during on-line operations. No attempt made to record duty cycle data for bell.

Table 19. Operational duty cycle data for the eight engine notch settings. The percentages are based on the effective crew "dose" time and the crew on-board time.

TEST RUN NUMBER	IDLE/NOTCH 1		NOTCH 2		NOTCH 3		NOTCH 4		NOTCH 5		NOTCH 6		NOTCH 7		NOTCH 8	
	Percent of T_{dose}	Percent of T_{O-B}	Percent of T_{dose}	Percent of T_{O-B}	Percent of T_{dose}	Percent of T_{O-B}	Percent of T_{dose}	Percent of T_{O-B}	Percent of T_{dose}	Percent of T_{O-B}	Percent of T_{dose}	Percent of T_{O-B}	Percent of T_{dose}	Percent of T_{O-B}	Percent of T_{dose}	Percent of T_{O-B}
1	55.6	75.9	17.1	9.3	6.4	3.5	5.2	2.8	2.5	1.4	4.3	2.3	6.8	3.7	2.2	1.2
2	28.3	54.5	8.7	5.5	7.5	4.8	6.7	4.3	6.1	3.9	5.0	3.2	3.8	2.4	33.8	21.5
3a	6.6	39.8	12.6	8.1	9.2	5.9	12.1	7.8	19.0	12.3	15.5	10.0	5.6	3.6	19.5	12.6
3b	22.4	66.8	18.6	8.0	16.1	6.9	9.0	3.9	8.0	3.4	7.3	3.1	4.8	2.1	13.7	5.9
4	31.2	70.7	11.6	4.9	16.9	7.2	15.0	6.4	3.6	1.5	3.2	1.4	5.0	2.1	13.5	5.7
5	31.9	70.1	7.7	3.4	3.3	1.5	5.4	2.4	7.1	3.1	6.1	2.7	3.2	1.4	35.3	15.5
6	6.5	49.4	5.7	3.1	18.2	9.9	12.2	6.6	5.3	2.9	8.7	4.7	13.1	7.1	30.2	16.4
7	30.3	69.1	7.5	3.3	7.3	3.2	5.0	2.2	3.9	1.7	2.6	1.1	4.6	2.1	38.8	17.2
8	31.0	69.4	5.1	2.2	14.5	6.4	4.8	2.1	3.5	1.5	1.9	0.8	1.2	0.5	38.1	16.9
9	20.0	75.1	12.1	3.8	2.0	0.6	9.0	2.8	3.4	1.0	2.7	0.8	3.2	1.0	47.6	14.8
10	20.0	47.2	2.5	1.7	5.5	3.7	1.9	1.2	1.3	0.9	1.3	0.8	1.2	0.8	66.3	43.8
11	21.1	58.0	2.2	1.2	9.7	5.1	3.1	1.6	6.9	3.7	1.3	0.7	1.1	0.6	54.7	29.1
12	29.6	59.2	2.4	1.4	4.1	2.4	1.1	0.6	2.8	1.6	4.4	2.5	2.0	1.2	53.6	31.1
13	35.9	66.5	4.8	2.5	2.6	1.4	5.0	2.6	4.3	2.3	6.3	3.3	4.9	2.6	36.2	18.9
14a	20.5	41.2	3.5	2.6	4.7	3.5	3.1	2.3	5.2	3.9	4.1	3.0	6.3	4.7	52.6	38.9
14b	3.0	75.3	1.2	0.3	0.9	0.2	0.8	0.2	2.4	0.6	3.0	0.8	4.6	1.2	84.1	21.4
15	26.6	56.5	3.3	2.0	4.5	2.7	7.1	4.2	6.6	3.9	3.7	2.2	5.3	3.1	42.9	25.4
16	24.6	67.2	3.7	1.6	2.9	1.3	3.5	1.5	2.7	1.2	5.7	2.5	2.4	1.0	54.4	23.7
MEAN	24.7	61.8	7.2	3.6	7.6	3.9	6.1	3.1	5.3	2.8	4.8	2.6	4.4	2.3	39.9	20.0
STANDARD DEVIATION	12.1	11.6	5.2	2.6	5.4	2.6	4.0	2.1	3.9	2.6	3.4	2.2	2.8	1.7	20.1	11.0

each test run, the percent time is given for the five grade conditions[8]. The other two columns are for cuts and tunnels. Cuts refer to locations where the terrain has been excavated for the track bed, leaving an earthen/rock wall on either or both sides of the track. Included in the tunnel breakdown are long underpasses which have a similar influence on the in-cab sound levels as do tunnels.

As shown by this table, tests were conducted over a wide variety of terrains. These range from mountainous for Test Runs 3, 10 and 11, to level and flat for Test Runs 8 and 9. The percent time and number of cuts and tunnels also vary widely. Due to the general features of the terrain, cuts and tunnels are most prevalent in mountainous areas. This is especially evident for Test Runs 10 and 11. The effects of these various terrain features on in-cab noise levels are discussed in Section 5.2.

The operational duty cycle data presented in Table 18 include those operations which are most likely to contribute to, or influence, the in-cab noise levels. The duty cycle for these operations is given in terms of percent of T_{dose} and the number of occurrences. As seen from this table, there is a high degree of operational variability among the different runs. This is indicated by both the wide range of values and the large standard deviations relative to the mean values. In general, even though the number of

[8]Unless advised by the locomotive crew, the breakdown of grade into light and heavy was dependent upon the subjective judgement of the NBS test personnel operating the operational keyboard. This judgement was influenced by the terrain features adjacent to the track and by the rate of change of the grade from light to heavy or from upgrade to downgrade, and vice versa. This judgement was difficult to make since railroad grade changes are usually very gradual. Also, several of the test runs were conducted at night making it even more difficult to judge grade.

occurrences is large, especially for operations such as horn soundings and radio receptions, the percentage of time required for the operations listed in this table is small relative to T_{dose}.

Some other, more specific, observations regarding this table are:

- The number of occurrences for horn soundings cannot be reliably related to the number of grade crossings because of the differing horn blowing techniques used by the 18 engineers. Some used four distinct horn blasts (four occurrences), while others used an essentially continuous blast with only a variation of the sound level (one occurrence).

- Measured data on brake use are lower than indicated by the existing data shown in Tables 8 and 9. This is due to a difference in the interpretation of the braking duty cycle in that the existing data refer to the length of time that the brakes are being applied, whereas the data in Table 18 refer to the length of time the brake pipe is being vented into the cab to achieve the required brake pipe pressure reduction. This latter definition is more appropriate as far as in-cab noise is concerned.

- The number of occurrences for the bell is approximately one-fourth as many as for horn soundings, even though the percent on-time is greater. The reason for this is that for grade crossings the bell is on continuously, whereas the horn is sounded four distinct times.

- There are very few occurrences of warning alarms except when there are persistent mechanical problems. This was the case for the locomotive in Test Run 12. If testing had not been in progress on this locomotive it would have been shut down until permanent repairs could have been made.

- If the weather conditions permit, the general tendency is to operate with the windows open. For 13 of the 18 test runs the windows were open for nearly the entire trip.

The locomotive diesel engine duty cycle for the eight notch settings is given in Table 19 in terms of percent time relative to the effective crew "dose" time, T_{dose}, and the crew on-board time, T_{O-B}. The reason for showing these two percentages is to illustrate the difference between on-line operation time (represented by T_{dose}) and the overall on-board time. As discussed earlier in this section, the difference between T_{dose} and T_{O-B} is the downtime when the locomotive is not operating on line (defined as $T_{notch\ 1}$ and listed in Table 16). For the purposes of defining a duty cycle for the total on-board time, $T_{notch\ 1}$ is added to the on-line idle/notch 1 time[9] and then the time in each notch setting is divided by T_{O-B}. The result is a reduction of the percentage relative to that based on T_{dose} for each notch setting, except idle/notch 1 which increases due to the addition of $T_{notch\ 1}$. This can be seen by examination of Table 19.

Further examination of Table 19 shows that there is a high degree of variability among runs. This variability is a function not only of the particular locomotive, train tonnage and terrain, but also whether there are any stops along the way to wait for other trains to pass, stops to pick up or set off cars, or stops because of mechanical problems. In general, the largest percentages of time are spent in idle/notch 1 and notch 8. On the average for on-line operations (i.e., based on T_{dose}), approximately 40 percent of the time is spent at notch 8, 25 percent at idle/notch 1 and the remaining 35 percent distributed about equally among notches 2 through 7. Including the time during which the locomotive is not operating on-line (i.e., $T_{notch\ 1}$), increases the average percent time spent at idle/notch 1 to almost 62 percent and reduces the average percent time at notch 8 to 20 percent.

Comparison of these results with the existing data for engine duty cycle in Tables 4 and 5 shows that there is relatively good agreement. The data

[9]The times spent at idle and notch 1 are combined because the electronic signals obtained from the MU cable system by the NBS designed instrumentation were the same for both throttle positions. This does not present any problems since the noise levels do not differ appreciably between idle and notch 1.

from Table 4, given in terms of various average duty cycles, are similar to the duty cycle based on T_{O-B}. The mean values based on T_{O-B} from this current study correspond very closely to both the GE first average and the ATSF medium duty cycles. A similar comparison of the duty cycle based on T_{dose} with the existing data given in Table 5 shows that the percent time in notch 8 was less in this current study. This reduction may be due to the inclusion in T_{dose} of some short periods of time when the locomotive is at idle. Nonetheless, the general trend of notch 8 time being high while the locomotive is under way is shown by both sets of data.

The important point to note about the operational duty cycle data is that for a good portion of the time the crew is in the cab, the locomotive is being operated such that the noise levels are most likely to be below the 90 dB threshold level. This is shown to be the case by the in-cab sound level and noise exposure data presented in the next two sections.

5.2 In-Cab Noise Levels

The acoustic data from the recorded tapes were analyzed using a measuring amplifier set for A-weighting and "slow" response as specified in the OSHA standard [2]. The logarithmic output signal of the measuring amplifier, which was proportional to the sound level in decibels, was digitally sampled 10 times per second and recorded on magnetic tape using a mini-computer. The operational parameter data were also digitized and arranged in such a format that they could be correlated with the acoustic data. Analysis of the digitized data was done on the NBS central computer facility. This analysis consisted of binning the acoustic data (rounded to the nearest whole decibel) according to the operational event. The binning procedure counted the number of times each sound level occurred, between the limits of 70 and 126 dB, for each event. The result of the binning process is a listing of the number of counts for each sound level that occurred during the entire test run. Since the counts correspond to 0.1 second samples, the counts can be converted into time in seconds by multiplying by 0.1. Thus, the binned data essentially represent a sound level histogram for each event during the test run.

The data were binned for 26 operational events. These were:

- 15 events from the operational keyboard [Table 14] plus windows closed (16)
- dynamic brake (1)
- engine notch settings (8)
- overall [regardless of event] (1)

During actual in-service runs, it is possible for more than one of these operational events to occur at the same time. In this case it is essential to know which operation is the predominant noise source so that the relative contribution of each operation to the crew noise dose can be determined. The approach used to make this determination in this study was to establish a hierarchy for binning the data based on maximum sound level. This hierarchy was determined from data obtained in a preliminary study conducted on a DOT test locomotive at the U. S. Department of Transportation Transportation Test Center (TTC) located in Pueblo, Colorado, and from stationary data for the locomotives in Test Runs 1 through 7. With these data, which are listed in Table 20, the following hierarchy was established:

1) brake
2) alerter
3) horn
4) call bell
5) radio

Table 20. Data used to establish hierarchy for binning of operational events: These data are the average A-weighted sound levels, L_{avg}, (except where noted) for the engineer's position obtained using "slow" response.

OPERATIONAL EVENT	A-WEIGHTED SOUND LEVEL, dB re 20 μPa		LOCOMOTIVE
	Windows Open	Windows Closed	NUMBER
Emergency Brake†	108.3	X	DOT Test Locomotive
Brake Application†	97.5	X	DOT Test Locomotive
Alerter	X	92.7-105.4	2,6
Horn†	94.5	91.6	DOT Test Locomotive
Call Bell	X	84.8-93.8	4,7
Radio	X	84.0-91.1	DOT Test Locomotive
Bell	83.3	81.1	2
Notch 8 (no engine load)	82.4	78.3	DOT Test Locomotive
Notch 8 (engine self-load)	83.2	78.9	DOT Test Locomotive

X - Not tested

† - Maximum A-weighted sound level reported

For the case of simultaneous occurrence of events, the data were assigned to the event which was highest in the hierarchy. For example, if the brake and radio were operating at the same time, the data were assigned to the brake in the binning process, and not to the radio.

This hierarchical approach is valid provided that either the sound level of one of the operations involved is 10 dB higher than the other, or the events very rarely, if ever, occur simultaneously. No case of simultaneous occurrence of any two events among the brake, alerter, horn or call bell was found in this study. There were cases where the brake and radio or horn and radio were operating simultaneously, but the horn and brake produced sound levels that were generally 8-10 dB higher than that of the radio and thus these were the predominant noise sources. The only events which frequently occurred simultaneously were the bell and horn. Since the sound levels of the bells were much less than those of the horns, the bell was not included in the event hierarchy. Instead, all the data were binned for the bell when its operational keyboard switch was on so that an accurate measure of the duty cycle of the bell could be obtained.

After the data were binned, the appropriate noise ratings and noise exposures were calculated. With the data binned according to operational event, the net contribution of sources such as horns or brakes to the overall noise environment in the cab were determined. The results are given in terms of one of the three following noise ratings:

L_{max} - maximum A-weighted sound level obtained using "slow" response; used for short duration, transient events such as horn soundings or brake applications.

L_{avg} - average A-weighted sound level (based on the arithmetic average of the digitized samples taken every one-tenth of a second); used for single events with relatively steady sound levels.

L_{eq} - equivalent A-weighted sound level (which has the same acoustic energy as does a time-varying sound for a given time period); used for long durations which include many different events.

Mathematically, L_{avg} and L_{eq} are given by

$$L_{avg} = \frac{1}{N} \sum_{i=1}^{N} L_i \quad , \qquad (3)$$

$$L_{eq} = 10 \log_{10} \left\{ \frac{1}{N} \sum_{i=1}^{N} 10^{L_i/10} \right\} , \qquad (4)$$

where L_i = digitized samples taken every one-tenth second,

N = total number of samples, and

$\log_{10}$ = common logarithm to the base 10.

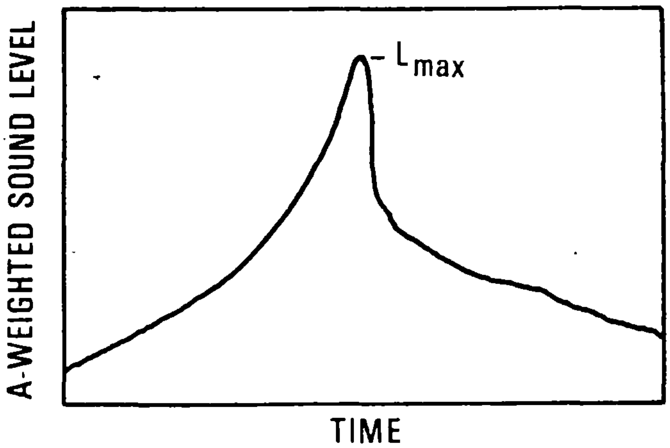
Examples of the relationships of these noise ratings to various sound level time histories are shown in Figure 8.

For events having sound level distributions that may be approximated by a normal (Gaussian) statistical distribution such as shown in Figure 9, L_{avg} is equivalent to L_{50}, where L_{50} is the sound level exceeded 50 percent of the time that the event is occurring. When the levels are normally distributed, L_{eq} can be related to L_{avg} by the following relationship [28]:

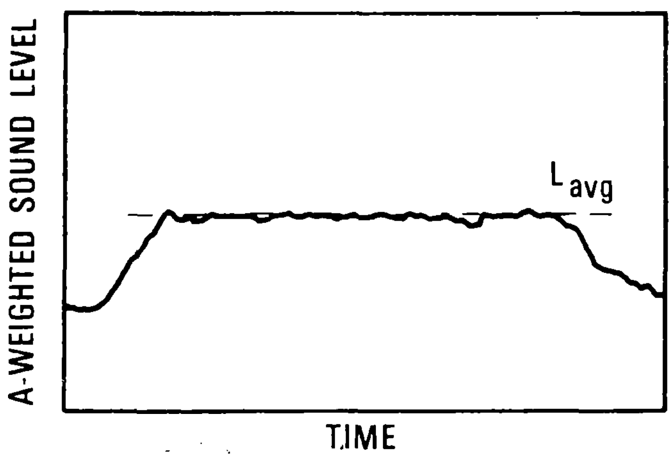
$$L_{eq} = L_{avg} + 0.115\, s^2 \quad , \qquad (5)$$

where s = standard deviation of the noise level distribution.

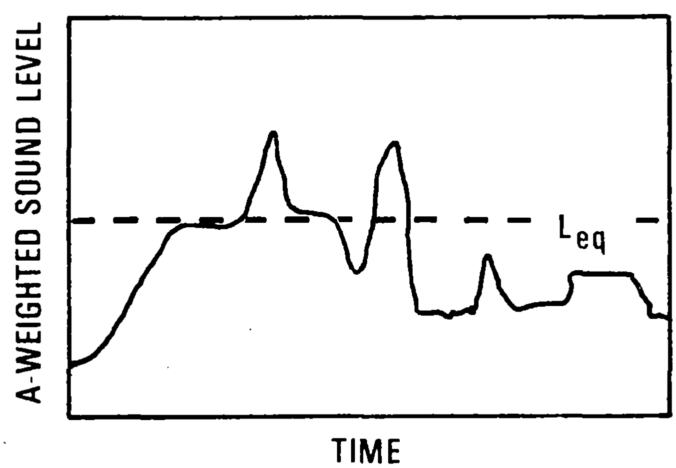
In the remaining portion of this section, these noise ratings are used to examine the relative influences of different operational variables on the in-cab noise environment. The assessment of this environment in terms of crew noise exposure is then discussed in Section 5.3.



a) L_{max} - short duration, transient events



b) L_{avg} - single events with relatively steady sound levels



c) L_{eq} - long durations which may include many events

Figure 8. Examples of the relationships of various noise ratings to different sound level time histories.

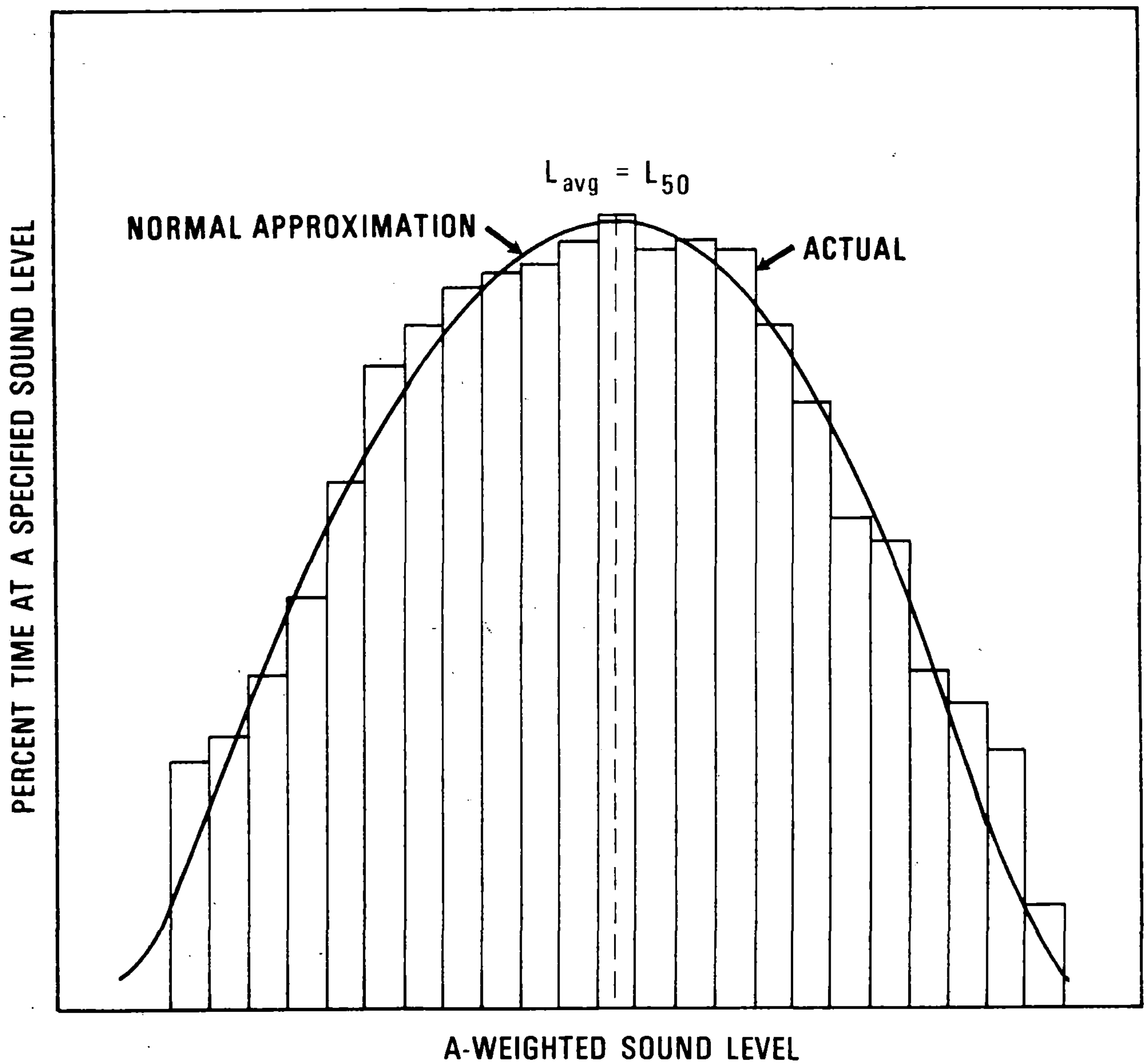


Figure 9. Example of noise level distribution that may be approximated by a normal statistical distribution.

5.2.1 Spatial Variation in the Cab

Because of the non-symmetrical location of certain sources in the cab, such as the brake pipe outlet near the engineer, four fixed microphones were used to obtain data to examine the spatial variation of the sound level in the cab. As discussed in Section 4.1, these microphones were located approximately 6 inches from the ear positions of the engineer and brakeman when they were seated.

The data for the 18 test runs (16 locomotives) show that there is variability of the sound level with position in the cab for some individual sources but for the overall trip the spatial variation of the sound level in the cab is statistically insignificant. This conclusion was based on analysis of the stationary test data for engine notch 8, horn, and brake with the windows open and closed and of the in-service data for the overall trip. These data are listed in Tables 21 through 24. In these tables, ELS corresponds to the engineer left-side microphone, ERS to the engineer right-side microphone, BRS to the brakeman right-side microphone and BLS to the brakeman left-side microphone.

Examination of the data for each locomotive shows that there is some spatial variability of the sound level in the cab. However, two-way analysis of variance shows that at the 95 percent confidence level there are no statistically significant differences in sound level among the levels at the four microphone locations (ERS, ELS, BRS and BLS) for the following sets of data for the 18 test runs:

notch 8 - L_{avg}, stationary, windows open

horn - L_{max}, stationary, windows closed

horn - L_{max}, stationary, windows open

overall trip - L_{eq}, in-service

Table 21. Stationary data for notch 8 for the 16 test locomotives. Values are for the four fixed microphone locations with windows open and closed.

LOCOMOTIVE NUMBER	AVERAGE A-WEIGHTED SOUND LEVEL, L_{avg}, dB re 20 μPa							
	Windows Open				Windows Closed			
	ERS	ELS	BRS	BLS	ERS	ELS	BRS	BLS
1	90.3	89.3	89.3	N/A	88.1	89.3	87.7	N/A
2	94.9	N/A	93.0	92.8	92.6	90.9	92.4	92.2
3	88.1	88.0	87.6	87.3	87.5	87.4	87.7	87.6
4	81.7	80.6	80.7	N/A	79.1	78.9	80.7	N/A
5	78.3	78.1	76.5	N/A	78.3	78.1	78.8	N/A
6	83.4	81.5	80.3	N/A	81.4	79.6	79.0	N/A
7	85.6	85.0	85.3	86.6	85.0	84.3	84.0	84.8
8	86.0	N/A	83.0	83.2	83.2	81.9	80.8	80.6
9	82.3	81.8	83.2	83.8	81.5	80.8	82.7	83.3
10	85.0	83.5	82.9	84.4	81.9	81.9	80.5	81.0
11	88.0	86.3	85.6	87.1	86.0	84.5	84.0	85.6
12	83.3	82.7	82.9	84.2	80.2	79.9	81.2	82.5
13	81.9	80.0	78.9	79.3	80.3	78.8	78.1	78.8
14	83.9	84.2	83.3	83.9	83.6	83.0	82.1	83.2
15	84.8	83.5	86.4	87.7	83.0	82.3	85.8	87.0
16	84.7	84.0	85.7	86.4	82.7	82.5	83.4	84.8
MEAN	85.1	83.5	84.0	85.6	83.4	82.8	83.1	84.3
STANDARD DEVIATION	3.9	3.1	4.1	3.3	3.7	3.8	3.8	3.6

N/A - Data are not available for this test condition.

Table 22. Stationary data for horn soundings for the 16 test locomotives. Values are for the four fixed microphone locations with windows open and closed.

LOCOMOTIVE NUMBER		MAXIMUM A-WEIGHTED SOUND LEVEL, L_{max}, dB re 20 μPa							
		Windows Open				Windows Closed			
		ERS	ELS	BRS	BLS	ERS	ELS	BRS	BLS
1	1	106.4	104.2	102.3	N/A	102.4	98.0	100.3	N/A
2	2	106.5	103.0	100.5	103.9	103.1	95.7	98.0	98.2
3	1	95.1	96.3	98.9	96.0	96.4	97.5	94.2	93.0
4	3	103.4	100.8	104.7	105.4	98.5	96.5	96.1	99.6
5	3	97.5	96.9	100.9	101.9	92.7	90.6	101.5	99.7
6	3	99.3	102.5	107.3	105.6	98.7	102.0	104.9	104.7
7	1	105.2	105.2	102.8	104.8	99.0	101.5	102.1	102.2
8	3	96.4	95.3	93.7	96.8	95.7	90.6	91.5	92.0
9	3	95.5	96.5	92.8	94.7	95.8	91.3	90.4	94.2
10	4	104.8	102.9	99.1	100.7	90.4	89.8	91.6	92.0
11	1	102.2	101.8	102.9	103.2	94.9	93.8	96.0	99.0
12	3	99.8	99.4	100.6	100.2	95.0	93.5	96.4	96.4
13	3	103.1	98.2	100.6	101.0	95.0	94.2	95.0	94.9
14	5	101.5	99.0	98.1	98.6	96.3	94.3	95.6	93.1
15	5	104.9	103.0	99.7	102.9	96.1	95.0	95.8	96.1
16	6	101.9	101.4	97.5	94.7	90.1	89.2	88.0	88.2
MEAN		101.5	100.4	100.2	100.7	96.3	94.6	96.1	96.2
STANDARD DEVIATION		3.8	3.1	3.7	3.8	3.6	3.9	4.5	4.4

N/A - Data are not available for this test condition.

Table 23. Stationary data for brake applications for the 16 test locomotives. Values are for the four fixed microphone locations with windows open and closed.

LOCOMOTIVE NUMBER	MAXIMUM A-WEIGHTED SOUND LEVEL, L_{max}, dB re 20 μPa							
	Windows Open				Windows Closed			
	ERS	ELS	BRS	BLS	ERS	ELS	BRS	BLS
1	97.0	100.8	95.7	N/A	97.2	101.7	95.6	N/A
2	101.9	105.2	105.1	103.7	X	X	X	X
3	X	X	X	X	102.3	103.6	102.4	101.6
4	97.0	102.2	95.1	96.4	97.1	102.4	97.9	97.8
5	X	X	X	X	101.3	101.0	99.3	99.1
6	X	X	X	X	102.2	103.0	101.7	101.7
7	104.1	102.4	104.5	100.4	101.9	103.4	103.1	101.5
8	X	X	X	X	102.3	102.1	102.5	101.9
9	98.3	100.2	97.5	96.4	X	X	X	X
10	87.9	87.3	86.8	86.0	85.2	87.1	85.7	85.0
11	X	X	X	X	83.2	83.9	80.9	81.0
12	X	X	X	X	89.3	90.0	87.3	87.3
13	96.1	97.9	91.2	90.6	X	X	X	X
14	X	X	X	X	100.4	102.5	101.9	100.3
15	104.6	105.2	102.7	101.9	X	X	X	X
16	94.5	96.2	90.1	90.6	X	X	X	X
MEAN	97.9	99.7	96.5	95.8	96.6	98.2	96.2	95.7
STANDARD DEVIATION	5.2	5.5	6.5	6.2	7.2	7.4	7.9	8.0

X - Data were not recorded for this test condition.
N/A - Data are not available for this test condition.

Table 24. In-service data for the overall trip. Values are for the four fixed microphone locations.

TEST RUN NUMBER	EQUIVALENT A-WEIGHTED SOUND LEVEL, L_{eq}, dB re 20 μPa			
	ERS	ELS	BRS	BLS
1	89.3	88.8	89.6	86.9
2	95.8	94.3	94.7	94.9
3a	87.5	87.2	88.3	87.9
3b	87.4	86.2	87.9	87.5
4	85.4	85.3	83.2	85.7
5	88.5	88.4	89.2	89.8
6	87.8	88.4	87.6	89.5
7	95.1	93.9	91.6	91.9
8	90.2	88.7	88.2	88.8
9	89.7	90.0	87.4	88.0
10	87.6	87.8	87.4	87.4
11	87.0	86.1	86.9	88.1
12	85.4	85.5	85.4	85.5
13	87.1	86.6	86.5	86.6
14a	92.9	92.3	91.8	91.4
14b	89.5	89.2	89.6	88.7
15	92.9	92.5	90.9	91.8
16	89.2	88.3	87.2	88.3
MEAN	89.4	88.9	88.5	88.8
STANDARD DEVIATION	3.0	2.8	2.6	2.4

The same was also proven to be true for the noise dose. This is discussed in the next section.

Further examination showed that the conclusion of no statistically significant difference in sound level can also be made when comparing the notch 8, L_{avg}, stationary, windows-closed data for the engineer right-side and brakeman right-side and left-side microphones (i.e., excluding the engineer left-side microphone).

As expected because of its location in the cab, the sound level due to venting of the brake pipe varies within the cab, with the highest levels recorded at the engineer left-side microphone position. Because of this and the fact that the radio is also located nearest to the engineer left-side microphone, examination of the effects of the various operational parameters on the in-cab levels is performed using the data for only this microphone. Since the values (L_{eq} or noise dose) for the overall trip are not a function of location in the cab, the discussion of crew noise exposure in Section 5.3 is also based only on data for the engineer left-side microphone.

5.2.2 Effect of Locomotive Operations

Of the locomotive sources or operations which were recorded for the operational duty cycle, the principal contributors to the in-cab noise environment are the horn, brake, radio and, of course, the diesel engine. Other sources such as the bell, dynamic brake, and the various types of warning alarms result in either no observable change in noise level in the cab or occur so infrequently that they may be disregarded. More is said about these sources at the end of this section.

In-service data for horn soundings, brake applications, radio receptions, and windows-open versus windows-closed conditions, plus stationary data for horns and brakes are given in Table 25. These data are

Table 25. Stationary and in-service sound level data, for the engineer left-side microphone, for various locomotive operations. The stationary data are given in terms of L_{max} and the in-service data in terms of L_{eq}.

TEST RUN NUMBER	A-WEIGHTED SOUND LEVEL, dB re 20 μPa								
	HORN			BRAKE*			RADIO	OVERALL TRIP	
	Stationary (L_{max})		In-Service (L_{eq})	Stationary (L_{max})		In-Service (L_{eq})	In-Service (L_{eq})	In-Service (L_{eq})	
	W/O	W/C		W/O	W/C			W/O	W/C
1	104.2	98.0	99.0	100.8	101.7	91.5	93.4	88.8	88.8
2	103.0	95.7	100.0	105.2	X	100.6	96.2	94.3	95.6
3a	96.3	97.5	91.3	X	103.6	95.0	91.4	87.3	86.5
3b	96.3	97.5	89.2	X	103.6	93.7	92.8	87.3	86.1
4	100.8	96.5	94.3	102.2	102.4	91.7	83.0	85.3	81.5
5	96.9	90.6	97.9	X	101.0	92.6	91.0	88.4	†
6	102.5	102.0	98.8	X	103.0	96.0	91.5	88.4	78.2
7	105.2	101.5	101.7	102.4	103.4	97.4	93.6	93.9	†
8	95.3	90.6	94.0	X	102.1	95.2	89.5	88.7	†
9	96.5	91.3	96.6	100.2	X	92.1	94.7	90.0	†
10	102.9	89.8	93.1	87.3	87.1	89.7	92.2	90.0	87.3
11	101.8	93.8	88.8	X	83.9	86.9	87.3	88.5	86.1
12	99.4	93.5	93.1	X	90.0	85.7	89.5	86.1	85.1
13	98.2	94.2	98.8	97.9	X	91.8	88.0	86.6	84.8
14a	99.0	94.3	96.1	X	102.5	100.1	91.9	92.3	83.1
14b	99.0	94.3	97.3	X	102.5	**	89.3	89.4	86.0
15	103.0	95.0	98.9	105.2	X	100.2	89.2	92.5	†
16	101.4	89.2	93.3	96.2	X	**	90.1	88.3	85.6
MEAN	100.4	94.6	95.7	99.7	98.2	93.8	90.8	89.2	85.7
STANDARD DEVIATION	3.1	3.9	3.7	5.5	7.4	4.4	3.0	2.6	4.0

X - Data not taken for this test condition
W/O - Windows Open
W/C - Windows Closed
* - As discsussed in the footnote to Table 14, "brake" includes both independent and train brake operations.
** - The only major brake applications took place after the instrumentation was dismantled.
† - The windows were left open during the entire trip.

for the engineer left-side microphone. The stationary data for horns, given in terms of L_{max}, show that the in-cab sound levels are strongly dependent upon whether the windows are opened or closed. The average reduction of in-cab level with the windows closed is 5.8 dB, with a range of reductions from 0.5 dB to 13.1 dB. This reduction is primarily a function of how well the windows and doors are sealed and to a lesser extent, the noise reduction characteristics of the cab roof. [For locomotive 3 there is actually an increase of 1.2 dB with the windows closed. This is highly unlikely and is probably due to a difference in how the horn was sounded between the stationary and in-service tests.] In almost all cases, the sound levels for horn soundings are above the 90 dB OSHA threshold level. A sound level time history for the typical operation of the horn at a crossing is shown in Figure 10. As seen in this figure, the sound level is relatively constant during the time the horn is being sounded, i.e. L_{max} is approximately equal to L_{avg}. Thus, because of the magnitude of the sound levels, even when the windows are closed, and the operational nature of the horn, horn soundings will definitely be a contributing factor to the crew noise exposure. Although the OSHA noise exposure is not based on L_{eq}, the fact that the in-service energy equivalent levels are, in all but two cases, above 90 dB, and in most instances 3 to 10 dB higher, supports this conclusion.

Based on the four cases for which there are both windows-open and windows-closed data, in-cab sound levels due to brake applications (includes both independent and train brake operations) are not a function of window position. This is as expected, since the brake pipe vent is located inside the cab. The maximum in-cab sound levels for brake applications, L_{max}, are greater than 90 dB for all locomotives except those on Test Runs 10 and 11.

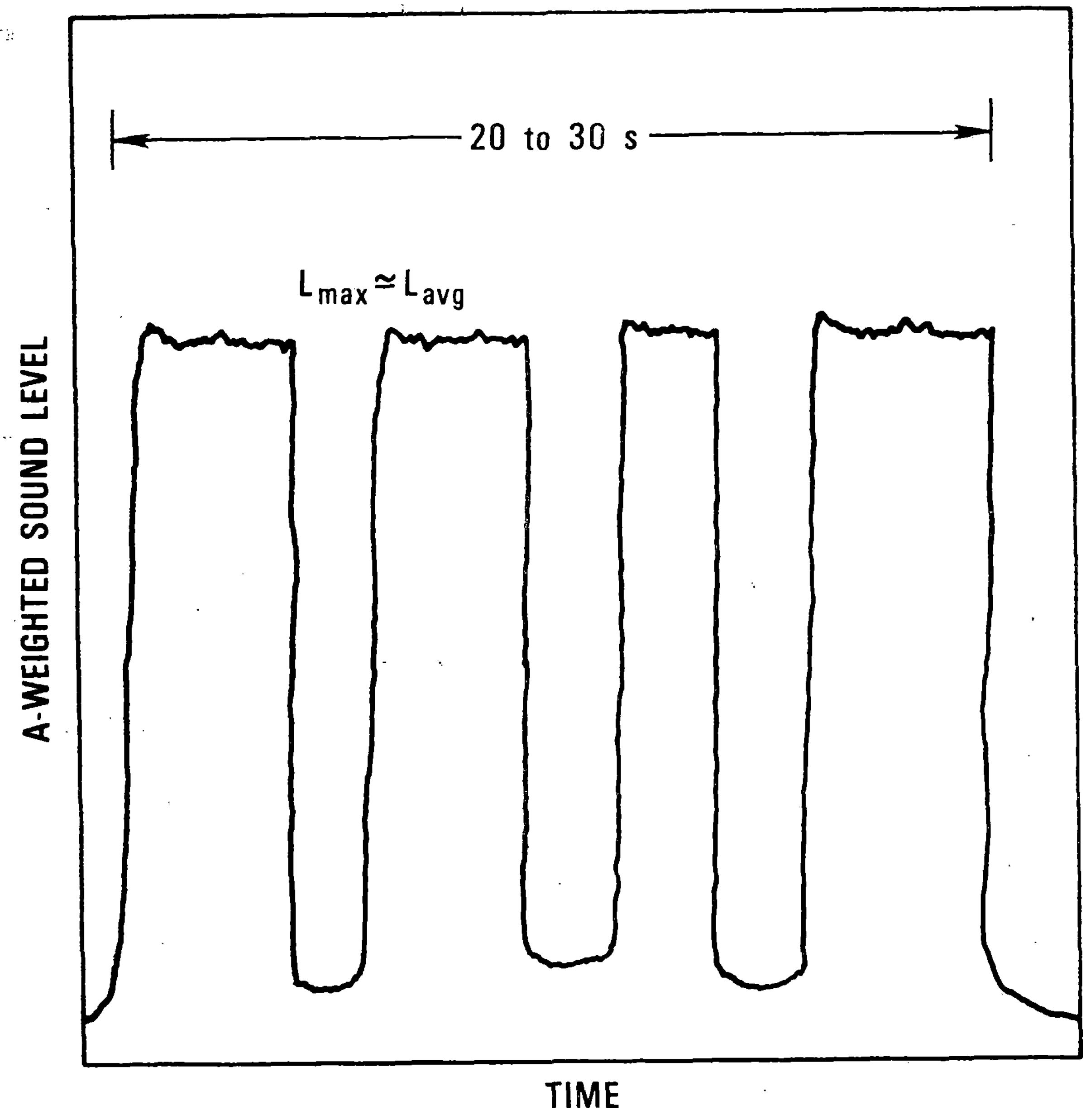


Figure 10. Sound level time history for horn operation at a crossing.

Unlike horn soundings, the sound level time history for various types of brake applications shows that the sound level varies widely while the brake pipe is being vented (see Figure 11). The duration is also variable, particularly for applications of the train brake. In this case the duration is dependent on the length of the train. Thus, although the maximum sound levels for brake applications are as high as those for horn soundings, the sound levels do not remain at these maximum values during the entire brake application. This indicates that the crew noise exposure will be influenced by brake applications but probably to a lesser degree than by horn soundings. This will be controlled by the number of occurrences and duration of each occurrence for brake applications relative to horn soundings.

The purpose of the radio is to be in communication with the dispatcher, other crew members, wayside personnel, and other trains so that all train movements can be coordinated. For obvious safety reasons, the volume of the radio is adjusted so that it can be heard above the noise generated by the engine. Because the volume is adjustable and is a function not only of the in-cab noise levels but also the personal preference of each engineer, no stationary data were recorded for radio operations. The in-service data listed in Table 25 correspond only to radio receptions since radio transmissions are normally inaudible above the noise in the cab. The range of equivalent sound levels is lower than that for horn and brakes, but the duration, given in terms of percent of T_{dose} in Table 18, is significantly higher. The effect on the crew noise exposure is a function of the sound level distribution relative to 90 dB, which cannot be judged from the equivalent sound level.

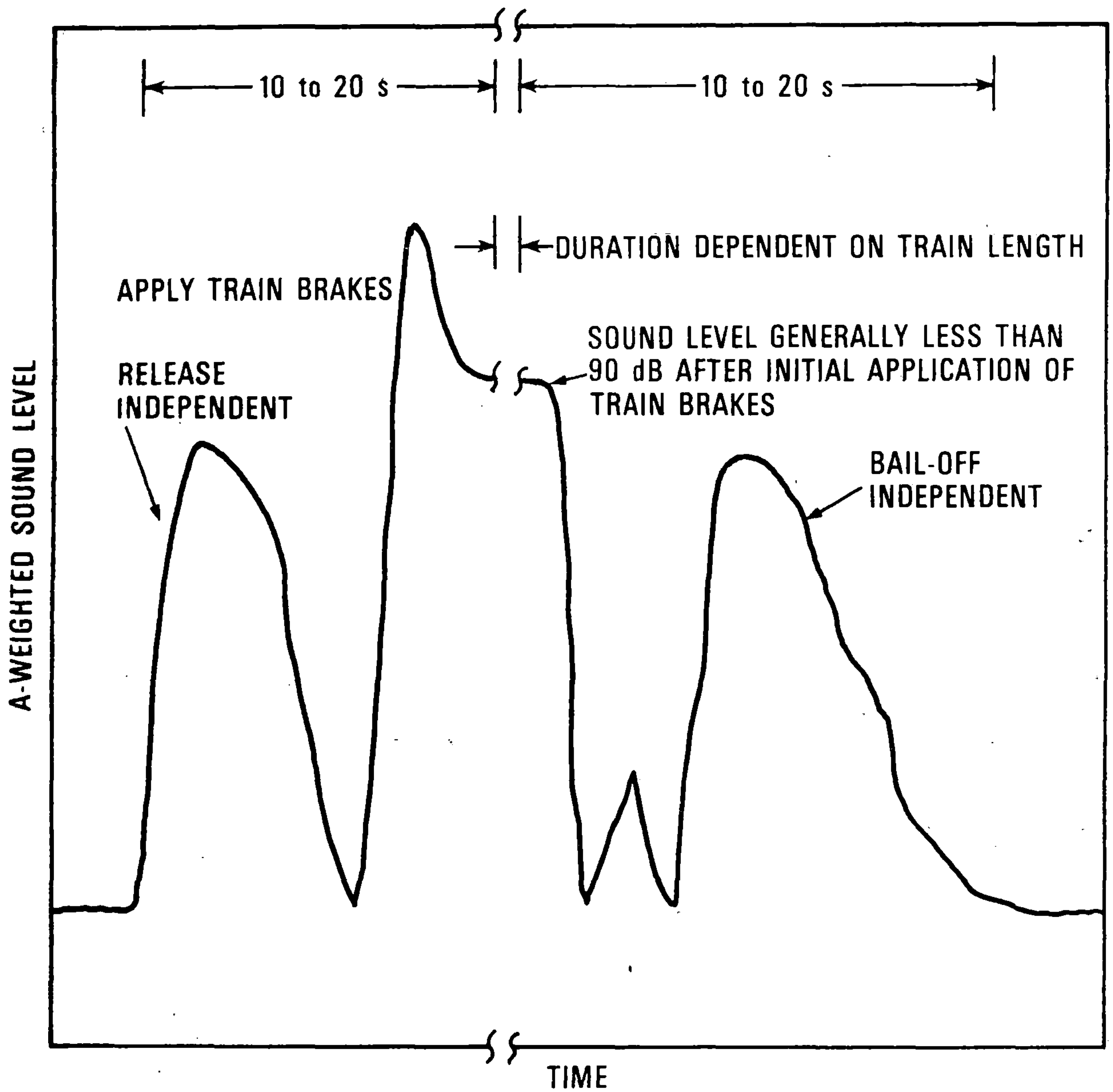


Figure 11. Sound level time histories for different types of brake applications.

The sound level data for the eight engine notch settings are given in Tables 26 through 28. Tables 26 and 27 list the stationary data in terms of L_{avg} for windows open and closed, respectively. Table 28 lists the in-service data in terms of L_{eq} for each notch setting, as well as the overall trip L_{eq}. In general, both the stationary and in-service data show that the sound level increases with notch setting. Figure 12 is a plot of the mean of the average A-weighted sound levels versus notch setting for the stationary and in-service data for all 18 test runs. The straight lines represent the linear regression lines based on the mean values for each set of data. Based on these regression lines, it is seen that the sound level increases approximately 1.5 dB per notch setting for stationary (no load) conditions (windows open or closed) and 0.6 dB per notch setting for in-service conditions. This difference is partially due to the fact that sources other than engine noise are included in the data binned for each notch setting. The only two sources which are not included in the in-service notch setting data are horns and brakes.

The stationary data for engine noise do not indicate that there would be any contribution to the crew noise exposure based on the OSHA standard [2], except for the locomotive in Test Run 2. This observation is slightly misleading since the stationary data are for engine operation without any load. Additional data were taken for the locomotive in Test Run 10 using the engine self-load capability (designated 10a in Tables 26 and 27). The data for this one locomotive show little effect of load for notch settings 1, 2 and 3, but for notch settings 4 through 8, the average increase of sound level due to engine load is 2.7 dB (range 1.8 to 4.6 dB). It is not known how well the engine self-load simulates in-service engine operation,

Table 26. Stationary sound level data for the eight engine notch settings. These data correspond to the engineer left-side microphone with the cab windows open and no engine load unless noted.

LOCOMOTIVE NUMBER	AVERAGE A-WEIGHTED SOUND LEVEL, L_{avg}, dB re 20 μPa							
	NOTCH SETTING							
	1	2	3	4	5	6	7	8
1	79.9	79.0	84.2	84.6	82.8	84.9	85.4	89.3
2†	86.9	84.7	87.9	88.3	89.5	92.1	92.9	94.9
3	74.1	76.8	77.6	79.2	81.0	81.5	83.6	88.0
4	71.7	71.4	73.7	74.9	75.6	77.4	78.5	80.6
5	76.7	73.5	76.1	75.1	74.0	76.3	79.5	78.1
6	74.1	73.6	73.8	74.7	75.5	77.1	78.9	81.5
7	N/A	75.5	77.0	79.8	80.7	82.8	85.6	85.0
8†	79.9	81.8	80.2	84.6	85.7	85.4	86.6	86.0
9	69.5	70.6	73.6	77.1	79.1	81.2	81.5	81.8
10	71.3	72.9	76.1	78.1	79.6	80.1	81.7	83.5
10a*	69.7	73.6	77.0	81.3	N/A	82.6	83.9	86.4
11	74.8	77.0	79.4	80.5	83.7	83.5	84.7	86.3
12	N/A	70.5	71.4	73.1	75.3	76.6	78.5	82.7
13	67.4	71.9	73.6	77.6	80.0	80.0	80.0	80.0
14	N/A	N/A	77.6	78.7	80.1	81.4	83.1	84.2
15	73.4	N/A	77.1	80.7	79.8	80.5	82.0	83.5
16	68.0	67.9	74.6	82.1	84.0	84.0	83.9	84.0
MEAN	74.1	74.7	77.1	79.4	80.4	81.6	83.0	84.5
STANDARD DEVIATION	5.4	4.5	4.1	4.0	4.1	3.9	3.6	4.0

† - Data for engineer right-side microphone
* - Stationary engine run-up with engine self-load
N/A - Data are not available for this test condition.

Table 27. Stationary sound level data for the eight engine notch settings. These data correspond to the engineer left-side microphone with the cab windows closed and no engine load unless noted.

LOCOMOTIVE NUMBER	AVERAGE A-WEIGHTED SOUND LEVEL, L_{avg}, dB re 20 μPa — NOTCH SETTING 1	2	3	4	5	6	7	8
1	72.5	76.7	82.6	84.2	86.1	84.7	89.2	86.7
2	78.6	80.8	82.6	83.1	85.7	87.2	89.0	90.9
3	77.0	81.7	78.3	N/A	81.8	81.3	83.3	87.4
4	N/A	69.5	72.5	73.2	73.7	75.2	76.6	78.9
5	69.5	67.8	69.1	70.5	73.8	74.1	76.4	78.1
6	N/A	72.8	73.4	74.3	75.5	75.9	77.5	79.6
7	72.9	75.4	75.6	78.1	80.1	81.3	83.2	84.3
8	N/A	N/A	N/A	N/A	80.8	80.4	80.7	81.9
9	N/A	N/A	73.4	76.0	78.0	80.0	80.7	80.8
10	N/A	N/A	74.0	76.6	78.2	78.8	80.0	81.9
10a*	N/A	73.1	74.1	79.8	82.8	80.8	81.8	83.7
11	72.4	75.8	78.0	79.3	80.9	83.2	84.3	84.5
12	69.6	69.0	69.5	71.0	72.3	74.1	74.8	79.9
13	66.4	71.6	72.6	77.1	78.7	78.8	78.7	78.8
14	71.7	76.1	N/A	76.8	78.2	79.6	80.3	83.0
15	72.4	75.4	75.7	79.6	78.2	79.6	80.2	82.3
16	68.1	68.1	74.0	80.9	82.6	82.5	82.4	82.5
MEAN	71.9	73.8	75.0	77.4	79.3	79.9	81.1	82.7
STANDARD DEVIATION	3.6	4.4	4.0	4.0	4.0	3.6	4.0	3.4

* - Stationary engine run-up with engine self-load.
N/A - Data are not available for this test condition.

Table 28. In-service sound level data, corresponding to the engineer left-side microphone, for the eight engine notch settings and the overall trip. Data are given in terms of L_{eq}.

TEST RUN NUMBER	EQUIVALENT SOUND LEVEL, L_{eq}, dB re 20 μPa								
	NOTCH SETTING								OVERALL TRIP
	1	2	3	4	5	6	7	8	
1	85.5	82.5	83.4	86.1	85.6	87.0	88.1	88.6	88.8
2	88.9	89.1	91.2	91.4	92.7	93.6	93.7	95.8	94.3
3a	82.9	85.6	83.5	83.5	85.0	86.2	85.7	87.5	87.2
3b	82.7	82.2	85.6	87.1	88.1	84.0	87.3	N/A	86.2
4	78.0	80.8	84.8	80.2	80.3	80.2	83.9	84.8	85.3
5	86.0	86.5	84.7	83.3	84.1	86.3	88.4	88.6	88.4
6	82.4	80.8	85.6	85.7	85.9	85.2	88.1	88.6	88.4
7	90.5	91.5	92.3	92.7	92.8	92.0	91.5	92.8	93.9
8	85.3	85.9	87.3	86.8	88.1	88.5	86.4	87.4	88.7
9	86.4	88.5	87.0	84.9	86.1	88.2	86.4	89.2	90.0
10	81.4	88.9	88.4	86.9	85.8	84.7	86.1	87.9	87.8
11	81.1	81.2	82.3	83.1	85.0	84.7	85.5	87.5	86.1
12	83.8	78.6	80.3	82.0	81.7	84.0	82.1	85.5	85.5
13	84.0	81.1	81.8	85.1	84.3	85.1	86.0	85.0	86.6
14a	86.1	85.9	85.1	86.5	87.8	85.7	88.3	88.5	92.3
14b	79.9	77.5	83.1	85.0	87.2	87.5	87.9	87.7	89.2
15	85.6	85.0	84.0	84.8	86.7	86.5	85.9	88.0	92.5
16	83.6	83.9	82.8	85.3	87.3	88.5	88.1	87.8	88.3
MEAN	84.1	84.2	85.2	85.6	86.4	86.6	87.2	88.0	88.9
STANDARD DEVIATION	3.1	3.9	3.1	3.0	3.1	3.0	2.6	3.0	2.8

N/A - Data are not available for this test condition.

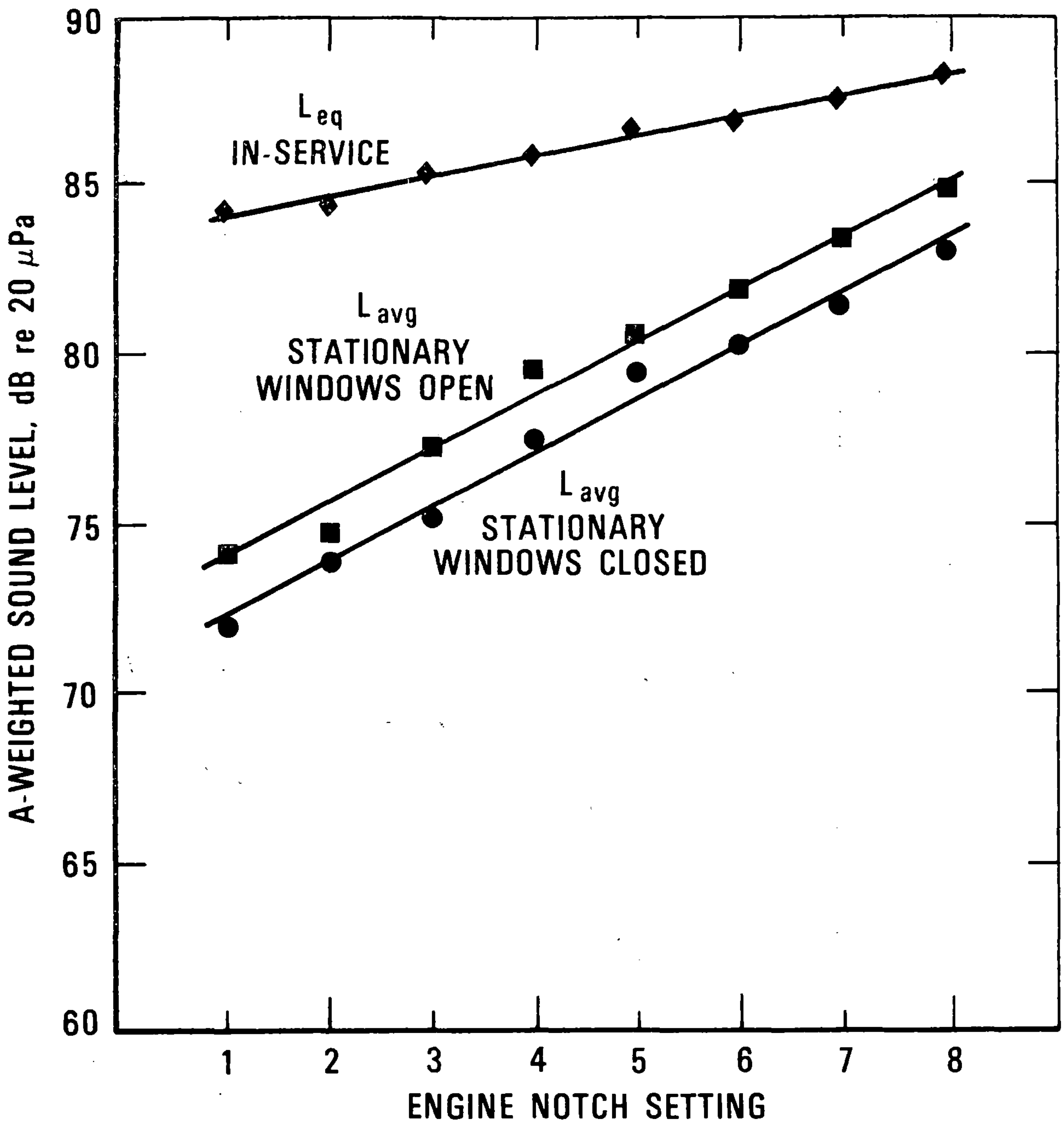


Figure 12. Mean of the average A-weighted sound levels for all locomotives versus notch setting for stationary and in-service test conditions corresponding to the engineer left-side microphone.

but if the sound levels do increase by approximately this amount when the engine is loaded, there is likely to be a significant contribution to the crew noise exposure. This is particularly true since on the average the engine is operating in notch 8 for 40 percent of the effective crew dose time (Table 19).

The effect of window position for each source can be summarized as:

- horn - 0.5 to 13.1 dB reduction with windows closed, dependent upon how well windows and doors are sealed.
- brake - not a function of window position.
- engine - 0.9 to 2.2 dB decrease with windows closed.

In general, if the source is located outside of the cab, window position will have a greater effect on the in-cab sound levels. Also, when running through a cut or tunnel the in-cab levels will be more dependent on window position because of reflections of the sound waves off the cut and tunnel walls. Examination of the in-service data for windows open and windows closed in Table 25 is not really meaningful because the windows were normally in one position (either open or closed) for the entire trip. Only Test Runs 1 and 12 had a relatively equal amount of time with the windows both open and closed (see Table 18). For these two cases, the equivalent sound levels for windows open versus windows closed are equal for Test Run 1 and 1 dB higher for windows open for Test Run 12. Although there is some effect, it is difficult to make any generalized statements based on only two test runs.

As mentioned at the beginning of this section, other sources such as the bell, warning alarms and dynamic brake either have little influence on the in-cab sound levels or occur very infrequently. Table 29 lists stationary noise level and operational duty cycle data for these operations.

Table 29. Stationary sound level and in-service operational duty cycle data for the bell and warning alarms. The sound level data are for the engineer left-side microphone.

TEST RUN NUMBER	A-WEIGHTED SOUND LEVEL, dB re 20 μPa				
	BELL		WARNING ALARMS		
	Stationary (L_{avg})		Stationary (L_{avg})		In-Service
	W/O	W/C	W/O	W/C	Occurrences
1	X	X	X	X	0
2	83.6	82.0	X	106.7†	1
3a	75.4	X	X	X	7
3b	75.4	X	X	X	12
4	74.4	X	84.8	X	0
5	77.2	76.0	X	86.0	0
6	84.7	84.7	X	91.3	4
7	74.8	X	X	93.8	0
8	72.3	X	85.7	X	1
9	72.3	X	X	X	0
10	79.0	78.8	85.4	85.3	0
11	81.7	77.0	X	X	1
12	78.6	X	86.5	X	29
13	74.7	72.5	X	X	0
14a	79.9	X	X	X	0
14b	79.9	X	X	X	0
15	76.0	73.8	X	X	0
16	69.9	67.6	X	X	0

W/O - Windows Open
W/C - Windows Closed
X - Data not taken for this test condition
† - Maximum A-weighted sound level; referred to as "dead man"

As shown by these data, the sound levels for the bell are such that they are normally less than the background levels due to the engine noise. Also, since the bell is used primarily at crossings, the horn sounding will predominate over the bell.

Data for warning alarms were taken for only a few locomotives because there often was no special alarm or it could not be manually controlled. Although the sound levels for certain alarms were above 90 dB, the number of occurrences is extremely small. Only for the locomotive on Test Run 12, which was experiencing mechanical problems, was the number of occurrences significant. As mentioned in Section 5.1, if it were not for these tests being conducted, the locomotive would have been shut down.

Data for operation of the dynamic brake are not reliable because the dynamic brake system was frequently inoperable even though the electronic signal from the MU cable indicated it was operating. Although this information might be useful for discussing the operational duty cycle, the dynamic brake had very little effect on the in-cab sound levels. This was verified by the NBS test personnel who noted that they could only determine that the dynamic brake was operating by observing the engineer place the locomotive in dynamic brake or by asking the engineer in what mode the locomotive was operating, and not by audible changes of the in-cab sound levels.

5.2.3 Effect of Terrain Features

The effects of terrain features on in-cab sound levels are both indirect and direct. Such features as upgrades and downgrades will indirectly influence the in-cab sound levels by changing the load on the engine and by necessitating changes of the engine notch settings and braking to control train slack. The direct effects of terrain occur when the locomotive is passing through a cut or tunnel. In this situation the sound reflects off the walls and/or ceiling of the tunnel or cut and results in an increase of sound level outside and inside the cab. This increase is a function of the overall dimensions of the cut or tunnel and the proximity of the walls and/or ceiling to the locomotive.

The in-service sound level data for these various terrain features, given in terms of L_{eq}, are presented in Table 30. Also listed in this table are the equivalent sound levels for the overall trip, which are used as a reference for comparing the effects of terrain. Because the breakdown of grade into light and heavy was normally a subjective judgement of the NBS test personnel operating the keyboard (see footnote 8 on page 57), grade is broken down into only two categories -- upgrade and downgrade. It should also be noted that long underpasses were recorded as tunnels since they cause a similar increase in the in-cab noise levels.

An approximation of the effect of grade on in-cab sound levels can be made by comparing the mean values for operations on grade to the mean value for the overall trip. Because the values for test runs with small percentages of time on a particular type of grade may not be representative, the mean values are based only on those runs with at least 10 percent of T_{dose} on that type of grade. A new mean value of the overall trip is then calculated for the same set of locomotives. Using this procedure, the mean values are:

Upgrade - 89.4 dB	Overall Trip - 88.8 dB
Downgrade - 86.4 dB	Overall Trip - 88.1 dB

Table 30. In-service sound level and duty cycle data for various terrain features. The sound level data are given in terms of L_{eq} for the engineer left-side microphone and the duty cycle data in terms of percent of T_{dose}.

TEST RUN NUMBER	EQUIVALENT SOUND LEVEL, L_{eq}, dB re 20 μPa						
	UPGRADE		DOWNGRADE		CUT	TUNNEL	OVERALL TRIP
	L_{eq}	Percent of T_{dose}	L_{eq}	Percent of T_{dose}	L_{eq}	L_{eq}	L_{eq}
1	88.1	36.0	91.1	6.7	88.1	*	88.8
2	96.0	40.4	93.3	18.7	93.3	91.4	94.3
3a	87.6	91.4	84.0	0.8	84.7	94.0	87.2
3b	87.9	65.8	84.5	11.6	86.0	84.2	86.2
4	87.0	17.6	81.3	<0.1	84.9	*	85.3
5	88.6	46.0	88.9	35.4	88.7	96.4	88.4
6	88.9	31.7	88.1	42.7	88.9	90.9	88.4
7	95.8	26.8	95.9	6.3	*	95.4	93.9
8	89.5	9.3	86.8	1.8	91.6	*	88.7
9	*	*	*	*	93.2	*	90.0
10	88.0	76.3	81.8	15.6	87.1	91.5	87.8
11	87.2	58.7	82.7	19.9	87.1	93.4	86.1
12	85.5	36.7	85.7	42.2	84.4	91.5	85.5
13	86.4	42.3	*	*	*	85.9	86.6
14a	91.6	48.9	91.4	2.2	91.3	88.1	92.3
14b	90.8	29.0	*	*	87.4	*	89.2
15	92.3	57.7	*	*	89.7	*	92.5
16	88.9	25.9	84.1	3.2	85.2	*	88.3
MEAN	89.4†	45.7†	86.4†	26.6†	88.2	91.2	88.9
STANDARD DEVIATION	3.1	20.0	4.0	13.1	2.9	3.8	2.8

† The mean and standard deviation are calculated only for those grades with a percent of T_{dose} greater than 10.

* These terrain features did not occur during the test run.

The effect of grade is, as might be expected, higher sound levels for upgrade operations when the engine is pulling and lower sound levels for downgrade operations when the engine is not pulling. The difference between these mean values is not a true indication of the effect of grade in an absolute sense because the equivalent sound levels for grade operations include other locomotive operations such as horn soundings and radio receptions and terrain features such as cuts or tunnels. An even more important factor in assessing the effect of grade relates to the length of the train relative to the length of the grade. Since the train can be over a mile long, it is common for the lead locomotive to have crested a hill and be going downgrade while most of the train is still on an upgrade. In this case, even though the locomotive is on a downgrade, it is still pulling the train upgrade. This would be especially true in general undulating terrain where the grade is changing frequently. In such a case, the in-cab sound levels are unlikely to be related to the grade upon which the lead locomotive is operating. A more appropriate parameter might be drawbar force, which would give a better indication of how hard the locomotive is pulling. Unfortunately, it was not possible to monitor drawbar force for these test runs.

The general effect of cuts and tunnels is to increase the in-cab sound levels because of sound reflections from the walls and/or ceilings. The data in Table 30 indicate that cuts have only a small effect on in-cab sound levels. This is due to the general engineering practices used in excavating cuts. To prevent earth and rock from sliding onto the tracks the cuts are normally sloped away from the track or cut back far enough so that if there is an earth or rock slide, it will not fall on the tracks. As a result, the reflected sound is directed away from the locomotive or is insignificant relative to the sound directly propagated into the cab. The same is not true for tunnels. Because of the expense involved in tunneling, the tunnel dimensions are held to the minimum required size. As a result, the walls and ceiling are very close to the locomotive causing the in-cab sound levels to increase because of sound reflections. As seen in Table 30, the mean L_{eq} is over 2 dB higher for operations in tunnels. For Test Runs 10, 11 and 12, which had a relatively large number of tunnels (see Table 17), the effect is more evident. The equivalent sound levels for tunnels are, respectively, 3.7, 7.3, and 6.0 dB higher than for the overall trip.

The in-cab sound levels for operations in tunnels are strongly influenced by window position, and when closed, the quality of window sealing. During the in-service runs for this program, the crew would always shut the windows when running through a tunnel to minimize the in-cab noise and exhaust fumes. In terms of the overall trip, the percent time spent operating in tunnels is small. As seen in Table 17, the largest percentage is 4.7 (based on T_{dose}) for Test Runs 10 and 11. However, as discussed in the next section, the effect on the crew noise dose can be important.

5.3 Crew Noise Exposure

The primary objective of this program was the assessment of the locomotive crew noise exposure. As discussed in Section 2, the OSHA occupational noise standard [2], which is the most commonly used hearing conservation criteria in U. S. industry, is used in this report to evaluate the crew noise exposure. The current OSHA standard has a criterion value of 90 dB for eight hours, with a 5 dB tradeoff per doubling of duration and a 90 dB threshold level. A potential problem when evaluating locomotive crew noise exposure is that the crew can work as long as 12 hours. Since this is an atypical work schedule relative to most U. S. industries, there are no legally established procedures for dealing with this case.

A more recently regulation on in-cab locomotive noise [8] recommend [7] and an FRA proposed regulation on in-cab locomotive noise [8] recommend the use of the existing OSHA relationship between sound level and exposure time with the threshold level reduced to 85 dB (at 16 hours), i.e. all sound levels above 85 dB are included in the noise exposure calculation.

The noise exposure assessments made in this study are based on the current OSHA standard utilizing a threshold level of 90 dB (although calculations of the noise dose are also made for this and other criteria).

The crew noise exposures are calculated from the binned data as discussed in Section 5.2. Since these data cover only the periods when the tape recorder is operating (column B of Table 16), the binned data are scaled by the tape changing and calibration time (column C of Table 16) so that the calculated noise exposure corresponds to T_{dose} -- the time the locomotive is actually operating and likely to be generating sound levels greater than 90 dB. This scaling merely involves multiplying the time at a particular sound level (the binned values in seconds) by the ratio of the effective crew dose time, T_{dose}, to the time the tape recorder is operating (column B of Table 16). Scaling by this technique assumes that the in-cab sound levels during the time the tapes are being changed and calibrated are statistically distributed the same as the sound levels for the overall trip. Since the types of locomotive operations that occurred during these times were not controlled and to an effect were random, this assumption appears to be reasonable.

5.3.1. Spatial Variation in the Cab

As discussed in Section 5.2.1, the sound levels do vary somewhat with position in the cab because of the nonsymmetrical location of sources. However, two-way analysis of variance showed that at the 95 percent confidence level there were no statistically significant differences in sound level among the four fixed microphone locations, except for brake applications. The same is also true for the crew noise exposure. The in-service noise exposures for the overall trip are listed in Table 31 for the 18 test runs. These noise exposures are based on T_{dose} and calculated using the current OSHA standard. Again using two-way analysis of variance, there is no statistically significant difference at the 95 percent confidence level among the noise exposures measured at the four fixed microphone locations. Thus, as in Section 5.2., only data for the engineer left-side microphone are presented for discussion of the crew noise exposure.

5.3.2. Crew Noise Exposure for the Overall Trip

The overall crew noise exposures presented in Table 31 show that there is only one case where the dose is greater than the maximum allowable value of 1.0 (see Equation (2) and subsequent discussion in Section 2). This occurs for Test Run 2 and only for the engineer right-side microphone.[10]

[10] As detailed in Appendix A, the locomotive on Test Run 2 was an EMD GP9, manufactured in 1957, with a 1750 horsepower engine. Because of its low horsepower and age, this unit wasn't normally used for over-the-road runs. It was used in this case because the NBS test personnel specifically requested this particular model of locomotive and this was the only unit available. The train on this run consisted of 110 cars weighing 6403 tons. During the trip the second unit in the consist developed electrical problems and was shut down. Thus, this test run represented the case of a relatively heavy train which, after losing the second unit, was underpowered. As a result, the test locomotive was forced to operate under adverse conditions for which it would not normally be used. However, since similar shut-downs can occur in regular service, this does illustrate that there can be cases where overexposure to noise occurs.

Table 31. In-service noise exposure data calculated using the OSHA criteria. These values are for the overall trip based on T_{dose} for the four fixed microphone locations.

TEST RUN NUMBER	CREW NOISE EXPOSURE			
	ERS	ELS	BRS	BLS
1	0.20	0.17	0.18	N/A
2	1.02	0.81	0.86	0.91
3a	0.07	0.07	0.10	0.08
3b	0.09	0.06	0.12	0.09
4	0.02	0.02	0.01	0.02
5	0.11	0.13	0.12	0.16
6	0.14	0.16	0.09	0.12
7	0.55	0.45	0.27	0.33
8	0.16	0.12	0.09	0.10
9	0.12	0.13	0.06	0.07
10	0.15	0.16	0.15	0.14
11	0.09	0.08	0.08	0.14
12	0.08	0.09	0.08	0.06
13	0.08	0.07	0.06	0.06
14a	0.43	0.35	0.39	0.40
14b	0.02	0.02	0.02	0.02
15	0.35	0.34	0.32	0.46
16	0.13	0.10	0.07	0.10
MEAN	0.21	0.19	0.17	0.19
STANDARD DEVIATION	0.25	0.20	0.20	0.22
RANGE	0.02 - 1.02	0.02 - 0.81	0.01 - 0.86	0.02 - 0.91

N/A - Data are not available.
ERS - Engineer right-side microphone
ELS - Engineer left-side microphone
BRS - Brakeman right-side microphone
BLS - Brakeman left-side microphone

Examination of the results for the other test runs shows that there are no other cases where the maximum allowable dose (based on the OSHA standard) is even close to being exceeded. This might appear to be due primarily to the fact that for the 18 test runs T_{dose} was normally much less than eight hours. However, if the crew noise exposures for each of the 18 test runs are scaled to an exposure time of eight hours, in a manner similar to that described earlier in this section, it is found (see Table 32) that even for these increased exposure times there would only be one additional locomotive which exceeds the allowable noise dose. Examination of the eight-hour scaled noise exposures for the overall trip (based on the data from the engineer left-side microphone) shows that only the locomotives on Test Runs 2 and 7 would exceed a noise dose of 1.0 for an eight-hour exposure time. Thus, based on the current OSHA standard, it does not appear that overexposure to noise is a widespread problem for locomotive crews.

The other criterion specified in the OSHA standard is that the sound level shall at no time exceed 115 dB (A-weighted, slow response). Table 33 lists the maximum sound levels (minimum duration at at least 1.0 s) which were measured for in-service horn soundings, brake applications and the overall trip. Examination of this table shows that only the locomotive on Test Run 2 had a measured sound level greater than 115 dB. This sound level was measured at the brakeman right-side location during a brake application. This value is substantially higher than the sound level measured during the stationary tests (105.2 dB from Table 25). This increase in sound level may be due to a difference of brake pipe pressure between the stationary and in-service tests, or to some additional source unaccounted for during the in-service run.

Table 32. Comparison of crew noise exposures for the engineer left-side microphone based on the actual exposure time, T_{dose}, and a scaled exposure time of eight hours.

TEST RUN NUMBER	CREW NOISE EXPOSURE	
	Actual Exposure Time, T_{dose}	8-hour Exposure Time*
1	0.17	0.28
2	0.81	1.24
3a	0.07	0.19
3b	0.06	0.12
4	0.02	0.11
5	0.13	0.25
6	0.16	0.26
7	0.45	1.10
8	0.12	0.35
9	0.13	0.45
10	0.16	0.26
11	0.08	0.11
12	0.09	0.11
13	0.07	0.11
14a	0.35	0.63
14b	0.02	0.29
15	0.34	0.66
16	0.10	0.26

* In scaling to an 8-hour exposure time, it is assumed that the in-cab sound levels during the additional exposure time are statistically distributed the same as the sound levels for the actual trip.

Table 33. Maximum A-weighted sound levels (slow response), in decibels, for horn soundings, brake applications and the overall trip. These values are based on a minimum duration of 1.0 s.

TEST RUN NUMBER	ENGINEER RIGHT-SIDE			ENGINEER LEFT-SIDE			BRAKEMAN RIGHT-SIDE			BRAKEMAN LEFT-SIDE		
	Horn	Brake	Overall	Horn	Brake	Overall	Horn	Brake	Overall	Horn	Brake	Overall
1	106	101	106	103	101	103	107	99	107	100	98	100
2	108	114	114	105	114	114	107	115	115	110	113	113
3a	96	103	103	97	104	104	97	102	102	99	101	101
3b	103	105	105	103	106	106	97	103	103	97	102	102
4	99	105	105	97	105	105	97	99	100	99	*	99
5	108	104	108	105	105	106	113	102	113	113	101	113
6	107	104	107	108	105	108	105	97	105	108	96	108
7	109	105	109	108	104	108	111	102	111	111	101	111
8	102	103	107	104	104	105	103	103	103	103	101	104
9	104	98	104	104	100	104	100	85	100	100	85	100
10	103	95	103	103	96	103	99	94	102	99	92	100
11	95	101	101	92	101	102	93	96	97	95	96	98
12	105	94	105	107	98	107	98	98	101	97	95	99
13	103	99	103	102	100	102	102	97	102	101	96	102
14a	104	109	109	102	108	108	100	104	104	101	103	105
14b	99	+	99	99	+	99	100	+	100	95	+	95
15	106	110	110	105	109	109	101	104	104	102	104	104
16	109	+	109	110	+	110	99	+	100	98	+	100

* This microphone channel was not operational during the brake applications.

\+ The only major brake application was made when stopping the train in the yard at the final destination. This occurred after the test equipment had been disassembled.

In general, the maximum sound levels measured for in-service operations of horns and brakes are greater than those measured for the stationary tests. This is shown in Table 34, which lists the maximum A-weighted sound levels measured at the engineer left-side position. The increase in sound level between the in-service and stationary test conditions can be due to such things as horn soundings alongside large reflecting objects (e.g., other locomotives and freight cars, buildings or the walls of a cut), or differences in air supply pressure. Although accurate prediction of the maximum in-service sound levels from the stationary measurements cannot be made because of operational and terrain variations, one can be reasonably sure that if the stationary sound levels are greater than 115 dB, the maximum in-service sound levels are also likely to be greater than 115 dB.

Another way of examining the crew noise exposure is to calculate the maximum allowable time the crew could work under those conditions and not exceed the OSHA criteria. This maximum allowable time per day is calculated from the actual noise dose and the crew exposure time by scaling the noise dose to equal 1.0. This is given by:

$$\text{Noise Dose} \times \frac{T_{max}}{T_{dose}} = 1.0, \qquad (6)$$

or,

$$T_{max} = \frac{T_{dose}}{\text{Noise Dose}}, \qquad (7)$$

where, T_{max} is the maximum allowable time per day that the crew could be on the locomotive. As before, this scaling assumes that the in-cab sound levels for T_{max} are statistically distributed the same as the sound levels for the actual trip.

Table 34. Comparison of the maximum A-weighted sound levels for stationary and in-service measurements of horn and brake applications. These data are for the engineer left-side microphone.

TEST RUN NUMBER	MAXIMUM A-WEIGHTED SOUND LEVEL, dB re 20 μPa			
	HORN		BRAKE	
	Stationary*	In-Service†	Stationary	In-Service†
1	104.2	103	101.7	101
2	103.0	105	105.2*	114
3a	96.3	97	103.6	104
3b	96.3	103	103.6	106
4	100.8	97	102.4	105
5	96.9	105	101.0	105
6	102.5	108	103.0	105
7	105.2	108	103.4	104
8	95.3	104	102.1	104
9	96.5	104	100.2*	100
10	102.9	103	87.1	96
11	101.8	92	83.9	101
12	99.4	107	90.0	98
13	98.2	102	97.9*	100
14a	99.0	102	102.5	108
14b	99.0	99	102.5	**
15	103.0	105	105.2*	109
16	101.4	110	96.2*	**
MEAN	100.4	103.0	99.6	103.8
STANDARD DEVIATION	3.1	4.5	6.6	4.4
RANGE	95.3 - 105.2	92 - 110	83.9 - 105.2	96 - 114

† Maximum values from binned data (1 dB bins)

* Locomotive cab windows open

** The only major brake application was made when stopping the train in the yard at the final destination. This occurred after the test equipment had been disassembled.

Using this T_{max}, an equivalent noise exposure level can be calculated. This level corresponds to the equivalent continuous sound level which would result in the same noise exposure as the actual time-varying sound level for an exposure time equal to T_{dose}. For this to be strictly true, it is necessary to assume that there is no threshold level and that exposure to all sound levels contributes to the noise dose. For the current OSHA standard, the equivalent noise exposure level is found by solving Equation (1) for L and substituting T_{max} for T, which gives:

$$L_{OSHA} = - 16.61 \log_{10} T_{max} + 105. \qquad (8)$$

Table 35 lists the maximum times per day and the equivalent exposure levels based on the engineer left-side microphone data for the 18 test runs. These values indicate that overexposure to noise based on the OSHA criteria is likely to occur only on the locomotives on Test Runs 2 and 7. This is true if the crew is on-board for a period of time greater than T_{max} and the locomotive operational duty cycle does not change drastically from what it was during the test run. This is the same conclusion drawn earlier from Table 32, except that it shows more dramatically that overexposure to noise based on the current OSHA standard is unlikely to occur on most locomotives. However, as discussed in the following section, this conclusion can change if different hearing conservation criteria are used.

5.3.3. Crew Noise Exposure for Alternative Criteria

In terms of the overall crew noise exposure, there is one more factor to consider. If, in the future, new or modified hearing conservation criteria are adopted, will locomotive crew noise exposures exceed these crtieria? Table 36 lists the noise exposures for the 18 test runs calculated using various schemes. These values are based either on the OSHA criteria or the proposed NIOSH criteria with various threshold levels

Table 35. Maximum allowable times per day and equivalent noise exposure levels based on the current OSHA standard. These values are based on the engineer left-side microphone data for the 18 test runs.

TEST RUN NUMBER	MAXIMUM ALLOWABLE TIME, T_{max}, hours	EQUIVALENT NOISE EXPOSURE LEVEL, L_{OSHA}, dB
1	29.02 *	80.7
2	6.45	91.5
3a	43.15 *	77.8
3b	64.13 *	75.0
4	72.65 *	74.1
5	31.67 *	80.1
6	30.30 *	80.4
7	7.28	90.7
8	22.72	82.5
9	17.61	84.3
10	31.00 *	80.2
11	74.75 *	73.9
12	72.12 *	74.1
13	71.38 *	74.2
14a	12.79	86.6
14b	28.03 *	81.0
15	12.06	87.0
16	30.27 *	80.4

* Although values of T_{max} greater than 24 hours have no physical meaning because there are only 24 hours in a day, the values which are greater than 24 hours indicate that the noise exposure could not exceed that allowed under the current OSHA standard unless the duty cycle were to change drastically from what it was on that particular test run.

Table 36. Actual crew noise exposures for the 18 test runs calculated using alternative hearing conservation criteria. These values are based on the data from the engineer left-side microphone.

TEST RUN NUMBER	Criterion Value: 90 dB at 8 hours Trade-off Rate: 5 dB per doubling of duration			Criterion Value: 85 dB at 8 hours Trade-off Rate: 5 dB per doubling of duration		
	Threshold Level			Threshold Level		
	90 dB[a]	87 dB[b]	85 dB[c]	85 dB	82 dB[b]	80 dB[d]
1	0.17	0.26	0.28	0.57	0.65	0.68
2	0.81	0.86	0.89	1.78	1.81	1.83
3a	0.07	0.13	0.15	0.31	0.39	0.41
3b	0.06	0.08	0.10	0.21	0.29	0.36
4	0.02	0.02	0.03	0.06	0.09	0.10
5	0.13	0.21	0.27	0.53	0.61	0.64
6	0.16	0.21	0.28	0.55	0.63	0.67
7	0.45	0.50	0.51	1.02	1.04	1.06
8	0.12	0.15	0.19	0.38	0.43	0.44
9	0.13	0.14	0.17	0.34	0.39	0.39
10	0.16	0.19	0.24	0.48	0.68	0.70
11	0.08	0.13	0.28	0.57	0.65	0.71
12	0.09	0.13	0.18	0.36	0.63	0.72
13	0.07	0.11	0.18	0.36	0.60	0.65
14a	0.35	0.45	0.49	0.99	1.07	1.09
14b	0.02	0.03	0.05	0.09	0.10	0.10
15	0.34	0.42	0.48	0.96	1.03	1.06
16	0.10	0.16	0.22	0.45	0.50	0.52

[a]Current OSHA standard (8-hour work period) [2].

[b]Threshold point for 12-hour work period.

[c]Proposed modification to OSHA standard [7] and current FRA standard.

[d]Proposed NIOSH criteria [9].

corresponding to 8 or 12 hour work periods. Values for the latest proposed revision to the OSHA standard [7] and the current FRA in-cab locomotive noise regulation [8] are also listed.

Examination of this table shows that for the 18 test runs there are no cases of overexposure to noise when the criterion value is 90 dB at 8 hours, regardless of the threshold level. When the criterion value is reduced to 85 dB at 8 hours with a threshold level of 85 dB, the noise doses for the locomotives on Test Runs 2 and 7 exceed the allowable limit of 1.0. If the threshold level is lowered to 80 dB (corresponding to the proposed NIOSH criteria [9]), the noise doses for the locomotives on Test Runs 14 and 15 also are greater than 1.0.

The differences among these various methods of calculating the crew noise exposure are best illustrated by T_{max}, the maximum allowable time per day that the crew could operate the locomotive without exceeding a noise dose of 1.0. These values of T_{max} are given in Table 37 along with the equivalent noise exposure levels. For shorthand purposes, the equivalent noise exposure levels are expressed as:

$$L_{x-y-z},$$

where,

x = threshold level for including values in the dose calculation,

y = the tradeoff rate (5 dB per doubling of duration for OSHA and proposed NIOSH criteria), and

z = criterion value (90 dB at 8 hours for OSHA and 85 dB at 8 hours for proposed NIOSH criteria).

For example, $L_{87-5-90}$ would be for the current OSHA criterion value, but with the threshold level set at 87 dB, corresponding to a 12-hour work period. For a criterion value of 90 dB at 8 hours with a 5 dB per doubling

Table 37. Maximum allowable times per day and equivalent noise exposure levels for various calculation methods. These values are based on the engineer left-side microphone data for the 18 test runs.

TEST RUN NUMBER	90-5-90[a]		87-5-90[b]		85-5-90[c]		85-5-85		82-5-85[b]		80-5-85[d]	
	T_{max}, hr*	L_{x-y-z}, dB	T_{max}, hr*	L_{x-y-z}, dB	T_{max}, hr*	L_{x-y-z}, dB	T_{max}, hr*	L_{x-y-z}, dB	T_{max}, hr	L_{x-y-z}, dB	T_{max}, hr	L_{x-y-z}, dB
1	29.02	80.7	18.35	84.0	17.01	84.6	8.50	84.6	7.48	85.5	7.10	85.9
2	6.45	91.5	6.04	92.0	5.86	92.2	2.93	92.2	2.88	92.4	2.85	92.4
3a	43.15	77.8	25.14	81.7	20.77	83.1	10.38	83.1	8.33	84.7	7.80	85.2
3b	64.13	75.0	46.37	77.3	37.87	78.8	18.93	78.8	13.48	81.2	10.76	82.9
4	72.65	74.1	64.50	74.9	49.38	76.9	24.69	76.9	16.54	79.8	14.11	80.9
5	31.67	80.1	18.99	83.8	15.34	85.3	7.67	85.3	6.65	86.3	6.33	86.7
6	30.30	80.4	23.28	82.3	18.04	84.1	9.02	84.1	7.84	85.1	7.40	85.6
7	7.28	90.7	6.56	91.4	6.42	91.6	3.21	91.6	3.14	91.7	3.10	91.8
8	22.72	82.5	18.66	83.9	14.57	85.7	7.29	85.7	6.51	86.5	6.27	86.8
9	17.61	84.3	15.95	85.0	13.27	86.3	6.64	86.3	5.73	87.4	5.60	87.6
10	31.00	80.2	25.38	81.7	20.53	83.2	10.26	83.2	7.20	85.8	7.02	85.9
11	74.75	73.9	45.11	77.5	20.06	83.4	10.03	83.4	8.70	84.4	8.03	85.0
12	72.12	74.1	50.44	76.7	37.65	78.8	18.82	78.8	10.65	82.9	9.41	83.8
13	71.38	74.2	48.53	77.0	29.73	80.5	14.87	80.5	8.93	84.2	8.26	84.8
14a	12.79	86.6	9.77	88.6	8.98	89.2	4.49	89.2	4.15	89.7	4.08	89.9
14b	28.03	81.0	15.62	85.2	11.18	87.6	5.59	87.6	5.24	88.0	5.23	88.1
15	12.06	87.0	9.76	88.6	8.55	89.5	4.27	89.5	3.96	90.1	3.87	90.2
16	30.27	80.4	19.24	83.7	13.90	86.0	6.95	86.0	6.19	86.9	6.05	87.0

[a] Current OSHA standard (8-hour work period) [2].

[b] Threshold point for 12-hour work period.

[c] Proposed modification to OSHA standard [7] and proposed FRA in-cab locomotive noise regulation [8].

[d] Proposed NIOSH criteria [9].

* Although values of T_{max} greater than 24 hours have no physical meaning because there are only 24 hours in a day, those values which are greater than 24 hours indicate that the noise exposure could not exceed that allowed under the current OSHA standard unless the duty cycle were to change drastically from what it was on each individual test run.

of duration tradeoff, the equivalent noise exposure level (for any given threshold level, x) is given by:

$$L_{x-5-90} = -16.61 \log_{10} T_{max} + 105. \qquad (9)$$

For a criterion value of 85 dB at 8 hours with a 5 dB per doubling of duration tradeoff, the corresponding relationship is

$$L_{x-5-85} = -16.61 \log_{10} T_{max} + 100. \qquad (10)$$

As seen in Table 37, T_{max} is significantly reduced for the three groups based on a criterion value of 85 dB at 8 hours (last three pairs of columns). For the 80 dB threshold point corresponding to the proposed NIOSH criteria, T_{max} is less than 8 hours for 11 out of the 16 locomotives. For this latter case (i.e., 80-5-85), the average T_{max} for all 16 locomotives is 6.85 hours (standard deviation of 2.78 hours and range of 2.85 to 14.11 hours).

For these particular locomotives and test runs, overexposure to noise is not a significant problem if the 90 dB criterion value is used. However, for the proposed NIOSH criteria (80-5-85), 4 out of the 16 locomotives which were tested, or 25 percent, would have problems with excessive noise.

5.3.4 Comparison of the Crew Noise Exposures for the Fixed and Lapel Microphones

One of the questions that was considered in developing this program was how the measured noise exposures would compare to results using a noise dosimeter. Although noise dosimeters were not used in this study (see footnote 4, page 42), data were obtained for microphones mounted on the engineer's and brakeman's shirt lapels in locations similar to that for the microphone of a noise dosimeter. The results obtained from analysis of the data recorded from these microphones are given in Table 38 in terms of the noise dose based on the current OSHA standard. For comparison, the noise exposures based on the data from the fixed microphones are also listed.

Table 38. Comparison of the in-service noise exposures based on the current OSHA criteria for the fixed and lapel microphones.

TEST RUN NUMBER	ENGINEER			BRAKEMAN		
	Right-Side	Left-Side	Lapel	Right-Side	Left-Side	Lapel
1	0.20	0.17	N/A	0.18	N/A	N/A
2	1.02	0.81	N/A	0.86	0.91	N/A
3a	0.07	0.07	N/A	0.10	0.08	N/A
3b	0.09	0.06	N/A	0.12	0.09	N/A
4	0.02	0.02	0.01	0.01	0.02	N/A
5	0.11	0.13	N/A	0.12	0.16	N/A
6	0.14	0.16	N/A	0.09	0.12	N/A
7	0.55	0.45	0.51	0.27	0.33	0.35
8	0.16	0.12	0.23	0.09	0.10	0.14
9	0.12	0.13	0.24	0.06	0.07	0.17
10	0.15	0.16	0.37	0.15	0.14	0.21
11	0.09	0.08	0.23	0.08	0.14	0.25
12	0.08	0.09	0.37	0.08	0.06	0.12
13	0.08	0.07	0.18	0.06	0.06	0.12
14a	0.43	0.35	0.54	0.39	0.40	0.45
14b	0.02	0.02	0.06	0.02	0.02	0.02
15	0.35	0.34	0.54	0.32	0.46	0.37
16	0.13	0.10	0.24	0.07	0.10	0.15
MEAN*	0.18	0.16	0.29	0.14	0.17	0.21
STANDARD DEVIATION*	0.17	0.14	0.18	0.12	0.15	0.13

N/A - Data are not available.

* The mean and standard deviation values are based on the results for locomotives 4 and 7 to 16 for the engineer and 7 to 16 for the brakeman.

Examination of Table 38 shows that the results for the lapel microphones are generally higher than those obtained with the fixed microphones. For the engineer the average noise dose is about 70 percent higher for the lapel microphone than for the fixed microphones, and for the brakeman it is about 35 percent higher (based on the averages for the locomotives which have lapel microphone results available). This increase can be explained by considering the different microphone locations relative to the engineer and brakeman, and the nature of operations in the locomotive cab. The lapel microphones were mounted on the shirt lapel closest to the center of the cab -- the left side for the engineer and right side for the brakeman. These locations were chosen to minimize the noise which is generated by wind from the open windows blowing on the microphone. With these locations for the lapel microphones, one would not expect there to be significant differences between the lapel and fixed microphones for typical locomotive noise sources. The one exception where microphone location is important is when the engineer and brakeman are talking to each other or when the engineer is using the radio. In either case, when the engineer and brakeman turn their heads toward the center of the cab to speak, their mouths are only 2 to 3 inches from the lapel microphones. Since the fixed microphones may be a foot or more away, particularly when the engineer leans forward to use the radio, the sound level due to conversation is lower at the fixed microphones because of distance attenuation. This was verified by listening to several of the tapes and comparing the fixed and lapel microphone channels. For Test Run 12, for example, the engineer was frequently discussing the locomotive's mechanical problems with the brakeman and with the dispatcher via radio. The effect of these conversations can be seen by comparing the noise doses, 0.08 and 0.09 for the engineer's fixed microphones versus 0.37 for the engineer's lapel microphone. The noise exposure based on the brakeman's microphone was only 0.12. This value was lower because the brakeman was not discussing the locomotive's mechanical problem as much as the engineer.

These results may be slightly atypical since some of the conversation was with the NBS test personnel regarding the instrumentation in the cab. On a normal run, there would probably be less talking. Nevertheless, verbal communication is an important part of the locomotive crew's job. As necessary safety precautions the engineer is in frequent contact with the caboose, the dispatcher, wayside personnel and other trains regarding the movement of the train, and the brakeman is calling out signals. Thus, the sound levels and calculated noise doses for the lapel microphones would be expected to be slightly higher than the fixed microphones, with the difference dependent upon the amount of conversation that takes place.

5.3.5. Effect of Locomotive Operations

One of the secondary objectives of this study was to determine which locomotive sources and/or operations were the primary contributors to the overall noise dose. Examination of these contributions, which were calculated from the binned data, showed that there were three principal sources contributing to the crew noise exposure. These were horn soundings, brake applications and the diesel engine. All other sources either generated sound levels less than 90 dB or were of such short duration that they had a negligible influence on the overall noise dose.

To determine the actual contribution of the diesel engine to the crew noise exposure, the data for the engineer left-side microphone were rebinned so that the engine notch setting bins did not include any values that occurred whenever the horn or brake were operating. This was necessary because the horn and brakes generate sound levels greater than those generated by the engine. The crew noise exposures for these rebinned engine-notch-setting data and the horn and the brake data are given in Table 39. These values show that engine notch 8 and the horn are the two principal operations contributing to the crew noise dose, with some smaller contribution from the brake[11] and from engine notch 1. The average noise dose contributions for engine notch 8 and the horn are about the same, but for different reasons. Although the sound levels characteristic of engine notch 8 operations are less than those for the horn, the duty cycle data show that the average duration for engine notch 8 operations is seven times greater than it is for horn soundings. The relative contributions of these two operations to the overall crew noise dose are about equal because of the dependence of the noise dose on duration.

The breakdown of the overall noise dose into three components -- engine, horn and brake -- is an important part of the development of the stationary measurement procedure. This is presented as part of a locomotive screening test discussed in Section 6.

One factor that has not yet been discussed is the effect on the calculated noise dose of neglecting horn or brake applications which may have occurred when the recorder was not operating. This occasionally occurred near the end of a test run after the instrumentation had been disassembled. Disassembly of the instrumentation was necessary due to operational constraints such as the train continuing on to another destination or test personnel and

[11]The one exception to this was Test Run 14a. During this run there was a problem with the brake system which was causing the brakes to stick on. Several times during the run the engineer vented the brake pipe system, almost to full service, and then re-pressurized it in an effort to release the brakes. These additional, relatively long, brake applications resulted in a corresponding increase of the brake contribution to the overall noise dose.

Table 39. Relative contributions from various locomotive operations to the overall crew noise dose. These data are for the engineer left-side microphone.

CONTRIBUTIONS TO THE NOISE DOSE BY SOURCE											
TEST RUN NUMBER	ENGINE NOTCH SETTING								HORN	BRAKE	OVERALL NOISE DOSE
	1	2	3	4	5	6	7	8			
1	0.03	0	0	0.01	0	0	0.01	0.01	0.07	0.03	0.17
2	0.06	0.02	0.03	0.02	0.03	0.04	0.03	0.44	0.08	0.05	0.81
3a	0	0.01	0	0	0	0.01	0	0	0.01	0.02	0.07
3b	0	0	0.01	0.01	0.01	0	0	0	0	0.02	0.06
4	0	0	0	0	0	0	0	0	0	0.01	0.02
5	0.02	0.01	0	0	0	0	0	0.04	0.03	0.02	0.13
6	0	0	0.02	0.01	0	0.01	0.02	0.05	0.04	0.01	0.16
7	0.06	0.02	0.02	0.02	0.01	0.01	0.01	0.18	0.11	0.01	0.45
8	0.02	0	0.01	0	0	0	0	0.02	0.06	0.01	0.12
9	0.01	0.01	0	0	0	0	0	0.04	0.06	0	0.13
10	0	0.01	0.01	0	0	0	0	0.10	0.03	0	0.16
11	0	0	0	0	0	0	0	0.06	0	0	0.08
12	0.01	0	0	0	0	0	0	0.04	0.03	0	0.09
13	0.01	0	0	0	0	0	0	0.01	0.05	0	0.07
14a	0.01	0	0	0	0.01	0	0.01	0.07	0.10	0.14	0.35
14b	0	0	0	0	0	0	0	0.01	0.01	0	0.02
15	0.01	0	0	0	0	0	0	0.02	0.27	0.02	0.34
16	0	0	0	0	0	0	0	0.03	0.05	0	0.10
MEAN	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.02	0.18
STANDARD DEVIATION	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.10	0.06	0.03	0.20

equipment being dropped off at an intermediate location instead of at the yard. In such cases this disassembling was normally done as soon as the locomotive entered the yard or within 3 to 5 miles of an intermediate drop-off point if the locomotive consist was to continue on with another crew. The small segment of time, for which the sound levels were not recorded, consisted primarily of operations at low notch settings, perhaps one or two very short horn soundings, and the final brake application to stop the train. Since the engine operations were at low notch settings and the horn soundings were of very short duration, the brake application was the only operation not recorded which might be of any significance. Assuming a steady sound level of 95 dB for one minute (typical values based on this study and existing data), the contribution to the noise dose would be less than 0.01. Since this contribution is small and is partially accounted for by scaling the exposure time to T_{dose}, the error introduced is considered to be negligible. Thus, no special calculations for these operations are necessary to maintain sufficient accuracy in determining the overall crew noise exposure or the relative contribution of the horn and brake to the noise dose.

5.3.6. Effect of Terrain Features

Unlike locomotive operations, the effects of terrain features on crew noise exposure are not as easy to discern. This difficulty results for two reasons: (1) the data binned for terrain features include other locomotive operations, such as horn soundings and brake applications, and (2) equivalent periods of time were not spent on each type of terrain so that the influence of duration outweighs any differences due to sound level. However, some general conclusions can be made.

Examination of the data given in Table 40 for various types of terrain shows that for upgrade and downgrade operations and cuts, the noise dose is primarily a function of duration and not the terrain; i.e., the more time spent on a particular type of grade or in a cut, the larger the percentage of the contribution to the overall noise dose. The locomotive on Test Run 6, for example, spent approximately 32 percent of the time on upgrade terrain and 43 percent on downgrade terrain. The breakdown of the overall noise dose corresponds almost exactly to this: 0.05 divided by the total noise dose of 0.16, or 31 percent for upgrade terrain and 0.07 divided by 0.16, or 44 percent for downgrade terrain. The results for the other test runs do not agree as well as this, but the general trend is the same.

Tunnels, on the other hand, can have a significant influence on the overall noise dose. This is shown by the results given in Table 40 for Test Runs 10, 11 and 12, which had a relatively large number of tunnels. The primary factor controlling the noise dose for tunnel operations in these three test runs is, however, not duration (although it is obviously important) but rather the increase of in-cab sound levels which results when the locomotive runs through a tunnel (see Section 5.2.3). This can be seen by examining the duty cycle data given in Tables 17. Although the percent times spent operating in tunnels are less than 5 percent for these three test runs, the relative contributions to the overall noise dose are approximately 18, 63 and 11 percent, respectively. As shown by this, it is important that the cab windows be well sealed and closed when operating in tunnels to minimize this contribution to the noise dose.

Table 40. Relative effect of various terrain features on the overall crew noise exposure. These data are for the engineer left-side microphone.

CONTRIBUTIONS TO THE NOISE DOSE BY TERRAIN FEATURE										
	UPGRADE		DOWNGRADE		CUT		TUNNEL		OVERALL
TEST RUN NUMBER	Noise Dose	% of T_{dose}	Noise Dose	% of T_{dose}	Noise Dose	% of T_{dose}	Noise Dose	% of T_{dose}	Noise Dose
1	0.02	29.3	0.03	11.1	0	2.3	0	0	0.17
2	0.54	40.4	0.09	18.7	0.03	3.4	0	0.1	0.81
3a	0.06	91.4	0	0.8	0	5.3	0	0.3	0.07
3b	0.03	65.6	0.01	11.7	0.01	20.6	0	2.2	0.06
4	0.01	17.8	0	0	0	3.4	0	0	0.02
5	0.06	45.9	0.06	35.5	0.01	7.2	0	0.2	0.13
6	0.05	31.7	0.07	42.6	0.01	8.2	0	0.4	0.16
7	0.14	26.8	0.04	6.3	0	0	0	0.1	0.45
8	0.01	9.1	0	1.7	0	0.1	0	0	0.12
9	0	0	0	0	0	0	0	0	0.12
10	0.13	76.4	0	15.6	0.03	22.0	0.03	4.7	0.16
11	0.07	58.8	0	19.9	0.02	17.9	0.05	4.7	0.08
12	0.03	36.7	0.04	42.2	0	9.6	0.01	1.2	0.09
13	0.03	42.4	0	0	0	0	0	0.1	0.07
14a	0.14	48.9	0.01	2.2	0.01	2.6	0	0.1	0.35
14b	0.01	29.0	0	0	0	1.4	0	0	0.02
15	0.19	57.7	0	0	0.01	4.2	0	0	0.34
16	0.03	25.9	0	3.2	0	2.4	0	0	0.10

5.4. Summary and Conclusions

This study was designed to investigate and assess typical in-cab diesel locomotive noise environments in terms of crew noise exposure. In addition, the effects of different locomotive operations and terrain features on the in-cab noise environment were to be determined. A field test program was conducted to provide the necessary information. Eighteen test runs (16 locomotives, two of which had two crews) were made. These 16 locomotives covered a range of locomotive models representing over 80 percent of the types found in the current U. S. locomotive fleet population. The 18 test runs covered a wide range of operational conditions (high speed through-freights, slow speed drag-freights, local transfer movements, etc.), varied terrains (mountainous, flat, undulating,), and varied trip lengths (6 to 12 hours). The data obtained from the program consisted of operational duty cycle information and in-cab sound level data. These were used to evaluate the crew noise exposure in terms of the OSHA noise dose (and other alternative criteria) and to determine which locomotive operations and/or terrain features significantly affected the noise exposure. The major results of the investigation and evaluation are:

- The operational duty cycle varies widely from run to run, and even from day to day over the same route depending upon the type of train, the train weight, the amount of traffic on the route and whether there are any cars to be picked up or set off or unscheduled stops because of mechanical problems.

- While the train is underway, approximately 40 percent of the time is spent in notch 8, 25 percent at idle/notch 1, and the remaining 35 percent distributed about equally among notches 2 through 7.

- Inclusion of the time that the train is standing and not operating on-line increases the average time spent at idle/notch 1 to almost 62 percent and reduces the average notch 8 time to 20 percent with the remaining 18 percent in notches 2 to 7. Thus, during a good portion of the time the crew is in the cab, the locomotive is being operated such that the engine noise levels are likely to be below 90 dB.

- In general, the sound levels are not a significant function of spatial location inside the locomotive cab. The sound generated by venting the brake pipe is the one exception to this. The highest sound levels for the brake occur at the engineer left-side microphone location which is nearest to the brake pipe vent.

- The three principal sources of in-cab locomotive noise are the diesel engine, horn and brake. The radio is also important, but the sound levels it generates vary as a function of both the in-cab sound levels due to the diesel engine and the personal listening preference of each engineer. Other sources, such as the bell, warning alarms, and dynamic brake, either have little influence on the in-cab sound levels or occur very infrequently.

- Both the stationary and in-service data show that the in-cab sound levels increase with notch setting. Based on linear regression analysis of the mean values for the 16 test locomotives, the sound level increases approximately 1.5 dB per notch setting for stationary conditions (windows open or closed), and 0.6 dB per notch setting for in-service conditions.

- The in-cab sound levels are more greatly influenced by window position for sources which are located outside the cab. This is particularly true for the horn (a range of 0.5 to 13.1 dB reduction with the windows closed) and to a lesser extent the diesel engine (0.9 to 2.2 dB decrease with the windows closed). Window position and quality of sealing are especially important for locomotive operations in tunnels.

- In general, terrain features, such as grades and cuts, do not have much effect on the in-cab sound levels. Tunnels, on the other hand, can lead to significant increases. For Test Runs 10, 11 and 12, which had a relatively large number of tunnels, the in-service equivalent sound levels for tunnels are approximately 4 to 7 dB higher than the equivalent sound levels for the overall trip.

- Based on the group of locomotives tested, it does not appear that overexposure to noise is a widespread problem for locomotive crews under the current OSHA standard. Of the 18 test runs, only the locomotive on Test Run 2 (which was being used in an atypical situation) failed the OSHA criteria.

- For a criterion value of 90 dB at 8 hours there is only one case of overexposure (Test Run 2) regardless of the threshold level (90, 87 or 85 dB). If the criterion value is reduced to 85 dB at 8 hours, the locomotives on Test Runs 2 and 7 would exceed the allowable limits for an 85 dB threshold level. For a threshold level of 80 or 82 dB, the locomotives on Test Runs 14 and 15 would also exceed the allowable limits.

- The crew noise doses calculated from the lapel microphone recordings are generally higher than the noise doses for the fixed microphones. This difference is due primarily to the fact that the lapel microphones are located closer to the crew members' mouths so that the sound levels due to conversation are higher than at the fixed microphones. This results in the noise dose also being higher.
- The two principal locomotive operations contributing to the crew noise dose are engine notch 8 and horn soundings, with some smaller contribution from the brake and engine notch 1.
- Of the various terrain features examined, only tunnels are found to have a significant affect on the crew noise dose. For features such as upgrades, downgrades and cuts, the noise dose is a function of duration and not the terrain.

Based on these results, there does not appear to be a widespread problem of overexposure to noise for locomotive crews under current FRA regulations. However, as was seen for the locomotive on Test Run 2, there can be cases where overexposure to noise can occur when certain locomotives are used on certain runs. With this in mind, the next question to be addressed is the type of monitoring which would be most advantageous for pinpointing those locomotives which might result in overexposure to noise. Since, based on the results of this study, the number of locomotives which fall into this category is estimated to be small relative to the total U. S. fleet, in-service measurements on every locomotive would be a very costly and time consuming method of testing, particularly since the noise dose can vary from run to run. Thus, some type of simplified test, which could be used to screen out these locomotives, would be desirable.

In the case of over-the-road trucks, the Bureau of Motor Carrier Safety (BMCS) of the U. S. Department of Transportation developed a simplified testing procedure for assessing in-cab driver noise exposure for in-service operations based on noise measurements with the vehicle stationary [29,30].

This stationary test procedure yields a value that is correlatable to the results obtained from continuous in-service measurements as required by OSHA [31].

A similar approach was examined in this study. Although the duty cycle for locomotives is highly variable, whereas for trucks it is generally repeatable, it was found that a stationary test, which can be used to assess in-cab locomotive noise exposure, could be developed. Such a stationary screening test is discussed in Section 6.

6.0. STATIONARY SCREENING TEST

Based on the results of the field test program, it appears that the most desirable approach for evaluating the in-cab noise exposure of locomotive crews is to develop a simplified test procedure for screening those locomotives which might result in overexposure to noise. For this screening test to be practical, it should involve a minimum number of measurements and little or no data analysis. The measurement procedure should be simple and the measured quantity easily related to the crew noise dose, without having to perform any complex calculations. The results must be repeatable and reliable in order to maintain any confidence in the screening procedure. An important question which must be addressed is the level of correlation required between the predicted and the actual noise doses for the screening test to be valid and yet still be practical.

6.1. Ideal Relationship

A way of illustrating the relationship between the noise dose predicted by a simplified test procedure and the actual noise dose is shown in Figure 13. The actual noise dose, based on continuous measurements, is plotted on the ordinate. The pass/fail limit of the hearing conservation criteria is shown as the horizontal dashed line. The noise dose predicted from the results of a simplified test procedure is plotted on the abscissa, with the test procedure pass/fail limit shown by the vertical dashed line. The solid diagonal line represents the ideal relationship, where the simplified test procedure exactly predicts the actual noise dose. The shaded region represents the range of values which may occur due to variability that can be expected in any "real-engineering" situation. The size of this band is dependent upon the complexity of the model and the assumptions used to derive the empirical relationship.

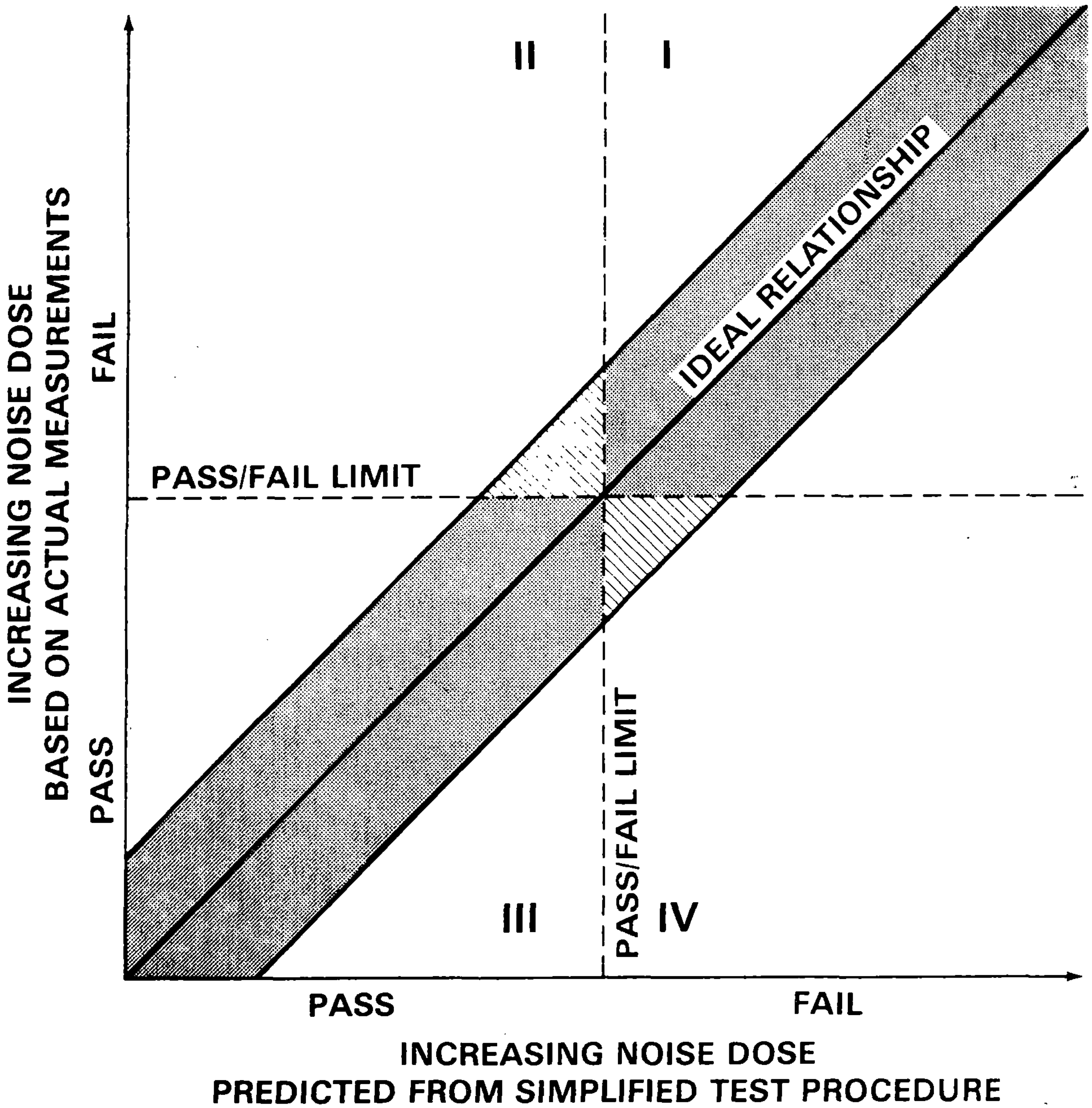


Figure 13. Hypothetical relationship between the actual noise dose and that predicted using a simplified testing procedure.

This plot is broken down into four quadrants. In terms of the predicted and actual noise doses, these quadrants represent:

Quadrant	Actual Noise Dose	Predicted Noise Dose
I	Fail	Fail
II	Fail	Pass
III	Pass	Pass
IV	Pass	Fail

For the screening test to be reasonable, the results should fall into Quadrants I or III. The scatter or range of values is not critical in these quadrants since the only real concern is whether the noise dose is below the criteria (pass) or above (fail).

Quadrant IV corresponds to cases which would be predicted to fail but would actually pass if continuous noise measurements were made. For the hypothetical relationship shown in Figure 13, this is represented by the hatched area in Quadrant IV. Although it is desirable to have as few cases as possible fall in this region, some type of verification test could be developed to ascertain whether the locomotive did indeed fail. The practicality of such a procedure would depend upon the number of locomotives which fall into this region and thus, the number of verification tests that would have to be conducted.

On the other hand, in the interest of hearing conservation, there should be no cases which fall into Quadrant II (shown by the hatched area in Quadrant II), i.e., when the noise dose would be predicted to pass but would actually be exceeded. Since the relationship between the predicted and actual noise dose is empirical in nature, the results can be shifted downward by simply adjusting the relationship so that the predicted values always exceed the noise dose actually measured by some safe margin, as illustrated in Figure 14. The only limitation to this is that it can result in an increase of cases falling into Quadrant IV. Thus, in the final development of the screening test procedures, consideration of which quadrant the majority of locomotives fall into will be an important factor in determining the final form of the screening test.

6.2. Existing Procedures

The first step in developing a screening test is to establish what the primary constraints are and what, if any, procedures currently exist. The constraints have already been discussed. These are:

- simple measurement techniques (repeatable and reliable, yet practical),
- minimum number of measurements,
- little or no data analysis, and
- no complex calculations to get final results.

At present, there are no standardized procedures commonly used for conducting noise measurements inside a locomotive cab. There is an International Standard (ISO 3381-1976(E), Acoustics - Measurement of Noise Inside Railbound Vehicles [32]) which recommends procedures for making noise measurements inside railbound vehicles. However, this standard gives only very generalized test procedures which are considered to be inadequate for characterizing the noise environment inside a locomotive cab because of the wide variety of noise sources present. In addition, since the measured result is in terms of a sound pressure level, the problem of determining the noise exposure still remains.

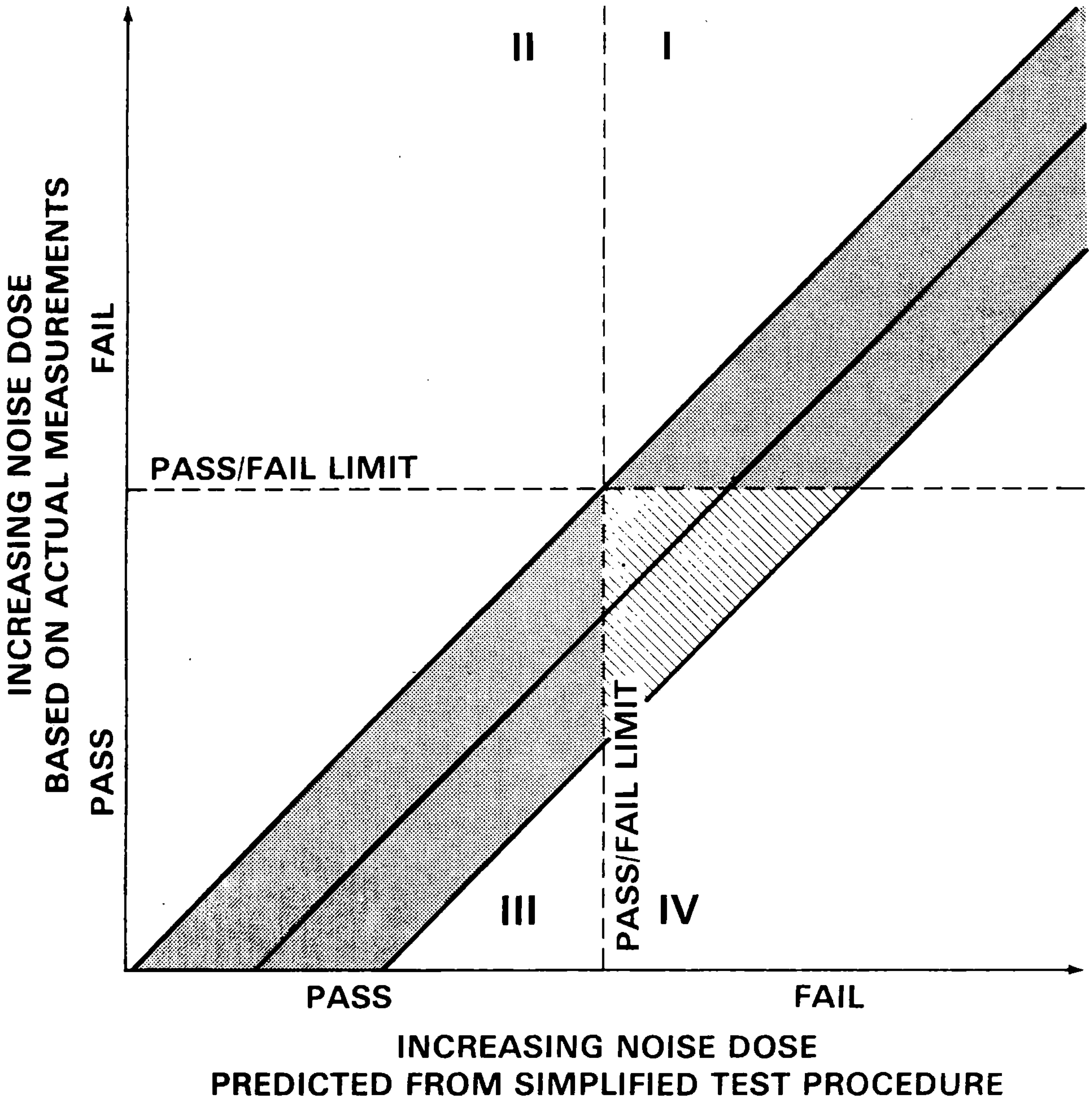


Figure 14. Shift of hypothetical relationship to avoid any cases falling into Quadrant II.

Although there are a variety of standards for measuring operator sound levels for other types of equipment and vehicles, e.g., see References 33-36, the measured results are expressed in terms of the maximum A-weighted sound levels at the operator's station, and not operator noise exposure. One exception to this is SAE Recommended Practice J1166--Operator Station Sound Level Measurement Procedure for Powered Mobile Earthmoving Machinery - Work Cycle Test [37]. This standard gives detailed recommendations for microphone location and operation of the equipment being tested. For each piece of equipment considered (nine altogether), a time-weighted average sound level (A-weighted, slow response, 5 dB per doubling of duration trade-off) is determined for a specified work cycle. This cycle is designed to simulate a typical work application for each general type of machinery. Procedures are given for determining the operator noise exposure for an entire day based on the measurements for this work cycle, any other operation commonly performed, and noise sources (other than the machine being tested) that may be present. A similar technique could be used for estimating locomotive crew noise exposure, provided that a suitable duty cycle can be established.

Another, but slightly different, approach is used by the Bureau of Motor Carrier Safety of the Federal Highway Administration, U. S. Department of Transportation, in enforcing their vehicle interior sound level standard for trucks [38]. Enforcement of this safety regulation calls for the stationary measurement of the in-cab noise level when, with the transmission in neutral, the engine is rapidly accelerated to the governed engine speed, allowed to stabilize at that speed and then returned to idle. The maximum sound level is measured for this operation and then compared to a predetermined value (90 dB plus a 2-dB tolerance) to determine whether the truck passes or fails. This procedure and the reference level of 90 dB were obtained by comparing the results for various types of simplified tests with the results for over-the-road trips [29]. The test procedure was based on the degree of correlation with over-the-road trips, with some consideration of the problems involved in conducting the tests during roadside enforcement. A slightly different test procedure is recommended in a similar, but independent study [31]; however, the results that are presented further substantiate the conclusions made in Reference 29. It was with this information as background that the stationary test procedure, described in the remainder of this section, was developed.

6.3. Development of the Stationary Screening Test

Unlike the case of over-the-road trucks where engine/drive-train noise is likely to dominate the in-cab noise levels (with some contribution from tire-road interaction noise), it was shown in earlier sections of this report that in-cab locomotive noise is generated by a variety of sources. Thus, a simple measurement of engine noise is not likely to be adequate for estimating in-service noise exposure. Instead, measurements of the sources that are the chief contributors to the crew noise exposure must be made. These, along with some assumptions about the operational duty cycle, can then be used to estimate the crew noise exposure.

Examination of the data have shown that the engine, the horn and the brake are the three chief contributors to the crew noise exposure. A breakdown of the noise dose contributions for these sources, given previously in Table 39, shows that engine notch 8 and horn are the two principal contributors to the noise dose, with some smaller contribution from the brake. The stationary test is therefore based on measurements of engine notch 8, the horn and the brake. Mathematically, this can be expressed as

$$ND = f\left\{A[\text{engine } (8)],\ B[\text{Horn}],\ C[\text{Brake}]\right\}, \qquad (11)$$

where,

ND = estimated noise dose for comparison with the pass/fail criteria,

A,B,C = empirical functions to relate the stationary test results to the in-service noise exposure.

The empirical functions A, B and C should take into account the difference between the stationary and in-service sound levels and the duty cycle for each operation. These factors plus the measured stationary test results and a knowledge of the trip "run time" can then be used to estimate the crew noise exposure. In general form, the noise dose is a function of the following variables:

$$ND = f\left\{T_t,\ P_8,\ L_{STAT(8)},\ K_8,\ P_H,\ L_{STAT(H)},\ K_H,\ P_B,\ L_{STAT(B)},\ K_B\right\}, \qquad (12)$$

where, T_t = trip "run-time,"

P_8 = percent "on-time" for notch 8,

$L_{STAT(8)}$ = average sound level for notch 8 -- stationary test,

K_8 = correction for the difference between the average stationary and average in-service sound levels for notch 8,

P_H = percent "on-time" for the horn,

$L_{STAT(H)}$ = maximum sound level for the horn -- stationary test,

K_H = correction for the difference between the maximum stationary and average in-service sound levels for the horn,

P_B = percent "on-time" for the brake,

$L_{STAT(B)}$ = maximum sound level for the brake -- stationary test, and

K_B = correction for the difference between the maximum stationary and average in-service sound levels for the brake.

Before proceeding to the final form of the noise dose equation, some discussion of the variables just listed is appropriate.

- Trip "Run Time" -- T_t

  The trip "run time" represents the time that the locomotive is actually operating on-line. It does not include any periods of time when the locomotive is waiting on a siding for another train to pass or waitng to get into or out of a yard since these periods are generally spent in idle/notch 1 where the sound levels are less than 90 dB. For development of the stationary screening test formula, T_t is set equal to the effective crew dose time, T_{dose}. For subsequent use of the stationary screening test, T_t can be set equal to any run time appropriate for the particular run under investigation.

- Percent "On-Time" -- P_8, P_H, P_B

  The percent on-time corresponds to the time that the particular operation (engine notch 8, horn or brake) is actually occurring or, in other words, the duty cycle for each event. For the development of the stationary screening test formula, the average values of the percent on-time for the 18 test runs are used. Because these percentages can vary widely among runs, as was shown in Section 5.1, the estimated dose may either be over- or under-estimated. The effect of different percent on-times upon the estimated dose, in terms of acceptable ranges of values, is discussed later in this section.

- Stationary Sound Levels -- $L_{STAT(8)}$, $L_{STAT\ (H)}$, $L_{STAT(B)}$

  The stationary sound levels are the measured variables used to characterize the noise inside a particular locomotive cab. These measurements are to be made with the locomotive stationary at a test site that is as free of obstructions (i.e., buildings, freight cars or other locomotives) as possible. For these tests the measurements are to be made at a position corresponding to the engineer left side with the cab windows open. The quantities to be measured (all A-weighted, "slow" response) are the average sound level for engine notch 8 (no load) and the maximum sound levels for a horn sounding and a brake application. More specific information regarding these measurements and why these particular procedures were chosen are discussed later in this section.

■ Stationary to In-Service Sound Level Corrections -- K_8, K_H, K_B

The purpose of these corrections is to adjust the sound levels from the stationary measurements to approximate the in-service sound levels. These corrections are simply the difference between the stationary sound level (average or maximum) and the average in-service sound level for each operation. These corrections are explained later in this section.

As shown in Equation (2) in Section 2, the noise dose is given by the sum of the C-over-T ratios, i.e., the ratios of the actual time exposed to a given noise level divided by the maximum allowable time at that level. Assuming that each of the operations can be characterized by a single sound level, the noise dose is given by

$$ND = \frac{C_8}{T_8} + \frac{C_H}{T_H} + \frac{C_B}{T_B} , \qquad (13)$$

where, C_8, C_H, C_B = estimated on-time for notch 8, horn and brake, respectively, where, $C_8 = P_8 T_t$, $C_H = P_H T_t$, and $C_B = P_B T_t$, and

T_8, T_H, T_B = maximum-allowable time at assumed sound level for notch 8, horn and brake, respectively (dependent upon hearing conservation criteria utilized).

Using the current OSHA criteria of 90 dB for 8 hours with a 5-dB per doubling of duration tradeoff, the maximum allowable time, T, at a particular sound level, L, is given by (Equation (1) in Section 2):

$$T = 8x2^{\left[\frac{90-L}{5}\right]} . \qquad (14)$$

Assuming that the characteristic sound levels of each source are given by

$$L_8 = L_{STAT(8)} - K_8, \qquad (15a)$$

$$L_H = L_{STAT(H)} - K_H, \qquad (15b)$$

$$L_B = L_{STAT(B)} - K_B, \qquad (15c)$$

and substituting, the equation for the noise dose is then

$$ND = \frac{P_8 T_t}{8x2^{\left[\frac{90-L_{STAT(8)}+K_8}{5}\right]}} + \frac{P_H T_t}{8x2^{\left[\frac{90-L_{STAT(H)}+K_H}{5}\right]}} +$$

$$\frac{P_B T_t}{8x2^{\left[\frac{90-L_{STAT(B)}+K_B}{5}\right]}} . \qquad (16)$$

This is the general equation for estimating the noise dose for locomotive crews. Before evaluating this equation and comparing the results to the in-service noise exposure actually measured, the percent on-times and stationary to in-service sound level corrections must be determined.

As mentioned above, the average values for the 18 test runs were chosen for the percent on-times. These values, taken from Tables 18 and 19 in Section 5.1, are given in Table 41. These values (expressed as a percentage of T_{dose} and rounded to the nearest integer) are:

$$P_8 = 39.9 \approx 40\%, \qquad (17a)$$

$$P_H = 5.7 \approx 6\%, \qquad (17b)$$

$$P_B = 3.2 \approx 3\%. \qquad (17c)$$

The stationary sound levels which are used to define the characteristic sound levels of the three sources are:

$L_{STAT(8)}$: average sound level for steady-state, no load, engine notch 8 operation, and

$L_{STAT(H)}$, $L_{STAT(B)}$: maximum sound level which occurs during sounding of the horn or initial venting of the air brakes, respectively.

Table 41. Sound level and duty cycle data used to derive the empirical parameters for the stationary screening test equation.

TEST RUN NUMBER	ENGINE NOTCH 8				HORN				BRAKE			
	Percent On-Time (% of T_{dose})	Average Stationary Sound Level, L_{avg}, dB	Average In-Service Sound Level, L_{avg}, dB	Stationary — In-Service Sound Level K_8, dB	Percent On-Time (% of T_{dose})	Maximum Stationary Sound Level, L_{max}, dB	Average In-Service Sound Level, L_{avg}, dB	Stationary — In-Service Sound Level, K_H, dB	Percent On-Time (% of T_{dose})	Maximum Stationary Sound Level, L_{max}, dB	Average In-Service Sound Level, L_{avg}, dB	Stationary — In-Service Sound Level, K_B, dB
1	2.2	89.3	88.4	0.9	4.7	104.2	98.0	6.2	4.7	100.8	82.3	18.5
2*	33.8	94.9	97.1	-2.2	3.2	106.5	102.1	4.4	3.4	101.9	89.4	12.5
3a	19.5	88.0	86.3	1.7	3.9	96.3	89.5	6.8	4.6	103.6‡	90.8	12.8
3b*	13.7	88.1	89.7	-1.6	3.2	95.1	87.4	7.7	5.4	102.3‡	86.9	15.4
4	13.5	80.6	84.5	-3.9	2.3	100.8	92.8	8.0	8.8	102.2	81.6	20.6
5	35.3	78.1	87.7	-9.6	2.3	96.9	95.4	1.5	4.2	101.0‡	86.6	14.4
6	30.2	81.5	86.9	-5.4	2.2	102.5	96.6	5.9	1.2	103.0†	91.4	11.6
7	38.8	85.0	91.7	-6.7	5.9	105.2	100.2	5.0	1.6	102.4	92.5	9.9
8*	38.1	86.0	87.8	-1.8	10.3	96.4	95.3	1.1	2.6	102.3†	87.7	14.6
9	47.6	81.8	86.5	-4.7	8.8	96.5	94.9	1.6	0.9	100.2	84.9	15.3
10	66.3	83.5	85.8	-2.3	5.5	102.9	90.8	12.1	0.4	87.3	88.3	- 1.0
11	54.7	86.3	86.4	-0.1	1.7	101.8	88.4	13.4	1.9	83.9†	82.5	1.4
12	53.6	82.7	83.7	-1.0	3.7	99.4	91.0	8.4	1.4	90.0‡	82.6	7.4
13	36.2	80.0	84.2	-4.2	2.2	98.2	97.7	0.5	0.9	97.9	85.9	12.0
14a	52.6	84.2	87.4	-3.2	8.8	99.0	94.9	4.1	8.4	102.5†	94.7	7 8
14b	84.1	84.2	86.6	-2.4	5.8	99.0	96.9	2.1	0‡	102.5‡†	-	-
15	42.9	83.5	87.2	-3.7	15.9	103.0	98.1	4.9	1.5	105.2	92.4	12.8
16	54.4	84.0	87.0	-3.0	11.5	101.4	91.7	9.7	0‡	96.2‡	-	-
MEAN	39.9	84.5	87.5	-3.0	5.7	100.3	94.5	5.7	3.2	99.2	87.5	11.6
STANDARD DEVIATION	20.1	3.9	3.0	2.7	3.9	3.4	4.1	3.7	2.6	6.3	4.1	5.6

*Because of incomplete information, all data for these three test runs are from the engineer right-side microphone.

‡Only major brake application occurred when stopping the train in the yard at the final destination, after the test equipment had been disassembled. These values are not included in the mean and standard-deviation calculations.

†Stationary tests were not conducted with the windows open. Windows-closed data are used.

These sound levels are to be measured using A-weighted "slow" meter response, as specified by OSHA [2], with the microphone positioned approximately where the engineer's left ear would be located when he is seated. The cab windows are to be open during the measurements (but all doors are to be closed) and the locomotive should be positioned in an open area with no other large objects nearby. The reasonings for these particular procedures are as follows:

- Average Versus Maximum Sound Level. The arithmetic average sound level is chosen for engine notch 8 because it is a relatively steady sound with only minor fluctuations. On the other hand, the horn and brake produce sound levels which are well above the engine noise so that when they are operated there is a sudden increase of sound level. For the horn this sound level can be held relatively steady by continued sounding of the horn, but the horn shouldn't be sounded for long periods of time, especially if the locomotive is in a yard where other people are working. Besides, the maximum sound level for the horn is approximately equivalent to the arithmetic average value over the sounding time (see Figure 10).

  For application of the brakes, the sound level can vary widely depending upon the type of brake application, the amount of brake pipe pressure reduction being made, and the total volume of the brake pipe system, i.e., the length of the train or number of cars in the train. As shown in Figure 11 and discussed in Section 5.2.2., the largest percentage of time during an in-service brake application is spent in applying the train brakes. However, after the initial peak, the sound level decreases to a lower value and remains at approximately this value for the remainder of the time the brake pipe is being vented. Since this lower sound level was found in most cases to be below the 90-dB threshold level, the portion of the brake application most likely to contribute to the noise dose occurs near the initial peak. Also, since the locomotive consist may or may not be coupled to the train, it is easier to measure this initial peak (which is not a function of train length) than to attempt to determine some average value.

- Windows Open Versus Windows Closed. These tests are conducted with the windows open for two reasons. First, it was found that, if the weather permitted, the crew would prefer to have the windows open during in-service operations. Second, as discussed in Section 5.2.2, for sounding of the horn during stationary operations, the reduction of in-cab sound levels ranged from 0.5 to 13.1 dB for windows-closed versus windows-open conditions. Therefore, testing with the windows open removes the variability which can be introduced by differences in window sealing, or changes of sealing with damage or age.

- **Microphone Location.** The engineer left-side microphone location was chosen primarily for convenience of testing. With the engineer seated, it is more difficult to position the microphone and observe a reading on the engineer's right side than on the left side. Although it is less critical for the stationary tests than it is for in-service operations, the engineer left-side microphone position would be less affected by wind noise (the primary reason for using it for comparison of in-service results) and to some extent extraneous background noise outside the cab.

Also given in Table 41 for engine notch 8, horn, and brake are the stationary and in-service sound levels and the differences between these values. These differences correspond to the stationary to in-service sound level corrections mentioned previously (K_8, K_H, K_B). These corrections, when subtracted from the measured stationary sound levels, are assumed to yield a sound level characteristic of in-service operations. For the horn and the brake, this amounts to reducing the maximum sound level to correspond to a value more representative of an average in-service sound level with all the variations in time averaged out. For engine notch 8, this correction accounts for several factors which differ between the stationary and in-service cases: wind noise from the open window, wheel-rail interaction noise, and radio noise. This last factor, namely the radio, can be a primary contributor to in-cab noise exposure. However, since the volume of the radio is variable and is normally adjusted to be just audible above the engine noise, its sound level is usually directly related to the sound level of the engine. Thus, it can be accounted for by adding (subtracting a minus K_8 is equivalent to adding) a correction to the stationary engine notch 8 sound level to increase it to approximate the in-service sound level.

As mentioned in the discussion of the hypothetical relationship shown in Figure 13, cases which fall into Quadrant II should be avoided. One way to try to ensure this is to shift the relationship as shown in Figure 14. This shift is accomplished by decreasing the stationary to in-service sound level correction factors in Table 41 by 1 dB[12]. This not only adds to the conservatism of the empirical relationship, but also partially accounts for any measurement error on the low side (up to 1 dB). The three corrections used in the screening test (rounded to the nearest integer value) are

$$K_8 = -3.0 - 1.0 \approx -4 \text{ dB}, \qquad (18a)$$

$$K_H = 5.7 - 1.0 \approx +5 \text{ dB}, \qquad (18b)$$

$$K_B = 11.6 - 1.0 \approx +11 \text{ dB}. \qquad (18c)$$

With these values and the values for the percent on-times given in Equation (17), the crew noise exposure can be calculated from Equation (16). The results of these calculations, based on the actual effective crew dose time, T_{dose}, for each of the 18 test runs, are given in Table 42. The results for the overall trip are plotted in Figure 15. As shown in this figure, the majority of data fall into Quadrant III, and in fact only the data for the locomotive on Test Run 2 falls outside this quadrant (in Quadrant I). Thus, for the 18 test runs made in this study there were no cases which fell into Quadrants II or IV and in fact no cases which were even marginally close. Although this is encouraging, it must be realized that this is a limited set of runs which, on a statistical basis, does not allow any broad sweeping conclusions to be made about how well the predicted and actual values are correlated. From a purely statistical viewpoint, more data are needed where the noise dose is approaching 1.0 or is greater than 1.0. The principal problem with this requirement is that it does not appear, at least based on

[12] A shift of 1 dB was found to be adequate for the 18 test runs examined in this study. After additional data are collected, as recommended in Section 6.6, this value should be reevaluated.

Table 42. Prediction of the crew noise dose for the 18 test runs using the set of fixed percent on-times and stationary to in-service sound level corrections given in Equations (17) and (18). The noise doses are calculated from Equation (16) using a trip run time equal to the actual effective crew dose time, T_{dose}, for each test run.

TEST RUN NUMBER	TRIP RUN TIME, $T_t = T_{dose}$, hours	ENGINE NOTCH 8			HORN			BRAKE			OVERALL TRIP	
		Average Stationary Sound Level, $L_{STAT(8)}$, dB	Noise Dose		Maximum Stationary Sound Level, $L_{STAT(H)}$, dB	Noise Dose		Maximum Stationary Sound Level, $L_{STAT(B)}$, dB	Noise Dose		Noise Dose	
			Predicted	Actual		Predicted	Actual		Predicted	Actual	Predicted	Actual
1	4.83	89.3	0.38	0.01	104.2	0.13	0.07	100.8	0.02	0.03	0.53	0.17
2*	5.21	94.9	0.89	0.59	106.5	0.19	0.13	101.9	0.02	0.05	1.10	1.02
3a	3.21	88.0	0.21	0	96.3	0.03	0.01	103.6	0.02	0.02	0.26	0.07
3b*	3.90	88.1	0.26	0.04	95.1	0.03	0	102.3	0.02	0.02	0.31	0.09
4	1.44	80.6	0.03	0	100.8	0.02	0	102.2	0.01	0.01	0.06	0.02
5	4.08	78.1	0.07	0.04	96.9	0.04	0.03	101.0	0.02	0.02	0.13	0.13
6	4.97	81.5	0.13	0.05	102.5	0.11	0.04	103.0	0.02	0.01	0.26	0.16
7	3.28	85.0	0.14	0.18	105.2	0.10	0.11	102.4	0.01	0.01	0.25	0.45
8*	2.78	86.0	0.14	0.03	96.4	0.03	0.08	102.3	0.01	0.01	0.18	0.16
9	2.23	81.8	0.06	0.04	96.5	0.02	0.06	100.2	0.01	0	0.09	0.13
10	4.92	83.5	0.17	0.10	102.9	0.11	0.03	87.3	0	0	0.28	0.15
11	5.69	86.3	0.30	0.06	101.8	0.11	0	83.9	0	0	0.41	0.08
12	6.76	82.7	0.21	0.04	99.4	0.09	0.03	90.0	0.01	0	0.31	0.09
13	5.35	80.0	0.12	0.01	98.2	0.06	0.05	97.9	0.01	0	0.19	0.07
14a	4.44	84.2	0.17	0.07	99.0	0.06	0.10	102.5	0.02	0.14	0.25	0.35
14b	0.53	84.2	0.02	0.01	99.0	0.01	0.01	102.5	0	0	0.03	0.02
15	4.09	83.5	0.14	0.02	103.0	0.09	0.27	105.2	0.03	0.02	0.26	0.34
16	3.12	84.0	0.12	0.03	101.4	0.06	0.05	96.2	0	0	0.18	0.16

*Because of incomplete information, all data for these three test runs are from the engineer right-side microphone.

P_8 = 40% K_8 = − 4 dB
P_H = 6% K_H = + 5 dB
P_B = 3% K_B = +11 dB

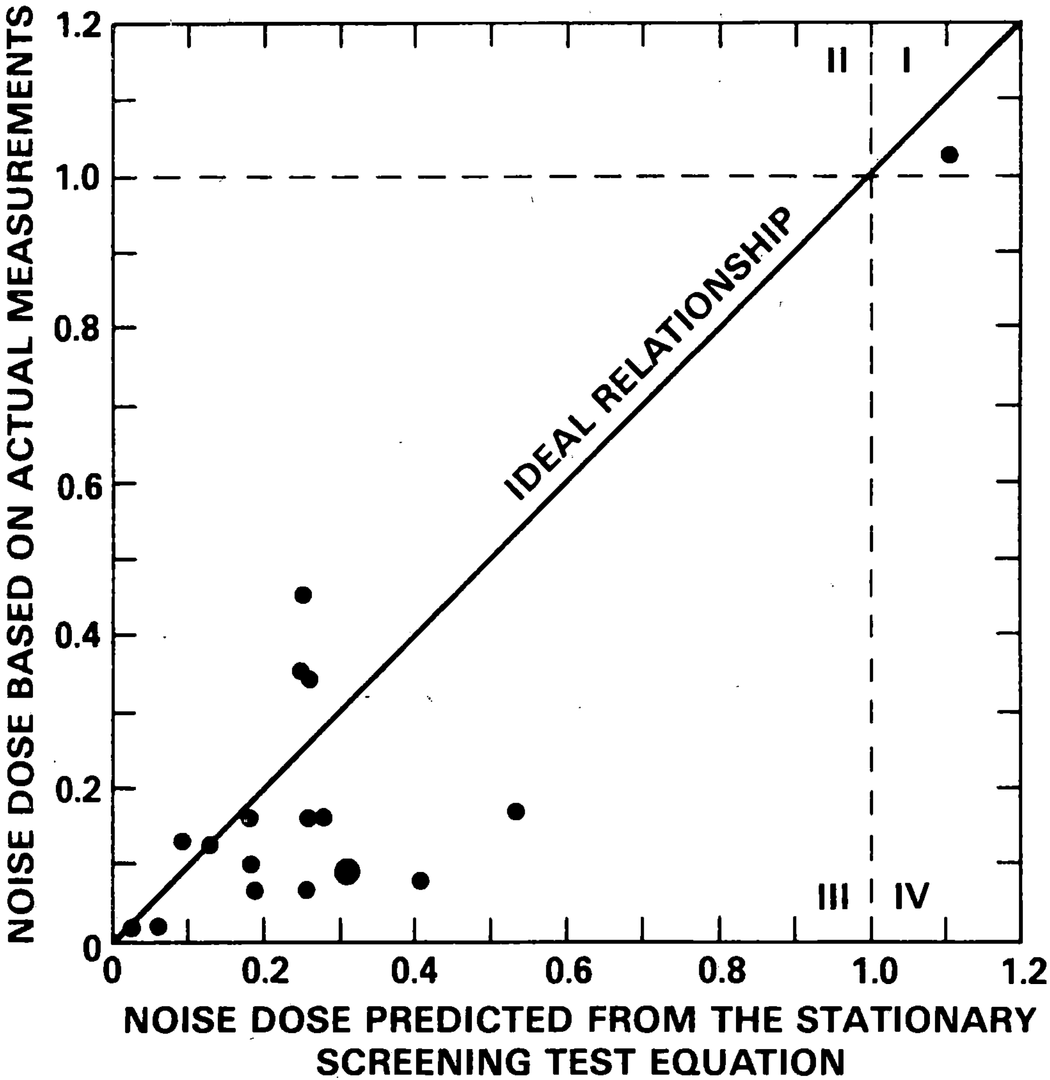


Figure 15. Relationship between the actual noise dose and the noise dose predicted from Equation (16) using the set of fixed percent on-times and stationary to in-service sound level corrections given in Equations (17) and (18). These data are listed in Table 42.

these 18 test runs, that there are many cases which fall into these regions. Thus, the data would be difficult to obtain and, more importantly, would be of only limited value since the majority of cases would fall down in the lower left portion of Quadrant III. To support this hypothesis further data are required.

Given this limitation, it still appears that the stationary screening test equation gives a reasonable prediction of the crew noise dose. This is especially true when considering that a single set of fixed percent on-times was used to represent the wide range of actual in-service duty cycles. For many of the cases where the predicted and actual noise doses are not the same, the deviation is due to a difference between the actual and assumed percent on-times. The locomotive in Test Run 1, for example, has predicted and actual noise doses of 0.53 and 0.17, respectively. This deviation is due primarily to a difference between the actual (2.2%) and assumed (40%) percent on-times for engine notch 8. If the actual percent on-time is used in the stationary screening test equation, the predicted noise dose is 0.11, which is a closer estimate of the actual noise dose. Unfortunately, even though the use of the actual percent on-times improves the agreement between the predicted and actual noise dose in some cases, in others it degrades the agreement. Table 43 and Figure 16 show the results when the actual percent on-times and actual stationary to in-service sound level corrections for each of the 18 test runs (from Table 41) are used to predict the noise dose. Comparison of Figures 15 and Figure 16 shows that the agreement between the predicted and actual noise dose is improved. This indicates that the average in-service sound level (the stationary sound level minus the actual value of K is merely the average in-service sound level) and the percent on-times for

Table 43. Prediction of the crew noise dose for the 18 test runs using the actual percent on-times and stationary to in-service sound level corrections listed in Table 41 for each test run. The noise doses are calculated from Equation (16) using a trip run time equal to the actual effective crew dose time, T_{dose}, for each test run.

TEST RUN NUMBER	TRIP RUN TIME $T_t = T_{dose}$, hours	ENGINE NOTCH 8			HORN			BRAKE			OVERALL TRIP	
		Average Stationary Sound Level, $L_{STAT(8)}$, dB	Noise Dose		Maximum Stationary Sound Level, $L_{STAT(H)}$, dB	Noise Dose		Maximum Stationary Sound Level, $L_{STAT(B)}$, dB	Noise Dose		Noise Dose	
			Predicted	Actual		Predicted	Actual		Predicted	Actual	Predicted	Actual
1	4.83	89.3	0.01	0.01	104.2	0.09	0.07	100.8	0.01	0.03	0.11	0.17
2*	5.21	94.9	0.59	0.59	106.5	0.11	0.13	101.9	0.02	0.05	0.72	1.02
3a	3.21	88.0	0.05	0	96.3	0.01	0.01	103.6	0.02	0.02	0.08	0.07
3b*	3.90	88.1	0.06	0.04	95.1	0.01	0	102.3	0.02	0.02	0.09	0.09
4	1.44	80.6	0.01	0	100.8	0.01	0	102.2	0	0.01	0.02	0.02
5	4.08	78.1	0.13	0.04	96.9	0.02	0.03	101.0	0.01	0.02	0.17	0.13
6	4.97	81.5	0.12	0.05	102.5	0.03	0.04	103.0	0.01	0.01	0.17	0.16
7	3.28	85.0	0.20	0.18	105.2	0.10	0.11	102.4	0.01	0.01	0.31	0.45
8*	2.78	86.0	0.10	0.03	96.4	0.07	0.08	102.3	0.01	0.01	0.18	0.16
9	2.23	81.8	0.08	0.04	96.5	0.05	0.06	100.2	0	0	0.13	0.13
10	4.92	83.5	0.23	0.10	102.9	0.04	0.03	87.3	0	0	0.27	0.16
11	5.69	86.3	0.24	0.06	101.8	0.01	0	83.9	0	0	0.25	0.08
12	6.76	82.7	0.19	0.04	99.4	0.04	0.03	90.0	0	0	0.23	0.09
13	5.35	80.0	0.11	0.01	98.2	0.04	0.05	97.9	0	0	0.15	0.07
14a	4.44	84.2	0.20	0.07	99.0	0.10	0.10	102.5	0.09	0.14	0.39	0.35
14b	0.53	84.2	0.03	0.01	99.0	0.01	0.01	102.5	0	0	0.04	0.02
15	4.09	83.5	0.15	0.02	103.0	0.25	0.27	105.2	0.01	0.02	0.41	0.34
16	3.12	84.0	0.14	0.03	101.4	0.06	0.05	96.2	0	0	0.20	0.10

*Because of incomplete information, all data for these three test runs are from the engineer right-side microphone.

Actual values of P_8, P_H, P_B, K_8, K_H, and K_B for each test run are used (see Table 41).

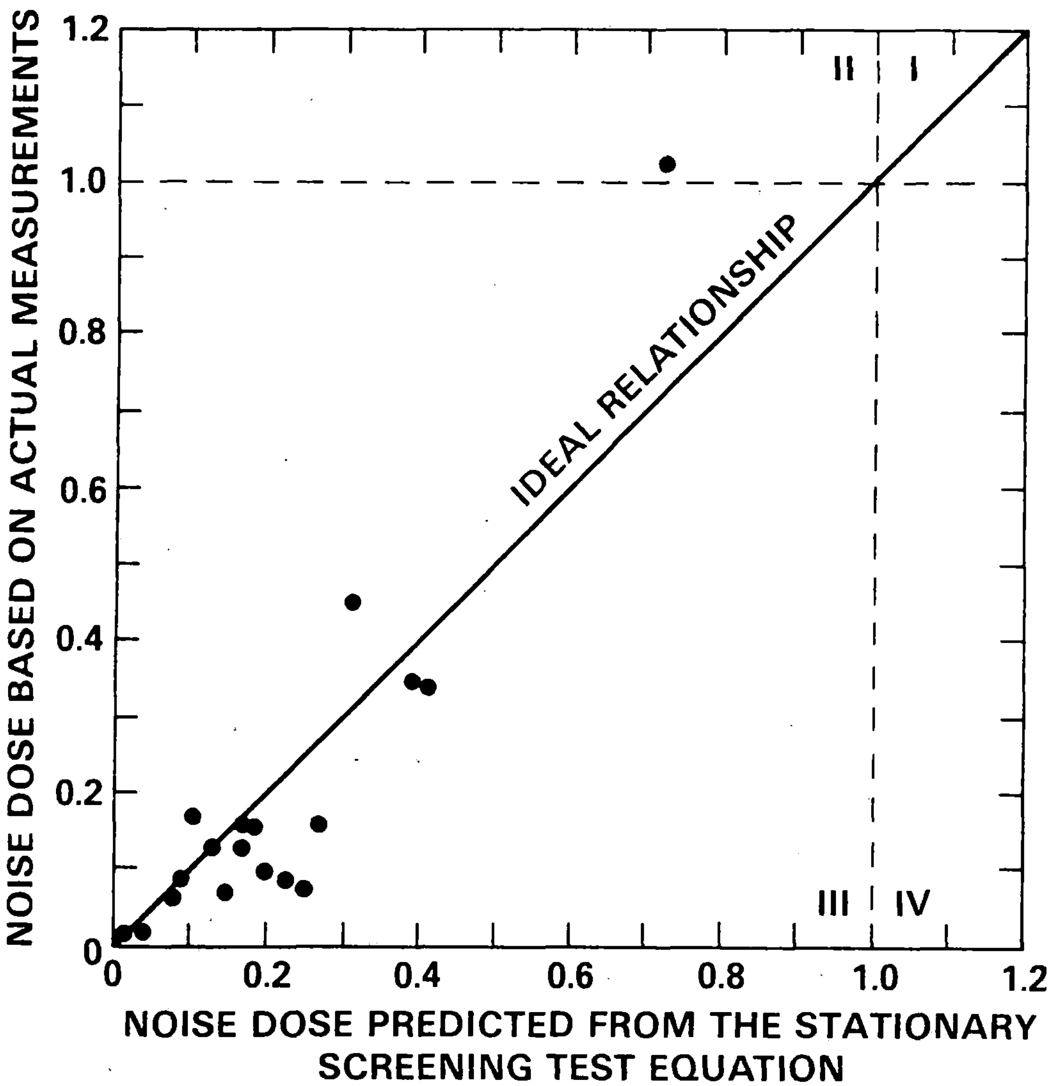


Figure 16. Relationship between the actual noise dose and the noise dose predicted from Equation (16) using the actual percent on-times and stationary to in-service sound level corrections listed in Table 41 for each test run. These data are listed in Table 43.

the horn, brake, and engine notch 8 are good estimators of the overall noise dose. However, it is inconvenient to measure these quantities for each run because it would be simpler to measure the noise dose directly. Since a simple pass/fail type of assessment is desired, and not a prediction of the exact noise dose, a certain amount of deviation, resulting from the use of average values for the percent on-times and stationary to in-service sound level corrections, can be tolerated. This is acceptable provided that any cases which fall into Quadrant II are avoided and that a minimum number fall in Quadrant IV. As shown in Figure 15, this is true for the 18 test runs examined in this study.

One question which arises is how variations of the actual values of P_8, P_H and P_B, and K_8, K_H and K_B relative to the assumed values (given in Equations (17) and (18)) affect the predicted noise dose. These effects can be determined by examining any one of the terms in Equation (16). Expressing this in general terms, the predicted noise dose is given by

$$ND = \frac{P\ T_t}{8 \times 2^{\left[\frac{90-L_S+K}{5}\right]}} , \qquad (19)$$

where P = percent on-time

T_t = trip run time

L_S = stationary sound level, and

K = stationary to in-service sound level correction.

Since the effect of the variations of P and K on the predicted noise dose is dependent upon the trip run time, a constant value of 4 hours will be used [this is approximately equal to the average value of T_{dose} of 3.94 hours for the 18 test runs (see Table 16)]. Using this value of 4 hours for T_t in

Equation (19), the relationships between the noise dose, ND, percent on-time, P, and characteristic sound level, L_S-K (see Equation (15)), are shown in Figures 17 and 18. The same functional relationship is shown in these two figures, with the only difference being that Figure 17 shows contours of constant percent on-time, and Figure 18 shows contours of constant characteristic sound level. In Figure 17 it can be seen that the noise dose increases rapidly with increasing sound level and percent on-time, i.e., exposure time. The effect of any variation of the actual percent on-time from the assumed value is dependent upon the characteristic sound level (and also the total exposure time). The same trend is shown in Figure 18. Thus, the effect of variations of the percent on-times or stationary to in-service sound level corrections on the predicted noise dose depends strongly upon the magnitude of the characteristic sound level and the total exposure time. The higher these values are, the more significant the effect of the variations of P and K.

For the 18 test runs examined in this study, the pass/fail assessment of the in-cab locomotive noise exposure is not adversely affected by variations of P and K (at least not for the range of values that were found). This results because, even though the percent on-time for engine notch 8 is relatively high (40%), the characteristic sound levels are generally below 90 dB. The converse of this is also true for the horn and the brake; the characteristic sound levels are high but the percent on-times are relatively low. Another, and perhaps the most important, reason that these variations are not critical is that a pass/fail type of assessment is being used. Since most cases fall well below the pass/fail value of 1.0, a little extra tolerance in the procedure does not cause any harm. On the other hand, if

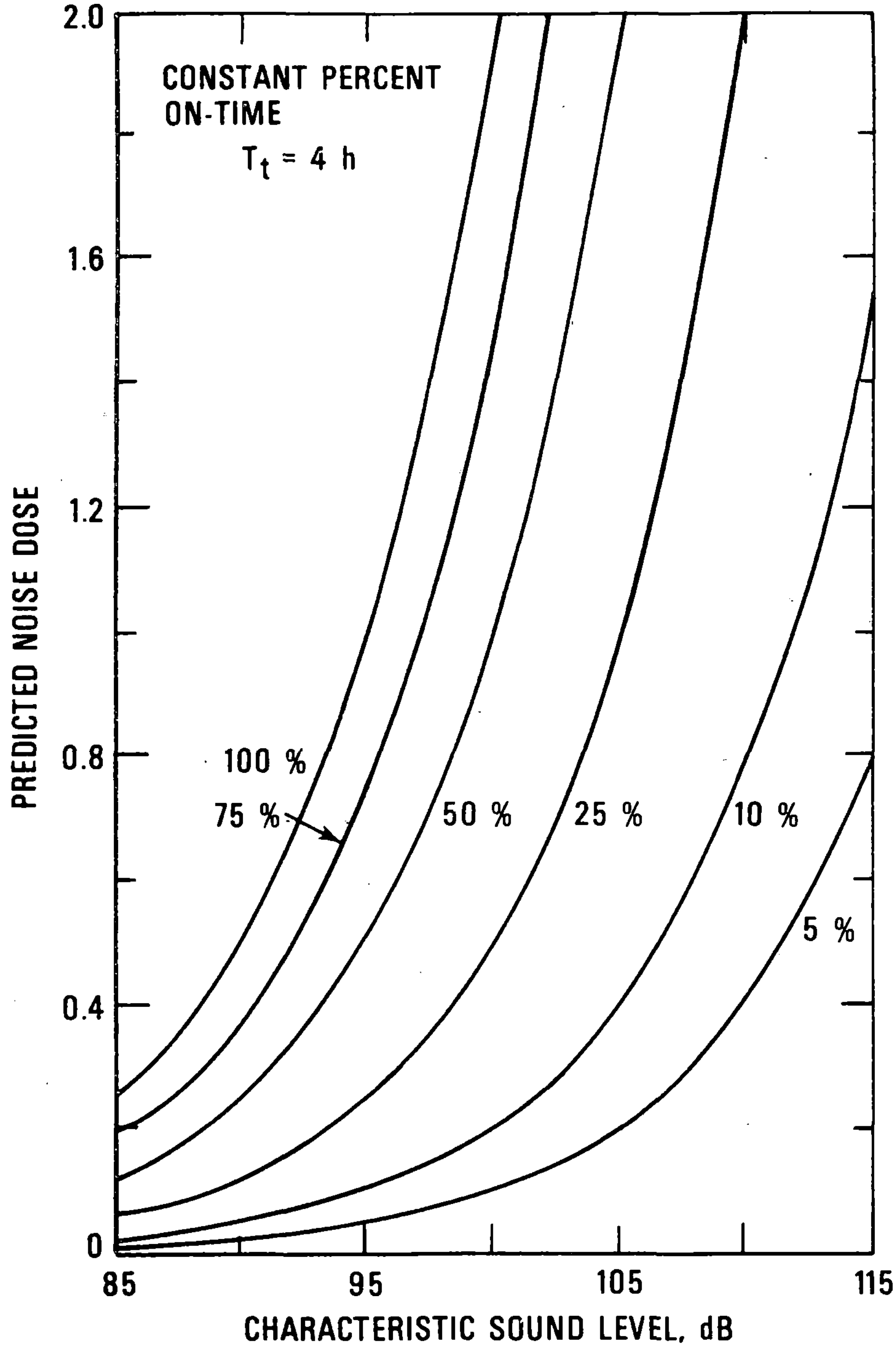


Figure 17. Predicted noise dose as a function of the characteristic sound level for constant percent on-time. These values are calculated from Equation (19) with T_t = 4 hours.

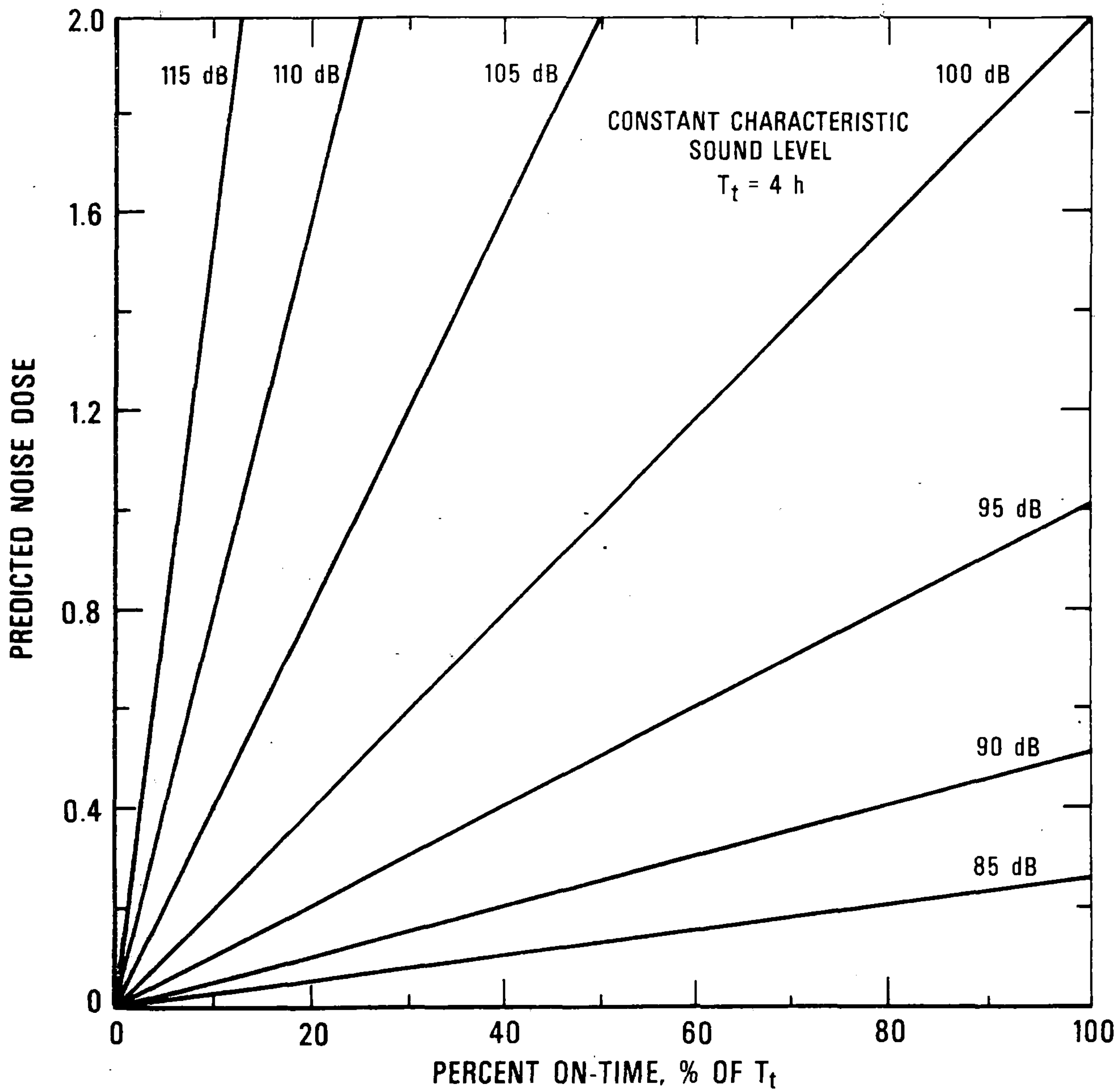


Figure 18. Predicted noise dose as a function of percent on-time for constant characteristic sound level. These values are calculated from Equation (19) with T_t = 4 hours.

the majority of cases were near the pass/fail cutoff, more accuracy would be required. Although it does not appear that this is the case based on the 18 test runs, increased accuracy would also be required if the noise exposure criterion were reduced to an 85-dB limit at 8 hours as proposed by NIOSH [7].

6.4. Stationary Screening Test Procedure

As discussed in the beginning of this section, the objective of this study is to develop a simplified testing prodedure for assessing in-cab noise exposure of locomotive crews. One approach for structuring such a procedure based on a stationary screening test is shown in Figure 19. This procedure would be used as the result of some need to test, such as certification testing of new locomotives or enforcement of some type of noise regulation. The locomotive would be moved to an open site, free of other large objects, where stationary sound level measurements would be made (to the nearest 0.5 dB) for engine notch 8, horn, and brake using the procedures described earlier in this section (see pages 125 to 130). Based on these measurements, the noise dose would be predicted and an assessment would be made of the crew noise exposure. If the noise exposure is within the prescribed limits, the locomotive "passes" and no restrictions are placed on its usage. If the allowable noise exposure is exceeded, some remedial action is required. Several possible options exist in this latter case. The sound levels in the cab can be lowered either by treatment of the noise sources or by restricting the locomotive to operations where there are fewer horn applications and/or the higher engine notch settings are used infrequently. If the option to treat the noise sources is selected, the locomotive would be modified and retested, the pass/fail assessment made again, and so on,

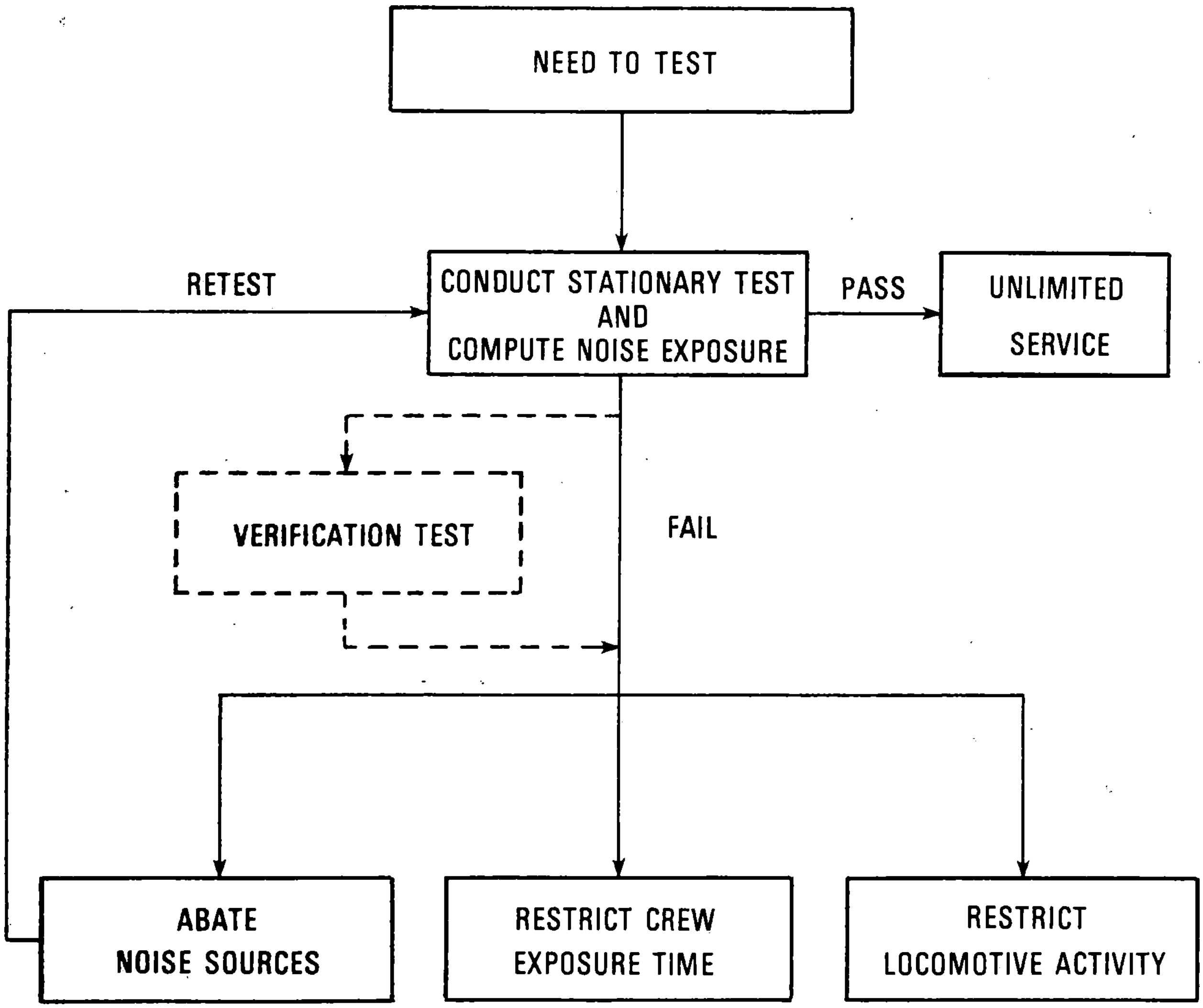


Figure 19. Procedure for assessing in-cab locomotive noise exposure based on the stationary screening test.

until the noise exposure is within acceptable limits.[13] The third option involves restricting the other factor which controls the noise dose, namely the exposure time. This can be reduced by limiting the number of hours a crew may be on the locomotive by replacing them with another crew or by restricting the locomotive to operations which have shorter work cycles.

Another possible option, shown by the dashed line in Figure 19, is to conduct some form of verification test on the locomotive during an in-service run. Since there is some conservatism in the noise dose predicted by Equation (16), the verification test could be used to show that the noise exposure was within acceptable limits. This test could be conducted by tape recording the noise levels during the run (as was done in this study), or by using a noise dosimeter. In either case, the results would apply only to that particular run and no other. However, if the locomotive was used only on that one run day after day, verification testing, to show that the noise exposure limits were not exceeded, would be beneficial.

When conducting a stationary screening test, it is undesirable to have to make any complex or detailed computations to determine if the locomotive passes or fails. To simplify this process, a set of "look-up" tables was

[13]Treatment of the noise sources, i.e., the engine, horn or brakes, may or may not be feasible. Little work has been done on examining the techniques for reducing locomotive noise, especially in-cab noise. Some studies have been done on the design of mufflers for the engine, but the primary concern was exterior noise. There is no information about the effect of mufflers on in-cab sound levels. Other than quieting the locomotive diesel engine itself or total redesign of the locomotive cab to isolate it from the main frame, the only way to reduce the effect of engine noise on the crew noise dose is to limit the exposure time or to restrict the locomotive to less noisy operations. There is also a lack of information about the horn and brakes in terms of reduction of in-cab noise. However, it would seem reasonable that the in-cab sound levels from the horn and brakes could be reduced by physically relocating them or by making design changes such as adding a muffler to the brake pipe vent outlet.

developed to provide the information necessary for making the pass/fail assessment. This information, broken down by noise source, is given in Tables 44, 45, and 46 for engine notch 8, the horn, and the brake, respectively. These tables give the estimated noise dose (multiplied by 100) for each source as a function of the stationary sound level and the trip run time. The total predicted noise dose for the locomotive is the arithmetic sum of the three values (divided by 100). If this sum is less than 1.0 the locomotive passes, and, if it is greater than 1.0 it fails. Thus, the stationary screening test consists of measuring the three stationary sound levels, selecting an appropriate trip run time, looking up and adding the three values from Tables 44, 45 and 46, dividing by 100, and comparing this with the pass/fail value of 1.0. For example, assume that the stationary sound levels for a particular locomotive were 86.0, 101.5 and 108.0 for engine notch 8, the horn and the brake, respectively. Also assume that the locomotive is used on the same run every day and that the trip run time never exceeds 5 hours. The corresponding stationary screening test values are 25 for the engine notch 8, 9 for the horn and 5 for the brake, or a total of 39. Dividing this by 100 gives a total predicted noise dose of 0.39. This is below the pass/fail value of 1.0, indicating that the locomotive passes.

For stationary sound levels less than the lowest values given in Tables 44, 45, and 46, the estimated noise dose contribution can be determined from the appropriate term in Equation (16) for that particular source. Also, if the operational duty cycle is known to be quite different from that used to develop the stationary screening test, these three tables should not be used. Rather, the noise dose should be estimated from Equation (16) by

Table 44. Stationary screening test values for engine notch 8. These values were calculated from the screening test equation [Equation (16)] using P_8 = 40% and K_8 = -4 dB.

ENGINE NOTCH 8 STATIONARY TEST--AVERAGE A-WEIGHTED SOUND LEVEL, dB ("Slow" Meter Response) [Windows Open]

Trip "Run Time" T_t	80.0	80.5	81.0	81.5	82.0	82.5	83.0	83.5	84.0	84.5	85.0	85.5	86.0	86.5	87.0	87.5
0.5	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3
1.0	2	2	2	3	3	3	3	4	4	4	4	5	5	5	6	6
1.5	3	3	4	4	4	5	5	5	6	6	7	7	7	8	9	9
2.0	4	5	5	5	6	6	7	7	8	8	9	9	10	11	11	12
2.5	5	6	6	7	7	8	8	9	9	10	11	12	12	13	14	15
3.0	7	7	7	8	9	9	10	11	11	12	13	14	15	16	17	18
3.5	8	8	9	9	10	11	12	12	13	14	15	16	17	19	20	22
4.0	9	9	10	11	11	12	13	14	15	16	17	19	20	21	23	25
4.5	10	10	11	12	13	14	15	16	17	18	20	21	22	24	26	28
5.0	11	12	12	13	14	15	16	18	19	20	22	23	25	27	29	31
5.5	12	13	14	15	16	17	18	19	21	22	24	26	27	29	32	34
6.0	13	14	15	16	17	18	20	21	23	24	26	28	30	32	34	37
6.5	14	15	16	17	19	20	21	23	25	26	28	30	32	35	37	40
7.0	15	16	17	19	20	22	23	25	26	28	30	33	35	37	40	43
7.5	16	17	19	20	22	23	25	26	28	30	33	35	37	40	43	46
8.0	17	19	20	21	23	25	26	28	30	32	35	37	40	43	46	49
8.5	18	20	21	23	24	26	28	30	32	34	37	40	42	45	49	52
9.0	20	21	22	24	26	28	30	32	34	37	39	42	45	48	52	55
9.5	21	22	24	25	27	29	31	34	36	39	41	44	47	51	55	58
10.0	22	23	25	27	29	31	33	35	38	41	43	47	50	54	57	61
10.5	23	24	26	28	30	32	35	37	40	43	46	49	52	56	60	65
11.0	24	26	27	29	32	34	36	39	42	45	48	51	55	59	63	68
11.5	25	27	29	31	33	35	38	41	44	47	50	54	57	62	66	71
12.0	26	28	30	32	34	37	40	42	45	49	52	56	60	64	69	74

Trip "Run Time" T_t	88.0	88.5	89.0	89.5	90.0	90.5	91.0	91.5	92.0	92.5	93.0	93.5	94.0	94.5	95.0	95.5
0.5	3	4	4	4	4	5	5	5	6	6	7	7	8	8	9	9
1.0	7	7	8	8	9	9	10	11	11	12	13	14	15	16	17	19
1.5	10	11	11	12	13	14	15	16	17	18	20	21	23	24	20	28
2.0	13	14	15	16	17	19	20	21	23	25	26	28	30	32	35	37
2.5	16	18	19	20	22	23	25	27	29	31	33	35	38	41	44	47
3.0	20	21	23	24	26	28	30	32	34	37	40	42	45	49	52	56
3.5	23	25	26	28	30	33	35	37	40	43	46	49	53	57	61	65
4.0	26	28	30	32	35	37	40	43	46	49	53	57	61	65	70	75
4.5	30	32	34	37	39	42	45	48	52	55	59	64	68	73	78	84
5.0	33	35	38	41	43	47	50	54	57	62	66	71	76	81	87	93
5.5	36	39	42	45	48	51	55	59	63	68	73	78	83	89	96	103
6.0	40	42	45	49	52	56	60	64	69	74	79	85	91	97	104	
6.5	43	46	49	53	57	61	65	70	75	80	86	92	98	106		
7.0	46	49	53	57	61	65	70	75	80	86	92	99	106			
7.5	49	53	57	61	65	70	75	80	86	92	99	106				
8.0	53	57	61	65	70	75	80	86	92	98	105					
8.5	56	60	64	69	74	79	85	91	98	105						
9.0	59	64	68	73	78	84	90	96	103							
9.5	63	67	72	77	83	89	95	102								
10.0	66	71	76	81	87	93	100									
10.5	69	74	78	85	91	98	105									
11.0	72	78	83	89	96	103										
11.5	76	81	87	93	100											
12.0	79	85	91	97	104											

LOCOMOTIVE FAILS STATIONARY SCREENING TEST

ENGINE NOTCH 8 STATIONARY TEST--AVERAGE A-WEIGHTED SOUND LEVEL, dB ("Slow" Meter Response) [Windows Open]

Trip "Run Time" T_t	96.0	96.5	97.0	97.5	98.0	98.5	99.0	99.5	100.0	100.5	101.0	101.5	102.0	102.5	103.0
0.5	10	11	11	12	13	14	15	16	17	19	20	21	23	25	26
1.0	20	21	23	25	26	28	30	32	35	37	40	43	46	49	53
1.5	30	32	34	37	40	42	45	49	52	56	60	64	69	74	79
2.0	40	43	46	49	53	57	61	65	70	75	80	86	92	99	106
2.5	50	54	57	62	66	71	76	81	87	93	100	107	115	123	
3.0	60	64	69	74	79	85	91	97	104	112					
3.5	70	75	80	86	92	99	106	114							
4.0	80	86	92	98	106	113									
4.5	90	96	103	111											
5.0	100	107													
5.5															
6.0															
6.5															
7.0															
7.5															
8.0															
8.5															
9.0															
9.5															
10.0															
10.5															
11.0															
11.5															
12.0															

Trip "Run Time" T_t	103.5	104.0	104.5	105.0	105.5	106.0	106.5	107.0	107.5	108.0	108.5	109.0	109.5	110.0	110.5	111.0
0.5	28	30	32	35	37	40	43	46	49	53	57	61	65	70	75	
1.0	57	61	65	70	75	80	86	92	99	106	113	121	130	139	149	
1.5	85	91	97	104	112	120	129	138	148							
2.0	113	121	130													
2.5																
3.0																
3.5																
4.0																
4.5																
5.0																
5.5																
6.0																
6.5																
7.0																
7.5																
8.0																
8.5																
9.0																
9.5																
10.0																
10.5																
11.0																
11.5																
12.0																

LOCOMOTIVE FAILS STATIONARY SCREENING TEST

Table 45. Stationary screening test values for the horn. These values were calculated from the screening test equation [Equation (16)] using $P_H = 6\%$ and $K_H = 5$ dB.

Trip "Run Time" T_t	HORN STATIONARY TEST--MAXIMUM A-WEIGHTED SOUND LEVEL, dB ("Slow" Meter Response) [Windows Open]																										
	90.0	90.5	91.0	91.5	92.0	92.5	93.0	93.5	94.0	94.5	95.0	95.5	96.0	96.5	97.0	97.5	98.0	98.5	99.0	99.5	100.0	100.5	101.0	101.5	102.0	102.5	103.0
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
1.0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2
1.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3
2.0	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5
2.5	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5	6
3.0	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	6	6	6	7
3.5	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8
4.0	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	9
4.5	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	5	6	6	7	7	8	8	9	10	10
5.0	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5	6	6	7	7	7	8	9	9	10	11	11
5.5	2	2	2	3	3	3	3	3	4	4	4	4	5	5	5	6	6	7	7	8	8	9	9	10	11	12	12
6.0	2	2	3	3	3	3	3	4	4	4	4	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14
6.5	2	3	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15
7.0	3	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	9	9	10	10	11	12	13	14	15	16
7.5	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	9	9	10	10	11	12	13	14	15	16	17
8.0	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18
8.5	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19
9.0	3	4	4	4	4	5	5	5	6	6	7	7	8	8	9	10	10	11	12	13	13	14	15	17	18	19	20
9.5	4	4	4	4	5	5	5	6	6	7	7	8	8	9	9	10	11	12	12	13	14	15	16	18	19	20	22
10.0	4	4	4	5	5	5	6	6	7	7	7	8	9	9	10	11	11	12	13	14	15	16	17	18	20	21	23
10.5	4	4	5	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	21	22	24
11.0	4	4	5	5	5	6	6	7	7	8	8	9	9	10	11	12	12	13	14	15	16	18	19	20	22	23	25
11.5	4	5	5	5	6	6	7	7	7	8	9	9	10	11	11	12	13	14	15	16	17	18	20	21	23	24	26
12.0	4	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	21	22	24	25	27

Trip "Run Time" T_t	HORN STATIONARY TEST--MAXIMUM A-WEIGHTED SOUND LEVEL, dB ("Slow" Meter Response) [Windows Open]																							
	103.5	104.0	104.5	105.0	105.5	106.0	106.5	107.0	107.5	108.0	108.5	109.0	109.5	110.0	110.5	111.0	111.5	112.0	112.5	113.0	113.5	114.0	114.5	115.0
0.5	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5	6	
1.0	2	3	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	9	10	10	11	
1.5	4	4	4	4	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	
2.0	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	21	22	
2.5	6	7	7	7	8	9	9	10	11	11	12	13	14	15	16	17	18	20	21	23	24	26	28	
3.0	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	21	22	24	25	27	29	31	34	
3.5	9	9	10	10	11	12	13	14	15	16	17	18	20	21	23	24	26	28	30	32	34	37	39	
4.0	10	10	11	12	13	14	15	16	17	18	19	21	22	24	26	28	30	32	34	36	39	42	45	
4.5	11	12	13	13	14	16	17	18	19	20	22	24	25	27	29	31	33	36	38	41	44	47	50	
5.0	12	13	14	15	16	17	18	20	21	23	24	26	28	30	32	34	37	40	42	45	49	52	56	
5.5	13	14	15	16	18	19	20	22	23	25	27	29	31	33	35	38	41	44	47	50	54	57	62	LOCOMOTIVE FAILS STATIONARY SCREENING TEST
6.0	15	16	17	18	19	21	22	24	25	27	29	31	34	36	39	41	44	48	51	55	58	63	67	
6.5	16	17	18	19	21	22	24	26	28	30	32	34	36	39	42	45	48	51	55	59	63	68	73	
7.0	17	18	20	21	22	24	26	28	30	32	34	37	39	42	45	48	52	55	59	64	68	73	79	
7.5	18	20	21	22	24	26	28	30	32	34	37	39	42	45	48	52	55	59	64	68	73	78	84	
8.0	19	21	22	24	26	28	30	32	34	36	39	42	45	48	51	55	59	63	68	73	78	84	90	
8.5	21	22	24	25	27	29	31	34	36	39	41	44	48	51	55	59	63	67	72	77	83	89	95	
9.0	22	23	25	27	29	31	33	36	38	41	44	47	50	54	58	62	66	71	76	82	88	94	101	
9.5	23	25	27	28	31	33	35	38	40	43	46	50	53	57	61	65	70	75	81	86	93	99		
10.0	24	26	28	30	32	34	37	40	42	45	49	52	56	60	64	69	74	79	85	91	97	104		
10.5	26	27	29	31	34	36	39	42	45	48	51	55	59	63	68	72	78	83	89	96	102			
11.0	27	29	31	33	35	38	41	44	47	50	54	57	62	66	71	76	81	87	93	100				
11.5	28	30	32	34	37	40	42	46	49	52	56	60	64	69	74	79	85	91	98	105				
12.0	29	31	34	36	39	41	44	47	51	55	58	63	67	72	77	83	89	95	102					

Table 46. Stationary screening test values for the brake. These values were calculated from the screening test equation [Equation (16)] using P_B = 3% and K_B = 11 dB.

Trip "Run Time" T_t	BRAKE STATIONARY TEST--MAXIMUM A-WEIGHTED SOUND LEVEL, dB ("Slow" Meter Response) [Windows Open]																								
	90.0	90.5	91.0	91.5	92.0	92.5	93.0	93.5	94.0	94.5	95.0	95.5	96.0	96.5	97.0	97.5	98.0	98.5	99.0	99.5	100.0	100.5	101.0	101.5	102.0	102.5
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
3.0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3.5	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
4.0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
4.5	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2
5.0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2
5.5	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3
6.0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3
6.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3
7.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3
7.5	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3
8.0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4
8.5	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4
9.0	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4
9.5	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4
10.0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5
10.5	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5
11.0	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5
11.5	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5
12.0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	6

Trip "Run Time" T_t	BRAKE STATIONARY TEST--MAXIMUM A-WEIGHTED SOUND LEVEL, dB ("Slow" Meter Response) [Windows Open]																							
	103.0	103.5	104.0	104.5	105.0	105.5	106.0	106.5	107.0	107.5	108.0	108.5	109.0	109.5	110.0	110.5	111.0	111.5	112.0	112.5	113.0	113.5	114.0	114.5	115.0
0.5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	
1.0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	
1.5	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	
2.0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	
2.5	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5	6	6	
3.0	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	6	6	6	7	7	
3.5	2	2	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	9	
4.0	2	2	2	2	3	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	9	10	
4.5	2	2	3	3	3	3	3	4	4	4	4	5	5	5	6	6	7	7	8	8	9	10	10	11	
5.0	2	3	3	3	3	3	4	4	4	5	5	5	6	6	7	7	7	8	9	9	10	11	11	12	LOCOMOTIVE FAILS STATIONARY SCREENING TEST
5.5	3	3	3	3	4	4	4	4	5	5	5	6	6	7	7	8	8	9	9	10	11	12	13	13	
6.0	3	3	3	4	4	4	4	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	
6.5	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	
7.0	3	4	4	4	5	5	5	6	6	6	7	7	8	9	9	10	10	11	12	13	14	15	16	17	
7.5	4	4	4	5	5	5	6	6	6	7	7	8	9	9	10	10	11	12	13	14	15	16	17	18	
8.0	4	4	5	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	
8.5	4	5	5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	21	
9.0	4	5	5	5	6	6	7	7	8	8	9	10	10	11	12	13	13	14	16	17	18	19	20	22	
9.5	5	5	5	6	6	7	7	8	8	9	9	10	11	12	12	13	14	15	16	18	19	20	22	23	
10.0	5	5	6	6	7	7	7	8	9	9	10	11	11	12	13	14	15	16	17	18	20	21	23	24	
10.5	5	6	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	21	22	24	26	
11.0	5	6	6	7	7	8	8	9	9	10	11	12	12	13	14	15	16	18	19	20	22	23	25	27	
11.5	6	6	7	7	8	8	9	9	10	11	11	12	13	14	15	16	17	18	20	21	23	24	26	28	
12.0	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	21	22	24	25	27	29	

substituting the appropriate values for P_8, P_H and P_B for the particular run under consideration.

The most difficult part of this process is determining what total trip run time should be used. The most conservative approach is to use a value of 12 hours, which is the legal limit for the number of hours of duty by one crew. For the previous example, the total predicted noise dose would be 0.94 [(60 + 22 + 12)/100], which indicates that this locomotive could be used without any time restrictions. If however, the total predicted noise dose for a 12-hour trip routine is greater than 1.0, then restrictions must be made on the crew exposure time, or abatement of the principal noise sources undertaken, as shown in Figure 19.

To get some idea of the impact of using this approach, the noise dose was recalculated for the 18 test runs using a trip run time of 12 hours. These results are given in Table 47. As shown in this table, only one additional locomotive (Number 1) would fail. Thus, a total of two out of the 16 locomotives that were tested would fail and require some type of remedial action to be taken. Although this represents over 10 percent of the locomotives tested, no estimates can be made regarding the entire locomotive population in the U.S. A more substantial data base, relating the stationary sound levels and in-service noise dose for all types of locomotives of varying age, would be required to make these estimates with any degree of confidence.

6.5 Determining the Principal Noise Source

One of the objectives of the stationary screening test is to be able to pinpoint the particular noise sources which are the primary contributors to in-cab noise exposure. This is especially important for cases where the locomotive fails the screening test and remedial action of some type is

Table 47. Comparison of the predicted noise doses for the 18 test runs based on the actual trip run times and on an assumed value of 12 hours.

TEST RUN NUMBER	PREDICTED NOISE DOSE	
	$T_t = T_{dose}$	T_t = 12 hours
1	0.51	1.27
2	1.10	2.53
3a	0.26	0.97
3b	0.31	0.95
4	0.03	0.25
5	0.06	0.18
6	0.26	0.63
7	0.26	0.95
8	0.18	0.78
9	0.08	0.30
10	0.28	0.68
11	0.41	0.86
12	0.30	0.53
13	0.06	0.13
14a	0.25	0.68
14b	0.03	0.68
15	0.26	0.76
16	0.18	0.69

required. The procedure for determining which source is the primary contributor is simply to compare the relative magnitudes of the stationary screening test values. For example, if the values are 82 for engine notch 8, 16 for the horn and 6 for the brake, the engine is the primary source. Any strategies for reducing the crew noise exposure should concentrate on engine noise, which as discussed previously, may be most effectively accomplished by restricting the crew exposure time or the type of operation for which the locomotive is used. Of course, the locomotive does not have to fail the screening test to justify efforts to reduce the crew noise exposure. For example, if the stationary screening test values are 34 for engine notch 8, 36 for the horn and 8 for the brake, it may be desirable to reduce the contribution from the horn (since it is relatively large compared to most cases) by relocating it or whatever other approach is feasible for reducing the in-cab sound level.

6.6. Conclusions and Recommendations

The basic conclusion that can be drawn is that the stationary screening test is a reasonable approach to making a pass/fail assessment of locomotive crew noise exposure. The primary reason that it is acceptable is that the majority of cases (at least for those locomotives examined in this study) are well below the pass/fail cutoff. Although the procedure appears to be acceptable as discussed here, additional data (particularly data near or above the pass/fail cutoff, if they exist) are necessary to improve the statistical confidence of the stationary screening test prediction. This might eliminate the need for verification testing, although this option should always be available. While additional data may not be critical at this time, if the noise exposure criterion were reduced to 85 dB at 8 hours as proposed by NIOSH, a serious problem could arise. Not only would the number of locomotives exceeding the pass/fail cutoff increase, but the stationary screening test procedure would have to be redeveloped. More data would be needed to improve the accuracy and confidence of the noise dose predictions because more locomotives would be near the pass/fail cutoff. These data would not necessarily have to be as extensive as the information obtained in this study. Measurements of the stationary sound levels with a sound level meter and the in-service noise dose with a noise dosimeter would be sufficient to verify the stationary screening test procedure.

In addition to obtaining more data to verify the stationary screening test procedure, work should be done on developing noise control techniques for locomotive cabs. As discussed in footnote 13 on page 142, little information is available on methods for reducing in-cab locomotive noise. If more stringent hearing conservation criteria, such as those proposed by NIOSH [9], are adopted, these techniques may be necessary to reduce the noise exposure below the allowable limits. Specific areas of possible research are:

- investigation of approaches for quieting locomotive noise generated by the diesel engine and auxiliary equipment, such as compressors and cooling fans,
- design of locomotive cabs to provide better vibration isolation and acoustic absorption characteristics,
- development of abatement techniques for brake pipe venting (e.g., moving outlet outside of cab or designing muffler for the outlet), and
- development of techniques for reducing horn noise (e.g., moving the horn location or design of a highly directional horn which has significantly reduced back radiation [39]).

Thus, collection of additional data to verify the stationary screening test procedure and development of feasible noise abatement techniques are recommended as the next steps for dealing with in-cab locomotive noise.

7.0 APPENDIX A. DESCRIPTIONS OF LOCOMOTIVE CHARACTERISTICS AND TRAIN PARAMETERS

This appendix contains descriptions of the locomotives and corresponding train make-ups examined in this study. Also listed here are summaries of the trip logs for the 18 test runs. This information is broken-down as follows:

Table A-1 - locomotive descriptions
Table A-2 - list of bell and horn locations
Figure A-1 - illustration of bell locations
Figure A-2 - illustration of horn locations
Table A-3 - description of other locomotives used in lead consist and as helpers
Table A-4 - description of the train make-up
Table A-5 - description of the 18 test runs
Table A-6 - trip log for test runs 1, 2, and 3a
Table A-7 - trip log for test runs 3b, 4, 5, and 6
Table A-8 - trip log for test runs 7, 8, 9, and 10
Table A-9 - trip log for test runs 11, 12, and 13
Table A-10 - trip log for test runs 14a, 14b, 15 and 16.

Table A-1. Descriptions of the sixteen test locomotives.

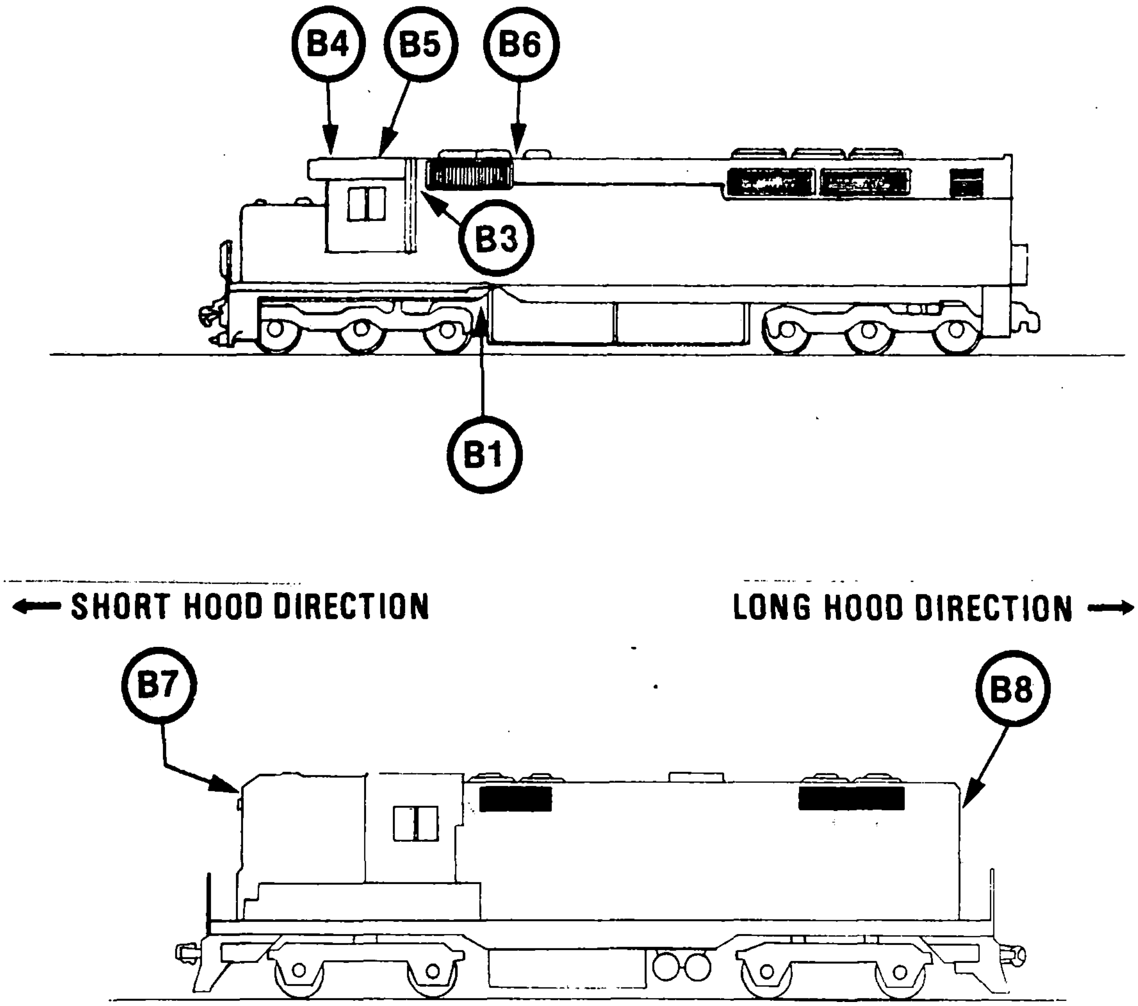
LOCOMOTIVE NUMBER	MANUFACTURER *	MODEL NUMBER	DATE OF MANUFACTURE	ENGINE DESCRIPTION Type	Design	Number of Cylinders	Horsepower	Number of Traction Motors
1	EMD	GP38	1970	645	2-stroke, naturally aspirated	16	2000	4
2	EMD	GP9	1957	567	2-stroke, naturally aspirated	16	1750	4
3	EMD	SD40	1970	645	2-stroke, turbocharged	16	3000	6
4	GE	U25B	1962	FDL-16	4-stroke, turbocharged	16	2500	4
5	GE	U25C	1965	FDL-16	4-stroke, turbocharged	16	2500	6
6	GE	U33C	1968	FDL-16	4-stroke, turbocharged	16	3300	6
7	EMD	GP40	1970	645	2-stroke, turbocharged	16	3000	4
8	GE	U18B	1973	FDL-8	4-stroke, turbocharged	8	1800	4
9	GE	U36B	1970	FDL-16	4-stroke, turbocharged	16	3600	4
10	EMD	SD45	1974	645	2-stroke, turbocharged	20	3600	6
11	EMD	SD40	1966	645	2-stroke, turbocharged	16	3000	6
12	GE	U30C	1968	FDL-16	4-stroke, turbocharged	16	3000	6
13	GE	U33C	1970	FDL-16	4-stroke, turbocharged	16	3300	6
14	EMD	SD24	1959	567	2-stroke, turbocharged	16	2400	6
15	EMD	SD35	1965	567	2-stroke, turbocharged	16	2500	6
16	GE	U23B	1975	FDL-12	4-stroke, turbocharged	12	2250	4

*The manufacturer and model number of the 16 locomotives are identified in order to adequately describe the tests conducted in this program. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards.

Table A-2. List of bell and horn locations for the sixteen test locomotives. See Figures A-1 and A-2 for illustration of these locations.

LOCOMOTIVE NUMBER	DIRECTION OF TRAVEL	BELL LOCATION	HORN		
			Cluster Location	Number of Forward Directed Horns	Number of Rearward Directed Horns
1	short hood forward	B1	H1	2	N/A
2	long hood forward	N/A	H2	3	0
3	short hood forward	B1	H1	2	1
4	short hood forward	B2	H3	2	1
5	short hood forward	B3	H3	3	0
6	short hood forward	B3	H3	2	1
7	short hood forward	B1	H1	3	N/A
8	short hood forward	B2	H3	3	2
9	short hood forward	B2	H3	N/A	N/A
10	short hood forward	B4	H4	2	1
11	short hood forward	B5	H1	2	1
12	short hood forward	B6	H3	2	1
13	short hood forward	B6	H3	2	1
14	short hood forward	B7	H5	3	0
15	short hood forward	B7	H5	3	0
16	long hood forward	B8	H6	3	0

Figure A-1. Illustration of various locations where the bells were mounted.



B1 - Brakeman's side, under the body of the locomotive, ahead of the fuel tank

B2 - Same as B1 except on engineer's side of locomotive

B3 - Brakeman's side of the locomotive, next to the rear window of the cab

B4 - Front edge of the locomotive cab roof, to the brakeman's side of the center of the cab

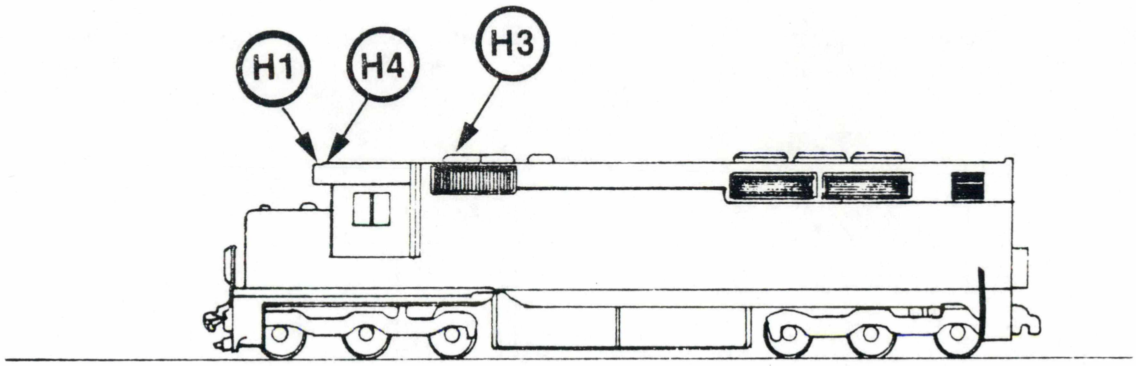
B5 - Center of the locomotive cab roof

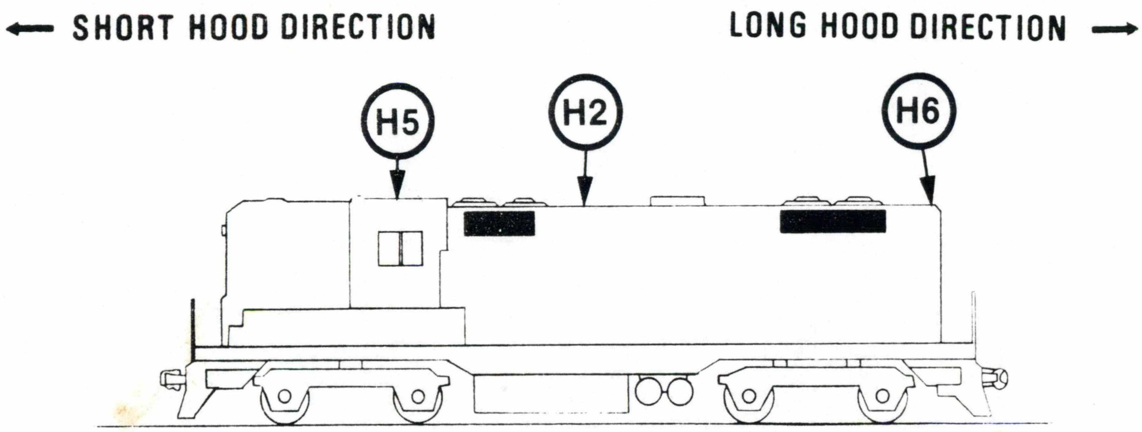
B6 - On top of locomotive body, rearward of the cab

B7 - Suspended from front hood of locomotive (short hood forward)

B8 - Suspended from front hood of locomotive (long hood forward)

Figure A-2. Illustration of various locations where the horn clusters were mounted.





H1 - Center of the front edge of the locomotive cab roof

H2 - Centered on top of locomotive body

H3 - On top of locomotive body, directly behind the cab

H4 - Same as H1 except to the engineer's side of the center of the cab

H5 - Center of the locomotive cab roof

H6 - On top of the front hood of the locomotive (long hood forward)

Table A-3. General descriptions of the road and helper locomotives used to power each train.

TEST RUN NUMBER	TIME OF DAY Crew On	TIME OF DAY Crew Off	LEAD CONSIST No. of Units	LEAD CONSIST Description of Trailing Units Unit No.	Date of Manuf.	HP	Comments	HELPER UNITS No. of Units	Description of Helper Units Unit No.	Date of Manuf.	HP	Location of Helper Units in Train	Comments
1	18:47	03:00	3		N/A	N/A		None					
2	08:00	15:52	3	1	1963	2250	Trailing unit 1 was shut down at 13:45.	None					
				2	1973	2000							
3a	20:18	01:03	4	1	1968	3000		None					
3b	01:03	09:30		2	1968	3000							
				3	1968	3000							
4	16:12	19:00	2	1	1965	2500		None					
5	09:00	17:30	4	1	1965	2500		None					
				2	1968	3300							
				3	1965	2500							
6	09:20	18:00	3	1	1968	3300		None					
				2	1965	2500							
7	05:12	12:10	2	1	1966	3000		None					
8	14:37	20:30	2	1	1971	3600		None					
9	05:00	11:30	2	1	1970	3600		None					
10	19:53	03:00	4	1	1968	3600	Trailing unit 3 was added to the consist at 22:20.	2	1	1974	3600	39 cars ahead of caboose	
				2	1966	3000			2	1966	3600		
				3	1973	1750							
11	12:18	22:30	3	1	1969	3600		2	1	1968	3600	24 cars ahead of caboose	Helper units were switched into the train at 14:16 and were switched out of the train at 18:09.
				2	1972	3600			2	1969	3600		
12	11:1[illegible]	22:15	9	1	1968	2300	Because of mechanical problems with trailing units 1 and 2, units 4-7 were added to the consist at 14:40. Unit 6 was never operational during the test run. Various combinations of these units were used depending upon whether the terrain was upgrade or downgrade.	7	1	1977	2500	Units 1-6 -- 51 cars ahead of caboose. Unit 7 behind caboose.	All helper units were switched out of the train at 16:35.
				2	1970	2300			2	1965	2500		
				3	1969	3000			3	1970	2300		
				4	1967	3600			4	1977	1750		
				5	1970	3600			5	1974	1750		
				6	1966	2800			6	1970	3300		
				7	1969	3600			7	1972	3300		
13	10:50	20:30	5	1	1966	3600		3	1	1975	3600	36 cars ahead of caboose	Helper units were switched into the train at 12:57 and were switched out of the train at 15:40.
				2	1962	2000			2	1969	3000		
				3	1973	3600			3	1974	3600		
				4	1975	3600							
14a	14:13	20:01	3	1	1960	2400		None					
14b	20:28	22:30		2	1965	2500							
15	13:22	20:00	3	1	1967	3600		None					
				2	1975	3000							
16	12:26	19:15	3	1	1973	2250		None					
				2	1974	2250							

N/A - Data are not available.

Table A-4. Descriptions of the train make-up in terms of the number of cars and the total load.

TEST RUN NUMBER	TIME OF DAY		NUMBER OF CARS			TOTAL LOAD, tons	COMMENTS
	Crew On	Crew Off	Loads	Empties	Total		
1	18:47	03:00	27 6	18 10	45 61	2979 N/A	Sixteen cars were picked up at 19:28. The tonnage of these cars was not recorded.
2	08:00	15:52	20 54	13 23	33 110	N/A 6403	Seventy-seven cars were picked up at 10:46.
3a 3b	20:18 01:03	01:03 09:30	26	56	82	2964	
4	16:12	19:00	44	8	52	3648	
5	09:00	17:30	65	20	85	6156	
6	09:20	18:00	44	36	80	4560	
7	05:12	12:10	23	120	143	6180	The values for the total number of cars and total load do not include a locomotive which was shut down.
8	14:37	20:30	52	23	75	4862	Fifteen cars were set off at 17:10. The tonnage of these cars was not recorded.
9	05:00	11:30	N/A	N/A	141	5850	The breakdown of the numbers of cars into loads and empties was not recorded.
10	19:53	03:00	24	85	109	5062	
11	12:18	22:30	77	11	88	6940	
12	11:15	22:15	88	20	108	8296	
13	10:50	20:30	75	64	139	8562	
14a 14b	14:13 20:28	20:01 22:30	73	62	135	7546	
15	13:22	20:00	75 16	65 4	140 160	7660 9169	Twenty cars were picked up at 17:41.
16	12:26	19:15	59	78	137	6513	The values for the total number of cars and total load do not include a locomotive which was shut down.

N/A - Data are not available.

Table A-5. General descriptions of the eighteen test runs.

TEST RUN NUMBER	TIME OF DAY		TOTAL TIME CREW WAS ON TRAIN, hours	TYPE OF TRAIN[1/]	APPROXIMATE LENGTH OF RUN, miles[2/]	GENERAL TERRAIN
	Crew on	Crew off				
1	18:47	03:00	8.22	local freight	90	undulating
2	08:00	15:52	7.87	local freight	90	undulating
3a	20:18	01:03	4.75	through freight	100	mountainous
3b	01:03	09:30	8.45	through freight	120	mountainous
4	16:12	19:00	2.80	local freight	15	flat
5	09:00	17:30	8.50	through freight	80	mountainous
6	09:20	18:00	8.67	through freight	80	mountainous
7	05:12	12:10	6.97	local freight	80	flat
8	14:37	20:30	5.88	local freight	80	flat
9	05:00	11:30	6.50	through freight	80	flat
10	19:53	03:00	7.12	through freight	110	mountainous
11	12:18	22:30	10.20	through freight	160	mountainous
12	11:15	22:15	11.00	through freight	150	mountainous
13	10:50	20:30	9.67	through freight	200	mountainous
14a	14:13	20:01	5.80	through freight	65	undulating
14b	20:28	22:30	2.03	through freight	30	undulating
15	13:22	20:00	6.63	local freight	95	undulating
16	12:26	19:15	6.82	through freight	110	undulating

1/ The only distinction intended between types of trains is that local freights involved switching cars into and out of the train at intermediate stops, whereas through freights did not.

2/ These are only approximate mileages given to help characterize the test runs. Exact mileages were not recorded.

Table A-6. Summaries of trip logs for test runs 1, 2, and 3a.

TEST RUN NUMBER	TIME OF DAY		CREW ON-BOARD TIME, hr	TRIP LOG	
	Crew On	Crew Off		Time of Day	Comments
1	18:47	03:00	8.22	18:47	Crew on board locomotive
				19:18	Picking up 16 cars
				19:28	Standing at notch 8 (no load) charging the brake system
				20:31	Brakeman leaves locomotive cab
				21:06	Brakeman returns to locomotive cab
				22:18	Train stopped on siding
				23:34	Train leaving siding
				01:37	Train stopped waiting to enter yard
				03:00	Crew off locomotive
2	08:00	15:52	7.87	08:00	Crew on board locomotive
				10:32	Picking up remainder of train (77 cars)
				10:42	Brakeman leaves locomotive cab to check train orders
				10:46	Brakeman returns to locomotive cab
				11:06	Train stopped on siding
				11:17	Train leaving siding
				12:40	Second unit in lead consist experiencing mechanical problems
				13:45	Second unit in lead consist shut down
				13:55	Stopped to receive train orders
				14:04	Train underway
				15:52	Crew off locomotive
3a	20:18	01:03	4.75	20:18	Crew on board locomotive
				21:26	Alerter sounded
				22:29	Alerter sounded
				22:46	Train stopped because of dragging equipment detector
				22:47	Brakeman leaves locomotive cab to check train
				22:56	Engineer leaves locomotive cab to check train
				23:01	Engineer returns to locomotive cab
				23:11	Brakeman returns to locomotive cab
				23:12	Train underway
				01:03	Crew off locomotive

Table A-7. Summaries of trip logs for test runs 3b, 4, 5, and 6.

TEST RUN NUMBER	TIME OF DAY		CREW ON-BOARD TIME, hr	TRIP LOG	
	Crew On	Crew Off		Time of Day	Comments
3b	01:03	09:30	8.45	01:03 04:41 05:30 09:30	Crew on board locomotive Drop off road foreman at main station Train stopped waiting to enter yard Crew off locomotive
4	16:12	19:00	2.80	16:12 16:42 16:57 18:12 18:42 18:59 19:00	Crew on board locomotive Brakeman leaves locomotive cab to couple up the consist to the train Brakeman returns to locomotive cab Locomotive backing up to switch-in cars Locomotive switching cars out of train Locomotive runs around train and is coupled to the caboose Crew goes to rear unit which is now the lead unit in the consist to continue to final destination
5	09:00	17:30	8.50	09:00 10:03 10:47 12:21 12:54 14:16 15:13 17:30	Crew on board locomotive Train stopped on siding Train leaving siding Train stopped on siding Train leaving siding Train temporarily stopped to crossover to another track Entering yard Crew off locomotive
6	09:20	18:00	8.67	09:20 11:58 12:42 16:02 16:16 16:51 16:54 18:00	Crew on board locomotive Train stopped on siding Train leaving siding Stopped for signal Train underway Stopped for signal Train underway Crew off locomotive

Table A-8. Summaries of trip logs for test runs 7, 8, 9, and 10.

TEST RUN NUMBER	TIME OF DAY		CREW ON-BOARD TIME, hr	TRIP LOG	
	Crew On	Crew Off		Time of Day	Comments
7	05:12	12:10	6.97	05:12	Crew on board locomotive
				06:08	Stopped to set out cars
				06:48	Train underway
				06:52	Stopped to pick up cars
				07:38	Train underway
				09:00	Train stopped on siding
				10:03	Train leaving siding
				11:03	Stopped for signal
				11:07	Train underway
				12:10	Crew off locomotive
8	14:37	20:30	5.88	14:37	Crew on board locomotive
				16:45	Locomotive uncoupled from train to set out cars
				17:10	Setting out 15 cars
				18:39	Train underway
				19:47	Moving through yard between two rows of freight cars
				20:30	Crew off locomotive
9	05:00	11:30	6.50	05:00	Crew on board locomotive
				08:22	Train stopped on siding
				08:41	Train leaving siding
				09:37	Stopped waiting to enter yard
				11:30	Crew off locomotive
10	19:53	03:00	7.12	19:53	Crew on board locomotive
				20:48	Stopped waiting to leave yard
				20:54	Train underway
				22:20	Stopped to add additional locomotive, brakeman leaves locomotive cab
				22:57	Brakeman returns to locomotive cab
				23:05	Train underway
				03:00	Crew off locomotive

Table A-9. Summaries of trip logs for test runs 11, 12, and 13.

TEST RUN NUMBER	TIME OF DAY Crew On	TIME OF DAY Crew Off	CREW ON-BOARD TIME, hr	TRIP LOG Time of Day	TRIP LOG Comments
11	12:18	22:30	10.20	12:18	Crew on board locomotive
				13:41	Train underway with two helper units in front of the test locomotive
				14:05	Stopped to switch in all helper units
				14:16	Train underway
				14:21	Stopped for signal
				14:30	Train underway
				15:28	Stopped for signal
				15:42	Train underway
				17:57	Stopped to cut out all helpers
				18:09	Train underway
				19:02	Train stopped on siding
				19:06	Train leaving siding
				19:19	Train slowed down while approaching signal but not stopped because signal changed
				20:12	Stopped waiting to enter yard
				22:30	Crew off locomotive
12	11:15	22:15	11.0	11:15	Crew on board locomotive
				13:54	Stopped waiting for another train to clear
				14:03	Train underway
				14:04	Stopped to add four locomotives to lead consist
				14:40	Train underway
				16:11	Stopped to cut off helpers
				16:35	Train underway
				17:43	Train stopped on siding
				18:10	Train leaving siding
				22:15	Crew off locomotive
13	10:50	20:30	9.67	10:50	Crew on board locomotive
				12:26	Train leaving yard
				12:46	Stopped to pick up helpers
				15:30	Switching helpers out of train
				15:40	Train underway
				16:20	Train stopped on siding
				16:24	Train leaving siding
				17:12	Train stopped on siding
				17:58	Train leaving siding
				20:30	Crew off locomotive

Table A-10. Summaries of trip logs for test runs 14a, 14b, 15, and 16.

TEST RUN NUMBER	TIME OF DAY		CREW ON-BOARD TIME, hr	TRIP LOG	
	Crew On	Crew Off		Time of Day	Comments
14a	14:13	20:01	5.80	14:13	Crew on board locomotive
				16:08	Stopped checking train because of sticking brakes
				16:57	Train underway
				18:05	Hit two torpedoes
				18:07	Stopped checking train because of sticking brakes
				18:12	Train underway
				20:01	Crew off locomotive (this crew had worked the previous night and had to go off duty before reaching the final destination because of the twelve-hour limitation of service rule)
14b	20:28	22:30	2.03	20:28	Crew on board locomotive
				21:06	Waiting in yard to get clearance to go to fueling rack
				22:30	Crew off locomotive
15	13:22	20:00	6.63	13:22	Crew on board locomotive
				15:46	Pulling into siding
				15:57	Train leaving siding (never came to complete stop)
				17:12	Stopped to pick up 20 cars
				17:41	Train underway
				20:00	Crew off locomotive
16	12:26	19:15	6.82	12:26	Crew on board locomotive
				15:00	Cannot hear bell even though engineer is using it. Will not throw the bell switch on the operational keyboard since you cannot tell when it is on.
				19:15	Crew off locomotive

8.0 REFERENCES

[1] Peterson, A. P. G., and Gross, Jr., E. E., Handbook of Noise Measurement (General Radio Company, Concord, MA, 7th ed., 1972).

[2] Department of Labor, Occupational Safety and Health Administration, Occupational Safety and Health Standards, Title 29, Code of Federal Regulations, Part 1910, U. S. Federal Register 36 (105), 10518 (May 29, 1971).

[3] Federal Railroad Safety Act of 1970, Public Law 91-458, October 16, 1970.

[4] Federal Railroad Administration, Advanced Notice of Proposed Rule Making, Railroad Occupational Safety Standards, Title 49, Code of Federal Regulations, Part 219, U. S. Federal Register 40 (46), 10693-10697 (March 7, 1975).

[5] American National Standard S1.4-1971, Specification for Sound Level Meters (American National Standards Institute, New York, NY, April 1971).

[6] Railroad Employees' Hours of Service Restriction, Public Law 91-169, December 26, 1969.

[7] Department of Labor, Occupational Safety and Health Administration, Occupational Noise Exposure -- Proposed Requirements and Procedures, Title 29, Code of Federal Regulations, Part 1910, U. S. Federal Register 39 (207), 37773-37778 (October 24, 1974).

[8] Federal Railroad Administration, Notice of Proposed Rulemaking, Locomotive Inspection, Title 49, Code of Federal Regulations, Parts 229 and 230, U. S. Federal Register 44 (99), 29604-29629 (May 21, 1979).

[9] Anon., Criteria for a Recommended Standard....Occupational Exposure to Noise, Report No. HSM 73-11001, U. S. Department of Health, Education, and Welfare, National Institute for Occupational Safety and Health, 1972.

[10] Robinson, D. W., The Relationships between Hearing Loss and Noise Exposure, AERO Report Ac32 (National Physical Laboratory, London, July 1968).

[11] Environmental Protection Agency, Railroad Noise Emission Standards, Title 40, Code of Federal Regulations, Chapter I, Part 201, U. S. Federal Register 41 (9), 2183-2195, January 14, 1976.

[12] Aurelius, J. P., The Sound Environment in Locomotive Cabs, U. S. Department of Transportation Report No. FRA-RP-71-2A (Systems Consultants Inc., New York, NY, July 1971).

[13] Campanella, A. J., Occupational Noise Measurement in Diesel Locomotives (Acculab, Columbus, OH, April 7, 1975).

[14] Campanella, A. J., Occupational Noise Measurement in a Switching Diesel Locomotive (Acculab, Columbus, OH, October 8, 1976).

[15] Rickley, E. J., Quinn, R. W., and Sussan, N. R., Noise Level Measurements of Railroads: Freight Yards and Wayside, U. S. Department of Transportation Report No. DOT-TSC-OST-73-46 (DOT Transportation Systems Center, Cambridge, MA, May 1974).

[16] Remington, P. J., and Rudd, M. J., An Assessment of Railroad Locomotive Noise, U. S. Department of Transportation Report No. DOT-TSC-OST-76-4/FRA-OR&D-76-142 (Bolt Beranek and Newman Inc., Cambridge, MA, August 1976).

[17] Campanella, A. J., Annex to Occupational Noise Measurements in Diesel Locomotives (Acculab, Columbus, OH, June 12, 1975).

[18] Storment, J. O., Wood, C. D., and Mathis, R. J., A Study of Fuel Economy and Emission Reduction Methods for Marine and Locomotive Diesel Engines, U. S. Department of Transportation Report No. DOT-TSC-OST-75-41 (Southwest Research Institute, San Antonio, TX, September 1975).

[19] Bender, E. K., Ely, R. A., Remington, P. J., and Rudd, M. J., Railroad Environmental Noise: A State of the Art Assessment, BBN Report No. 2709 (Bolt Beranek and Newman Inc., Cambridge, MA, January 11, 1974).

[20] Jacobs, M. E., Fuel Efficiency Improvement in Rail Freight Transportation: Multiple Unit Throttle Control to Conserve Fuel, FRA Report No. FRA/ORD-78/13 (Federal Railroad Administration, U. S. Department of Transportation, Washington, D. C., February 1978).

[21] Blaine, D. G., Grejda, F. J., and Kahr, J. C., Braking Duty in North American Freight Train Service and Effects on Brake Equipment, Brake Shoes and Wheels, ASME Paper No. 78-RT-9 (Westinghouse Air Brake Company, Wilmerding, PA, 1978).

[22] Eck, H. C., The Modern Locomotive Handbook (The Railway Fuel and Operating Officers Association, Chicago, IL, 1976).

[23] Anon., Background Document for Railroad Noise Emission Standards, U. S. Environmental Protection Agency Report No. EPA-550/9-76-005 (EPA Office of Noise Abatement and Control, Washington, D.C., December 1975).

[24] Peterson, W., Current Major Railroad Stats, Extra 2200 South -- The Locomotive Newsmagazine, Issue 63, 11 (10), 6 (January - March, 1978).

[25] Manika, J. P., Electro-Motive Division of General Motors Corporation, private correspondence to M. A. Popjoy, American Association of Railroads, August 5, 1977.

[26] Popjoy, M. A., American Association of Railroads, private correspondence to R. M. Clarke, Office of Rail Safety Research, Federal Railroad Administration, August 10, 1977.

[27] Popjoy, M. A., American Association of Railroads, private correspondence to R. M. Clarke, Office of Rail Safety Research, Federal Railroad Administration, March 9, 1977.

[28] Anon., Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, EPA Report No. 550/9-74-004 (U. S. Environmental Protection Agency, Washington, D. C., March 1974).

[29] Close, W. H., and Clarke, R. M., Truck Noise-II, Interior and Exterior A-Weighted Sound Levels of Typical Highway Trucks, Report No. OST/TST-72-2 (U. S. Department of Transportation, Washington, D. C., July 1972).

[30] Morrison, D. W., and Clarke, R. M., Regulation of Commercial Motor Vehicle Interior Noise Levels, SAE Paper No. 720697 (U. S. Department of Transportation, Washington, D. C., August 1972).

[31] Sharp, B. H., and Weiss, W. R., Correlation of Truck Cab Interior Noise to Existing Regulatory Limits, Report No. WCR 73-2 (Wyle Laboratories, El Segundo, CA, March 1973).

[32] ISO International Standard 3381-1976(E), Acoustics -- Measurement of Noise Inside Railbound Vehicles (International Organization for Standardization, Geneva, 1976).

[33] SAE Recommended Practice J336a, Sound Level for Truck Cab Interior (Society of Automotive Engineers, Inc., Warrendale, PA, 1968).

[34] SAE Recommended Practice J919b, Operator Sound Level Measurement Procedure for Powered Mobile Construction Machinery -- Singular Type Test (Society of Automotive Engineers, Inc., Warrendale, PA, 1976).

[35] SAE Recommended Practice J1160, Operator Ear Sound Level Measurement Procedure for Snow Vehicles (Society of Automotive Engineers, Inc., Warrendale, PA, 1976).

[36] SAE Recommended Practice J1174, Operator Ear Sound Level Measurement Procedure for Small Engine Powered Equipment (Society of Automotive Engineers, Inc., Warrendale, PA, 1977).

[37] SAE Recommended Practice J1166, Operator Station Sound Level Measurement Procedure for Powered Mobile Earthmoving Machinery -- Work Cycle Test (Society of Automotive Engineers, Inc., Warrendale, PA, 1976).

[38] Federal Highway Administration, Motor Carrier Safety Regulations, Title 49, Code of Federal Regulations, Part 393.94, U. S. Federal Register 38 (215), 30881-30882 (November 8, 1973).

[39] Fisher, R. L., Toth, D. D., Blomquist, D. S., and Forrer, J. S., The Development and Testing of a Highly Directional Dual-Mode Electronic Siren, NBS Special Publication 480-28 (National Bureau of Standards, Washington, D. C., February 1978).

9.0 ACKNOWLEDGEMENTS

The author expresses his sincere appreciation to the organizations who contributed their time, personnel and equipment to bring about the successful completion of this project. The list of individuals who were involved with this project is too long to give here, but their efforts are greatly appreciated. The author thanks the staff and personnel of the Federal Railroad Administration, Association of American Railroads, Consolidated Rail Corporation, Seaboard Coast Line Railroad Company, and Southern Railway System for their support during this project. In particular, the advice and suggestions of Mr. R. M. Clarke and Mr. R. J. McCown of the FRA were extremely useful.

The author also wishes to recognize the contributions made by the NBS staff: Mr. J. S. Forrer, Mr. D. E. Mathews, Ms. T. M. Savoy, and Mr. C. O. Shoemaker, Jr., for their work in developing the instrumentation system; Dr. D. M. Corley and Mr. R. L. Fisher, for assistance in data reduction and analysis; Mr. D. R. Flynn, for help in evaluating the stationary screening test model and review and comments on the final report; Ms. D. A. Neal and Ms. C. Smith, for typing and preparation of the manuscript; and, in particular, Mr. D [illegible] upport dur-

i [illegible]