1143

TRANSPORTATION RESEARCH RECORD

Environmental Issues: Noise, Rail Noise, and High-Speed Rail

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1987

Transportation Research Record 1143
Price: $7.50
Editor: Naomi Kassabian
Typesetting and layout: Betty L. Hawkins

modes
1 highway transportation
2 public transit
3 rail transportation
4 air transportation
5 other (bicycle, pipeline, pedestrains, waterways. etc.)

subject area
17 energy and environment

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Printed in the United States of America

Library of Congress Cataloging-in-Publication Data
National Research Council. Transportation Research Board.

Environmental issues: noise, rail noise, and high-speed rail.

p. cm. — (Transportation research record, ISSN 0361-1981 ; 1143)
1. Transportation noise—Environmental aspects. 2. Railroads—Noise—Environmental aspects. 3. High speed ground transportation—Noise—Environmental aspects. I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 1143 [TD893.6.T7] 380.5 s—dc 19 88–16053
ISBN 0-309-04652-1 [363.7'41] CIP

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Foreword

Five papers in this Record deal with transportation-induced noise and its effect on the environment. One paper is a report on the proposal to construct a high-speed rail line between Los Angeles and San Diego, California.

Hall and Welland address the problem of how highway noise affects house prices and how noise barriers alter that effect. The study site was the Toronto metropolitan area. The pooled sample coefficient of noise level estimated was $778/dB (in 1981 dollars). It was further found that house sales in areas protected by noise barriers reflect the same kind of valuation of noise as do house sales in unprotected noisy areas. Bragdon summarizes the status of airport noise regulations enacted by municipalities within the United States. The study inventoried 2,000 municipalities and evaluated more than 200 airports regarding applicable operational and land use controls.

Houtman and Immers report on a study at Delft University of Technology in the Netherlands in which the possibilities were investigated of reducing traffic noise annoyance in urban areas without reducing the total amount of travel by influencing car drivers' route choice. The researchers modified an equilibrium assignment algorithm in their investigation of ways to influence route choice.

Urman presents measured noise levels for various railroad industry noise sources, specifically results of noise surveys in railroad classification yards, locomotives, and cabooses. Nelson and Saurenman have developed a procedure for predicting groundborne noise and vibration caused by rail transportation systems. The primary focus of their paper is the estimation of low-level, low-frequency groundborne noise and vibration in buildings near at-grade and subway track.

The high-speed rail proposal between Los Angeles and San Diego, California, is the topic of the last paper in this Record. Smith and Shirley present the ambitious project from its initiation to the time when the proposal was dropped from further consideration by a private firm that had considered it for a profitable business venture. Many of the controversial issues such as noise, vibration, beach access, safety, and others are described.

Transportation Research Record 1143

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Contents

The Effect of Noise Barriers on the Market Value of Adjacent Residential Properties

FRED L. HALL AND J. DOUGLAS WELLAND

The problem of how highway noise affects house prices and how highway noise barriers alter that effect is addressed. The project began with a set of house price data available in the Property Office of the Ontario Ministry of Transportation and Communications. These data were augmented with housing characteristics and sales data obtained from the Toronto Real Estate Board. All of the data were from three residential areas of Toronto situated behind highway noise barriers. In a multiple linear regression, in which a variety of other housing characteristics are controlled for, the coefficient of noise level (in 1981 dollars) varies from –$312/dB at one site to –$356/dB at a second site, to –$2,971/dB at a third site, all of which coefficients are statistically significant at the .05 level. The pooled sample estimate is –$778/dB. The first two values are generally consistent with results of earlier studies, although perhaps a bit lower. Nonlinear regressions of noise level and functions that ignored noise until it was around 65 db were also investigated. Those results supported neither a quadratic function nor any clear threshold effect. Close inspection of the data at the site with a –$2,971/dB value suggests that these data may not be representative of the relevant population, in that expensive houses in high noise environments are not properly represented in the sample. As a result, the extremely large estimated noise penalty is probably a statistical anomaly. Because the pooled sample noise penalty of –$778/dB reflects in part the data from that site, it too may be nonrepresentative of the population noise penalty. It is clear from these data that house sales in areas protected by noise barriers reflect the same kind of valuation of noise as do sales in unprotected noisy areas.

Highway noise is detrimental to those living adjacent to highways. When the noise level is high enough, these effects are severe enough to be reflected in housing prices. Several previous studies have been conducted to estimate these effects, but none have been conducted in areas where highway noise barriers are present.

The main question addressed in this study is whether and to what extent barriers overcome the impact that highway noise has on house prices. In particular, is the dollar-per-decibel effect at locations with noise barriers commensurate with that at sites without barriers? In order to obtain a good answer to this question, the research also considers whether it is correct to speak of a dollar-per-decibel effect (which implies a linearity of effect over the range of the data), or whether the effect is a nonlinear function of the decibel level.

The most relevant of the previous studies for purposes of comparison is the one reported by Taylor et al. in 1982 *(1)* from work done for a master's thesis by Breston at McMaster University. That study utilized data on 2,277 individual housing sales at 51 sites in southern Ontario, and involved collection of highway noise data at those sites specifically for the analysis. The results showed that noise was valued at approximately $250/dB to $300/dB (in 1977 dollars), comparing similar housing at different distances (and therefore noise levels) from the roadway. For the average house price of $60,000, this represents a depreciation rate of 0.5 percent per decibel. Noise-level differences between the first two rows of houses parallel to a highway ranged from 7 to 16 dB in that study, implying that the effect of the noise varied between 3.5 and 8 percent of the price of similar but quieter houses. Because that study was conducted in southern Ontario and used detailed noise-level data, its results should provide the most appropriate comparison for results of the current study.

Nelson *(2)* reports on a study using 1970 census data for 456 tracts for the Washington, D.C., metropolitan area. His results (*2*, p. 95) "imply that a 1 dBA increase in L_{dn} will decrease a given property value by about 0.8 percent, all other things being equal." Unfortunately, this study did not collect noise data and was not based on individual sales data. Instead, census tract data for average sales prices and average housing characteristics were used, and noise levels were estimated on the basis of population densities.

Nelson also provides a summary of three earlier studies of the effects of road traffic noise on house prices, for which the results are all remarkably similar. Gamble et al. *(3)* find decreases in property values of between 0.20 and 0.42 percent/dB, except for one site where the decrease as estimated by the regression equation was 2.22 percent/dB. Anderson and Wise *(4)* obtain a pooled sample result of 0.25 percent/dB, which compares very closely with a pooled sample result of 0.26 percent/dB for Gamble et al. Both Gamble et al. and Anderson and Wise used the same data—individual real estate records for four eastern U.S. communities. The Gamble et al. data were for the period 1969 to 1971, with an average house price of $31,100 across the sample. The Anderson and Wise study covered 1965 to 1971. No average value is available. Within specific sites, however, the Anderson and Wise results varied considerably, from a nonsignificant effect at two sites to as high as 1.0 percent/dB. Vaughn and Huckins *(5)* found results ranging from 0.4 to 0.6 percent/dB, depending on the noise measure and regression form, with a best estimate of about 0.6 percent/dB. They used a Chicago-based sample for 1971 to 1972, with an average house price of $22,500.

This paper is based on data collected at two sites in Toronto, Ontario, with noise barriers and on data from a third site before and after barrier construction. The study began with data

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previously acquired by the Property Office of the Ontario Ministry of Transportation and Communications (MTC). The existence of those data determined the sites to be used for the current study, which was limited to three locations in the Toronto metropolitan area. The first analysis reported here was based solely on the MTC data. A second analysis drew upon additional data for the same three sites collected from the Toronto Real Estate Board. Those analyses are described, starting with the available data for each, comparing these results with those from the earlier studies, and suggesting some possibilities for additional research.

DATA FROM MTC PROPERTY OFFICE

Recent data available in the MTC Property Office files come from three sites in Toronto:

1. Etobicoke along Highway 427 before barrier construction and with a few observations since a concrete barrier was erected,
2. Between Leslie Street and Bayview Avenue along Highway 401 after barrier construction, and
3. Between the Don Valley Parkway and Victoria Park Avenue along Highway 401 after barrier construction.

For these sites, the files contain information on the recent sale price and the date of the sale, the original sale price at the time that the house was first built and the date of that sale, the lot size, and the amount of cash paid as part of the sale.

The first step to prepare these data for a multiple regression analysis of house price on its determinants was to remove the effects of inflation from the house prices over the period covered by the data. Several price indexes were considered for this purpose: the owned-accommodation component of the consumer price index (CPI), the residential construction cost index, and an index of average prices for Toronto real estate sales. The real estate index was chosen for four main reasons. First, it clearly incorporates seasonal effects and the effects of brief periods of speculative activity in the housing market, which neither of the other indexes does. Second, the owned-accommodation index includes many items that are extraneous for consideration of sale price (for example, utility and heating charges and repair costs) and also costs associated with condominium ownership. Third, the construction cost index cannot include the various factors that affect resale prices of housing, such as market demand, because it is based solely on costs of new home construction. Fourth, the real estate index is available for each of the three Toronto sites, making it the index most representative of the price experience of the homes in the study. These factors combine to make the real estate index the best choice for measuring house price behavior.

The Toronto Real Estate Board made available information on the average selling price, for houses only, in each of three districts within Metropolitan Toronto for each month from January 1977 through November 1985. These prices were used to construct a housing price index, using 1981 as the base year. The sale price for each of the individual sales in the file was then converted to 1981 dollars by division by the index value for the month, year, and location of the actual sale.

Several other variables were also added to the data file. Noise data for each site, used in these and later calculations, were obtained from Soren Pedersen of the Highway Design Office of MTC, who generated the values appropriate to each site by using the noise prediction model STAMINA 2.0. In all, 107 observations were available for this analysis.

Two regressions were run to identify the dollar-per-decibel effect. The first used the original sale price as a proxy for the housing characteristics; the second excluded that variable. Results for the two runs are shown in Table 1. The first result to note is that the coefficient of sound is consistent between the two runs: noise is valued at about –\$466/dB to –\$486/dB. This coefficient is significant in both cases at the 5 percent level, but the sample is small. With a larger sample, one might expect this to be significant at more stringent acceptance levels. This value is reasonably close to that found by Taylor et al. *(1)* of –\$312/dB at expressway sites. The difference between that value and the new one may be due either to the variation still present in the current small sample (standard errors of the regression coefficients are about 270) or to general inflation. Taylor's values are in 1977 constant dollars; the ones in this paper are in 1981 dollars. Applying the price index value from June 1977 to Taylor's results would bring them to –\$505/dB in 1981 dollars, which is remarkably close to the current results.

However, inspection of the coefficients of the other variables suggests that this particular regression is not the strongest one possible. The coefficients of Toronto West and "detached house" change substantially when "original price" is excluded from the equation, suggesting that original price is correlated with these other variables. The simple correlation matrix confirms this. Although the original price acts to some extent as a proxy for housing characteristics, it is at best an imperfect measure for this purpose, because variation in this variable is due to several factors, including inflation. Because the housing price index does not go back as far as these original sales, many of which took place in the early 1960s, it is not possible to standardize the original price variable to the 1981 base. Although the effects of inflation are removed from the variable on the left-hand side in the regressions, these effects are presented in the original price variable on the right-hand side. Thus, these results with original price, though quite suggestive, argue strongly for expansion of the data set to include a complete set of housing characteristics.

The secondary question for consideration here is whether the noise effect is linear or nonlinear in decibels. There was some indication by Taylor et al. of a threshold noise level below which a noise discount was not found. It seems plausible to expect people to put a larger (negative) dollar value on noise at high levels than at low ones, and it is reasonable to suppose also that levels below 55 dB are not likely to engender may negative reactions or negative pricing. The foregoing analysis implicitly assumes that the same dollar penalty is placed on a 5-dB noise increment at 70 dB as at 50 dB. Four additional regression runs were carried out to consider other possibilities.

The first two of these were based on a suggestion by Eldred *(6)* that the integral over time of the total sound pressure experienced, measured in Pascal-squared seconds, may better reflect individual reaction to noise than a measure based on a logarithmic scale. Eldred's measure contains the assumption that changes in the squared pressure rather than changes in

TABLE 1 RESULTS OF ANALYSIS TO FIND DOLLAR-PER-DECIBEL VALUE: MTC DATA SET

	Including Original Price			Not Including Original Price		
Variable	Regression Coefficient	Std. Error	t value	Regression Coefficient	Std. Error	t value
Original Price	1.90	0.769	2.48	-	-	-
Sound Level	-486.2	267.0	-1.82	-466.0	273.0	-1.70
Lot Area	1.50	1.45	1.03	2.73	1.40	1.95
Toronto Centre	5917.0	3755.0	1.58	6415.0	3845.0	1.67
Toronto West	-10950.0	9739.0	-1.12	-29440.00	6412.0	-4.59
Detached House	10320.0	9607.0	1.07	27780.0	6690.0	4.15
Interest Rate	-39.03	390.0	-0.10	37.42	398.5	0.09
Constant	79890.0	22380.0	3.57	101600.0	21110.0	4.81

decibels are valued equally. For example, moving from 50 to 55 dB would be reflected in a move from roughly 3 to roughly 10 $Pa^2 \cdot sec$, or an increase of 7 $Pa^2 \cdot sec$. An increase from 70 to 75 dB would be reflected in this measure in an increase of 680 $Pa^2 \cdot sec$ (from 320 to 1,000 $Pa^2 \cdot sec$). Clearly the implication is that a given decibel increment at higher decibel values will be evaluated much more severely on this scale than on the logarithmic decibel scale if the coefficient of this variable is significant.

The results appearing in Table 2 for this analysis are not encouraging. Without the original price variable in the equation, Eldred's measure is not significant at any conventional level. Even when original price is included, the *t*-statistic of the coefficient of sound (–1.34) is still not very close to conventional acceptance levels. On the basis of these data, it appears that house prices are more closely related to decibel measures of sound than to measures based on the total sound pressure experienced.

A second procedure to identify nonlinearity involved use of a set of dummy variables to characterize the sound levels in place of the actual decibel value. Intervals of 3 dB were used, starting at 55 dB and going up to 73 dB. The results (Table 3) suggest that there are some anomalies in this small data set that may be producing misleading results. In particular, the coefficients of the noise variable set in this sample do not show a sensible progression, in that people in this sample are willing to pay more, other things being equal, for a home in the noisiest category than for one a bit quieter. This finding is questionable because only 5 of the 107 sales in the sample are in this noisiest group. The procedure itself, however, has some promise for uncovering nonlinearities in the house price effect of highway noise, as shown by the shift from positive to negative valuations at 60 dB. The current sample is not, however, appropriate to uncover this effect completely.

DATA FROM TORONTO REAL ESTATE BOARD

The Toronto Real Estate Board keeps as part of the historical record of sales a copy of the original Multiple Listing Service (MLS) card on the sale. Thus there is a brief verbal description of key features of the house, as well as a summary of the most relevant characteristics. A university student was hired to collect and code information from that source to be entered into the computer for analysis. Some of the sales in the MTC Property Office file could not be retained in this new data set because they were not carried on the MLS files, and therefore the detailed housing characteristics were not available. On the other hand, because the MLS records spanned a number of years not covered in the MTC studies, there were many more sales for the three sites in the multiple-listing files than were contained in the Property Office reports; thus there is a much larger data base for this analysis. The complete sample based on the Toronto Real Estate Board data acquisition contains 394 observations, of which 136 are from the Highway 427 site, 103 are from the Highway 401 and Leslie Street site, and 155 are from the Highway 401 and Victoria Park site.

The complete list of variables used for the regressions is shown in Table 4. As is clear from this list, the Toronto Real Estate Board sample permits regression estimation of noise

TABLE 2 REGRESSION RESULTS FOR PASCAL-SQUARED SECONDS (ELDRED): MTC DATA SET

	Including Original Price			Not Including Original Price		
Variable	Regression Coefficient	Std. Error	t value	Regression Coefficient	Std. Error	t value
Original Price	1.90	0.78	2.48	-	-	-
Eldred Measure	-0.000394	0.0003	-1.34	-0.00037	0.0003	-1.23
Lot Area	1.53	1.46	1.05	2.75	1.41	1.95
Toronto Centre	6571.0	3750.0	1.75	7048.0	3837.0	1.84
Toronto West	-9931.00	9806.0	-1.01	-28390.0	6424.0	-4.42
Detached House	10856.0	9669.0	1.12	28240.0	6724.0	4.20
Interest Rate	-35.30	388.0	0.09	109.0	397.0	0.28
Constant	48350.0	13100.0	3.69	71260.0	9397.0	7.58

TABLE 3 DUMMY-VARIABLE REGRESSION FOR NOISE LEVELS: MTC DATA SET

	Including Original Price			Not Including Original Price		
Variable	Regression Coefficient	Std. Error	t value	Regression Coefficient	Std. Error	t value
Original Price	1.68	0.79	2.12	-	-	-
Noise Levels:						
58-60.9	2856.0	4177.0	0.68	4783.0	4150.0	1.15
61-63.9	-4087.0	3872.0	-1.06	-3536.0	3933.0	-0.90
64-66.9	-3010.0	4122.0	-0.73	-2671.0	4193.0	-0.64
67-69.9	-6251.0	3761.0	-1.66	-5569.0	3814.0	-1.46
70-72.9	-1565.0	5914.0	-0.27	-100.0	5979.0	-0.02
Toronto Centre	5856.0	4290.0	1.36	5769.0	4367.0	1.32
Lot Area	1.40	1.50	0.93	2.45	1.44	1.70
Toronto West	-11627.0	10222.0	-1.14	-27550.0	7052.0	-3.91
Detached House	10877.0	9965.0	1.09	25720.0	7214.0	3.56
Interest Rate	-152.6	400.0	-0.38	-105.9	407.0	-0.26
Constant	57230.0	14152.0	4.04	77640.0	10550.0	7.36

TABLE 5 REGRESSION COEFFICIENTS FOR FUNCTIONS CONTAINING 24-HR L_{eq} USING ALL 21 VARIABLES FOR THE VICTORIA PARK SITE (N = 155)

Independent variables	Regression coefficient	t-statistic
24-hour L_{eq}	-312.11	-1.68
constant term	93828.00	7.46
1-storey semi-detached	-11834.00	-4.92
2-storey detached	25461.00	6.82
1-car garage	6844.00	3.85
swimming pool	6096.00	3.40
number of rooms	1357.00	1.73
number of bedrooms	1393.00	1.03
mortgage interest rate	257.00	0.98
partly finished basemt	-2792.00	-1.48
number of bathrooms	1984.00	1.17
number of fireplaces	1491.00	0.71
finished basement	-1383.00	-0.78
2-car garage	3343.00	0.80
carport	1253.00	0.71
no. of additional apts	-1920.00	-0.53
shared driveway	1020.00	0.41
2-storey semi-detached	1161.00	0.20
no. of appliances incl	-68.00	-0.18
lot size	-0.0664	-0.11
central air condition	-58.00	-0.04

The adjusted R-squared for the equation is 0.6416

Notes: The implied base case for the regression is a 1-storey detached house with an unfinished basement and a private driveway.

The value of t required for significance at the 5% level for a one-tailed test is 1.645, and for the 1% level is 2.326

its mean for the full sample as shown in Table 4, namely, a 60-dB noise level, a 5,300-ft² lot, seven rooms, 1.5 bathrooms, three bedrooms, one appliance included, and an interest rate of 14.1 percent):

$$\begin{aligned}\text{Price} &= 93{,}828 - 312 * 60 - 0.06639 * 5{,}300 + 1{,}357 * 7\\ &\quad + 1{,}984 * 1.5 + 1{,}393 * 3 - 68 * 1 + 257 * 14.1\\ &= \$94{,}966\end{aligned}$$

This example is a reasonable indication of the nature of the equation. One drawback, however, is that some of the coefficients are not statistically significant in that equation (see Table 5). For example, the coefficient of lot size, −0.06639, has a negative sign, which is contrary to expectations, although it is not significantly different from zero. More important, in some equations, the noise variable itself does not have a significant coefficient. Consequently, it has been chosen to report results based on the equations with all variables entered, as indicated by the result in Table 5. Table 5, however, is the only one that will show all the coefficients. Subsequent discussion will be focused solely on coefficients for the noise variables from similar equations. These coefficients for all four data sets are summarized in Table 6 for three of the noise variables and in Table 7, which describes results for the threshold functions.

The results in Table 6 for all three noise variables for the Victoria Park site are relatively easy to interpret. The 24-hr L_{eq} is significant at the 5 percent confidence level, and its coefficient indicates that each additional decibel reduces the price of a house by, on average, $312.

It is important to be aware that a single coefficient, particularly the one on decibels, cannot be interpreted in isolation. In particular, it is not correct to say from this result that locating a house in a 60-dB neighborhood reduces the selling price by $18,700. The correct interpretation, and the important result of this analysis, is that within the range of data available at this site (roughly 55 to 70 dB, 24-hr L_{eq}), each added decibel decreases house prices by roughly $312. Given that the average house price in the area is $87,187 (in constant 1981 dollars), this translates to a change of 0.35 percent of the house price per decibel. The large product obtained when number of decibels is multiplied by this coefficient also explains the large constant term in the equation.

The second variable used to represent noise is Eldred's measure. This variable is also significant at the 5 percent level. The change in magnitude of the estimated coefficient is a function of the different scale of the underlying noise variable, as discussed earlier. When translated back to its decibel equivalent, this measure gives a nonlinear shape for the relationship.

TABLE 4 VARIABLES USED IN ANALYSIS OF TORONTO REAL ESTATE BOARD DATA AND POOLED SAMPLE CHARACTERISTICS (N = 394)

CATEGORIES, REPRESENTED BY BINARY VARIABLES	percentage of sample in each category
Location in the city:	
West (near Hwy 427)	34.5%
Central (Leslie St)	26.1%
East (Victoria Park)	39.3%
Dwelling type:	
one-storey detached	44.4%
two-storey detached	14.0%
one-storey semi-detached	41.1%
two-storey semi-detached	0.5%
Driveway type	
private	97.0%
shared	3.0%
Size of garage	
single-car	25.9%
two-car	14.7%
carport	10.7%
no garage	48.7%
Basement condition	
finished	51.8%
partly finished	33.2%
unfinished	14.2%
Presence of central air conditioning	24.9%
Presence of a swimming pool	14.5%
VARIABLES MEASURED ON RATIO SCALE	mean value in sample
Number of rooms	6.89
Number of bedrooms	3.38
Number of bathrooms	1.64
Number of fireplaces	0.22
Number of appliances included	1.43
Number of additional apartments in the house	0.04
Lot size (sq. ft.)	5307.
Recent sale price (constant 1981 $)	102476.
VARIABLES OBTAINED ELSEWHERE	mean value in sample
Calculated sound level at house (dB, 24-h L_{eq})	60.3
Presence of a barrier (absent at most Etobicoke sales)	69.3%
Price index for housing sales (1981 = 100)	0.9517
Interest rate on 5-yr mortgages at time of sale	14.1%

effects while an extensive set of characteristics likely to influence house prices is held constant.

As with the MTC Property Office data set, three measures of noise are used: the 24-hr L_{eq}, Eldred's proposal, and a set of dummy variables. Each one is used in a separate regression equation. As an additional test of whether nonlinear functions of noise might be appropriate, equations are estimated by using a noise variable computed as the difference (in decibels) between the measured level and a threshold level.

The discussion, then, covers four ways of treating the noise variables and involves estimation across four data sets: the Victoria Park Avenue, Etobicoke, and Leslie Street sites, plus the pooled set consisting of all of these. Each of the three sites will be discussed separately and then the pooled results will be considered.

Victoria Park Site

The Victoria Park or Toronto East site has the largest number of observations (155). The complete equation based on 24-hr L_{eq} is shown in Table 5. The implied base case for these estimates is a one-story detached house with an unfinished basement, no air conditioning, no pool, and a private driveway but no garage. For such a house, the equation using the decibel measure yields an estimated selling price (in 1981 dollars) as follows (assuming that each of the other relevant variables had a value close to

TABLE 6 REGRESSION COEFFICIENTS OF NOISE BY AREAS IN TORONTO

Noise measure		Victoria Park site	Etobicoke site	Leslie Street site	Pooled sample
24 hour L_{eq}		-312.11	-356.00	-2970.67	-775.26
		(-1.68)	(-2.36)	(-2.30)	(-3.28)
Pascal-squared seconds		-23.06	-12.33	-99.45	-27.34
		(-1.96)	(2.21)	(-2.05)	(-2.67)
Intervals:	58-60	1816.00	-6809.00	base	1648.00
		(1.072)	(-3.05)	case	(0.59)
	61-63	451.00	1583.00	-18208.00	-6634.00
		(0.16)	(0.68)	(-1.77)	(-1.92)
	64-66	54.00	-5889.00	-7208.00	-4453.00
		(0.03)	(-1.77)	(-0.37)	(-1.23)
	67-69	-3384.00	-3660.00	-20107.00	-9222.00
		(-1.31)	(-1.49)	(-1.69)	(-2.54)
	70-72	zero	-9060.00	-34386.00	-9857.00
		observatns	(-2.19)	(-1.52)	(-1.30)
Sample Size		155	136	103	394

t-values in parentheses

The critical values of t are 1.645 for the .05 level and 2.326 for the .01 level.

This figure led to an attempt at quadratic functions of the 24-hr L_{eq}, which were not supported by the data, as well as the threshold functions reported in Table 7. Not only does the pressure-squared measure produce a nonlinear function (which it should by the very nature of the variable), but also the set of dummy variables representing noise intervals constitutes an approximation to a nonlinear function.

The interval results also suggest some peculiarities of these data at the Victoria Park site, which stand out very clearly in Figure 1 as well as in Table 6. In particular, at one level, an increase in the noise level is associated with an increase in the selling price of the house: moving from levels in the 55- to 57-dB range to levels in the 58- to 60-dB range adds $1,816 to the selling price. However, none of the coefficients for the intervals is statistically significant.

The fourth treatment of the noise variable was by way of a series of regression equations, using a threshold function for noise. The noise variable was defined as

$$x = 0 \qquad \text{for } dB < T$$
$$x = dB - T \qquad \text{for } dB > T$$

where T is the threshold. Values of the threshold T from 55 to 65 dB were used in steps of 1 dB. These results (Table 7) can be interpreted in two ways. The first is to note that there is very little difference in the adjusted R^2 for any of the equations. Hence an argument could be made that a threshold function is not necessary and offers little improvement over a linear function. The second interpretation focuses on the changes that do occur (in the third and fourth decimal places of the adjusted R^2 and in the t-statistic). In this view, the best threshold for the Victoria Park site is 65 dB, and above that level, additional noise is valued at –$1,804/dB. Selection from among regression equations on the basis of differences in R^2, however, normally requires differences greater than this, and so the first view is probably correct. There is no evidence from these data that nonlinear functions are needed.

Etobicoke Site

The results for the Etobicoke site appearing in Table 6 are largely similar to those just discussed for three of the treatments of the noise variable. The coefficient of 24-hr L_{eq} is –$356/dB, about $40 lower than for the Victoria Park site, but quite comparable. The coefficient of Eldred's measure is significant, although smaller than before. The threshold functions again show a change only in the third decimal place of the adjusted R^2. This time if one were to selected the highest R^2, a threshold of 56 dB would appear to be best. Hence the conjunction of the results for the two sites supports the notion that [illegible] threshold function is not warranted.

For the set of dummy variables representing noise intervals, however, there is a difference in these results, in that three of the coefficients are significant. The problem of increasing house prices in noisier areas is still present, however—this time for two steps: that from 58–60 dB to 61–63 dB and again in the move from 64–66 dB to 67–69 dB. The anomalous coefficients are not significant, however, and so this may be a problem because of a relatively small sample with a nonrepresentative distribution of prices across the range of noise levels.

Leslie Street Site

The results for the Leslie Street site are quite different from those for the two previous sites. For example, the coefficients of 24-hr L_{eq} and Pascal-squared seconds are roughly an order of

TABLE 7 THRESHOLD CALCULATIONS FOR THE FOUR DATA SETS

Threshold Level, dB	Regression Coefficient ($/dB)	t-statistic	adjusted R-squared
Victoria Park Site			
56	-312	-1.68	.6416
57	-330	-1.83	.6430
58	-349	-1.82	.6428
59	-369	-1.72	.6420
60	-429	-1.75	.6422
61	-524	-1.80	.6427
62	-658	-1.87	.6433
63	-883	-1.96	.6442
64	-1172	-1.93	.6440
65	-1804	-2.07	.6454
Etobicoke			
56	-342	-2.19	.3845
57	-342	-2.03	.3805
58	-350	-1.93	.3797
59	-360	-1.81	.3786
60	-365	-1.67	.3771
61	-403	-1.67	.3770
62	-472	-1.75	.3783
63	-577	-1.88	.3807
64	-660	-1.88	.3805
65	-775	-1.87	.3803
Leslie St. site			
56	-2971	-2.31	.6636
57	-2971	-2.31	.6636
58	-2971	-2.31	.6636
59	-2971	-2.31	.6636
60	-3056	-2.09	.6599
61	-3387	-2.04	.6591
62	-3658	-1.73	.6545
63	-4160	-1.75	.6548
64	-5391	-1.79	.6554
65	-7220	-1.79	.6533
Pooled Sample			
55	-757	-3.23	0.7540
56	-803	-3.24	0.7543
57	-837	-3.35	0.7545
58	-913	-3.43	0.7549
59	-1090	-3.86	0.7569
60	-1148	-3.60	0.7556
61	-1219	-3.36	0.7546
62	-1242	-2.96	0.7529
63	-1409	-2.83	0.7524
64	-1581	-2.61	0.7517
65	-1855	-2.45	0.7511

Notes: The noise variable used in the regression was defined to be zero if less than or equal to the value shown in the left hand column, and (L-threshold) if greater.

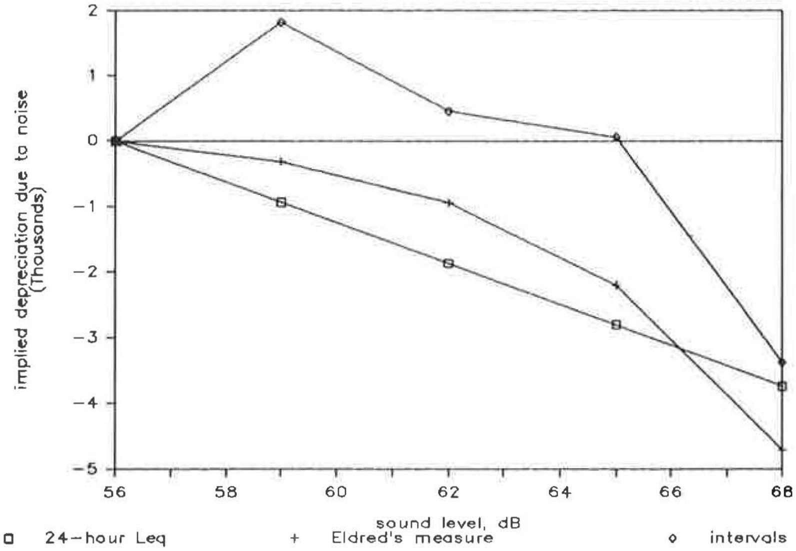

FIGURE 1 House-price effect relative to 55 dB.

magnitude larger than the earlier ones. Likewise the results for the dummy variables and for the threshold functions show much larger coefficients, although otherwise they support the same conclusions as did results for the two previous sites. The question that needs to be addressed is why the coefficients are so much larger at the Leslie Street site.

The first approach attempted was to look for something different about the Leslie Street site. Three possibilities were considered, arising from the fact that noise is highly correlated with distance from the roadway, and that therefore the coefficient of the noise variable may be biased by the omission of some other correlate of housing price in this area that is also related to distance from the road.

The first possibility is that the important difference is in the type of barrier built at the site. The barrier at the Leslie Street site is of green metal, whereas the other two sites have concrete barriers. If such a barrier is deemed to be unpleasant, there may well be a property value effect based on living with it in the backyard as opposed to simply being able to see it as opposed to not being able to see it. This explanation seems unlikely, however.

A second possibility draws on an unusual aspect of the topography at the site. For about half the length of the site, measured along the expressway, the roadway is elevated relative to the housing. Consequently, the barrier is exceedingly high in some of the backyards, and is very dominant visually. It may well be this "Great Wall" effect rather than the green metal barrier material that is leading to the difference, but in the same way just explained for the first possibility.

The third possibility is also based on this unusual topography. The prices for the houses closest to the roadway may reflect some kind of fear of the traffic on the elevated roadway on the part of buyers or prospective buyers and of the prospect of damage or injury from vehicles leaving the road. The prices would then reflect a risk discount in addition to a noise discount.

To test these last two possible explanations, the site was revisited and the exact addresses of the houses that experience this Great Wall effect were recorded with the intention of adding a dummy variable to the analysis to represent it. To the authors' considerable surprise, none of the houses with the "Great Wall" in their backyard was represented in the data file. Therefore, the second and third possibilities can be rejected as irrelevant, and only the first one remains. The only site-related difference identified was the difference in the type of barrier.

There is, however, a second answer to the question of how this difference between areas may arise. There is the possibility that the result is simple a statistical anomaly. There is some tentative support for this view. It can be seen in Table 8 that the sample for the Leslie Street site contains very few observations at high noise levels—only 2 in the 70- to 72-dB range; 11 in the 67- to 69-dB range, and only 2 in the 64- to 66-dB range. Sixty-six percent of the observations fall in the 58- to 60-dB range. These features of the sample raise serious questions about the representativeness of the sample to the population of house prices; a few unusual house prices at high noise levels could easily bias the coefficient of the noise variable.

To further investigate this explanation, the noisiest houses were deleted from the central Toronto sample, and the analyses were rerun. The results are surprising. When all houses experiencing levels of 67 dB or above were deleted, the regression coefficient of 24-hr L_{eq} dropped sharply (and became nonsignificant). This suggests some unusual behavior in the joint distribution of noise levels and house prices, which is shown for the Leslie Street sample in Table 8 and Figure 2, examination of which reveals that at this site the more expensive houses are located in quieter environments. For the 13 data points at noise levels of 67 dB and above, the highest house price (in 1981 constant dollars) is $152,500. Forty-two homes in this sample have higher constant-dollar values (ranging up to $272,000) and all of these are at noise levels below 64 dB. To the extent that higher-valued houses exist at the higher noise levels, this particular sample may be nonrepresentative of the population joint distribution of house prices and noise levels, and thus noise coefficient estimates based on this sample may be seriously biased.

TABLE 8 HOUSE-PRICE AND NOISE-LEVEL DISTRIBUTION FOR LESLIE STREET SITE

	All obs. at site	50K-100K	100K-150K	150K and Up
52-54.9 dB	0	0	0	0
55-57.9 dB	0	0	0	0
58-60.9 dB	68	11	17	40
61-63.9 dB	20	13	5	2
64-66.9 dB	2	1	1	0
67-69.9 dB	11	6	4	1
70-72.9 dB	2	1	1	0
Sample size	103	32	28	43

Note: Values are expressed as frequencies.

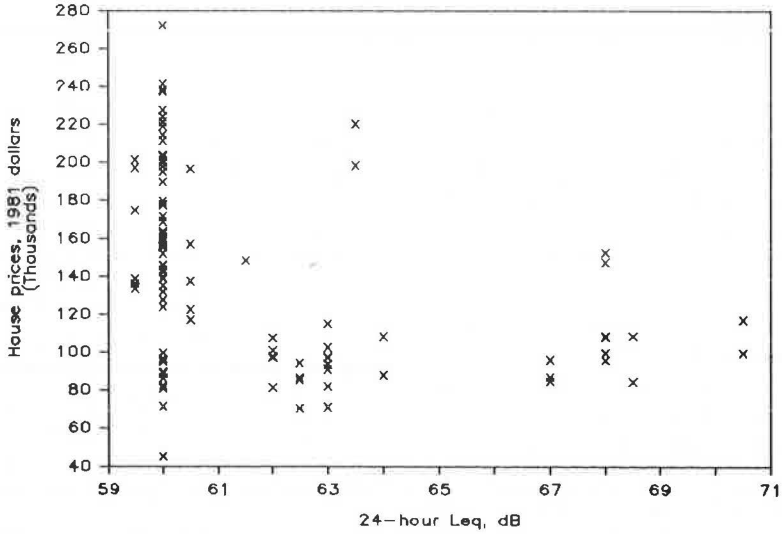

FIGURE 2 Leslie Street data.

Given the scale of Figure 2, a population $350/dB noise penalty would be consistent with a population regression function with only a slight negative tilt from the horizontal, to reflect a drop of $4,550 over the 13-dB range from 59 to 72 dB in the Leslie Street sample. It is clear from the scatter, however, that an estimated regression line through these data points will have a much steeper slope than this, because, except for outliers at 64 dB, all of the remaining observations at noise levels of 61 dB and above occur at house prices below $153,000, with the majority at prices of less than $120,000. These features lead to the much higher noise penalty (almost $3,000/dB) than was found at the Etobicoke and Victoria Park sites. It is easy to see in Figure 2 that discarding the high noise observation (at or above 67 dB) only leads to a steeper negative relationship between house prices and noise levels, as was observed in the calculations. Accordingly, the results for the Leslie Street site should be viewed with skepticism.

Pooled Sample

These remarks about the joint distribution of house prices and noise levels for the Leslie Street site also call into question the representativeness of the results estimated for the pooled sample, for example, the coefficient of –$775/dB for 24-hr L_{eq} (Table 6). It is clear that the Leslie Street sample is the source of the difficulty, because it contains all but one of the high-valued homes, all but one of which have low noise levels. Because the Leslie Street sample forms part of the pooled sample, any bias in the noise effect at that site due to nonrepresentativeness of the sample will be built into the pooled sample noise coefficient; if the Leslie Street sample is nonrepresentative, the value of –$775/dB simply cannot be generalized to the population as a whole. The same reasoning applies to the other pooled sample coefficients for noise variables in Tables 6 and 7. Basically, because of the nature of the sample at the Leslie Street site, any results that incorporate those data are probably suspect. With a different sample design, this problem might be eliminated. However, given the fact that the sample was not (and could not have been) designed to maximize the variation in the noise levels, or to have representative numbers of observations at each of the several noise levels, it is unavoidable to have problems of this kind, which can strongly affect the results. In the pooled sample only 30 percent of the observations occur in the noisiest four of the seven noise-level categories. This is, of course, to be expected, given the way sound propagates (with equal reductions per doubling of distance, rather than for equal increases of distance away from the source). However, it makes estimating regression coefficients difficult, particularly when housing prices are distributed irregularly as well.

CONCLUSIONS

Two main questions were identified for this paper. Is the dollar-per-decibel value found in other studies of highway noise property values also found at sites with noise barriers? And is it correct to consider property value effects as a linear function of noise? Unfortunately, this study has not been able to provide unequivocal answers to those questions. The general indication is that the results for housing sales behind barriers are consistent with those of other studies, but there are some differences. Linear functions of noise level perform as well as any other function, but one of the nonlinear approaches also performed well.

The main question was whether the dollar-per-decibel effect at locations with noise barriers is consistent with the effect at sites without barriers. The bases for this comparison were described briefly in the introduction to the paper: studies done in the United States summarized by Nelson *(2)*, which reported results in terms of percent change in house price for a 1-dB change in noise level; and the study by Taylor et al. *(1)* conducted in the Toronto area, which reported results in a dollar-per-decibel format. (For the comparison, only the decibel noise measure from this study is appropriate; the other nonlinear measures were not used in the previous studies.)

The various studies reported by Nelson showed effects of noise on house price that ranged from 0.20 to 2.22 percent/dB, with the great bulk of them being between 0.2 and 1.0 percent/dB. Pooled sample estimates varied from 0.25 percent/dB for two studies to 0.8 percent/dB. For the Property Office data set, the results showed a change, on average, of 0.52 percent/dB. For the Real Estate Board data, the changes were 0.335 percent/dB in Victoria Park, 2.10 percent/dB at Leslie Street, 0.39 percent/dB in Etobicoke, and 0.76 percent/dB for the pooled sample. These are broadly consistent, even to having one outlier at a value above 2.0 percent/dB.

Results based on the MTC Property Office data set showed a dollar-per-decibel value of –$466 or –$486. This compared very favorably with the results of Taylor et al. of –$505/dB (in 1981 dollars). The results from the more detailed Toronto Real Estate Board data set are not so close to the Taylor results: dollar-per-decibel values range from –$312 in the Victoria Park sample to –$2,971 at the Leslie Street site, with a pooled sample estimate of –$775 (in 1981 dollars). This is 50 percent higher than in the Taylor study, yet without the Leslie Street data, it appears as though these results would be only about 60 percent of the Taylor (and Property Office data) results.

This leads to some interesting speculation. With coarse data (the MTC Property Office set, lacking housing characteristics), the dollar-per-decibel results for noise barriers are broadly consistent with those of other studies. With more complete data, the new results are generally lower (ignoring the unusual data for the Leslie Street site). If the lower estimate for the noise barrier sites is accepted, this may be partial evidence in favor of a nonlinear function between noise levels and house prices. The Taylor et al. result came from locations where the highest noise levels experienced were all above 70 dB. For the two sites whose results are accepted in this study, only 4 of the 291 observations were at levels above 70 dB. Alternatively, these results may be viewed as partial evidence for the proposition that the noise penalty is lower at barrier sites than at sites without barriers; that is, barriers do matter. However, that must remain speculation; the data are certainly inadequate to provide a clear test of that suggestion.

The overall conclusion is that the results from these analyses are generally consistent with the earlier studies of the house-price effects of road traffic noise. This means that noise barriers appear to be fully effective in improving the aural environment, at least as perceptions of that characteristic are reflected in housing prices.

ACKNOWLEDGMENTS

The support of the Ontario Ministry of Transportation and Communications, through the Ontario Joint Transportation and Communications Research Program, is gratefully acknowledged. In addition, thanks are due to several individuals who contributed in a number of ways to this project. Jennifer Britney spent a number of days in the offices of the Toronto Real Estate Board collecting data kindly provided by Nick Munaretto, whose cooperation was most appreciated. Soren Pedersen of MTC provided the noise estimates. Helpful discussions with MTC staff, including Fred Jung, Aleksandr Kazakov, Soren Pedersen, and Chris Blaney, were much appreciated.

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Publication of this paper sponsored by Committee on Transportation-Related Noise and Vibration.

Control of Airport- and Aircraft-Related Noise in the United States

CLIFFORD R. BRAGDON

Regulatory control of aircraft noise in the airport community environment is becoming increasingly common. Such controls are being applied to both civilian and military activities. These controls apply to two aspects of the noise problem: operational control of aircraft, both fixed and rotary wing, and land use controls around airports enacted by communities potentially affected by aircraft. A summary is given of the status of airport noise regulations enacted by municipalities (i.e., cities, counties) within the United States. To date, 2,000 municipalities have been inventoried in terms of existing noise controls that have land use implications. In addition, more than 200 airports have been evaluated regarding applicable operational and land use controls that are now in effect. The results of this analysis will be a discussion of 28 categories of noise control measures, categorized primarily in terms of operational and land use controls. Emphasis will be on describing these noise-control-related techniques and where they are being applied (i.e., case-study method), but not on their legal or political standing.

Aircraft-related noise is recognized as a primary noise source within airport communities. It is estimated that there are approximately 5,000,000 residents in the vicinity of civilian airports affected by aircraft noise where the annual day-night average sound level (DNL) is 65 or greater *(1)*. Although it appears that there may be a possible decline in the total population exposed to aircraft-related noise in the future, the effect on the airport community will not be eliminated. Major advances are being made to reduce this exposed population, including operational and land use controls.

These noise control efforts involve both civilian and military airport environments. The problem of airport noise was documented as a national concern by the Doolittle Commission report, *The Airport and Its Neighbors (2)*. Prepared for President Truman in 1952, the report identified conflict between airport noise and community land use as a future national problem. It was the military that first responded to the problem: the U.S. Air Force initiated a noise program in 1962 for ensuring compatible land development for their airfield operations. This subsequently evolved into the Airport Installation Compatible Use Zones (AICUZ) program *(3)*.

The U.S. Air Force, Navy, and Marine Corps began AICUZ planning at each of their installations in 1973. In 1982 the U.S. Army joined this process and has expanded the concept by requiring such planning around each army installation generating any type of noise, including airfields *(4)*. This is referred to as the Installation Compatible Use Zone (ICUZ) program and such studies are being initiated at most army bases.

Although its program was initiated after that of the Department of Defense, the Federal Aviation Administration (FAA) has taken a very active role regarding civilian aircraft and airports. Aircraft noise has been reduced by the enactment of Federal Aviation Regulation (FAR) Part 36, Aircraft Noise Certification *(5)*. This regulation applies to aircraft on the basis of gross weight, with maximum permissible noise limits measured at three distinct locations. The initiation of FAR Part 150, Airport Noise Compatibility Planning, is beginning to have a positive influence on airport community noise impact and planning *(6)*. Today there are more than 75 studies under way funded by the FAA that involve operational and land use compatibility planning for civilian airports.

The focus of all these effects has not been only at the federal level. Historically, significant interest has been expressed by municipal and state governments. Currently there are approximately 1,900 municipal and 26 state noise control laws in existence *(7,8)*. Many of these relate to specific airports or to the control of land surrounding airports, both civilian and military. These laws, with acoustical limits, involve a variety of controls, as summarized in Figures 1 and 2.

There is an increasing interest in the regulation of noise around airports. These measures involve operational control of aircraft, as well as land use controls. A survey of 402 airports has been analyzed to determine the characteristics of these noise control measures *(9,10)*. This information was gathered from a variety of sources and involves civilian-operated airports that include air carrier and general aviation facilities.

OPERATIONAL NOISE CONTROL MEASURES

Several approaches for operationally controlling aircraft have been instituted at civilian airports. These measures are summarized by rank order in Table 1. A wide range and number of operational noise measures are being used at these airports. The following a brief description of each measure.

Noise-Abatement Flight Tracks

The most common operational noise measure, use of noise-abatement flight tracks, involves arrival and departure patterns over the least-sensitive land use areas where feasible. Approach and departure procedures over bodies of water and agricultural or open-space corridors are usually designated (e.g., Los Angeles International Airport and Washington, D.C., National Airport).

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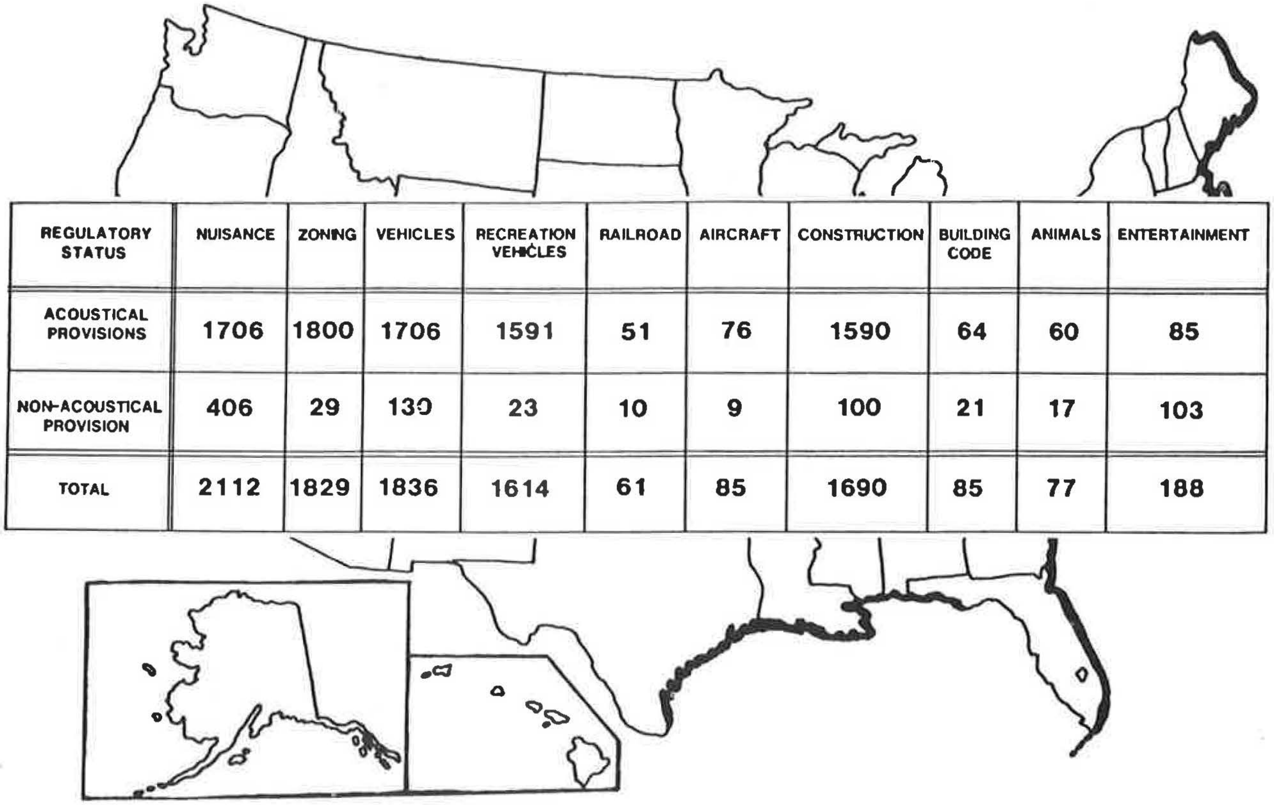
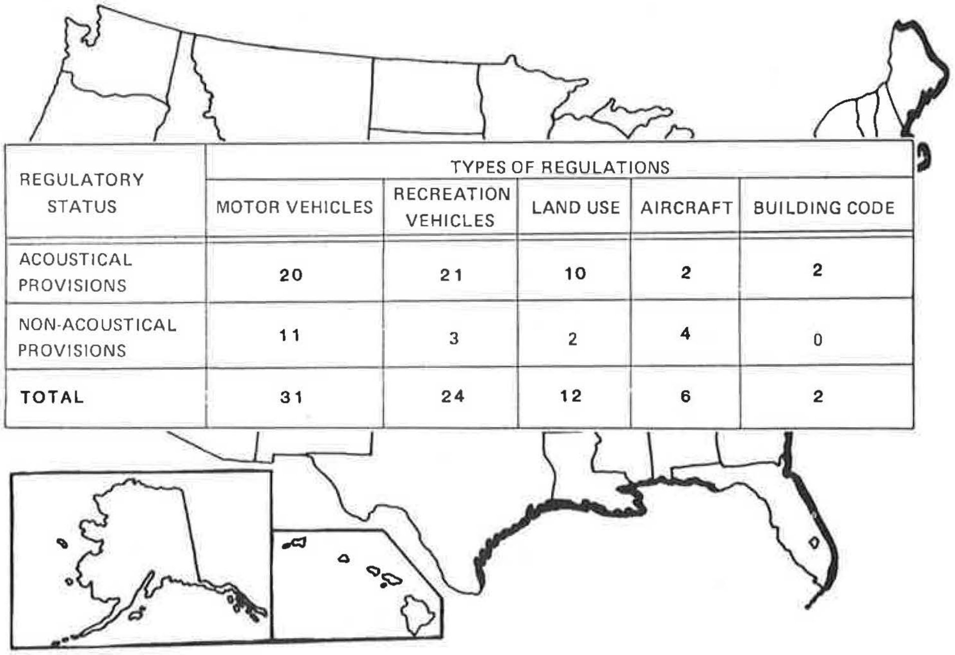


REGULATORY STATUS	NUISANCE	ZONING	VEHICLES	RECREATION VEHICLES	RAILROAD	AIRCRAFT	CONSTRUCTION	BUILDING CODE	ANIMALS	ENTERTAINMENT
ACOUSTICAL PROVISIONS	1706	1800	1706	1591	51	76	1590	64	60	85
NON-ACOUSTICAL PROVISION	406	29	130	23	10	9	100	21	17	103
TOTAL	2112	1829	1836	1614	61	85	1690	85	77	188

FIGURE 1 Municipal noise legislation: summary.



REGULATORY STATUS	TYPES OF REGULATIONS				
	MOTOR VEHICLES	RECREATION VEHICLES	LAND USE	AIRCRAFT	BUILDING CODE
ACOUSTICAL PROVISIONS	20	21	10	2	2
NON-ACOUSTICAL PROVISIONS	11	3	2	4	0
TOTAL	31	24	12	6	2

FIGURE 2 State noise legislation: summary.

TABLE 1 AIRPORT NOISE CONTROL STRATEGIES: OPERATIONAL

RANK ORDER	OPERATIONAL CONTROLS	AIRPORT COMMUNITIES NUMBER	PERCENT*
1	Preferential Runway	139	34.5
2	Ground Runup Restrictions	94	23.3
3	Flight Training Restrictions	81	20.1
4	Noise Abatement Flight Tracks	68	16.9
5	Noise Abatement Profiles	55	13.6
6	Aircraft Bans	42	10.4
7	Partial Curfew/Ban	41	10.1
8	Noise Monitoring	36	8.9
9	Slots	35	8.7
10	Noise Emission Levels	26	6.4
11	Displaced Landing Thresholds & Takeoff Points	24	5.9
12	Capacity Limits	6	1.4
13	Aircraft Towing	5	1.2
14	Curfews	4	0.9
15	Operational Fees	3	0.7

*Percent of Sample (402 Airports)

Ground Runup Restrictions

Restrictions are frequently applied to aircraft power checks when they are performed as part of ground runup maintenance. This noise measure usually involves a time-of-day restriction and noise emission and duration limit. Runup areas are generally designated and are often remote sites or are designed to minimize sound propagation with engineering and architectural control techniques.

Noise-Abatement Profiles

Frequently airports develop aircraft profiles based on the FAA recommended advisory circular or its equivalent. This may involve a three-segment departure procedure or a higher-than-minimum altitude until glide slope intercept occurs on arrival. Such procedures are adopted by an airline using FAA guidance to maximize height (altitude) from ground (land use) exposure.

Preferential Runways

Often an airport will specify a preferred runway to minimize aircraft flights over noise-sensitive areas. This applies particularly during nighttime conditions between 10:00 p.m. and 7:00 a.m. For example, at McCarran International Airport, Las Vegas, Nevada, crosswind Runway 25 is used whenever possible to minimize use of Runway 1R-19L.

Aircraft Bans and Curfews

Bans range from prohibiting all aircraft from operating during certain time periods to restrictions among types or categories of aircraft during certain times or in certain areas of the airport. In most cases, restrictions are involved rather than the absolute banning of aircraft on the basis of type, weight, manufacturer, category, occurrence, and so forth.

Slots and Capacity

A limitation on the number of aircraft operations that can be allowed within a specified time period, a passenger limit, or a limit on other airport services have been used, for example, at Islip Long Island MacArthur Airport using an index of total noise level.

Training Restrictions

Aircraft are frequently restricted from making practice takeoffs and landings. The restrictions may range from partial (e.g., allowed during certain times of the day) to complete. Accident potential has been dramatically increased when training flights are interspersed with air carrier (jet) operations.

Noise Emission Levels

Airport- or community-based single event or integrated noise levels may be applied to an individual aircraft operation or to the total number of operations over a specified time period. Noise caps, using an annual average, are now being applied to many commercial airports.

Displaced Landing

Aircraft are required to land at a point on the runway closer than the actual end, so that the approach trajectory, being steeper, will place aircraft higher above noise-sensitive land uses. The general concept sounds attractive; however, on the basis of the elevation and distance (e.g., runway length), there are only nominal acoustical benefits.

Aircraft Towing

Generally, aircraft engines may be shut off and the aircraft towed to a specified area of the airport for performing any runup-related activity, in compliance with runup provisions. Such procedures are more common at military installations than at civilian airports.

Operational Fee

A monetary fee may be applied to aircraft on the basis of their noise emission performance and time of operation. This is paid to the airport proprietor for noise abatement. Very few programs in the United States [e.g., Palm Beach International Airport (PBIA)] apply this technique as compared with those in Europe. Approximately $1 million a year will be collected from airlines at PBIA, all of which must be applied to noise abatement.

LAND USE NOISE CONTROL MEASURES

Off-airport control of land use for noise compatibility purposes is essential, especially for airport affected communities. Table 2 presents, in rank order, these land use measures. A brief description of each land use control technique is given in the following sections.

TABLE 2 AIRPORT NOISE CONTROL STRATEGIES: LAND USE

RANK ORDER	LAND USE CONTROLS	AIRPORT COMMUNITIES NUMBER	AIRPORT COMMUNITIES PERCENT*
1	Zoning	133	33.0
2	Comprehensive Plan	108	26.8
3	Land Acquisition	77	19.1
4	Avigational Easement	49	12.1
5	Noise Disclosure	34	8.4
6	Environmental Impact Review	33	8.2
7	Building Code	32	7.9
8	Capital Improvements	18	4.4
9	Sound Insulation	16	3.9
10	Development Rights	10	2.4
11	Site Design	9	2.2
12	Land Banking	7	1.7
13	Subdivision Regulations	6	1.4
14	Purchase Assurance	4	0.9
15	Tax Incentives	3	0.7

*Percent of Sample (402 Airports)

Zoning

Zoning is a form of power that enables governments to enact ordinances protecting the public health, safety, and welfare. Performance requirements specify noise limits by zoning-district classification.

Comprehensive Plan

The comprehensive plan, often referred to as the general or master plan, is usually an official public document adopted by a government projecting the future uses of land development.

Land Acquisition

A fee-simple purchase of incompatible land in the vicinity of an airport is an effective method for ensuring land compatibility.

Avigational Easement

An easement being the legal right for one property owner to use the land of another, an avigational easement allows the trespass of aircraft and their associated impact for an agreed-on price and time period.

Noise Disclosure

A noise disclosure informs the public or a prospective buyer, or both, of the existing or projected noise level on the subject property. A disclosure can be either advisory or regulatory.

Building Code

Building codes establish noise performance requirements typically associated with the building envelope, including minimum sound transmission requirements.

Capital Improvements

Public improvements for budgeting purposes can be examined in terms of noise generation and noise impact.

Sound Insulation

The application of sound control materials to a structure, including the building envelope, to reduce the transmission of sound around airports is common. Some 10 airports are now insulating nearly 2,500 residences.

Development Rights

Development rights to a property may be purchased and then transferred to another piece of property.

Site Design

In site design a review procedure is established whereby the environmental factors, including noise, are considered and solutions are integrated into a plat or land plan.

Land Banking

Land banking can be defined as a system in which a government acquires a substantial fraction of land in a region that is available for future development for the purpose of implementing a public land use policy.

Tax Incentives

Special or preferential tax assessment of land by a local government allows an owner of a piece of property to pay a lower or no property tax.

Subdivision Regulation

Subdivision regulations are the means by which a local government can ensure that proper lot layout, design, and improvements are made for a proposed residential development.

Environmental Impact Review

In environmental review, public-related projects are assessed that may have some potential impact on land use and the public interest.

CONCLUSION

There is a diversity of land and operational noise control techniques potential available. The application of these techniques depends many factors, including legal authority, financial consequences, degree of land use impact, and social and political conditions. These techniques represent three distinct methods for controlling noise: at the source, the path, and ultimately the receiver (person or property). Considerable progress is occurring in both the civilian and military sectors of airport planning and noise control. It appears that airport proprietors and their respective political jurisdictions must take the initiative to address airport-related community noise problems and solutions. Both military and civilian airports now have sufficient authority to proceed on the basis of current federal legislation.

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Publication of this paper sponsored by Committee on Transportation-Related Noise and Vibration.

A Traffic Assignment Model To Reduce Noise Annoyance in Urban Networks

JAN WILLEM HOUTMAN AND BEN H. IMMERS

The possibilities of reducing traffic noise annoyance in urban networks without reducing the total amount of automobile traffic are investigated. The basic idea is to reduce noise levels by influencing drivers' route choice. Possibilities to influence this choice were investigated by modifying an equilibrium assignment algorithm.

In the past few decades noise annoyance has become an increasing problem, especially in the Netherlands with its dense population. Therefore a law has come into force, *Wet Geluidhinder,* that specifies permissible noise levels under various circumstances. This study concerns road traffic *(1)*. Investigations have shown that the noise annoyance problem is most severe within towns, which restricts the possibilities for traffic engineers to solve the problem: noise barriers cannot be applied in the inner cities, for instance.

This study seeks to determine whether modified route choice might help to solve the noise problem. On roads with few houses, or with few houses close to the road, traffic flow should be increased in order to reduce the flow on roads where noise annoyance occurs or can be expected. Thus a comprehensive rather than an ad hoc approach is provided. This study involves unmodified fixed travel demand and an unmodified travel mode choice and is restricted to motor traffic.

Because the noise level is a logarithmic function of the flow, it is expected that the best solution will be created when most traffic is concentrated on a small number of main routes. However, it is also possible that a concentration of traffic on several routes combined with a diversion of oversaturated flows to low-density roads will be a feasible solution as well. The model to be discussed appears to support this hypothesis.

HOW TO MEASURE TRAFFIC NOISE

Noise can be quantified objectively in various ways:

- Noise level (in decibels)
- Loudness (in sones)
- Loudness level (in phons)
- Frequency characteristics (in Hertz)
- Interval time (in seconds)

Noise level is the most instructive, especially when it is A-weighted. This means that the measures are adapted to the way humans observe different frequencies.

In the Netherlands the equivalent noise level (L_{eq}) in A-weighted decibels is the most commonly applied measure. It smooths a fluctuating noise as follows:

$$L_{eq} = 10 \log \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2_{\text{eff}}}{p_0^2} \, dt \right) \quad (1)$$

where

p_{eff} = effective sound pressure,
p_0 = reference pressure,
$t_2 - t_1$ = observed time interval, and
L_{eq} = duration-sensitive noise level.

It should be pointed out, however, that such a noise level gives less representative values for nighttime traffic, when isolated cars pass by, than in steady flows.

Basically, traffic noise is a function of flow, traffic composition and speed, and the distance between the facade of the houses and the heart of the road (hereafter called the facade distance). In accordance with the current legal standards, trucks are subdivided into medium-heavy and heavy traffic according to certain criteria. Buses belong to the heavy-traffic category.

Unlike noise levels, noise annoyance is subjective. All kinds of personal characteristics influence a person's sense of annoyance. Nevertheless, investigations have shown a remarkable correspondence when the number of strongly annoyed persons is determined as a function of noise level.

An inquiry in Amsterdam resulted in the following relationship:

$$\text{Percentage of strongly annoyed persons} = 0.0038 * \exp(0.1143 * L_{eq}) \quad (2)$$

This means that a doubling of the traffic flow resulting in a 3-dB(A) increase of the noise level causes a 40 percent increase in the number of strongly annoyed people.

HOW TO MODEL THE NOISE PROBLEM

Background of the Problem

The model assumes the existence of an origin-destination (O-D) table for motor traffic, which means that it concentrates on route choice and assignment. Within optimization problems, a distinction can be made between user-optimizing and system-optimizing theories. Wardrop *(2–4)* formulated these two principles as follows:

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1. Travel costs on all the routes actually used are equal, and less than those that would be experienced by a single vehicle on any unused route, and
2. At equilibrium, the average journey cost is minimal.

These two optimums do not usually coincide.

Although the system equilibrium creates the most efficient traffic pattern for the community, it should be observed that it is an idealized target that will not be observed in practice without some form of enforcement.

Beckmann et al. *(5)* proved that this is equivalent to a convex minimization problem. Using the network concept proposed by Florian *(6)*, this can be written as

$$\min Z = \sum_a \int_0^{f_a} c_a(x)\, dx \tag{3}$$

where

Z = objective function,
f_a = flow on link a, and
c_a = average travel cost function for link a (in this paper a travel-time function).

Furthermore, the objective function Z should meet such conditions as positiveness, monotonous increase, and convexity to guarantee the existence of a solution and to warrant that it is unique and stable.

Regarding these conditions and given the background of the two different optimization approaches, one should realize that

1. Although a system optimization would seem the obvious way to reduce noise levels and noise annoyance within a town, such a solution is too unrealistic to be practicable. At best it gives an idea of the most favorable situation that can be reached.
2. The logarithmic noise-level and noise-annoyance functions do not meet the above conditions, which are necessary for applying the existing optimization techniques.

Extension of the Set of Constraints

The arguments mentioned in the previous section led to the choice of the following approach: a user minimization of the travel time with the addition of an extra condition. This condition, giving the maximum flow X on a road as a function of facade distance, traffic composition and speed, and the noise standards to be met, is not a constraint in the traditional sense, because it is incorporated in the link travel-time functions as follows:

$$\begin{aligned} C^* &= X \quad \text{for } X < C \\ &= C \quad \text{for } X > C \end{aligned} \tag{4}$$

where

C = link capacity in traffic theory,
C^* = capacity to be used in the link travel-time function, and
X = calculated maximum flow.

This results in an unmodified travel-time function for $X > C$ and a compressed function for $X < C$.

As a consequence, all travel times will increase if $X < C$. This can easily be understood, because the objective is to reduce high noise levels. Therefore flows on these links must be reduced. In the chosen user optimization this can only be realized by increasing travel time on these links. As a consequence, alternative routes that originally were longer become attractive. This is shown in Figure 1a for the Bureau of Public Roads (BPR) function *(7)*. Figure 1b shows how the resulting increase in travel time would be realized in practice: it is easier to increase the free-flow travel time than to reduce the link capacity. The possibilities for these practical realizations have been investigated in a follow-up study *(8)*.

The reason for the conversion presented above is that an extra constraint like $f_a > X_a$, for all a, might make a feasible solution impossible. Furthermore, equilibrium according to Wardrop's first principle might become impossible as well.

The maximum flow of each link is called the environmental capacity (EC). These environmental capacities have a minimum value of 245 vehicles/hr because the current legal standards only cover roads with a minimum flow of 2,450 vehicles per day.

It should be noted that a real noise optimum will not be obtained. The result is one of a set of feasible solutions. In the results section, an analysis will be presented for a moderately large Dutch town in 1995, for which year a population of 85,000 inhabitants is projected. The network contains 264 nodes—among them 57 centroids—and 766 links.

THE ASSIGNMENT MODEL

Description

Although it is not impossible for the environmental capacity to be exceeded, this should not occur. Traffic on oversaturated links should be redistributed over the network. It is important, therefore, to choose a good link travel-time function. Both Davidson's hyperbolic function *(7, 9)* and the BPR polynomial have proved to be good delay functions. The Davidson function was expected to result in a more pronounced redistribution because of the asymptote at capacity.

BPR:

$$t = t_0 \cdot [1 + 0.15 \cdot (f/C)^4] \tag{5}$$

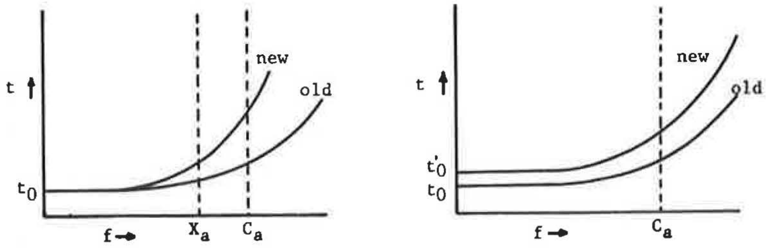
Davidson:

$$t = t_0 \cdot \left[\frac{1 - 0.6\,(f/C)}{1 - (f/C)}\right] \quad (f < C) \tag{6}$$

For computational reasons the hyperbolic function is extended with a linear part for saturation degrees of 0.99 and over.

To test this assumption, the assignment was performed with both functions.

The Dutch legal standards offer two calculation methods *(10, 11)*. One method is very exact and detailed, which makes it unsuitable for the calculation of noise levels on such a large



a) Reduction of the capacity b) Increase of the free-flow travel time

FIGURE 1 Alternatives to increase link travel time.

scale as is intended here. Therefore the other method was used, from which the environmental capacity can be derived as follows:

$$X = \frac{d}{p_1 \cdot 10^{y(1)} + p_m \cdot 10^{y(m)} + p_z \cdot 10^{y(z)}} \cdot 10^{L_{\max}/10} \tag{7}$$

where

$y(1)$ = $5.12 + 0.021 * v - \log v$,
$y(m)$ = $6.84 + 0.009 * v - \log v$,
$y(z)$ = $7.62 + 0.003 * v - \log v$,
p_1 = percentage of automobiles,
p_m = percentage of medium-heavy traffic,
p_z = percentage of heavy traffic,
v = speed (km/hr),
d = facade distance (m), and
$L_{\max}$ = noise standard [dB(A)].

Input

The network was divided into different link types, each with its specific traffic composition, speed, and theoretical capacity. For roads within the built-up area p_1 ranges from 0.94 to 1.00, p_m ranges from 0 to 0.004, and p_z from 0 to 0.02. Only the facade distance may differ for each separate link.

However, in a network description, a road consists of two directed links. Therefore, a final point to be dealt with was the fact that assignments are performed for each directed link separately, whereas the noise level on a road is dependent on the flow on both links together. In the model a 50-50 division of the total flow on a two-way road is assumed, corresponding to a maximum flow per link of half of the environmental capacity. This is the most unfavorable and therefore the safest assumption; a full utilization of the road capacity will seldom occur under these conditions.

Sensitivity Analysis

To determine the trade-offs between the variables in the model, a simple sensitivity analysis of the noise-level calculation was carried out. The results are as follows:

1. A 1-dB(A) elevation of the noise standard corresponds to a 26 percent increase in the environmental capacity; every 3-dB(A) elevation results in a doubling of *EC*.
2. The influence of heavy traffic on the noise level—and thus on the environmental capacity—is considerable, especially in built-up areas, as can be seen from Table 1.
3. The direct influence of speed on environmental capacity turned out to be very small in built-up areas. A 35-km/hr speed results in $X = 304$ vehicles/hr and a 55-km/hr speed results in $X = 288$ vehicle/hr. The environmental capacity reaches a maximum at ±45 km/hr.

TABLE 1 EXAMPLE OF INFLUENCE OF HEAVY TRAFFIC ON NOISE LEVEL

p_1	p_m	p_z	X	f_1	f_m	f_z
0.94	0.04	0.02	308	290	12	6
1	0	0	778	778	0	0

NOTE: $d = 20$ m; $L_{\max} = 60$ dB(A); $V = 45$ km/hr; X = environmental capacity (vehicles/hr); $f_1 = p_1 \cdot X$ (vehicles/hr); $f_m = p_m \cdot X$; $f_z = p_z \cdot X$.

4. Environmental capacity is inversely proportional to the facade distance, which is responsible for the lower environmental capacity of most streets in a built-up area as opposed to their theoretical traffic capacity.

RESULTS

Criteria

First the following four alternatives were calculated and compared:

1. An assignment model with Davidson's travel-time function and extended with noise standards,
2. An assignment model with the BPR travel-time function and extended with noise standards,
3. An assignment with Davidson's function without additional constraints, and
4. An assignment with the BPR function without additional constraints.

Comparisons were made by observing the differences between Alternatives 1 and 2 and 3 and 4. These differences happened to be very small, so it was decided to perform the rest of the assignments with only the BPR polynomial. The expected advantages of the hyperbolic function did not show up and a disadvantage of this function is that the travel-time values became very large and hard to handle when full capacity is approached.

Alternatives 2 and 4 have been compared on the basis of the following five criteria:

1. The number of links in each noise bracket i (i = 1, . . . , 5). For noise levels beyond the noise standard of 60 dB(A), noise brackets of 3 dB(A) have been defined, because this bracket size corresponds to a doubling of the traffic flow.
2. A noise index value *INi* for each bracket. By adding the lengths of all road sections within one bracket, weighted noise index values were obtained.
3. A total noise index value *INTOT* for the whole network. For each bracket the noise index value *INi* is multiplied by an annoyance factor c_i. The products, added over all brackets, give the *INTOT* value. The annoyance factors were derived by Wardrop *(1)*. The noise standard $L_{\max} = 60$ dB(A) corresponds to a factor equal to 1; an excess of x dB(A) results in an annoyance factor $c_i = \exp(0.1143x)$ (Table 2).

TABLE 2 ANNOYANCE FACTORS BY NOISE LEVEL

Noise Level			
No.	Range [dB(A)]	Avg. Exceeding	Annoyance Factor c_i
1	60–63	1.5	1.19
2	63–66	4.5	1.68
3	66–69	7.5	2.36
4	69–72	10.5	3.32
5	>72	13.5[a]	4.68

[a] Estimated.

4. The total travel performance in vehicle kilometers.
5. The saturation degree. To get an impression of the eventual oversaturation throughout the network, the average saturation degree for the busiest directions of all roads together and the quietest directions of all roads together are determined. Alternative 2 will always show larger values than Alternative 4 because most saturation degrees depend on the environmental capacity (which usually is smaller than the theoretical capacity).

Analysis

At first the results were rather poor and disappointing. The number of road sections where the noise standard was exceeded had increased (rather than decreased) by 30 percent and the total travel performance increased by 64 to 75 percent. A closer observation of the plots, however, showed several locations where the input specifications required modification. One such location was a highway north of the town with an important traffic function. A low environmental capacity for such a road is not realistic. In these cases it is better not to impose any restrictions on the flow and to install effective noise-reducing facilities if necessary.

Furthermore, the network structure was improved. As a consequence the number of links (including dummy links connecting centroids to the network) increased to 859. The results of the model at this stage are shown in Table 3. Redistribution of the traffic (in order to reduce the noise levels) now resulted in a 21 percent increase in travel performance versus a 6 percent improvement in the total index value *INTOT*.

TABLE 3 COMPARISON OF RESULTS

	BPR Function	
Criterion	With Extra Constraint	Without Extra Constraint
No. of road sections		
$60 < L \leq 63$ ($i = 1$)	55	24
$63 < L \leq 66$ ($i = 2$)	24	30
$66 < L \leq 69$ ($i = 3$)	13	28
$69 < L \leq 72$ ($i = 4$)	0	3
$L > 72$ ($i = 5$)	0	0
Total	92	85
Noise index value (m)		
$IN1 = \sum_{a \varepsilon i} 1 * 1{,}000$	15 400	7230
$IN2 = \sum_{a \varepsilon i} 1 * 1{,}000$	7 570	8790
$IN3 = \sum_{a \varepsilon i} 1 * 1{,}000$	4 310	7650
$IN4 = \sum_{a \varepsilon i} 1 * 1{,}000$	0	690
$IN5 = \sum_{a \varepsilon i} 1 * 1{,}000$	0	0
Total noise index value (m), $INTOT = \sum_i c_i * INi$	41 140	43 628
Travel performance (vehicle-km)	108 717	89 750
Average *f/C* (%)		
Quiet	35.4	15.7
Busy	44.8	20.3

It is obvious that noise levels higher than 66 dB(A) are stongely reduced by incorporating the noise standard. Moreover, more than half of the noise levels in the 60- to 63-dB(A) noise bracket are less than 61 dB(A). The fact that the total number of noise levels exceeded has increased follows from the equilibrium principle: alternative routes are used and travel distances increase.

Figure 2 shows these phenomena quite clearly. It shows the total length of the road sections where a certain noise level is exceeded as a function of this noise level.

The findings corroborate the earlier hypothesis that traffic flows on noise-sensitive roads are indeed reduced and flows on undersaturated roads are increased. The flow reductions, however, are not always sufficient to guarantee a noise level of 60 dB(A) or less in the new situation.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the comparison of the alternatives, the following conclusions were reached:

1. Mechanical application of the model may lead to wrong and unfavorable results. In particular, roads or road sections that should serve or maintain an important traffic function must be selected beforehand. Such roads have to be treated as described in the previous section for the highway north of the town.
2. The results and improvements that can be obtained are dependent on the size and structure of the network. When few

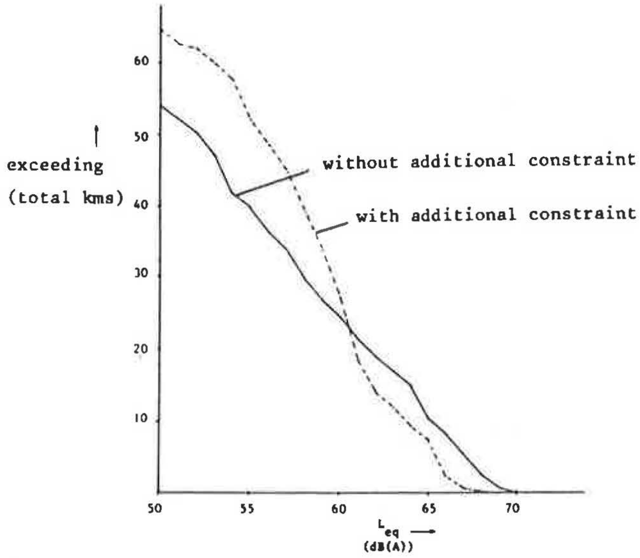


FIGURE 2 Total length of road sections where noise level is exceeded as a function of that noise level.

alterative routes are available, the possible improvements will be moderate, but when many surrounding roads are taken into account, redistribution of traffic is possible but will result in a strong increase in the total travel performance.

3. One should be aware that the final result is not an optimum, but only one of a series of possible solutions that meet the given constraints as closely as possible.

4. It is always dangerous to weight the results because it may resemble manipulation. However, in this case a mere unweighted comparison of the results could have resulted in a serious misinterpretation. Of the different ways to weight, the simplest and most transparent one was chosen.

The redistribution of traffic in this test case led to obvious improvements for the inhabitants of the city. Instances of exceeding the noise standard by 6 dB(A) or more decreased by 58 percent, whereas 28 of the 55 instances in the 60- to 63-dB(A) noise bracket are less than 61 dB(A), an amount that cannot even be perceived by the human ear.

However, it is questionable whether similar improvements can be expected in every arbitrary network. Furthermore, the differences between actual travel time and desirable travel time need to be moderate to make practical realization possible.

The results, however, can be further improved by perfecting some aspects of the model. The following recommendations are made:

- Introduction of a separate O-D table for heavy traffic, because of the considerable influence of this category.
- Introduction of the number of houses or the number of inhabitants per link in order to get a more exact weighting of the results.
- Performance of a true minimization of the noise annoyance to get an impression of the maximum improvement that can be obtained.

ACKNOWLEDGMENTS

This study was performed as an engineering graduate project in the Traffic Division of the Department of Civil Engineering at the Delft University of Technology. It was guided by R. Hamerslag of the Transportation Research Laboratory and P. H. L. Bovy and G. R. M. Jansen, all from the Delft University of Technology.

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Publication of this paper sponsored by Committee on Transportation-Related Noise and Vibration.

A Survey of Railroad Occupational Noise Sources

Stephen C. Urman

Measured noise levels are presented for various railroad industry noise sources, including railroad classification yards, locomotives, and cabooses. Alternative control methods for sound reduction are outlined.

Various safety acts and regulations have been passed to improve working conditions in the railroad industry. These reforms date back to the late 19th century when the Interstate Commerce Commission was directed to enforce statutory provisions requiring the use of various safety appliances on railroad cars and engines for the protection of employees and travelers. The Federal Railroad Administration (FRA) is responsible for issuing and enforcing regulations governing the safety of rail operations. As a result, FRA has been called upon frequently to respond to complaints that noise levels within locomotives, cabooses, or railyards are excessive.

INJURY AND ILLNESS STATISTICS

The industry is subject to expensive reporting requirements in the area of railroad safety. Federal regulation requires that all railroads file monthly accident-incident reports with FRA (U.S. Code of Federal Regulations, Title 49, Chapter II, Part 225). The purpose of reporting the occupational injuries and illnesses of employees, damage to railroad equipment and structures, and injury to nonrailroad persons arising from the operation of a railroad is to carry out the intent of Congress as expressed in the Federal Railroad Safety Act of 1970 (Public Law 91-458, 91st Congress, S. 1933, Oct. 16, 1970). For those occupational injuries and illnesses meeting the threshold of reportability, railroads must itemize appropriate job, nature of injury, and casualty occurrence codes, as well as the number of lost work days resulting from each incident. (Data from these reports are used by the Department of Labor to calculate industrywide occupational injury and illness incidence rates.)

The recording and reporting of occupational hearing loss present measurement problems because, unlike injuries, such hearing losses may develop over a period of years. Identification is made even more difficult because an employee may leave the job where the harmful exposure occurred and may work in another area under different working conditions.

The three main areas in which employees are exposed to noise in the railroad industry are maintenance of way, maintenance of equipment, and transportation.

Maintenance-of-way employees are involved in the repair and maintenance of railroad structures such as bridges, trestles, tunnels, and communications and signal systems, as well as the maintenance and laying of the track system. Typical job classifications are carpenter, painter, signalman, lineman, track laborer, and so on.

Maintenance-of-equipment employees are responsible for the repair and maintenance of railroad rolling stock. Their typical duties are those normally associated with the repair of heavy equipment—use of welding, cutting, or grinding equipment; material handling; painting; heavy machining; and so on. Typical job classifications include machinist, electrician, coach cleaner, and carman. Carmen also participate as part of "wreck crews," which are involved in derailment clean-up operations, and as car inspectors.

Transportation employees are directly concerned with the movement of railroad rolling stock over the rails, either in yards or along the right-of-way. The engineers, conductors, firemen, and brakemen in this category work with moving locomotives and railcars as part of their normal routine.

Noise-induced hearing loss ("disorders associated with repeated trauma") does not rank high in the tabulation of occupational illnesses. However, many cases contracted at the work site may not be recognized and consequently not be reflected in those estimates. In addition, if an employee does associate the hearing loss with his job, he may not report it in the earlier stages because he does not want to jeopardize his job.

The extent of the problem becomes more significant when compensation data are examined. The railroad industry is not subject to the normal procedures on workman's compensation. Rather, personal injury claims are handled under the Federal Employer's Liability Act (FELA). The limit of compensation is not set, but is determined in a trial by jury. Activities by the unions have aided employees in this regard.

A recent analysis of the cases of five railroad employees seeking compensation for occupational hearing loss showed that they suffered from 37- to 82-dB hearing losses and received awards of a mean value up to $16,000. These employees were in their late fifties; one equipment operator who suffered hearing damage in part because of faulty silencing equipment *(1)* was younger.

RAILROAD NOISE SURVEYS

Noise surveys were performed in railyards, locomotives, and cabooses.

Federal Railroad Administration, U.S. Department of Transportation, 400 Seventh Street, S.W., Washington, D.C. 20590.

Classification Yards

The noise sources of yard operations are many and are unpredictable in terms of cycling and duration of any one cycle. Typical noise levels in railroad yards are as follows:

Noise-Producing Operation	*Noise Level at 100 ft [dB(a)]*
Switcher engine movement	
Steady pull through yard	76-80
Classification start-stop cycle	80
Idling locomotive	
Road	71
Switcher	65
Car impacts	
Coupling	91
Chain reaction	91
Car retarders	
Master	110
Group or individual track	110
Inert or pull-out	95
Other	
Loudspeakers and PA systems	90-95
Engine load tests	92

The major activity in a classification yard is the receiving and rerouting of freight cars. The rerouting process consists of disengaging cars from incoming trains and reassembling them into outgoing trains bound for different destinations. A typical retarder hump yard is shown in Figure 1. A switcher locomotive pushes a string of cars up a man-made hill (or hump) on a single lead track. At the crest of the hump the first car is manually uncoupled and allowed to roll by gravity down the opposite slope of the hump through a series of switches into one of the many tracks in the classification yard.

Retarders

Because rail freight cars differ in size, weight, rolling friction, and so on, and because each car has a different distance to travel from the crest of the hump into the classification yard where it self-couples with a waiting car of its new train, some means must be employed to control its speed. This is accomplished by a mechanical braking device known as a retarder. This is essentially two steel rails attached to an actuating device located astride each rail of a section of track. The retarder slows a moving car by squeezing the lower portion of the wheels of the car between the lengths of steel rail with a particular force. The first retarder is called the master retarder.

After a car has passed the master retarder, it goes through one or more switches and then makes a pass through a "group" retarder. Master and group retarders are usually of identical construction and operated by pneumatic or hydraulic cylinders. Because hump yards have a slight grade, inert retarders are required to hold a classified cut of cars from rolling out the bottom of the yard. Inert retarders are either a constant retardation spring type or a self-energizing weight-sensitivity controlled type.

This braking action produces noise emissions known as "retarder squeal," which is similar to that produced by a steel-wheeled car on steel track negotiating a tight turn. Maximum sound pressure levels appear to be the same for both master and group retarders, although inert retarders are nominally about 15 dB(A) lower (see previous tabulation). Inert-retarder squeal may occur in two situations: (a) when a cut of cars is being pulled out of the classification tracks and (b) when a car being humped collides with a stationary cut of cars, thus forcing the end car to move slightly in the inert retarder. The lowered car speed and requisite retardation force most likely account for the difference in sound pressure level from active retarders. The duration of master and group retarder squeal usually varies from 1 to 5 sec, and may yield noise levels that exceed 110 dB(A) at 100 ft.

The duration of squeal is considerably longer for inert retarders. The frequency at which the retarder squeals occurs is between 2,000 and 4,000 Hz. Noise levels in railroad yards due to other sources and operations are identified in the earlier tabulation.

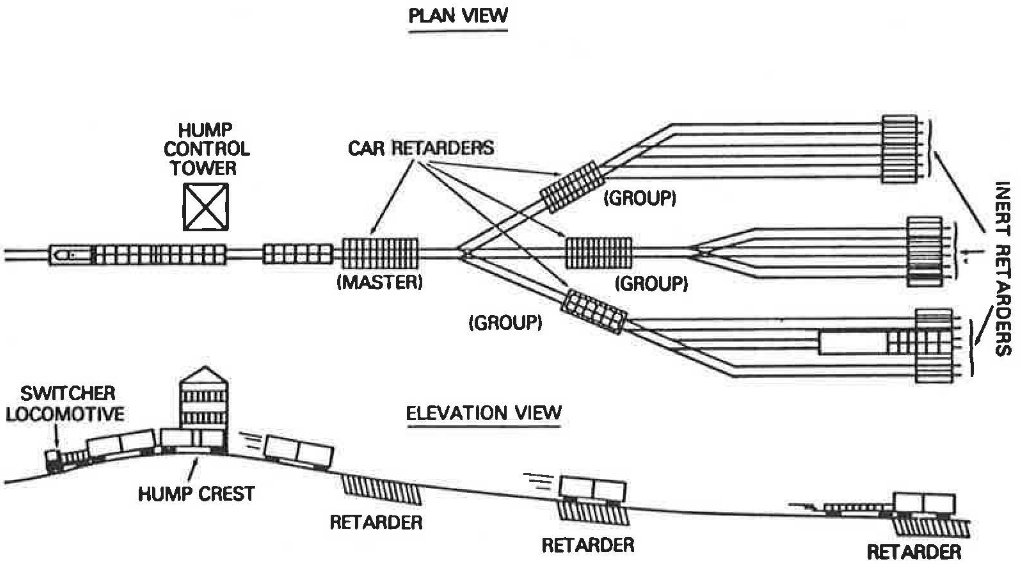

FIGURE 1 Hump yard retarder system.

Road and Switcher Engines

Both road engines and switcher engines are operated within the yard property. The engines, dependent on design, will generally run at a number 1–2 throttle setting (275 to 400 rpm), which produces a noise dominated by a low-frequency content with a primary peak at 100 Hz and a secondary peak at 500 Hz *(2)*. Average noise levels in the range of 76 to 80 dB(A) at 100 ft are emitted by switcher operations of this nature that involve steady pulling at low speeds.

It is common practice in railroad yards to leave road engines and switchers idling while not is use. These engines are left running because diesels can become difficult to start when cold, and starting a cold engine can cause excess wear. Noise generation by idling locomotives is attributed to several sources—exhaust outlet, cooling fans, and mechanical radiation from side panels. Standard idling revolutions per minute for road engines and switchers varies between 275 and 450, depending on the model of locomotive. As indicated earlier the noise output of idling road engines is approximately 6 dB(A) above that emitted by switchers.

Car Impacts

Car impacts produce noise either when two cars are coupled or when the slack in the coupler assembly of a line of cars is suddenly taken out or in. The impact from coupling is the predominant type of impact in a hump yard. However, when a car being humped couples with a cut of stationary cars, a chain reaction of impacts often occurs.

The impact noise is due to the impulse, seen in the couplers as the knuckles meet, that transmits vibration into the body of the car. Typical impacts last about 1 sec, with a frequency content of 2,500 Hz.

Other Sources

Public address (PA) loudspeakers typical of those utilized in railroad yards will reproduce speech with sufficient fidelity to maintain a high degree of intelligibility. To meet speech intelligibility requirements, PA system levels of 90 to 95 dB(A) at 100 ft must be generated.

Diesel locomotives are generally subject to a series of static performance tests and functional inspections during engine service or repair operations. These include tests of engine performance under load. By the nature of their traction motor propulsion system, locomotives can be essentially dynamometer tested at all throttle settings, including full power, by routing the electric power generated into resistor banks, termed "load boxes," adjacent to the test site. The time required for a locomotive to complete load testing may be up to 60 min or more, with at least 50 percent of the time spent at the highest throttle setting.

In summary, these surveys found the retarders to be clearly the dominant source of yard noise to employees. Also, because of its intensity and frequency content, retarder noise is perceived to be even more annoying then indicated by the A-weighted levels.

Noise Control and Regulation

Retarder noise levels are influenced by car type, car weight land loading, type of wheels, structure and composition of the retarder, and the decelerating force that the retarder applies to moving cars. Although lubricating and damping the retarder shoes have not been successful in reducing the level of the noise generated for a given retarder squeal, they have tended to reduce the probability of occurrence of squeal from a given car when retarded. The use of lined barriers, when practical, has resulted in attenuation of retarder sound level by 20 dB or more. Mechanical release devices have been installed on some inert retarders that permit strings of cars to be pulled through the retarders without retarder squeal. Other methods that have been tried with varying degrees of success include the use of ductile iron shoes and retarder control by computers.

A retarder without a clasp was developed in the United Kingdom and has been installed in one U.S. railyard. This system, which acts like an adjustable shock absorber, is made up of a series of movable mushroom-shaped heads that are forced down on the wheel on contact with the flange. Because the wheel is not squeezed, retarder squeal does not occur. Application of this retarder has not been widespread because of maintenance difficulties as well as operating problems under heavy snow conditions.

On January 6, 1980, the Environmental Protection Agency (EPA) issued railroad noise emission standards (U.S. Code of Federal Regulations, Title 45, Part 1252) that set limits on noise from four railyard sources: active retarders, load-cell test standards, car-coupling operations, and switcher locomotives. FRA under Section 17 of the Noise Control Act has responsibility for enforcing these standards, which became effective on January 15, 1984.

These standards are "triggered" at the receiving property of the affected public. Thus, they are not expected to have a significant impact on railroad employee noise exposure.

Locomotive Cabs

Typical noise levels in locomotive cabs are as follows:

Noise-Producing Operation	*Noise Level [dB(A)]*
Engine noise	80-90
Locomotive horn	110-120
Air brake operation	
Service application	105-115
Release	100-105
Emergency application	110-115
Release of independent brake	100-110
Engine room	115-120

Diesel-electric locomotives have a diesel engine driving an electric alternator or generator, which in turn powers electric traction motors on the wheels. The electric system acts as an "automatic transmission" and in a given throttle setting maintains a constant load on the engines for differing train speeds. These throttle settings, eight plus an idle notch, relate to engine speed and horsepower.

Thus, as the throttle setting is increased, the engine speed and horsepower increase, which results in an increase in in-cab noise levels. The noise level increases approximately 2 dB(A) per throttle setting. Although the train is under way, the majority of time is spent in throttle 8, followed by idle or throttle 1. The window position influences in-cab noise levels at throttle 8 more than at the lower settings.

In-cab noise levels show little speed dependency because wheel-rail noise is lower than that from other sources. Noise levels due to the diesel engine were not significantly different at the engineer's position or the brakeman's position in the cab. This was expected because of the hard, reverberant surfaces in the cab. As indicated earlier, sound produced by the locomotive diesel engine is dominated by low-frequency components. The other major sources of in-cab noise that contribute to the occupants' exposure dose are the horn and brake.

Air horns are used on the majority of locomotives in the United States as audible warning devices. They operate by the use of an air stream that causes a metal diaphragm to vibrate. A trumpet is incorporated to couple the sound energy to the outside air, to modify the tone of the horn, and to provide directivity. Frequency analysis shows that the energy in a multichime horn peaks at about 1,000 Hz, and the lowest pitch is seldom less than 220 Hz *(3)*. Manufacturers rate their locomotive horn sound levels at 114 dB 100 ft forward of the locomotive. Noise levels as high as 120 dB(A) were recorded in the cab. Noise exposure in the cab, of course, depends on the location of the horn, whether the windows are opened or closed, the number of times the signal is sounded, and so on. For example, closing the window was noted to reduce noise levels by as much as 10 dB(A) in some cases. Differences in horn-blowing techniques also affect the duration of the blasts.

Train brakes are applied by pneumatic operation through a brake pipe system that is pressurized to about 80 psi and runs the length of the train. The brakes are applied by venting a specific amount of air from the brake pipe system through the automatic and independent brake valves in the locomotive cab. The air escaping from the brake lines during application creates high-frequency noise that can be quite high depending on the particular brake application. Its duration and intensity depend on the length of the train and the type of application. For example, "emergency" reductions involve a very high rate of venting so that the brakes will be quickly applied. Typical noise levels due to air-brake operation range from 95 to 115 dB(A), in some cases as high as 120 dB(A).

The fireman or engineer on occasion will go into the engine compartment of the locomotive, where the noise level exposure is very high—up to 120 dB(A).

On March 31, 1980, FRA incorporated noise exposure limits as part of its Locomotive Safety Standards *(2)*. An 8-hr time-weighted average of 90 dB(A) with a doubling rate of 5 dB(A) was specified. Under the Hours of Service Act, the maximum work day for operating employees is 12 hr. Therefore, the 5-dB doubling rate was extended to a duration of 12 hr with an allowed exposure of 87 dB(A).

Locomotive manufacturers have achieved significant reduction in interior noise levels in recent years by additional insulation installed in the cab roof and electrical cabinets, piping the brake valve exhaust out the cab, and horn location.

Major locomotive manufacturers now offer, as an option, a method for piping the automatic brake valve service application and independent brake valve exhaust into the subbase of the locomotive. This option provides an audible indication of brake performance and, at the same time, has been estimated to reduce the cab occupants' noise dosage by 15 to 20 percent.

Excessive air horn noise in the cab is most easily controlled by proper location of the horn on the locomotive. It should be located away from air vents and not on the cab roof in close proximity to any crew member's seat. On some locomotives, the horn was located near the window where the engineer sits. A preferred location in locomotives operated with the long hood in front is the end of the hood to reduce the nuisance of the horn to the crew and improve performance.

Cabooses

Interior noise levels in cabooses moving at high speeds can make radio communication difficult and generally degrade working conditions for the crew. Sound levels typically range from 84 to 93 dB for speeds greater than 45 mph. Contact between wheels and rails, which causes structure-borne vibration, is the primary cause of noise in railroad cabooses. Effective isolation of the car body from the tracks is necessary to achieve substantial interior noise reduction. G. E. Warnaka *(4)* demonstrated that noise levels in cabooses can be lowered by the use of vibration isolation, structural damping, and acoustic absorption measures to levels at which conversation can be held at nearly normal speaking volume.

CONCLUSIONS

Efforts to reduce noise exposure have been limited by factors unique to the railroad industry. For example, poor maintenance of equipment is cited in employee complaints as a source of excessive noise levels. Of course, it must be realized that the very nature of the industry makes maintenance a problem. Because this is a "moving industry," an engine or caboose on which a complaint has been registered may be out of state the nex day, making it difficult to effect repairs. Nevertheless, significant noise reduction has been achieved in the industry, often without the imposition of excessive costs. Of course, costs involved in lowering employee exposure may be balanced by reduced compensation costs associated with high-noise work environments.

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Publication of this paper sponsored by Committee on Transportation-Related Noise and Vibration.

A Prediction Procedure for Rail Transportation Groundborne Noise and Vibration

JAMES TUMAN NELSON AND HUGH J. SAURENMAN

A procedure has been developed for predicting groundborne noise and vibration caused by rail transportation systems. The primary focus is the estimation of low-level, low-frequency groundborne noise and vibration between 6.3 and 200 Hz in residential and commercial buildings near at-grade and subway track. Two particular features of the method are the use of impact-testing procedures to characterize vibration propagation in soils and the use of 1/3 octave band force densities to represent specific vehicle and track systems. Directions for future research are discussed, including numerical modeling of subway structures and vibration propagation in soils, truck and track dynamics, and propagation of vibration through buildings.

A prediction procedure for groundborne noise and vibration from rail transportation systems has been developed by Wilson, Ihrig and Associates, Inc. (WIA), funded by the Transportation Systems Center of the U.S. Department of Transportation (DOT/TSC). The work included a literature review of the existing state of the art as of 1980 *(1, 2)*, numerical and theoretical modeling of transit vehicle trucks and subway-soil interaction, and extensive field experimental work. Contributions to the project were made by London Transportation International as subcontractor to WIA in performance of the literature review and initial development of testing procedures *(3–5)*.

The primary focus of the method is estimating low-level groundborne noise and vibration between 6.3 and 200 Hz for a variety of building types, soil conditions, and transit system designs. Resilient direct-fixation (DF) fasteners, floating slab track, resiliently supported ties, continuous welded rail, vehicle suspensions, and other design features of a rail transportation or subway system are considered. A major feature of the method is the use of normalized 1/3 octave band vibration force densities to represent the vibration source characteristics of vehicle and track systems. Predictions may be made for vehicles with different truck suspension systems and different soil conditions. The method hinges on the use of 1/3 octave band line source responses measured by an impact-testing technique and standard transfer function analysis of force and response velocity data. The result is a comprehensive prediction procedure that may be used as a design tool for rail transportation system design.

Although a discussion of a comprehensive prediction procedure is not complete without discussion of suitable criteria, the focus of this paper will be limited to predicting vibration. A complete discussion of criteria for groundborne noise and vibration is presented elsewhere *(1)*.

NATURE OF GROUNDBORNE NOISE AND VIBRATION

Groundborne noise and vibration in buildings consist of low-frequency rumbling noise and perceptible vibration with possibly secondary noise generation, such as rattling windows, picture frames, plates, and so on. Groundborne noise and vibration have caused varying degrees of community reaction at several systems, such as the Toronto Transit Commission (TTC), Washington Metropolitan Area Transit Authority (WMATA), New York City Transit Authority (NYCTA), and the Metropolitan Atlanta Rapid Transit Authority (MARTA) *(1, 2)*. In some isolated cases, litigation over ground vibration impact has delayed construction of new subway sections, with substantial financial impact. In Toronto, groundborne noise has been heard in basements up to several hundred feet from the Yonge Subway Northern Extension (YSNE) tunnel *(6)*. "Perceptible" ground vibration produced by trains on at-grade ballast-and-tie track is more significant than vibration from subway track.

As a result of these experiences, groundborne noise and vibration from rail transit systems and also railroads have become significant factors in designing and locating new subways and at-grade track. For example, as a result of the experience gained with the YSNE tunnel, TTC adopted the policy of providing floating slab track vibration isolation throughout new subway constructions. Floating slabs are a major design feature of the WMATA system in Washington, D.C., the MARTA system in Atlanta, and the Baltimore Region Rapid Transit (BRRT) system. As a result of the high capital cost of providing vibration control provisions at new systems and retrofit of old systems, the need for an accurate and reliable prediction procedure developed.

MAJOR FACTORS

Groundborne noise and vibration are influenced by the following major factors:

- Wheel and rail roughness
- Truck design

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- Subway-soil interaction
- Propagation in soil
- Building foundation response
- Vibration propagation in buildings
- Room acoustics

Wheel and rail roughness is assumed to be the major cause of wheel and rail forces *(7)*. To this might be added inhomogeneities in the material properties of the wheels and rails, imbalance of truck rotating components, and the effect of fastener or cross-tie spacing. Trains running on jointed rail and special trackwork produce vibration levels 5 to 10 dB higher than trains running on continuous welded rail, and rail corrugation will seriously degrade the performance of continuous welded rail in maintaining low levels of vibration *(8)*.

The magnitude of the wheel and rail forces resulting from wheel and rail roughness is strongly controlled by the dynamic characteristics of the truck. One of the single most significant truck design parameters affecting groundborne vibration in the range of 8 to 30 Hz is the primary suspension stiffness and corresponding primary suspension resonance frequency. Tests conducted at the Transportation Test Center in Pueblo, Colorado, reveal that trucks with chevron suspensions exhibiting a primary resonance frequency of 8 Hz produce as much as 15 dB lower ground vibration levels between 16 and 30 Hz than do trucks with elastomer journal bushing suspensions exhibiting a primary resonance frequency in excess of 20 Hz.

Track design has a substantial effect on groundborne noise and vibration. The track support system includes ballast-and-tie track, resilient DF fasteners, or, where substantial vibration isolation is required, floating slab track. Lowering the rail support stiffness usually produces lower levels of vibration at frequencies above, perhaps, 30 Hz. Too high a rail support stiffness may not only give poor isolation, but may contribute to excessive rail corrugation and thus excessive vibration and noise.

Vibration forces transmitted to the ground or subway invert cause vibration to be radiated into the surrounding soil. Interaction between the soil and subway structure influences vibration over a broad frequency range, especially in the case of heavy cut-and-cover subways. For rock tunnels, the effect of the tunnel structure is less significant than it is for soil-founded tunnels. However, below 30 to 60 Hz, vibration from rock tunnels tends to be 10 to 20 dB lower than from soil tunnels because of the high stiffness of the rock relative to that of soil. Vibration from ballast-and-tie at-grade track is higher at low frequencies than vibration from either soil or rock tunnels, especially within 50 ft of the track *(1, 2)*.

Vibration attenuates with increasing distance between source and receiver because of energy spreading and dissipation in the soil. Layering in the soil greatly complicates simple analytical modeling of attenuation with distance. For typical train lengths and source–receiver distances, the train is an incoherent line source, giving a 3-dB spreading loss per doubling of source–receiver distance for shear and compression waves in the ground, and no spreading loss for surface Rayleigh waves. In the case of a shallow soil layer overlying rock, most of the vibration energy may be concentrated in the upper layer, with little or no spreading loss.

In almost all the measurements performed under this project, the observed wave group velocities indicate that the predominant carriers of vibration energy are shear waves or Rayleigh surface waves, or both. Compression waves, though attenuating at a relatively lower rate, are not significant at typical source–receiver distances and at frequencies below about 50 to 100 Hz.

Excess attenuation due to dissipation in saturated or partially saturated layered soils is difficult to model. Most of the data collected in this study suggest that for typical situations attenuation of the level of vibration in decibels is roughly proportional to the logarithm of the source–receiver distance. Although this is inconsistent with usual models of dissipation, similar observations have been made by other researchers *(9)*.

A building foundation's response to incident ground vibration is a complicated function of foundation mass and geometry, soil characteristics, and type and direction of incident vibration. The most practical way to handle the foundation response is by an experimentally or numerically determined "coupling loss," representing the vibration response of the foundation relative to ground surface vibration in the absence of the foundation or structure. Slab-on-grade floors have little or no coupling loss, whereas deep friction pile foundations may exhibit a substantial coupling loss with respect to ground surface vibration. Foundations supported on piers imbedded in stiff soil layers or rock have lower responses than do floating foundations or slab-on-grade floors. On the other hand, direct connections to rock may increase the transmission of high-frequency vibration from rock and mixed-face subways. Massive foundations tend to respond less to incident ground vibration at high frequencies than do foundations with a small ratio of foundation mass to soil-bearing surface area. Amplification of ground vibration due to resonance can occur for heavy foundations with a large ratio of mass to soil-bearing surface areas.

An attenuation of 1 to 3 dB per floor is typical for vibration as it travels to upper floor levels. The attenuation is due to dissipation in the floor and splitting of vibration energy at each floor-wall joint. Data reported by Ishii and Tachibana *(10)* indicate that near the top of a large building, the floor-to-floor attenuation is less than it is near the ground. Vibration is amplified by resonances of the floors and walls at resonance frequencies.

Vibrating walls, floors, and ceilings radiate noise into rooms, and rooms with a large amount of absorption, provided by carpeting, drapes, and furniture, have lower levels of noise than "live" rooms with very little absorption. At very low frequencies, the relationship between sound pressure level (SPL) and wall vibration velocity is controlled by the bulk air stiffness, size of the room, and leakage *(11)*.

PREDICTION PROCEDURE

Early during the course of the study, a need for normalizing measured ground vibration data and removing the effects of soil characteristics and source–receiver distance became apparent. Vibration data collected in one city were being used for estimating vibration at another city in spite of the fact that different vehicles were being used and different geological conditions existed. Ground vibration in Toronto along the TTC is entirely different in character from that at BART in San Francisco or at WMATA in Washington, D.C. Accordingly, the prediction method attempts to separate these various factors by using impact-testing procedures for quantifying the vehicle and trackbed vibration forces and the vibration response of the ground. The remaining aspects of the prediction problem—building foundation, structural responses, and noise—have been dealt with in the same way as in previous methods *(1)*. The problem is reduced to estimating ground surface vibration in the absence of buildings. Once ground surface vibration estimates have been obtained, generic curves for coupling losses, floor resonance corrections, and so on, can be applied.

There are four major steps in the prediction procedure:

1. Selection of a trackbed force density,
2. Application of a line source response,
3. Calculation of building response, and
4. Calculation of noise

These steps are described individually in the following sections.

Force Density

The fundamental starting point is the 1/3 octave trackbed vibration force density, or simply force density. The unit of force density is force divided by the square root of train length, represented in decibels re $1\ \mathrm{lb/(ft)^{1/2}}$. The force density represents an incoherent line source of vibration forces for the transit vehicle and the track support system.

Force densities have been developed from tests with two light rail and two heavy rail vehicles at the Transportation Test Center in Pueblo, Colorado; from tests at BART in a cut-and-cover subway with DF fasteners; and from tests in San Diego and San Francisco with light rail vehicles. More recently, force densities have been developed for the BART and MARTA vehicle on at-grade ballast-and-tie and resilient DF track.

Figure 1 shows the trackbed force density for modern transit trains with elastomer journal bushing and chevron primary suspension systems on ballast-and-tie and subway DF fastener track. These data clearly indicate the advantage of representing individual vehicle types with specific force densities to account for differences of as much as 10 to 15 dB.

Adjustments are added to the trackbed force density if the measured force density does not correspond to the actual design track configuration, strain speed, and so on. Adjustments (not discussed here) are provided for resilient DF fasteners, floating slabs, ballast mats, primary suspension stiffness, and so on.

Line Source Response

The second major element in the prediction procedure is the 1/3 octave band line source response, which is the ground vibration velocity level at the receiver point relative to the

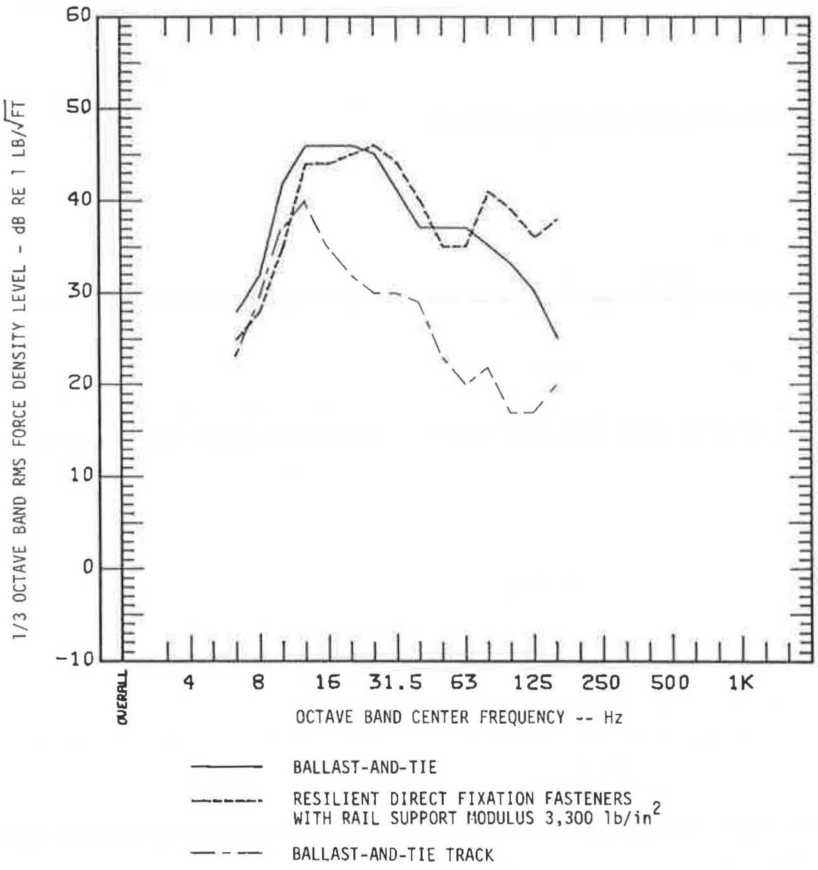

FIGURE 1 Force densities for heavy rail transit vehicles.

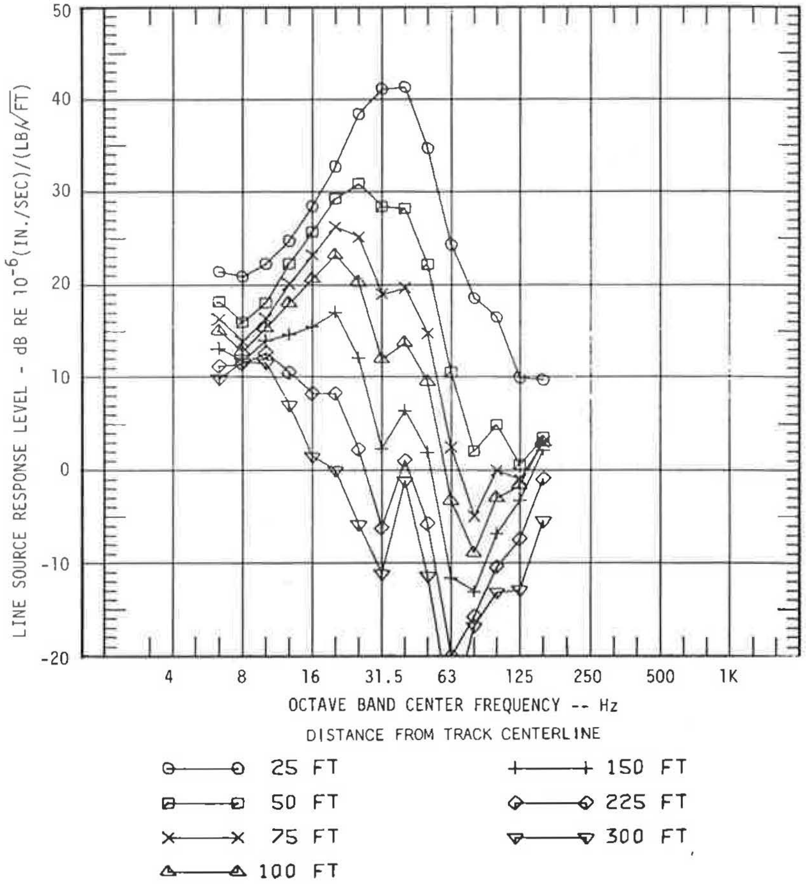

FIGURE 2 Line source response for BART Concord line ballast-and-tie track drive for a source length of 400 ft.

vibration force density level in decibels re (1 micro-in./sec)/ $[\mathrm{lb}/(\mathrm{ft})^{1/2}]$. One of the significant innovations of the study is the development of a field-testing procedure for determining line source responses by measuring the transfer mobilities from the subway invert to the ground surface, from the bottom of a borehole to the ground surface, or between two points on the ground surface. Numerical regression and integration methods are used to convert the two-point transfer mobilities to the line source response.

Line source responses are used to normalize measured train passby vibration data to obtain the force density estimates introduced earlier. The line source response is thus the key to applying the prediction procedure to transit systems with widely varying train types and soil conditions.

To date, line source responses have been measured at San Francisco's BART and MUNI systems, the MARTA system in Atlanta, the San Diego Trolley, the Guadalupe Corridor light rail system in San Jose, the proposed Los Angeles Southern California Regional Transit District (SCRTD) system, and the Transportation Test Center in Pueblo, Colorado. Recently, line source responses were measured in Carbondale, Illinois, to assess the vibration impact resulting from lowering a railroad about 15 to 20 ft below grade, at the BRRT system in Baltimore to assess vibration impact in the operating theaters of hospitals located near the proposed subway alignment, and along the proposed alignment for the DART system in Dallas.

Figure 2 provides examples of $^{1}/_{3}$ octave band line source responses for at-grade track at various source–receiver distances, measured along the BART Concord line with impact-testing procedures. These line source response curves may be contrasted with those in Figure 3 for a BART cut-and-cover double box structure at the Oakland approach to the transbay tube. These two sets of data clearly illustrate a wide disparity between line source responses for at-grade track and subway structures.

Building Vibration Response

The response of buildings to incident groundborne vibration is considered in three parts:

- Foundation coupling loss
- Floor resonance amplification
- Floor-to-floor attenuation

The approach presented in the *Handbook of Urban Rail Noise and Vibration Control* (*12*) has been adopted for estimating building responses. The approach has been used for many transit systems and is based on a variety of groundborne noise and vibration measurements performed over the years, most notably at the Toronto Transit System.

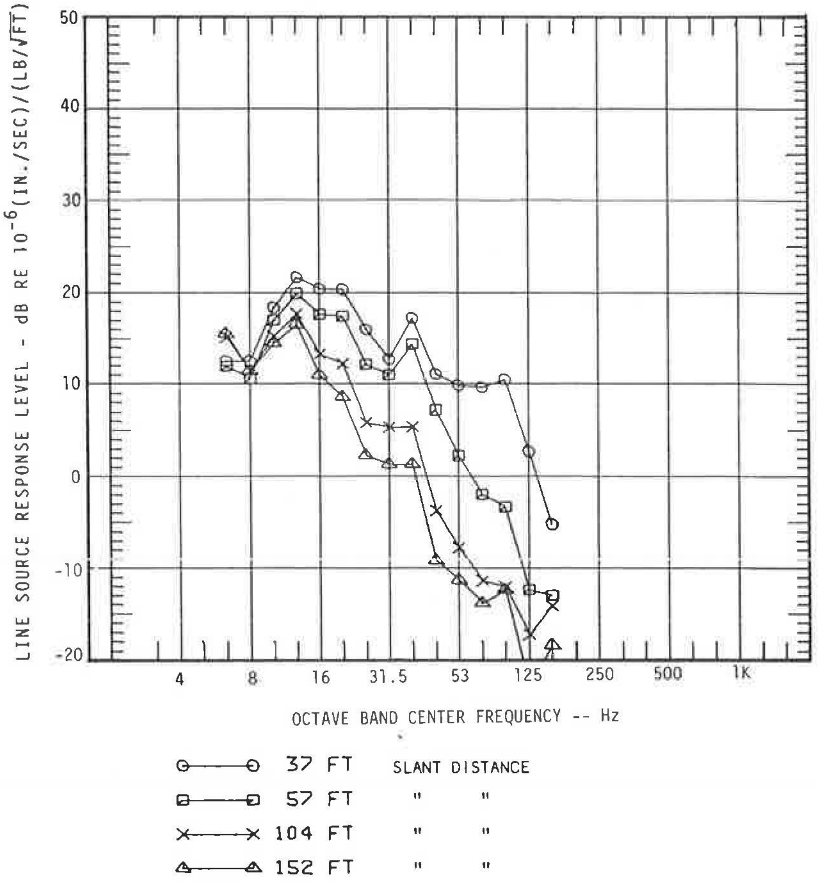

FIGURE 3 BART double box subway line source response for source length of 600 ft (subway depth = 27 ft).

One-third octave band foundation responses are shown in Figure 4. The foundation response is the level of actual foundation vibration relative to the level of incident ground surface vertical vibration that would exist in the absence of the building structure and its foundation. The appropriate response is added to the estimated ground surface vibration levels to estimate building foundation vibration. No correction is applied to the ground surface vibration to estimate basement floor and wall vibration or vibration of slab-on-grade floors.

A range of amplification due to floor resonances is shown in Figure 5. Well below the fundamental floor resonance frequency, little or no amplification may occur, whereas above the resonance frequency a number of vibration modes exist, each mode potentially producing an amplified response. For wood-frame structures, the first bending mode frequency is 8 to 16 Hz, whereas for reinforced-concrete waffle slab floors, the first bending mode frequency may be as high as 20 or 25 Hz. Floor surface areas are generally larger than wall surface areas and thus may have lower bending mode frequencies than do walls.

Noise Generation

The final step in the procedure is the prediction of noise in rooms. Ungar and Bender provide an analysis of the interior room noise due to bending waves in walls, floors, and ceilings *(11)*. For the purposes of this study, the following relation may be used for converting $^1/_3$ octave or $^1/_1$ octave band vibration levels to noise levels.

$$SPL = L_v - 10 \log(a) - 1 \quad (1)$$

where

SPL = sound pressure level (dB re 20 micropascals),
L_v = vibration velocity level (dB re 1 micro-in./sec), and
a = absorption coefficient.

An alternative approach is to apply the range of observed difference between floor vibration and interior noise (Figure 6) on the basis of measurements in Toronto of simultaneous rail transit groundborne noise and vibration in buildings *(13)*. The theoretical conversion based on the foregoing formula is comparable with the range of observed differences.

Margin of Error

The predicted levels are "best estimates" of the $^1/_3$ octave band levels, and no margin of error is included. For design review and recommendation of noise and vibration control provisions, some safety factor should be applied. At this time, about 5 to 10 dB should be added to the predicted levels to protect the major part of the potential receivers. The method is most accurate in the critical frequency range of about 8 to 30 Hz, where the primary suspension resonance frequencies usually occur and where attenuation in soil is least.

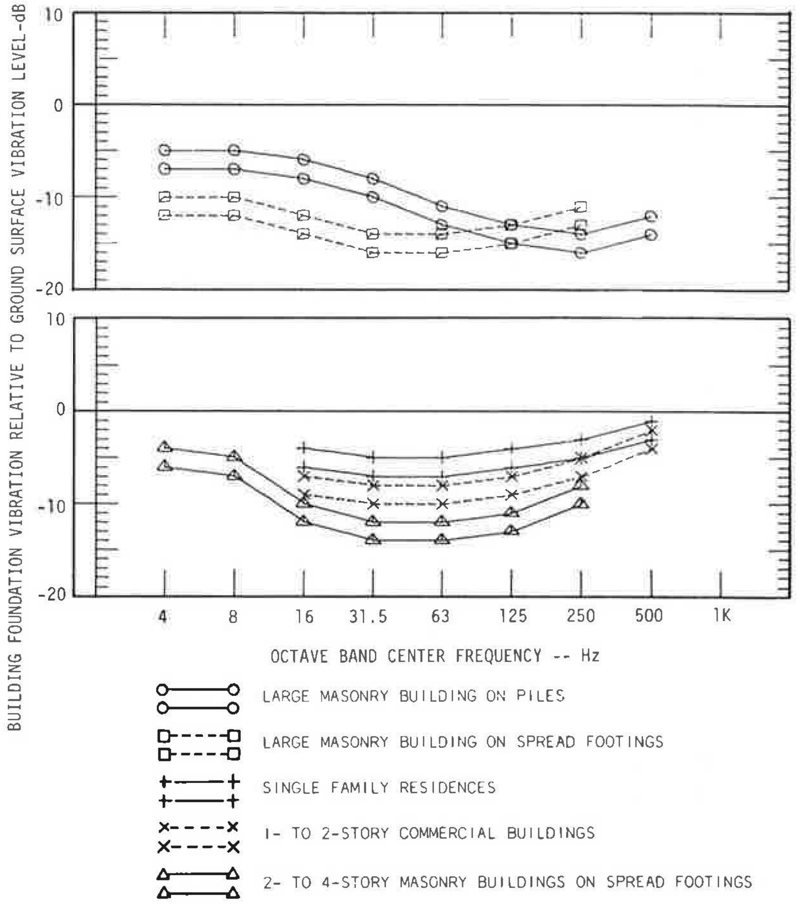

FIGURE 4 Foundation responses for various types of buildings.

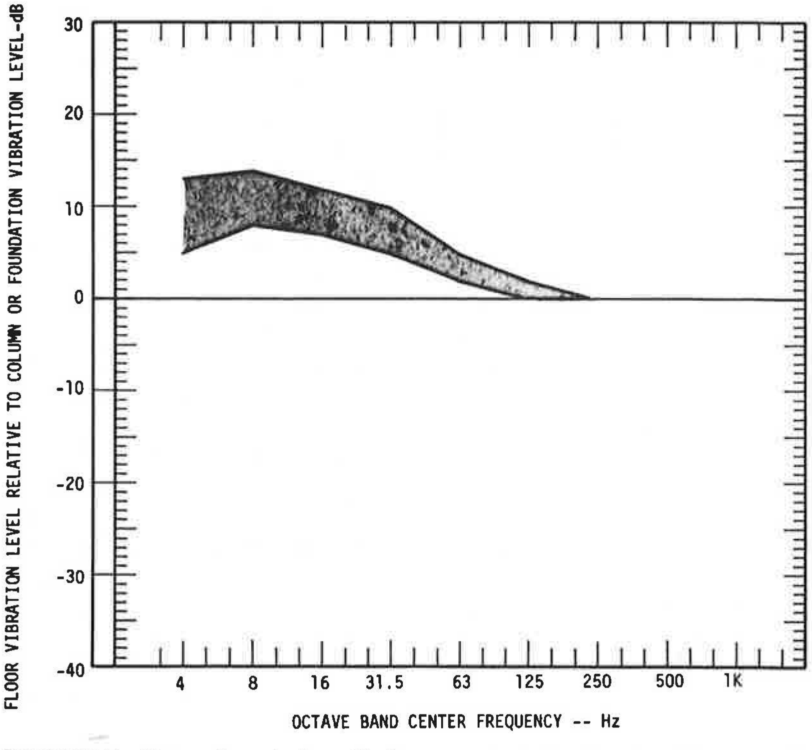

FIGURE 5 Corrections to be added to expected vibration level because of floor vibration amplification.

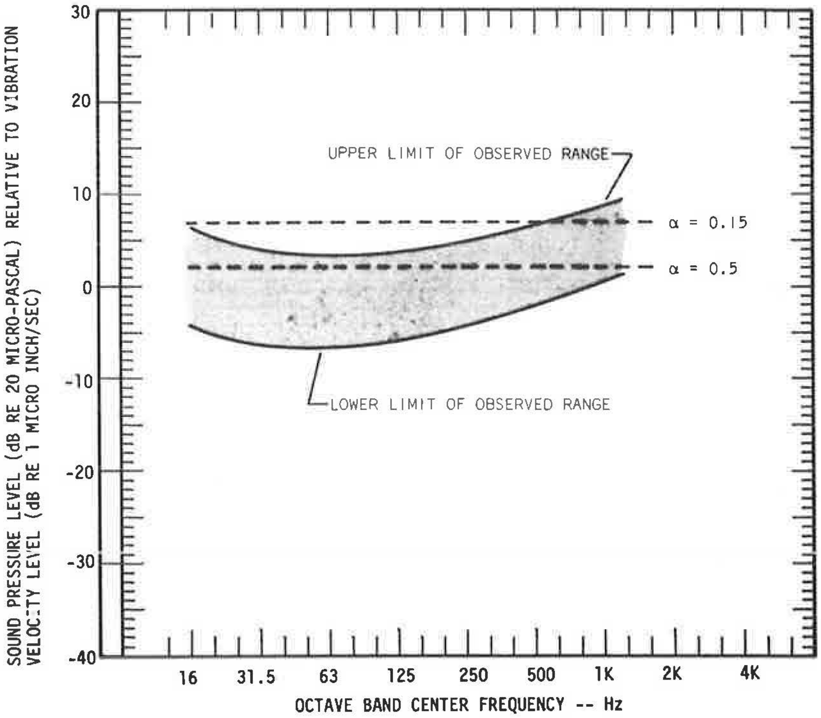

FIGURE 6 Room interior sound pressure level relative to average floor vibration velocity.

LINE SOURCE RESPONSE DETERMINATION

The line source response is a pivotal feature of the groundborne vibration prediction procedure: it provides the connection between the force density and ground vibration at receiver locations and allows normalizing wayside vibration data to remove effects of propagation and attenuation and obtain the trackbed force density, which is the starting point of the prediction procedure. Thus, measurement of the line source response is crucial for supporting the prediction method. By performing field tests, site-specific predictions of ground vibration can be made.

Line source responses can be measured practically. The costs for performing such tests are a small fraction of the capital costs of floating slab vibration isolation provisions, which might be saved if detailed testing indicates that such provisions are unnecessary at even a few locations. The testing procedure is also similar in scope to seismic refraction surveys.

There are five basic steps for measuring the line source response:

1. Measurement of transfer mobilities (Green's functions) between a source and several receiver locations,
2. Conversion of transfer mobility magnitudes to $^1/_3$ octave band frequency responses via energy averaging over each $^1/_3$ octave,
3. Regression analysis of $^1/_3$ octave band transfer mobility levels versus distance,
4. Integration (energy sum) of point source regression curves over train length to obtain line source responses at representative distances from the track centerline, and
5. Regression analysis of line source response levels versus distance.

The transfer mobility is the ratio of the magnitude of a sinusoidal velocity response at a receiver point to the magnitude of a sinusoidal driving force at an input point, expressed as a function of frequency.

Steps 2 through 5 are performed with a computer, without which the procedure would be tedious and easily subject to error. The result of the final step is a polynomial approximation of the line source response level versus distance. The technique also provides a direct measure of the rate of attenuation of vibration with distance.

To measure the transfer mobility, or Green's function, the ground or subway invert is struck with an instrumented hammer and the input force and resulting vibration responses at distances up to 300 ft from the hammer are recorded for laboratory analyses. For predictions along proposed subway alignments, the impact is at the bottom of a borehole drilled to the approximate depth of the proposed subway structure. For at-grade track the impact is delivered at ground surface. Where subways exist and are accessible, impacts at the invert provide a direct measure of the line source response for the structure and soil combination; otherwise a subway-borehole correction must be used to convert borehole test results to line source responses for subways. The line source responses shown in Figures 2 and 3 are the direct result of this measurement procedure.

The underlying assumption for borehole testing is that subway line source responses vary similarly with borehole line source responses as functions of depth, soil stiffness, and dissipation. A correction is applied to the borehole test results to account for soil-structure interaction; this is the subway

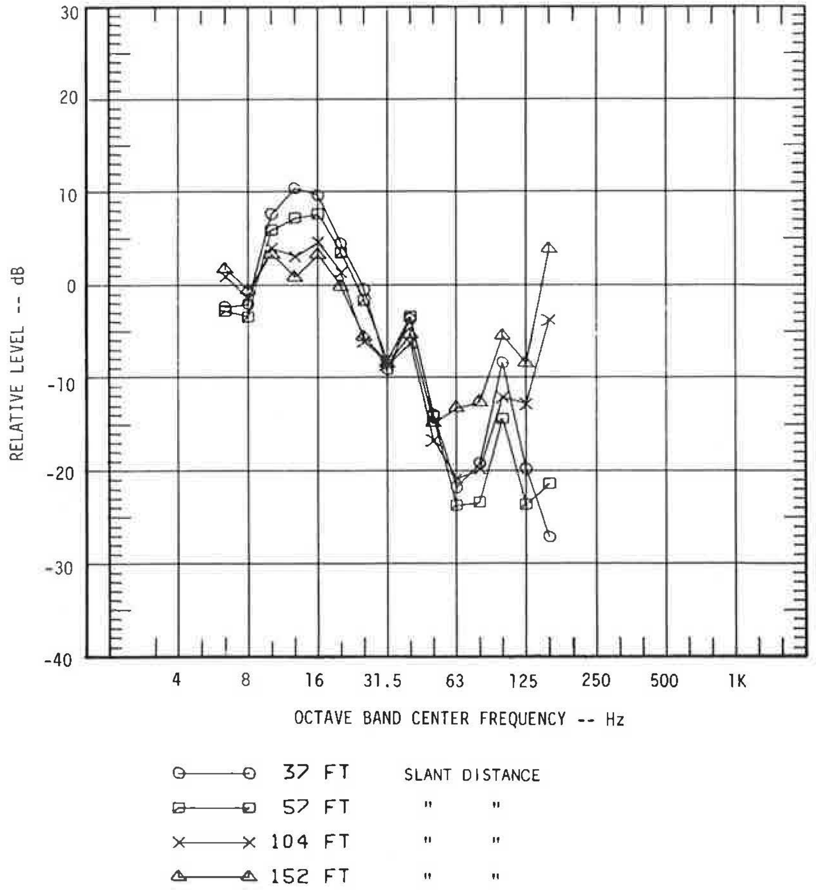

FIGURE 7 Subway relative to borehole line source response for borehole source depth of 30 ft and source length of 600 ft.

borehole correction. The negative of the subway borehole correction in decibels is the subway structure's coupling loss.

The borehole test procedure includes measuring the transfer mobility from the bottom of the borehole to an array of points on the ground surface. For tests conducted during the project, transfer mobilities were measured at 10-ft increments from ground surface to as much as 60 ft below grade. The analysis of borehole data is the same as that for surface and subway track. Line source responses are developed for each impact depth, and the line source response corresponding to the proposed subway invert depth is used for prediction. The approach is descriptive of the soil's vibration transmission characteristics, providing a direct measure of the effect of subway depth.

Line source responses for boreholes have been measured at BART, MARTA, BRRT, the proposed SCRTD system in Los Angeles, and the DART system in Dallas. The borehole tests for BART and MARTA were conducted adjacent to existing subways for which line source responses were measured directly by striking the subway invert. Subway borehole corrections were then estimated for the BART double box subway by using measured borehole line source responses and direct measurements of the line source response from the subway invert to the ground surface. The results of these measurements are shown in Figure 7. These results cannot be simply extended to other subway structure types and soil conditions, specifically lightweight circular tunnels and very stiff or very soft soils, without allowing for structure size and mass and differing soil conditions.

In coordination with this study and research, a feasibility study was conducted by Structural Software Development, Inc. (SSD) regarding numerical finite-element modeling procedures for use in dynamic analysis of subway structures *(14)*. Numerical calculations were carried out for four model designs by using a plane-strain representation corrected for three-dimensional geometrical effects with the aid of a factor developed from a three-dimensional analytical model of a circular tunnel imbedded in an infinite elastic medium. The four models considered were designed to evaluate effects of grid size, soil layer depth, and soil damping. Numerically computed and measured transfer mobilities for the BART KE Line circular steel tunnel in downtown Oakland, California, are compared in Figure 8. These results are for ground surface response velocities caused by a point force at the outer rail bench.

The data presented in Figure 8 indicate a surprisingly close agreement between measured and calculated levels, except perhaps at 25 Hz and possibly again at about 57 Hz. The basic shape and level of the measured response curve are captured by the numerical result. Even some of the measured dips in the transfer mobility are predicted at about 45 and again at 60 to 70 Hz. The case selected for comparison with the measurement data was Case 2 of the SSD report and was the most representative of actual conditions. The basic conclusion of this feasibility study is that meaningful line source responses can be computed by a suitable extension of the procedures used to produce the results in Figure 8. Future efforts toward numerical

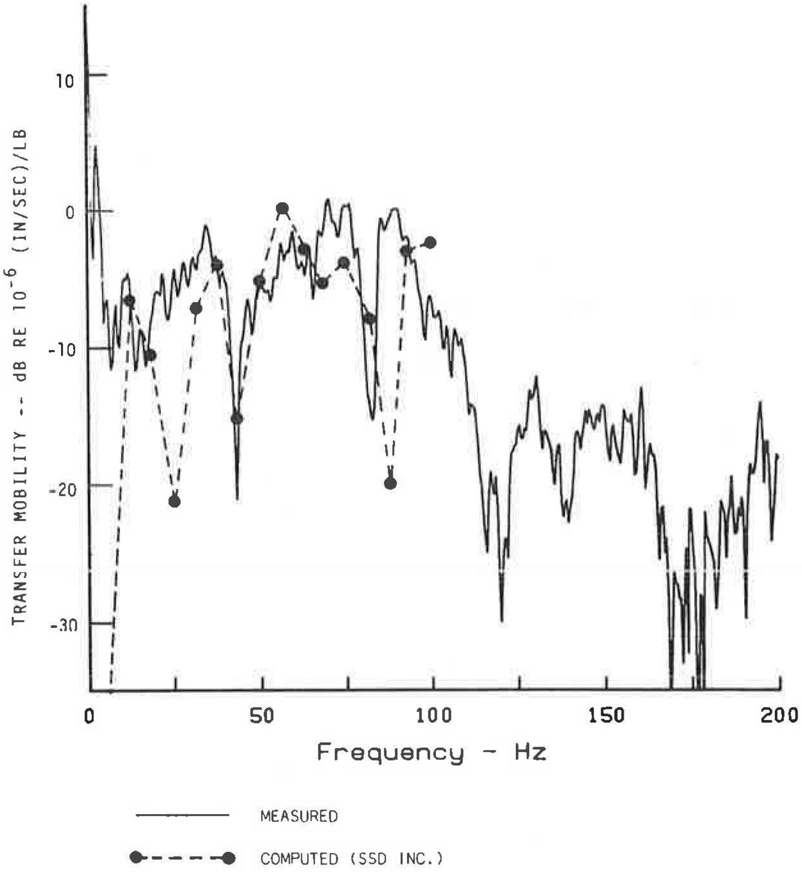

FIGURE 8 Comparison of measured and computed surface transfer mobilities at the BART KE line for impacts at the outer rail bench.

evaluation of subway structure designs with respect to vibration control can only be encouraged.

DIRECTIONS FOR FURTHER RESEARCH

There are several areas that may benefit from additional research and development. These include

- Numerical modeling of subway and soil line source responses and use of borehole test results or soils data, or both as input data;
- Numerical simulation of line source responses for surface and borehole impacts, using soils data as input parameters;
- Modeling and field study of vibration propagation in buildings; and
- Truck and track system dynamics.

Numerical analysis of line source responses will probably be the next phase in advancing the state of the art in predicting groundborne vibration. Numerical modeling software is available that, perhaps with modification, can be used for detailed dynamic modeling of subways as well as general soil-structure interaction, a field that has achieved a relatively high state of development. Recent advances in the boundary element method may further reduce the computer memory normally associated with the finite-element method.

Geophysical research regarding numerical synthesis of seismograms has yielded models of layered media that can be adapted for calculation of line source responses for surface or subsurface sources. Modeling of surface and borehole impact data would aid the theoretical understanding of measured responses and attenuation rates and allow extension of the method to predicting line source responses on the basis of soil properties and layering.

New truck designs have evolved during the course of this study. Many of these incorporate chevron primary suspensions rather than elastomer journal bushing designs. These designs represent a significant advancement for control of groundborne noise and vibration. Computer models were used during the study to model effects of primary suspension stiffness reductions on ground vibration. However, a great deal more may be done. Specific areas that deserve further study include

- Effect of resilient wheels and axle bending stiffness on vibration and
- Interaction of the track with the vehicle truck, including control of rail corrugation.

The view developed during this study and inherent in the concept of the force density is that the vehicle and track are considered together as a system. Interaction between the truck and track support system is of particular interest because it may influence the development of rail corrugations. Control of rail corrugation is as much a vibration (and wayside noise) control problem as it is a maintenance problem.

Finally, miscellaneous factors such as foundation coupling loss and floor resonance amplification deserve additional study.

In a society with ever-increasing technological demands and the need for manufacturing and research facilities with low levels of ambient vibration, the importance of the response of various building floors and foundations to vibration will only increase, regardless of the source of vibration, whether it be vibration produced by trains, truck and automobile traffic, or stationary sources.

ACKNOWLEDGMENT

The development of procedures for predicting groundborne noise and vibration from transit systems was funded by the Transportation Systems Center, U.S. Department of Transportation.

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Publication of this paper sponsored by Committee on Transportation-Related Noise and Vibration.

High-Speed Rail in California: The Dream, the Process, and the Reality

GEORGE C. SMITH AND EARL SHIRLEY

The 1983 high-speed rail proposal between Los Angeles and San Diego, California, was high technology and privately financed. It was initiated by the American High Speed Rail Corporation (AHSRC), a private firm, to develop a profitable business venture and offer a major new component to the transportation system. The 130-mi, electrically powered $3.1 billion system was to be based on the high-speed technology and design of the Japanese bullet train. The route was to be largely within or parallel to existing Interstate highway (I-5) and railroad right-of-way. AHSRC had an ambitious schedule, too ambitious, however; it underestimated the processing time and effort required of a major environmental study and a complex decision-making process, including public involvement. Assuming a minimum of problems, AHSRC might have been able to begin construction in September 1986, almost 2 years later than had originally been envisioned. The project proved to be very controversial, with the proponents eventually unable to obtain financing to continue. Opposition to the project centered mainly on environmental and economic impacts. Important considerations were noise, vibration, and visibility; beach access and lagoons; safety and property values; and transportation, namely, Amtrak service, local traffic and circulation, and local public transportation. The professional community seriously questioned AHSRC's ridership estimates and methodology. The content and process of communication between the project proponents and the public and governmental agencies were important factors in the outcome. The proponents were not accustomed to working closely with these groups. Elements of an approach to minimize communication problems in large-scale projects are as follows: exercise political diplomacy at all levels of government, maintain an open data process, establish open communication with the public and governmental agencies and keep the loop closed by continuing to provide feedback, maintain credibility by accepting criticism and handling it professionally, and avoid any perception of arrogance.

High-speed rail in the United States is being studied seriously in several parts of the country. The purpose of this paper is to add to the growing and necessary data bank of such efforts. Although not quite a case study, this paper describes a large-scale, privately initiated and financed high-speed train project (The Dream) and the environmental process for the proposal (The Process). It also analyzes the controversy surrounding the project and suggests measures for optimizing opportunities in communication and cooperation and for minimizing problems (The Reality). The paper concludes with what is perhaps the most important lesson to be learned: the public has grown accustomed to having a voice in large-scale projects, and the public participation process is not likely to disappear. With the increasing involvement of private enterprise in such projects, it would serve well to continue the search for and to find middle ground that would optimize opportunities for both the developer and the public.

THE DREAM

A study reported in April 1981 by the Federal Railroad Administration (FRA) and the National Railroad Passenger Corporation (Amtrak) *(1)* identified the San Diego–Los Angeles Transportation corridor as having the best potential for development of 25 rail passenger corridors studied. Shortly thereafter, a group familiar with the study and possessing good credentials formed the American High Speed Rail Corporation (AHSRC). Under their own initiative and without being solicited by any governmental agency, they proposed to construct, operate, and maintain a privately funded $3.1 billion high-speed passenger train service between Los Angeles and San Diego (Figure 1). Their goal was to have the full route in operation by 1990. The purpose of the project was to develop a profitable business venture and offer a major new component to the transportation system.

Founded in December 1981, the AHSRC unveiled its plans for the project in March 1982. Reasons for proceeding included the following projections and assumptions:

- Highway congestion would increase dramatically over the next 10 years (an automobile trip between Los Angeles and San Diego would take $3^1/_2$ hr in 1990);
- Gasoline prices would increase sharply;
- Growth in the corridor would be at a high in terms of population, employment, travel, and tourism;
- Not only would the population increase in numbers, but the population density would increase as well;
- Local parking and feeder services would be available and coordinated with the high-speed train; and
- Fares for the high-speed train service would be competitive with airline and Amtrak fares.

In addition, benefits were to include the following:

- With a nonstop run of 59 min, the "bullet train" would be faster than airplanes when the trip from the Los Angeles downtown to the San Diego downtown was considered (currently, airplanes take about 35 min to travel from airport to airport). Also, the bullet train would be faster than the conventional train (2 hr and 40 min) and the automobile (2 hr and 30 min);

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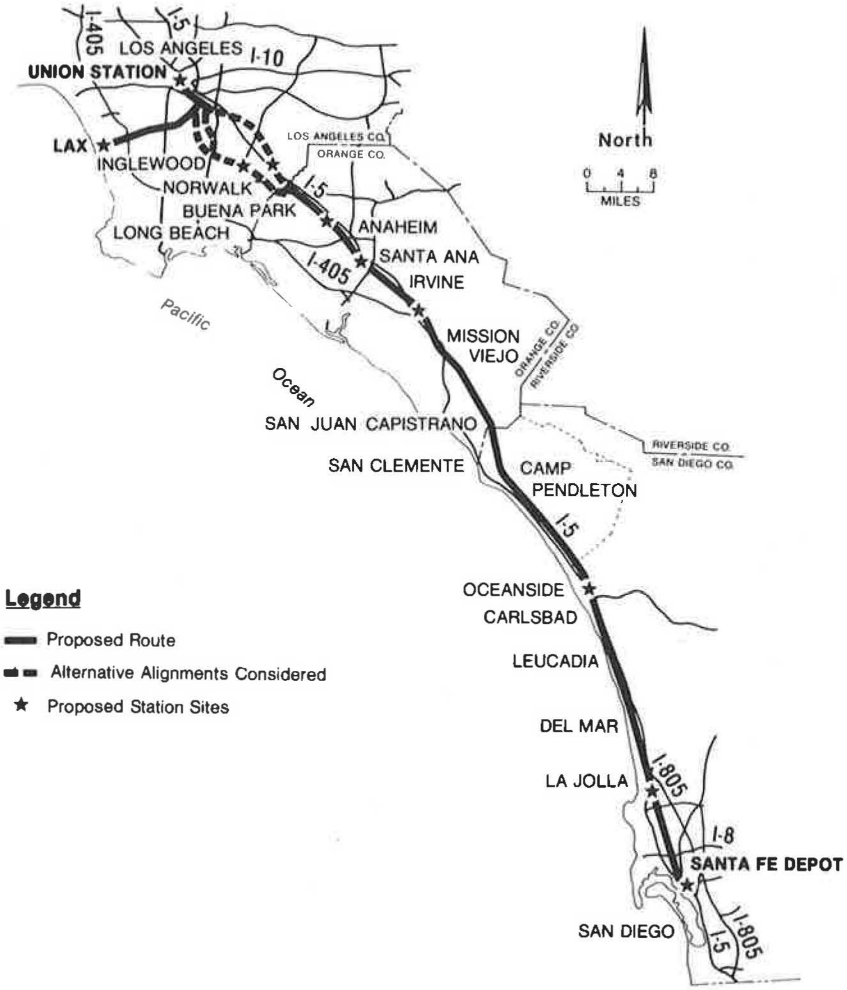

FIGURE 1 Route of proposed high-speed passenger train service between Los Angeles and San Diego, California.

- The project would reinforce existing local and regional plans for improvements to local transit systems;
- Capital costs of $1.5 billion of the $2.1 billion total cost would be expended in the United States;
- The project would involve about 8,600 person-years of direct construction labor during the 4-year construction period; indirect employment would be two to three times greater *(2)*;
- Operating and maintaining the system would require about 1,040 person-years per year of labor and would create indirect economic impacts from local purchases of materials and services and from local spending by passengers and workers *(2)*; and
- Government revenue would increase from taxes, permit fees, and other available sources.

The AHSRC described the high-speed rail proposal at several public meetings and in published documents. Most of the following project and financial information is derived from their published material *(2–4)*.

The train system was based on the high-speed technology and design of the bullet train *(Shinkansen)* developed by the Japanese National Railway. It was to be electrically powered by an overhead catenary system, operate on exclusive right-of-way, and have a maximum cruising speed of 160 mph. Approximately 34 percent of the route was to be constructed on elevated, grade-separated structures, about 51 percent at ground level or cut and fill (with grade separation for street, rail, and other crossings), and about 15 percent through tunnels. Of all nontunnel portions, about 80 percent of the alignment was to be within or closely parallel to existing railroad and Interstate highway (I-5) right-of-way.

The proposed route was to pass through Los Angeles, Orange, and San Diego counties for a total route length of 130 mi: 18 mi from the Los Angeles International Airport (LAX) to Union Station in downtown Los Angeles, and 112 mi from Union Station to the Santa Fe Depot in downtown San Diego. Other stations would be located in Norwalk, Anaheim, Santa Ana, Irvine–Mission Viejo, Oceanside, and North San Diego.

AHSRC estimated that, depending on the station stops, market conditions, and pricing structure, up to 100,000 passengers would use the high-speed service daily, more than 36 million passengers per year. These person trips would represent about 12 percent of the 875,000 trips projected to be made daily from the transportation market areas within the study corridor. The AHSRC defined these market areas as those within a 5- or 10-mi radius of the proposed stations. Only those passengers with trip origins and destinations within these areas were considered potential riders.

In order to meet projected traffic demands and generate adequate revenue, AHSRC proposed to provide service at half-hour intervals or less, using 15 train sets of 8 cars each with a seating capacity of about 500 passengers per train. Twelve train sets would be used at the peak period to provide service, two sets would be used as spares, and one set would be scheduled in heavy overhaul. The system was costed on the basis of 86 trains a day *(5)*.

Nonstop service would be offered from LAX to Union Station, and a combination of local and nonstop service would be offered from Union Station to Santa Fe Depot. The 18-mi trip from LAX to Union Station would take about 15 min, and the nonstop run from Los Angeles to San Diego would take about 59 min. Approximately 6 min would be added to the running time for each intermediate station stop.

AHSRC planned to operate a portion of the route by mid-1987 in order to generate revenue during construction. The corporation estimated an operating cash flow of $10 million in 1987 and about $193 million in 1988. AHSRC proposed to use this revenue to offset capital requirements: there was a difference of $200 million between projected capital costs and the preliminary financing plan.

Projected costs to build and equip the proposed system were as follows:

Cost	*Amount ($ billions)*
Capital costs	2.1
Inflation	0.5
Interest	0.5
Total	3.1

The preliminary financing plan, providing for several sources of capital, was as follows:

Source	*Amount ($ billions)*
Equity	0.5
Japanese debts and credits	0.7
Commercial bank	0.4
Tax-exempt bonds and notes	1.3
Total	2.9

The equity sources were to include investors who would be economic beneficiaries from the project through enhancements of land values, creation or expansion of markets, preferential treatment as vendors, or utilization of tax benefits. The primary source of the tax-exempt bonds was to be the California Passenger Rail Financing Commission Act (Chapter 1553, Statutes of 1982), which established the California Passenger Rail Financing Commission (CPRFC). The CPRFC was authorized to issue up to $1.25 billion for the financing of rapid-rail transit system projects. Rapid-rail transit was defined as that with peak speeds in excess of 120 mph. The bonds were to be repaid solely from revenues of the project and were not to be claims against the credit of the state itself.

Although construction period financing on a tax-exempt basis was to utilize the authority of the CPRFC, the financing for the short term was to be tax-exempt debt borrowing and was to be backed by third-party bank guarantees or letters of credit, or both. Long-term tax-exempt bonds were to be issued under the authority of the CPRFC only after the commencement of revenue service in 1987 or 1988.

As indicated, AHSRC's goal was to have a portion of the route in service by mid-1987 and the full route in operation by 1990. The corporation's processing schedule was therefore ambitious: environmental reviews were to be completed by the end of 1984 [18 months to process a document complying with the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA)]; the application for a Certificate of Public Convenience and Necessity was to be approved by the California Public Utilities Commission by the end of 1984 (18 months of processing); design and construction were to be completed by the end of 1989 (7 years of effort); the initial segment was to be in operation by mid-1987; and the full route was to be in operation by 1990. As far as the environmental review process and the processing time required for a Certificate of Public Convenience and Necessity were concerned, the schedule was to prove to be too ambitious. Following is a description of the environmental process required and followed for the proposed high-speed rail project.

THE PROCESS

The legislation that provided for the tax-exempt bonds also amended CEQA with respect to rapid-rail transit. The intent of the amendments was to facilitate processing of rapid-rail projects. Unfortunately, they caused confusion by appearing to exempt such projects from CEQA or at least to prevent logical candidates such as the California Coastal Commission, the State Department of Parks and Recreation, the California Public Utilities Commission (PUC), and the California Department of Transportation (Caltrans) from being the state environmental lead agency. Only the CPRFC appeared to be unaffected by the amendments.

Shortly after the governor signed the legislation, the AHSRC and its environmental consultant began discussing the bullet train with state and federal agencies. AHSRC met frequently with the staff of Caltrans, FHWA, PUC, and others to determine the format and type of information required for project approval and to begin the environmental process. Coordination and scheduling were of high priority. The AHSRC was also to be conducting technical forums in Southern California to introduce the project to the public and local and regional agencies.

Anticipating a high-speed–rapid-rail transit project application by AHSRC, the governor's Office of Planning and Research (OPR) organized the effort to provide for an effective and efficient response. After deliberations on the project and the real effects of the legislation, the project was determined to be subject to CEQA and to require an environmental impact report (EIR). The project was a major undertaking requiring discretionary action by a wide variety of public agencies that could not act without first considering the environmental impacts of the project. FHWA had already determined that the project would be subject to the provisions of NEPA and would require an environmental impact statement (EIS). This decision made the EIR question moot.

Following these discussions, it was decided that Caltrans should be the state environmental lead agency for the following major reasons: PUC took the position that their discretionary action (granting of a Certificate of Public Convenience and Necessity) was exempted from CEQA; no state agency other than Caltrans was to have as much involvement with the project throughout the transportation corridor; no other state agency had as many experts on environmental impact; no other state agency had as much experience with the NEPA process; and no state agency had as much experience working with FHWA (any alternative use of the I-5 right-of-way necessitates review and approval by FHWA). FHWA was later named as the federal environmental lead agency.

The culmination of all these meetings and decisions was a letter dated August 4, 1983, from the AHSRC to the director of Caltrans and the Division Administrator of FHWA requesting them to formally begin the environmental process. Specifically, it was a letter of intent to file applications for encroachment permits and commencement of environmental review.

On August 5, the secretary of the Business, Transportation and Housing Agency of the state supported Caltrans in its role as lead agency. The secretary advised the department, however, to conduct a thorough environmental analysis fulfilling all of the requirements of CEQA and NEPA and not to support or oppose the project. In addition, the secretary recommended that Caltrans apply several policies to carry out its lead agency responsibility. These included expediting the processing of the bullet train proposal, but not in such a manner that the activities would interfere with the delivery of the State Transportation Improvement Program (STIP); requiring that the applicant (AHSRC) pay Caltrans for all departmental costs (state law required reimbursement for all costs directly related to any application or approval of a rapid-rail transit system or project); considering contracting with consultants or other governmental agencies or both for environmental studies but continuing to have the authority to determine the nature, extent, and cost of any such studies; if necessary, taking more than one year to complete the EIR/EIS to ensure a thorough evaluation; and entering into a formal written agreement with the applicant clearly establishing responsibility for funding and other requirements. This the department did, effective November 1, 1983.

On August 22, 1983, Caltrans responded to the AHSRC acknowledging receipt of the letter of intent and also explaining that it had begun establishing the framework for conducting the environmental analysis. The department's activities included beginning the coordination process with the PUC and other public agencies, working with the AHSRC on such matters as information needed for the encroachment permits and environmental studies, estimating costs and timing involved, appointing a project manager and staff, and initiating actions needed to retain a consultant.

Regarding the actions needed to retain a consultant, the department had earlier reviewed the primary options needed to produce an environmental document. Not surprisingly, they were either to hire a consultant or to produce a document in house. The department preferred a consultant because in-house production would divert too many person-years (PY) of environmental staff from the Caltrans highway program.

Once it had been decided that a consultant was to be retained, the problem arose as to the timing involved in the selection of a consultant. Because of the desire to move as rapidly as possible, the department proposed that AHSRC pay for the consultant services and Caltrans select the consultant and supervise the work. The department was to be expected to prepare the document for circulation and to meet federal requirements.

The AHSRC accepted the proposal. The department decided to retain the consultant previously employed by AHSRC and enter into an agreement with AHSRC and the consultant clearly spelling out roles and responsibilities. All parties made every effort to avoid conflicts of interest. The department had confidence in the ability of the consultant because of the quality of information they produced as the environmental manager for AHSRC, their professionalism exhibited at meetings, and the depth and scope of expertise of their staff to be assigned to the project.

Upon appointment of the project manager and his staff, the department launched into the formal environmental process. In cooperation with FHWA, the department published a Notice of Intent in the *Federal Register* on November 19, 1983, announcing Caltrans and FHWA as the lead agencies and describing the proposed project. At this time, the department also published a Notice of Preparation to satisfy CEQA requirements. The department also sent similar information to "potentially affected interests."

Scoping meetings were conducted by Caltrans as follows. From November 21 through December 1, 1983, six meetings were held with local agencies; from December 5 through December 16, nine public scoping meetings were held, three in each county affected: Los Angeles, Orange, and San Diego; and from January 11 through January 13, 1984, six scoping meetings were held with state and federal agencies. These latter meetings had two purposes: (a) to exchange information, prepare an initial list of other issues for inclusion in the draft EIS, and identify the necessary agency discretionary permits; and (b) to identify cooperating agencies.

The department conducted a major organizational meeting on February 8, 1984, with FHWA, the consultant, representatives of cooperating agencies, and Caltrans technical experts. Roles were defined: as lead agencies, Caltrans and FHWA were to be solely responsible for the content of the entire environmental document, and the consultant was to prepare the main body of the environmental input to the EIS under Caltrans-FHWA supervision. The cooperating agencies were to be continually informed and were expected to participate as much as necessary.

The department's technical experts were to assist Caltrans high-speed rail staff to review issues for the consultant's proposed study plan and the preliminary environmental information that the consultant had prepared for AHSRC. They were to assess, and propose if necessary, the methodology to be implemented by the consultant. They were also to maintain quality control over the environmental study effort, evaluate and guide

- CEQA/NEPA/PERMITS
- PROJECT DESCRIPTION
- PURPOSE AND NEED
- ALTERNATIVES/PROJECT
- ALTERNATIVES/NO PROJECT
- NATURAL SYSTEMS
  - Air Quality
  - Biology/Flora
  - Biology/Fauna
  - Coastal Zone
  - Electromagnetic
  - Energy
  - 4(F) Properties
  - Geotech./Geology
  - Geotech./Seismology
  - Geotech./Soils
  - Geotech./Other
  - Hydrology/General
  - Hydrology/Flood Plains
  - Noise
  - Parklands
  - Vibration
  - Visual/Aesthetics
  - Water Quality/General
  - Water Quality/Waste Management
  - Wetlands
- SOCIAL AND GROWTH INDUCING IMPACTS
  - Cultural Resources
  - Growth/Community
  - Housing/Relocation
  - Land Use
  - Planning
  - Public Health
  - Public Institutions/Services
  - Safety/General
  - Safety/Toxic and Hazardous Materials
  - Transportation
- ECONOMICS
  - Business
  - Feasibility/Financial Failure
  - Feasibility/Ridership
  - Residential Property Values
  - Taxes/Fiscal
  - Utility Rates
- ABANDONMENT IMPACTS
- CUMULATIVE IMPACTS
- CONSTRUCTION IMPACTS
- MILITARY OPERATIONS
- OTHERS

FIGURE 2 Subject categories for California high-speed train scoping comment file.

the consultant's work under the overall supervision of Caltrans high-speed rail staff, and ensure that the document adequately identified and addressed all relevant issues. The technical experts were to make on-site reviews of the consultant's work as needed to ensure that appropriate methods and personnel were used. Task leaders were named for each of the environmental areas to be discussed in the EIS.

Caltrans high-speed rail staff formalized the technical reviews and the results of scoping into "letters of direction" to the consultant. The consultant, in turn, prepared "scopes of work" on the various disciplines required for the adequate preparation of the EIS. These efforts were concurrent; the department provided letters of direction from March through June 1984 and the consultant prepared scopes of work from March into the summer.

During this time, Caltrans held several important planning meetings with the consultant, AHSRC, and PUC to clarify direction and the scopes of work, to obtain information that only the project proponents could supply, and to incorporate the recommendations of the project proponent into the process as appropriate.

Coordination with PUC was crucial because issuance of their Certificate of Public Convenience and Necessity was perhaps the most important discretionary action that had to take place if the project was to be implemented. Objectives included the following:

- The results of Caltrans environmental studies would neither duplicate nor be inconsistent with PUC's own environmental analysis, which is required as part of their process and is outside the provisions of CEQA. Being able to use the department's environmental studies, or as much of the information as possible, would also save the AHSRC time and money in processing costs;
- The results of Caltrans studies would be available to PUC for the making of their decisions. Impacts and mitigation identified in the CEQA-NEPA process, for example, could affect project feasibility, with which the PUC is largely concerned.

The direction provided to the consultant was based partially on their preliminary environmental information and the review and guidance received from the department's technical experts. Equally important, however, were the results of scoping. Primary resources in this regard were the scoping report produced by the high-speed rail staff *(6)* and a compilation of all written comments received (see Figure 2 for a listing of all subject categories addressed). These comments were cross-indexed according to the person or agency who commented and according to the area of discipline, such as air quality and electromagnetic interference.

Among the many environmental considerations raised at the public scoping meetings, the most important were

- Noise, vibration, and visual impacts;
- Pedestrian and bicycle access to the beach and community facilities across the tracks;
- Impacts on the ecology of the lagoons;
- Safety;
- Possible decline in property values;
- Possible preemption of improved or enhanced Amtrak service and planned local light rail service;

- Local traffic and circulation impacts, especially around stations and during the construction process; and
- Impacts on the local public transportation system to provide access to the new facilities as well as to continue or to improve existing local service.

As indicated, the AHSRC had an ambitious schedule for preparation and review of required environmental studies. The corporation had estimated an 18-month process that was to coincide with the project approval process, especially that of PUC. At the first planning meeting in May 1984, Caltrans, FHWA, and the consultant began to develop a preliminary, minimum-processing time schedule. After evaluating additional information from AHSRC and PUC and assuming a minimum of problems, the department adopted an optimistic preliminary schedule providing for an EIS processing and approval time of 20 months.

The clock was to begin when the department was confident that the necessary project-related data upon which to conduct the technical studies were in hand. The period was to end when Caltrans and FHWA had approved the final environmental impact statement (FEIS). Several important steps would have to occur, of course, before the FEIS could be approved. Important ones included having all the necessary technical data, preparing the draft EIS, circulating the draft EIS for public and agency comment, and adequately responding to the comments in the preparation of the FEIS.

The department knew from its own experience that traffic estimates were one key constraint on the speed with which the environmental document could be produced. The department therefore made an extensive effort to review the travel estimates of the proponent, to develop data on feeder traffic to the stations, and to make estimates on the alternatives that were to be developed in depth. Also, many technical studies such as air quality, noise, and energy are dependent on traffic information that allows the models to run.

The department had reasons to believe, however, that there would be a minimum of problems in preparing the EIS. They included cooperation from AHSRC in providing needed technical data; preliminary work already accomplished by the consultant; the comprehensive results of scoping; the expressed cooperation of local, state, and federal agencies, as well as of the department's technical experts; the department's experience; and an open relationship with citizens groups watching the proposal. The department had already laid the foundation for a representative citizen-agency panel to provide ongoing review of Caltrans efforts.

During the scheduling meetings, the parties discussed the timing involved in obtaining decisions on the merits of the project itself from the various public agencies having approval authority, including FHWA, Caltrans, and PUC. Because of California statutory requirements governing the application for a Certificate of Public Convenience and Necessity, PUC was expected to act before the FEIS had been approved but during a period when the department was preparing the FEIS. It was assumed that most, if not all, of the requisite environmental information would be available for PUC's consideration.

The timing of approvals by the other agencies, however, depended on the availability of the approved FEIS. Because these processes and decisions were beyond the scope of the EIS preparation and approval process, the department and FHWA could only estimate the time it would take for the AHSRC to obtain necessary permits. The estimate was a minimum of 4 additional months. The most optimistic schedule that AHSRC could reasonably expect, therefore, was 24 months: 20 months for the EIS and 4 more months for project approvals.

On the assumption that the department would have all the needed technical data from AHSRC by September 1984, that PUC would issue a Certificate of Public Convenience and Necessity in the estimated time frame, that all other applications for permits would be processed expeditiously, and that AHSRC would obtain financing, AHSRC would have been able to start construction in September 1986, almost 2 years later than had been envisioned.

THE REALITY

On November 13, 1984, AHSRC requested the department to stop work as the state environmental lead agency for the proposed bullet train. According to AHSRC, it suspended its plans to build and operate the train because of a lack of short-term financing. The request came one year after Caltrans and FHWA had notified cooperating agencies of the proposal.

The failure of the project and the perceptions of those close to the project as to the cause of failure can be very instructive. This is especially true in light of the several high-speed rail proposals under serious consideration in other parts of the United States. Although the failure of the bullet train to proceed was a direct result of a lack of venture capital, there were several undercurrents of concern that persisted throughout the life of the project, countered the credibility of the proposal, and probably were major factors in decisions not to risk large amounts of capital in the project. Belden *(7)* said that "AHSRC officials placed virtually all the blame for the collapse of their project on money trouble, despite the fact that other important issues, including political diplomacy, environmental impact and the reliability of ridership figures were also at work, as they are in all proposed high-speed projects."

Two other concerns, also listed by Belden, were expressed as post mortem comments by independent observers who believed that "AHSRC from the outset essentially told Southern Californians what it was going to do for them, rather than asking what people wanted. It also was accused of playing fast and loose with the political process."

The latter concern, of course, refers to the legislation mentioned earlier, which was passed under strange circumstances and which was thought to have exempted the project from complying with certain aspects of California environmental law. Studer *(8)*, writing about this legislation, said, "So quickly did the pieces go together in the final drama, just hours before the end of the legislative session, that there was time for only one perfunctory hearing, which left more questions unanswered than answered."

The formation of the United Citizens Coastal Protective League, the largest citizens organization opposing the project, was attributed by its leader, Robert Bonde, to the indignation resulting from the passage of that piece of legislation *(9)*. Although the possible CEQA exemption was the catalyzing issue at the time, the group later became very concerned that, should the project fail subsequent to the issuance of the tax-exempt revenue bonds, the state government would feel obligated to pick up the payments and possibly operate the system at the expense of the taxpayers. Because the financial health of the project was to depend ultimately on ridership, AHSRC demand estimates were subjected to even greater scrutiny and the group questioned the lack of an impartial feasibility study.

It was in the arena of demand forecasting that the professional community first became involved. About mid-1983, the media were quoting well-established members of academia, such as an associate professor of economics and urban and regional planning at the University of Southern California, who termed the project a "boondoggle" *(10)*. A study by Jonathan Richmond *(11)* was released by the City of Tustin a few months later *(12)*. This study concluded that the methodology used in the ridership estimates, "which turned reality upside down," and inadequacies in the cost estimates would make the project "a massive unplanned burden on the public sector." The study also concluded that, because the public would have to support the project, "it should be the public and not the corporation who decided whether the plan goes ahead."

The professional planning staff for the San Diego Association of Governments also lacked confidence in the ridership forecasts and believed that adequate environmental analysis was of paramount concern because the coastline was the area's "most valuable physical resource" *(13)*. They asked that AHSRC proprietary studies be made available to them for analysis.

In the meantime, the Office of Technology Assessment was readying a report on passenger rail technologies *(14)* to be officially released early in 1984. Although this study did not evaluate specific proposals for high-speed corridors in the United States, the report stated that "based on foreign experience and current U.S. market factors, however, it seems that any U.S. corridor with totally new high-speed rail service would have difficulty generating sufficient revenues to pay entirely for operating and capital costs."

There was a third sector of criticism or opposition in addition to citizens groups and academics and professionals. Local government, mainly cities acting alone or in concert with others and in association with local, state, and federal politicians, took their case to the media and eventually to the courts *(15)*.

Thus, the project had three classes of critics: citizens groups, local governments, and professionals. The ways in which the opposition was expressed ran the gamut from court action to a country and western ballad with the title "Stop The Bullet," containing the following chorus *(16)*:

> Stop the bullet! They got the trigger aimed at you, they want to pull it. There ain't no place the noise won't reach; They want to screech right by the beach; So we can't let 'em, come on, stop the bullet!

The main citizens group, the United Citizens Coastal Protective League, was also active in contacting government leaders and heads of financial institutions, both in the United States and in Japan *(17)*.

Although opposition was vocal, diverse, and well organized, and had the attention of the media, some observers believed that the real damage to the project lay in the manner in which AHSRC responded. The corporation was very defensive when criticized and, except for the environmental process, the forum for discussion of the project became the media. AHSRC had refused to make public any marketing or ridership studies on the grounds that possible competitors could use the material to their advantage. In response to criticism of ridership estimates, AHSRC charged local government with spending "scarce public tax dollars to harass a private company" *(18)*. Criticism from a citizens group was termed "propaganda." The media reported that AHSRC officials were perceived by some as being arrogant and lacking credibility. Credibility, in fact, became an issue in the environmental scoping meetings when citizens and local government sought assurance that recommended mitigation would indeed be carried out. At the time the project was stopped, Caltrans high-speed rail staff was putting together a citizens committee to monitor the environmental process and begin bridging the credibility gap.

The public controversy surrounding the project has had repercussions in several areas. Locally it stimulated interest in upgrading the Los Angeles–San Diego Amtrak service. A task force was formed to make recommendations, and improvements in service are forthcoming. Nationally, a conference *(19)* was sponsored by Louis Thompson of FRA to try to make demand forecasting for high-speed rail a more logical process. Although not precipitated directly by the project failure, a presentation by Elizabeth Deakin at the 1986 Annual Meeting of the Transportation Research Board was titled, "Ethics of Private Infrastructure Finance." Among other things, she remarked that making choices on which assumptions to use in modeling trip-generation rates and modal shares is a major ethical issue facing the transportation analyst. The High Speed Rail Association developed standard guidelines for revenue and ridership forecasting because of the "tentative quality, lack of disclosure of methods and uncertain comprehensiveness of some early high speed rail travel analyses in proposed corridors elsewhere in the United States. These early studies had led to confusion and even disbelief among the public, the investment community and government officials" *(20)*.

It is difficult, if not impossible, to determine the extent to which failure to obtain financing can be attributed to the actions of the opposition. In any event, the proponents, who were not accustomed to working closely with the public, made mistakes that caused problems. Although the mistakes may be obvious to public agencies used to involving the public, it may be worthwhile to discuss elements of an approach that could at least minimize problems:

- Political diplomacy should be exercised at all levels of government: federal, state, and local. Actions that may seem expedient at the time may prove to be adverse in the long term. The legislation discussed in this case (California Passenger Rail Financing Commission Act) is a good example of such an action.
- An open data process should be maintained. Relatively open access to project material is important. True discussion and debate can only take place when both parties base their positions on the same data. To withhold data is to invite skepticism. The treatment of the ridership forecast in this project is a good example of what not to do. Had the study been

made available, the forum would have been the scientific community rather than the media.

- Open communication should be established with the public and governmental agencies, especially at the local level, and the loop kept closed by continuous feedback on issues that have been raised. This is difficult advice to follow because it involves a lot of listening and iterative, sometimes elementary, discussion. It involves understanding and satisfactorily addressing the point of view of the public. In such a large project with pervasive impacts, the community at large has to be accepted, in fact, as a partner. As Cooper and Shea expressed it *(21)*, "Public approval, therefore, is expedited if the plan first deals with issues the public cares about, showing that the developer and the designer understand the place and polity and are willing to balance profit with public interest." Silver and Burton conclude *(22)*, "If a comprehensive plan is to be acceptable as a total package (in this case, the legislation and the proposed 'bullet train' project) it must arise out of widespread debate and compromise; it cannot be the result of elite, backroom bargaining that magically crystallizes into social consensus."
- Credibility should be established through an open data process and open communication and credibility maintained by accepting criticism and handling it from a professional standpoint. A position of defensiveness erodes credibility and blocks a comprehensive understanding of the reasons for the criticism.
- Any perception of arrogance should be avoided. Nothing can crystallize opposition and give it a personal focus more quickly than a perception of arrogance. Once perceived, the opinion is very difficult to change. In this project, the media reported that the public believed that once the corporation got the "official blessing" from the legislature, it would dictate necessary action and not consider the opinions of others.

As the reservoir of public funds dwindles and the involvement of private enterprise in public transportation projects grows, the size and scope of privately financed projects will increase. The public, following the passage of NEPA in 1969, has grown accustomed to having a large part in determining the nature of such projects. Although the process that allows this to happen may be somewhat tedious and lengthy, and therefore, perhaps, inimical to short-range interests of private enterprise, it is not likely to disappear. It thus behooves us to continue to search for a middle ground that will optimize opportunities for both the public and the developer.

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Publication of this paper sponsored by Committee on Environmental Analysis in Transportation.