barriers on attitudes would seem useful given the amount of money that has been and will be spent on improving such appearances (7).

The important conclusion of this analysis depends on whether one construes the problem of traffic noise narrowly or broadly. If one sees the problem narrowly, then this study suggests that the adverse effects specifically attributed to road traffic noise are equally affected no matter what shielding is used. If one sees the problem as one related more generally to the quality of life in urban areas, the type of shielding used does appear to have some effect. This in turn argues for the importance of an explicit study of the effect of the visual appearance of barriers. An acoustically effective barrier will clearly reduce the adverse effects of traffic noise. Will an aesthetically pleasing barrier improve general attitudes even more?

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Effects of Highway Noise on Residential Property Values

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Previous studies of highway noise have shown an effect on the price of housing that seems to vary considerably with location. In this analysis, six sites that consist of similar housing in parallel rows adjacent to major roads were identified, and data on real estate transactions and noise levels were collected. Analysis of variance indicated that there were significant differences in price between rows of houses only at the two noisiest sites. Consequently, multiple regression analysis was performed for two subsets of the sites based on noise level. The results show that at very noisy locations [daytime L_{eq} of 73 dB(A) or higher] noise is strongly related to differences in housing prices and is valued at approximately $650/dB. At less noisy sites [daytime L_{eq} less than 70 dB(A)], noise is not significantly related to differences in housing prices. These results suggest that some noise impacts are not a linear function of sound level and that noise reduction at very noisy locations is more important than at less noisy ones.

Noise from road traffic has been recognized as an environmental problem in many countries, and many studies have documented the relation between traffic noise and annoyance (1, 2, 3). As these countries have begun efforts to reduce traffic noise, or at least its adverse effects, it has become obvious that this reduction cannot be accomplished cheaply. The construction of effective noise barriers is perhaps the least expensive approach, and even this is costly. Other approaches to noise reduction, such as sound insulation of buildings and reduction of noise at the source through vehicle modification, are considerably more expensive. Even land-use controls on properties near highways are indirectly if not directly expensive.

Noise reduction efforts must compete with other environmental improvement projects and in fact with the whole range of government and private expenditures. How are noise-related projects to be justified in the competition for tight funds? Studies that detail the relation between noise and annoyance or between noise and activity interference are informative and are useful for specifying the nature of the problem of noise. However, such consequences of noise cannot compete with such obvious threats to public health as water and air pollution. Annoyance—even a high level of annoyance—does not seem a particularly compelling reason to spend large amounts of money on noise reduction.

Complaints, the tangible manifestation of annoyance, may of course be compelling in specific instances, but they are not appropriate as the basis for a national or regional program. Several studies have shown that the occurrence of complaints is affected by variables of socioeconomic status whereas the level of annoyance and other adverse effects of noise are not (4). As a result, a program based on complaints would be inequitable. Even more important, a program based on complaints must necessarily be reactive rather than preventive. It could identify problem areas only after they occurred rather than before a highway or development was constructed. Consequently, the ultimate cost of such a program would undoubtedly be much higher than would the cost of a preventive program.

There appear to be two consequences of excessive traffic noise that would be effective arguments for the expenditure of large amounts of funds on noise reduction efforts. The first is some measure of the direct economic consequences of highway noise. The second is a clear statement of the effects of road traffic noise on health—either as it affects morbidity rates or as it causes increased health-related expenditures.

In general, these effects might in fact be the best arguments for government action on environmental matters. In the first case, if there are measurable monetary effects of noise, then it would appear that the population generally recognizes and can put a price on the benefits of (comparative) quiet. If so, present transportation construction efforts do not involve adequate compensation for the disbenefits they cause people, and it seems obvious that this should be corrected. (It might also mean that construction of barriers on existing roads results in a "windfall" benefit to property owners who have purchased since the highway began generating significant levels of noise, which might be a reason for shared-cost arrangements.) In the second case, if traffic noise has unrecognized effects on the health of people who are exposed to it for long periods of time, government bodies are the only ones with the ability to act, and it would seem most important to keep the adverse effects on health of their own projects to a minimum.

The question of effect on health is beyond the scope of this paper but is clearly a problem that warrants detailed attention in the near future. People who live near highways feel that traffic noise affects their health, most obviously in terms of irritability and sleeplessness (see the paper by Taylor, Hall, and Gertler elsewhere in this Record). Are they right? Do these effects in turn lead to other problems such as high blood pressure or ulcers? Some people have suggested that they do (5), but there are as yet no clear answers. A definitive study is needed.

This paper investigates the direct economic consequences of road traffic noise on the prices of residential property. Residential land use is probably the most sensitive to noise of any activity likely to be located adjacent to roadways; it also provides more sales data than any other land use would. The effects of transportation noise on residential property values have been studied before for both highway and aircraft noise. Those earlier studies offered some suggestions about analytical methods and also raised a number of questions that require further study.

The obvious way to approach a problem of this type is to use multiple regression analysis; this should include some measure of noise at each housing unit and numerous housing characteristics as the independent variables to explain housing prices. This approach is taken in a study by Gamble, Sauerlender, and Langley (6) that found a significant effect of noise levels on housing prices. Their data came from four residential areas in the eastern United States and consisted of household interviews, property sales data from 1969 to 1971, and data on noise level and air pollution level. Their findings indicate that noise level was significant in explaining a variation in property values in all four communities and that there was an average loss of \$2050/property abutting the highway. This result is supported by Langley's further analysis of one of the four areas (7). Although these multiple regression analyses produced clear results on the relation between prices and noise, there are also some surprising results. For example, the number of bedrooms in the home was a significant variable at only two of the four sites, and the presence of a finished basement was significant at only one of the four. Most likely there was not sufficient variation at each of the other sites for these variables to enter the analysis. Another possible problem with multiple regression, however, is that it will not be effective in identifying all relevant variables because of multicollinearities in the data.

The more striking result was the large variation in the effect of noise among the four sites. Dollars-per-decibel values ranged roughly from \$60 to \$600; this variation was not adequately explained. If the variation really is of this order, then economic effects cannot be used with much confidence in decisions on highway location or barrier construction.

Studies that attempt to relate housing prices to aircraft noise have not produced as consistent results as have studies of highway noise (8). They do, however, clarify some of the acute data-collection problems encountered in attempting to relate noise levels to property values and also point to another analytical method. Plowden and Sinnott (9) identify three major problems with data for such studies. The first is to find comparable housing for which recent sales are known, the second is to ensure that the homes are subjected to different noise levels, and the third is to interpret the data correctly. Although the problems are more difficult in studies of aircraft noise, they apply as well to studies of highway noise.

The obvious way to overcome these difficulties in studies of highway noise is to choose sites for analysis that consist of parallel rows of identical housing where the first row is adjacent to a major arterial roadway or a limited-access expressway. The parallel rows of housing at each site provide uniform sound-level characteristics within each row, and the identical housing ensures that any differences in price are caused by proximity to the highway. Analysis of variance can then identify the significance of such differences in price.

The data collection for this analysis was undertaken with analysis of variance primarily in mind. The criteria for site selection resulted in restriction of the size of potential sites, and the number of sales at each site turned out to be relatively small. In addition, it proved difficult to control for housing characteristics as closely as we wished. Therefore, the analysis reported here is based primarily on a number of multiple regressions augmented by the results of an analysis of variance.

SITE SELECTION AND DATA COLLECTION

Initially, 14 potential sites were identified. These resulted from field observations and met the criteria mentioned earlier—that is, each consisted of parallel rows of very similar housing adjacent to a major road. Information on the successful sale of any home in each area from 1975 to June 1977 was obtained from multiple listing sources through the cooperation of two local real estate offices. Sales before 1975 were not considered because of the rapid increase in housing prices in 1973 and 1974, which would tend to obscure the effect of any other variable. By 1975, housing prices had stabilized; this provided 2.5 years of data. Because of insufficient sales in different rows at half the sites, only 6 of the potential sites could be used in this investigation (Table 1). This confirms half of Plowden and Sinnott's first warning on finding sufficient recent sales (9). There were a total of 88 sales at the 6 sites but, because of the incompleteness of the data sources, not all of the housing characteristics were available for all of the sales.

Information on the sound levels at each site was collected by using either a BBN model 614 community noise monitor or a DA603A monitor. The monitor was located to approximate the closest face of the dwelling to the major roadway on each row of housing. The monitors were left in place for a 24-h weekday period. In keeping with the practice of the Ontario Ministry of the Environment, one of the project sponsors, the sound levels have been reduced to three periods of the day: daytime (7:00 a.m. to 7:00 p.m.), evening (7:00 to 11:00 p.m.), and night (11:00 p.m. to 7:00 a.m.). For simplicity, only the average sound level (L_{eq}) has been reported for each period, as follows:

	L_{eq} [dB(A)]		
Site	7:00 a.m.-7:00 p.m.	7:00-11:00 p.m.	11:00 p.m.-7:00 a.m.
1	76	73	73
2	67	65	61
3	65	64	58
4	70	65	63
5	69	68	67
6	73	70	67

ANALYTICAL RESULTS

The initial approach for analyzing these data was based on an analysis of variance of the selling price of the housing for each site. Had the site selection been more successful in achieving comparable housing within each site, this approach alone might have been sufficient. However, almost all sites had at least one housing characteristic that differed between the rows of housing (Table 2). At several sites, this turns out not to complicate the interpretation of results; at others it does. For this reason, multiple regression analysis was used in the statistical analysis, and the data in Table 2 were

Table 1. Description of six sites used in the analysis.

Site	City	Location	Source of Noise	Type of Housing	Number of Total Sales (1975-1977)
1	Mississauga	South Service Road and Exbury Crescent	Queen Elizabeth Way	Single-family	16
2	Mississauga	Grassfire Crescent	Dixie Road	Single-family	12
3	Mississauga	Flamewood Drive	Burnhamthorpe Road	Town-houses	9
4	Burlington	Palmer Drive	Guelph Line	Town-houses	25
5	Ancaster	Hatton Drive, Enmore Avenue, and Calvin Street	Highway 403	Single-family	15
6	Burlington	Cloverleaf Drive, Glen View Avenue, and Marley Crescent	Queen Elizabeth Way	Single-family	11

Table 2. Average housing characteristics at each site by row.

						Number of Houses With			
Site	Row	Number of Rooms	Number of Bathrooms	Size of Garage (number of automobiles)	Percentage With Pool	No Basement	Unfinished Basement	Partially Finished Basement	Fully Finished Basement
1	1	6	2	1	0				3
	2	5.9	1.25	0.63	0				5
2	1	7.2	2.0	2.0	17		1	1	3
	2	8.0	2.84	2.0	33		1		3
3	1	6.0	2.0	1.0	0			1	3
	2	6.0	2.0	1.0	0				3
4	1	6.4	2	1	0				2
	2	8.0	2	1	0				3
	3	6.0	2	1	0				4
5	1	7.3	1.7	0.33	0				3
	2	6.0	1.0	0.5	0			1	1
	3	5.0	1.0	1.0	0				1
6	1	5.5	1.25	0.25	0				3
	2	7.0	1.25	1.0	26				4

used only qualitatively to help direct the regression analysis.

The analysis of variance shows that at two of the six sites there is a significant difference in the selling price:

Site	Row	Selling Price Average ($)	Standard Deviation ($)	Significance of Differences
1	1	56 750	1 475	0.017
	2	60 600	3 247	
2	1	90 900	16 690	0.365
	2	99 333	14 010	
3	1	51 700	3 421	0.624
	2	50 625	2 689	
4	1	42 767	1 979	
	2	43 717	881	0.686
	3	43 823	1 993	
5	1	54 810	4 615	
	2	54 271	8 652	0.503
	3	49 333	289	
6	1	50 000	4 619	0.001
	2	64 543	4 779	

At site 1, the first row of housing sold for an average of $3850 less than the second row, or roughly 7 percent of the first-row price. The difference in sound level between the two rows is quite large [14 dB(A) in daytime L_{eq}), and the level at the first row [76 dB(A) in daytime and 73 dB(A) at nighttime] is close to the maximum that one is likely to encounter near normal highways. At site 6, the first row of housing sold for an average $14 543 less than the second row, or a 29 percent difference. However, at this site, three of the housing characteristics differ, and all indicate that the second row of housing is better than the first. Hence, it would be incorrect to assign all of that difference in housing price or even most of it to the difference in the noise environment of the two rows. Since, however, the sound levels differ by roughly 10 dB(A) and the level at the first row is nearly as high as at site 1, it is plausible that noise is also a contributing factor to the difference in price.

At the remaining four sites, any existing differences in average housing prices are not significant at the 0.05 level. This absence of a difference may provide further information about the occurrence of differences in housing prices attributable to road traffic noise. In particular, at all four sites that do not show significant differences, the daytime L_{eq} is 70 dB(A) or less at the first row of housing. At the two sites that do show price differences, the daytime L_{eq} is 73 or greater.

Table 3. Multiple regression results for sites that experience 70-dB(A) daytime L_{eq}.

Variable	All Variables in Set: Coefficient[a]	Standard Error	Order of Entry	Four Variables Only: Coefficient	Standard Error	Order of Entry
Daytime L_{eq}	-729	104	1	-658	89	1
Number of rooms	-	-		-	-	
Number of bathrooms	7864	1342	2	7252	1116	2
Size of garage	-	-		-	-	
Presence of swimming pool	9332	2362	3	9739	2266	3
Year of sale	2554	823	4	2325	768	4

[a] Reported only for variables significant in the equation at the 0.05 level or better.

The possibility of a threshold noise level below which the price of housing is unaffected suggests that in performing multiple regression analyses it may be useful to separate the sites on the basis of the noise level experienced.

One difficulty in analyzing factors that affect housing prices is that relative location within a metropolitan area clearly has a significant effect; there is in fact a large body of literature on this factor alone (10). The seven sites in this study, as indeed the four sites reported in the study by Gamble, Sauerlender, and Langley (6), are widely dispersed throughout the area. To control for the location price, all regression results reported here use as the dependent variable the difference between the selling price of a house and the average selling price for all houses at that site. If some such technique is not used, combining data from all sites is likely to yield misleading results.

The difference in price was regressed against the L_{eq} and the following housing characteristics: number of rooms, number of bathrooms, garage size (number of automobiles), and presence of a swimming pool (included as a dummy variable). Information on the condition of the basement had been obtained during data collection but could not be used directly in this analysis because it is only ordinal data. Length and width of the lot were not included in the analysis partly because of a high proportion of missing data, which would have reduced the sample severely, and partly because of the high degree of correlation of these variables with number of rooms for those cases in which data were available. To be sure that there were no major shifts in prices over the 2.5-year period, the final variable used in the analysis was the year of the sale. Subsequent work with these data will use constant-dollar prices.

The data were analyzed in two subsets—as suggested by the results of the analysis of variance—as well as in the entire set. The first subset consisted of the two noisy sites, which contained a total of 27 house sales. Clearly, this is a very small data set for multiple regression, and underlying relations must be fairly strong to be identified as significant. Because values were missing for some variables, the actual number of cases available for regression is even smaller. A second analysis, restricted to those variables that were significant at the 0.05 level in the first regression, was performed to see if coefficients remained stable with an increased number of data points. The results of the analyses are given in detail in Table 3 and can be summarized as follows:

Subset	Number of Cases	Multiple R	Adjusted R^2
All variables in set	15	0.949 66	0.862 59
Four variables only	21	0.931 70	0.835 07

For the noisy sites, inclusion of all variables provides only 15 data points, but the resulting adjusted R^2 is 0.86, and the overall equation is significant (F) at the 0.0001 level (Table 3). The absence of the number of rooms from the equation seems attributable primarily to the low variation in this variable. Noise is valued at just over $700/dB—a value that is higher than that at any site in the paper by Gamble, Sauerlender, and Langley (6). Restriction of the analysis to the four significant variables in this first equation (Table 3) increases the number of cases to 21, which has the effect of altering all the coefficients and slightly reducing the R^2. However, the new coefficients are all within one standard deviation of the old ones, so they are in no sense contradictory, and for all coefficients the standard error has decreased. The new value for the noise effect is just over \$650/dB. It should be emphasized that this value applies only to the noisy sites—that is, 73 to 76 dB(A) in daytime L_{eq}.

The implications of these regression parameters are most easily demonstrated for site 1. A difference of 14 dB(A) between rows implies roughly a \$10 000 difference in housing prices. The actual difference is only \$4000. However, houses in the second row have an average 0.75 fewer bathrooms. Since these appear to be valued at close to \$8000, the \$6000 discrepancy is accounted for. Another interpretation is that construction of a barrier that causes a 15-dB(A) reduction in L_{eq} probably increases the value of the adjacent property by close to \$10 000. At noisy sites, it seems clear that traffic noise can make a sizable difference in housing prices.

At the remaining sites, which experience 70 dB(A) or less daytime L_{eq}, no such effect is apparent. The noise measure is the last of the six variables to enter the equation and is significant at only the 0.61 level. In fact, none of the variables are significant at the 0.05 level, and the adjusted R^2 indicates that the full set of variables explains less than 10 percent of the variation in price differences from each site's average; thus, these results are not given in a table. (Of the 61 possible sales, only 30 have full data for this analysis.) The reason for this poor result appears to be the importance of the basement variable in this subset. Allowing it to be used in an exploratory regression (which is not valid because basement condition is only an ordinal-level variable) shows it to be the first variable entered and results in two other variables being significant at the 0.05 level in a multivariate equation and the adjusted R^2 being 0.49. The noise measure is still not significant, however. It would be the fourth variable entered, but its coefficient in the four-variable equation is only 154 with a standard error of 216.

In an effort to improve the regression for these less noisy sites and to emphasize the noise variable, site 2 was deleted from the analysis. It has the smallest difference in noise levels between rows [only 6 dB(A) as opposed to more than 10 dB(A) at the other 3 sites] and the largest variation in prices as well as much higher prices overall. The remaining three sites (3, 4, and 5) seemed more nearly comparable. For this subset of the data, 20 cases were usable. A three-variable equation (size of garage, number of bathrooms, and year of sale) explains 55 percent of the variation, and all three variables are significant in the equation. The next variable to enter is the pseudo-variable on basement condition, which brings the adjusted R^2 up to 0.76. The noise measure enters next but does not increase the R^2 and has a coefficient of only 28 with a standard error of 50, so it is clearly not significant. Noise level does not appear to affect housing prices significantly when the daytime L_{eq} is below 70 dB(A) even where a 10-dB(A) difference exists between rows of housing.

Analyzing all of the sites together can be expected to mask these two separate effects and to show a lower average price per decibel than the first subset did, and this does indeed happen. For the set of variables that excludes basement condition, the noise measure is the last variable to enter and is significant only at the 20 percent level: The coefficient is only 187 with a standard deviation of 140. For this equation, with all variables entered, the adjusted R^2 is only 0.22, which suggests that basement condition remains important for the full data set. When basement condition is added to the set of variables, it is the first variable to enter, and the final adjusted R^2 for all variables increases to 0.50. Clearly, it would help the explanatory value of these equations if a valid interval-level measure of basement condition were available. Several efforts were made to provide this, at least as a dummy (0, 1) variable (since all houses had basements and almost all were finished) by deleting two or three cases and by dichotomizing to totally finished and not totally finished. These produce valid regressions in which basement condition is always among the first three variables to enter and in which the adjusted R^2 ranges from 0.43 to 0.60. However, the important point is that, in all analyses with the full data set, the place of the noise variable changes little. It is usually the fourth variable entered but is only significant at about the 16 percent level. Its coefficient is similar in most instances—in the 170s—and the standard error is in the 120s or 130s. Clearly, then, this combination of data from sites that experience a range of noise levels has obscured the strength of the effect of traffic noise on housing prices.

CONCLUSIONS

The principal conclusion of this analysis is that major differences in housing prices are clearly related to high levels of noise from highway traffic. Both parts of that statement must be emphasized. First, high sound levels—above 73-dB(A) daytime L_{eq} or higher, for example—are necessary if housing prices are to be significantly affected. Levels of 60 and 65 dB(A) have been shown to be associated with annoyance but appear not to affect housing prices. [A daytime L_{eq} of 70 dB(A) is approximately the level at which 50 percent of the population is disturbed by traffic noise (3).] Second, for these high noise levels, the cost of noise appears to be roughly \$650 to \$700/dB. A noise barrier that produces a 15-dB(A) reduction would be worth approximately \$10 000/housing unit.

Although these conclusions are fairly clear from the data presented here, two questions warrant consideration. Are the results consistent with earlier findings? Can one be sure that the differences in housing price are the result of noise?

The obvious results with which to compare for consistency are those of Gamble, Sauerlender, and Langley (6) for two reasons: The analytical approach was similar, and their results showed a considerable variation in the dollars-per-decibel value at the different sites. If that variation was related to noise levels, the results reported here would be strengthened. At first glance, their results do not support ours. The highest dollars-per-decibel value, 646, occurs at the lowest noise pollution level (NPL), 80 dB(A). The other three sites have NPL readings over 85 and dollars-per-decibel values of less than 150. However, the noise measure used in that study is not directly comparable with that used here. The NPL adds a factor, related to variability, to the L_{eq} (11), which gives added weight to sites with intermittent noisy events. There is a strong possibility that the choice of NPL as the noise measure has obscured the result we have found and that it is present in the data of Gamble, Sauerlender, and Langley as well. If one looks at their site descriptions, it is at least plausible that the site with the highest dollar-per-decibel value has the highest L_{eq}. The percentage of trucks is double that at the sites with similar traffic volumes, which would increase the L_{eq} and reduce the variability. Consequently, it is not clear at the moment whether their results do or do not support our conclusions.

The second question receives a more definite answer that likewise leaves our results a bit tentative. One cannot be sure that the differences in housing price associated with traffic noise are in fact caused by the noise. They may be caused by several other factors, such as air pollution or dust. Because noise is a good correlate of distance from the highway, it serves as a proxy for these variables as well. Gamble, Sauerlender, and Langley (6) point out the difficulties of isolating these several effects of road traffic. Rather than undertaking the extensive data collection that would be necessary to provide sufficient data to isolate such factors, it may be more practical simply to study the economic consequences of the construction of noise barriers along very noisy stretches of road. If they are associated with differences in housing prices of the magnitude we have identified, they are apparently effective in reducing whatever effects people are reacting to.

The results reported in this study have one very important implication for noise-abatement policies: Noise impacts, as expressed in house price differentials, are a nonlinear function of sound levels. Our results show these economic consequences to be not significantly different from zero at roughly 65 dB(A) daytime L_{eq}, and to be considerable ($650/dB) at daytime average sound levels in the mid-70s [dB(A)]. More data than were available for this study would be needed to specify the nature of the relation fully, but the nonlinearity of the impact is clear. Consequently, it is more important to achieve noise reduction at the noisiest locations than it is to achieve an equal reduction at locations that are not quite so noisy. Such a proposition has seemed intuitively reasonable to many people, but existing studies did not provide strong support for it. This analysis does support it and suggests that future research on differences in housing prices should focus on locations that experience 70-dB(A) (daytime L_{eq}).

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