# The Effects of Traffic Sound and Its Reduction on House Prices

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ABSTRACT

Sales histories of two residential neighborhoods bordering on an Interstate highway were examined to determine the effect of traffic sound reduction on house prices. Sound levels were reduced in one of the neighborhoods by building a barrier along the highway. The second neighborhood, which remained unshielded, served as a comparison area. Before the barrier was built in the first neighborhood, sound levels in both neighborhoods were determined primarily by proximity to the highway. Analysis of house prices showed that, in the absence of shielding, houses nearest the highway sold for less than equivalent houses farther away. The magnitude of this highway-proximity effect, measured in percent of house value per decibel of sound gradient, was consistent with similar estimates previously reported in the literature. The proximity effect on prices appears to have persisted long after the barrier was built. Hence, although the barrier reduced the level of traffic sound and annoyance in the shielded neighborhood, there was no evidence that these benefits were capitalized into higher house prices. The results of this study therefore suggest that hedonic price regressions (which are not based on true treatment-control data) may overestimate the potential economic benefits of traffic sound reduction.

One way to estimate the potential benefits from traffic sound reduction is to determine the relation between traffic sound and residential property prices. Many analysts view traffic sound as an environmental pollutant that can depress property values. Assuming that purchasers of property exposed to traffic noise trade off annoyance for lower prices, then the difference between the price of a house in a noisy environment and the price of a comparable house in a quieter area is a measure of the value of noise.

Several studies have sought to estimate the value of noise. Nelson (1) recently reviewed 9 empirical studies covering 14 housing sites in Canada and the United States. Among other findings, each study reported some type of property price-reduction rate (or depreciation rate), that is, for each decibel increase in outdoor sound level a corresponding property price reduction was specified. Because some of the studies used different measures of price reduction, Nelson expressed all price changes in percentage terms. Similarly, because the studies used various measures of sound intensity, he converted the sound intensity measures to the LEQ scale. (LEQ stands for equivalent sound level, a measure widely used for describing time-varying environmental noise.) In this way, he was able to compare the 9 studies on the basis of their estimates of the Noise Depreciation Sensitivity Index (NDSI), which specifies the percentage decrease in the value of a residence that would result from a 1-decibel (dB) increase in LEQ.

Nelson's review "suggests noise discounts in the range 0.16% to 0.63% per decibel, with a mean of 0.40%" (1,p.129). A similar NDSI estimate of 0.5 percent per decibel was produced in a more recent study not included in Nelson's review (2,p.540). Another recent study, which used a new data-analysis technique, also found a noise effect on property prices (3). Hence, the evidence suggests that traffic sound can cause a measurable reduction in property prices.

In the research cited here, the sound-level differences were associated with distance from a sound source rather than with any action to reduce sound. Yet, as Taylor et al. (2) have noted, homeowners would also be expected to experience monetary benefits in the form of higher property prices if traffic sound levels were reduced. Accordingly, this study was undertaken to investigate whether homeowners receive monetary benefits from higher property prices when traffic sound levels are decreased in a residential area. The sound-level reductions in this study were obtained by constructing an earth berm between the homes and the sound source, an Interstate highway.

## HISTORY AND GEOGRAPHY OF STUDY AREA

During the summer of 1973, a group of residents from the Troy Meadows and Lakewood subdivisions of Troy, Michigan, petitioned their city government to reduce traffic sound and other annoyances associated with nearby Interstate Route 75 (I-75). These homeowners requested construction of a pair of earth berms to shield their houses from roadway-related disturbances. Because the homes in Troy Meadows and Lakewood were built several years after the construction of I-75, the Troy city officers and Michigan state highway authorities decided that the berms should be paid for by the residents who were affected. After a lengthy public debate about the project and its costs, a berm to shield Troy Meadows was completed in the summer of 1974. Lakewood residents, however, abandoned plans to build a berm in their subdivision.

A before-and-after study was conducted to measure sound levels, annoyance, homeowner willingness to pay for noise reduction, and perceived benefits derived from the Troy Meadows berm (4). In this paper, some of these measurements will be combined with data on real estate transactions that have taken place in the two subdivisions from the time of their initial development through May 1980.

Figures 1 and 2 are maps of Troy Meadows and Lakewood that show the location of houses and streets relative to I-75. In both figures, individual homes are labeled by house row number. The two subdivisions lie directly east of I-75 and are separated by Wattles Road, which spans the highway with an overpass. The prevailing wind in this region is from west to east across I-75. Because the land is relatively flat and open, there were no natural barriers to impede the transmission of traffic sound. Each of the two subdivisions will be discussed further.

Troy Meadows is a relatively affluent neighborhood with paved streets and attractive tall trees. It was developed between 1971 and 1973, and contains 65 well-maintained houses aligned in 5 rows approximately parallel to the highway. The near lane of I-75 is 70 m from the abutting property line of the closest home in Row 1 and 230 m from the farthest house in Row 5. All of the houses except two have two stories and most contain 204 to 214 $m^2$ (2,200 to 2,300 $ft^2$) of living space. The majority of homes face either directly toward or directly away from I-75.

Lakewood, a somewhat less affluent subdivision, was developed between 1968 and 1971. The homes in this subdivision form 12 rows roughly parallel to I-75, although they actually face side streets perpendicular to I-75; some of these streets are still unpaved. Forty-seven of the 68 houses in Lakewood are single-story houses and 21 are two-story houses, and most have 121 to 158 $m^2$ (1,300 to 1,700 $ft^2$) of living space. The near lane of I-75 is 55 m from the closest house in Row 1 and 425 m from the farthest house in Row 12. All of the backyards have some direct view of the highway. Characteristics of typical Troy Meadows and Lakewood houses are summarized in Table 1.

At this location, I-75 is a limited-access divided highway with three lanes in each direction. In 1973, it handled approximately 49,000 vehicles during an average 24-hr period. By 1975, traffic volume had increased to 59,000 vehicles/day. Trucks of all kinds account for about 20 percent of the traffic at times other than those of maximum use, and heavy trucks may constitute as much as 10 percent of the total mid-morning traffic. Traffic flow occasionally exceeds 3,000 vehicles/hr in one direction during the morning and evening rush hours.

## TROY MEADOWS EARTH BERM

The homeowners who circulated petitions protesting noise and other annoyances were familiar with traffic sound-reduction methods. They determined that earth berms would be the most cost-effective and aesthetically acceptable sound barriers for the region. Construction of two separate berms was originally proposed because the overpass embankment at Wattles Road divides the I-75 right-of-way between the two subdivisions. As indicated, plans to build a berm on the Lakewood side of Wattles Road were abandoned before construction could begin.

Figure 3 is a photograph of the Troy Meadows berm taken from the overpass spanning I-75 at Wattles Road. The berm is 610 m long and 3.4 m high relative to the pavement surface on I-75 and cost $41,700 to construct in 1974. Table 2 gives the payment schedule for recovery of construction costs. These variable payments were assigned by the Troy city assessor and

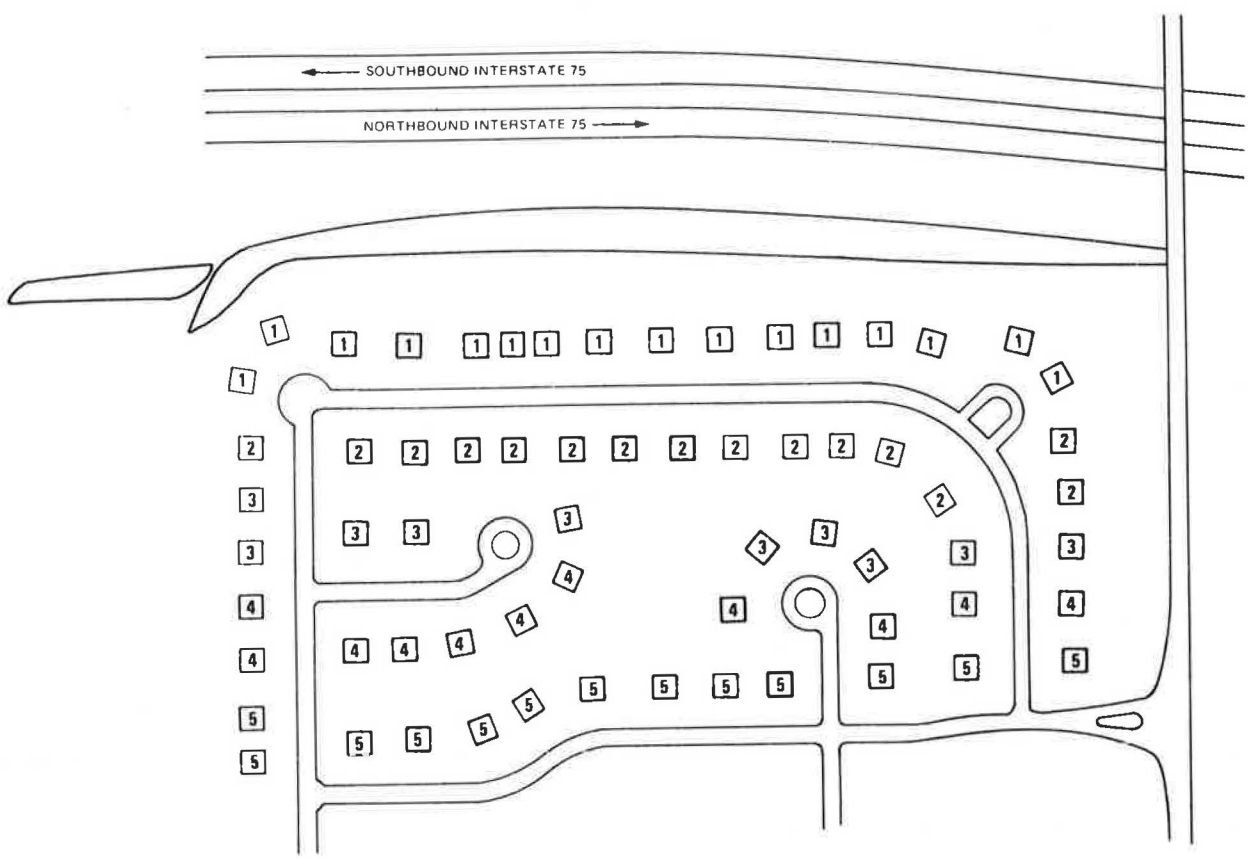


**FIGURE 1 Troy Meadows subdivision.**

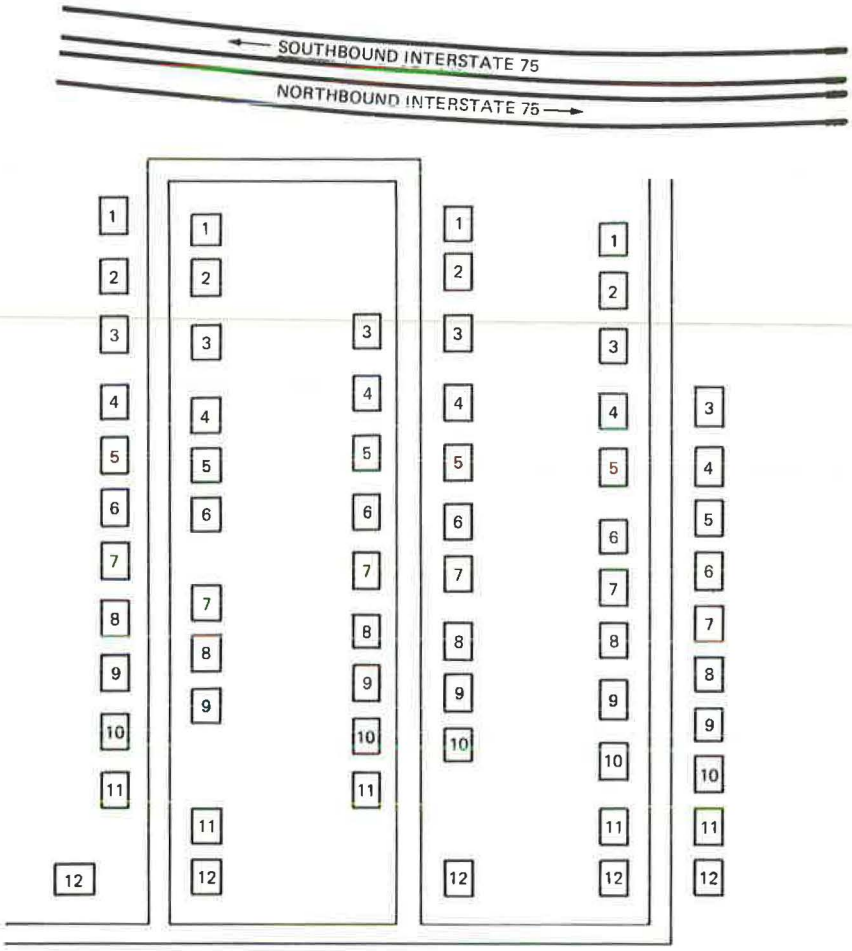


FIGURE 2 Lakewood subdivision.

TABLE 1 Typical Housing Characteristics

| | Troy Meadows | Lakewood |
|---|---|---|
| Type | Two-story houses | One- and two-story houses |
| Size | 204 to 214 $m^2$ (2,200 to 2,300 $ft^2$) | 121 to 158 $m^2$ (1,300 to 1,700 $ft^2$) |
| Orientation | Face directly toward or away from I-75 | Face at a right angle to I-75 |
| Date built | 1971 to 1973 | 1968 to 1971 |

could be financed over an 11-yr period at an interest rate of 8 percent.

## Effects of Berm on Sound Levels and Homeowners' Perceptions of Effects

The results of the before-and-after study (4) are summarized here. As is suggested in items 3 and 4 in particular, the berm might be expected to have a positive impact on the future resale values of the homes benefiting from it.

1. Originally, significant annoyance from traffic noise was confined primarily to Rows 1 and 2 in Troy Meadows and to Rows 1 to 4 in Lakewood; both of these areas were exposed to an LEQ (24 hr) greater than 60 dB. Moreover, willingness to pay for the berms was concentrated in these high-annoyance areas. In other parts of the subdivisions, LEQ (24 hr) was less than 60 dB and willingness to pay for the berms tended to be low.
2. The berm reduced sound levels in Troy Meadows by 6 to 7 dB at the property line of houses in Row 1, where backyards abut the highway right-of-way. At this property line, maximum LEQ (1hr) sound levels were decreased from 71 to 65 dB, and LEQ (24 hr) levels were reduced from 67 to 61 dB. The reduction in Row 2 was estimated to be between 5 and 6 dB. After installation of the berm, houses in Rows 1 and 2 of Troy Meadows were exposed to an LEQ (24 hr) of 60 dB or less.
3. Annoyance ratings in Rows 1 and 2 of Troy Meadows decreased by a large and statistically significant amount, so that with the berm in place the annoyance ratings in all rows were comparatively low and at approximately the same level.
4. The Troy Meadows homeowners who perceived that they were receiving major benefits from the berm lived primarily in Rows 1 and 2. They believed that they had received their money's worth from the

FIGURE 3 Troy Meadows earth berm.

TABLE 2 Payment Schedule for Troy Meadows Earth Berm

| Row | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Payment ($) | 1,017 | 814 | 610 | 407 | 203 |
| No. of houses | 16 | 15 | 10 | 11 | 13 |

berm, while persons in Rows 3 through 5 considered the benefits of the berm to be worth less than their assessed payment.

5. The berm reduced by one-half or more perceived loudness of traffic sound in Rows 1 and 2 of Troy Meadows, but in Rows 3 to 5 there was little change in perceived loudness. Noise reduction was the principal benefit experienced in Rows 1 and 2, while elsewhere residents perceived there to be greater benefits from visual shielding than from noise reduction. These visual benefits included improved appearance of the neighborhood, greater privacy, and elimination of the "visual noise" of seeing passing vehicles.

6. Disadvantages associated with the berm included weeds, unattractive ground cover, and annoying sounds from motorbikes whose riders were attracted to the berm. In addition, a few residents complained about not being able to see traffic on the highway.

## ANALYZING REAL ESTATE DATA

Real estate transactions from the first new homes sales through March 1980 were analyzed to determine how prices in the two subdivisions were affected by highway proximity and the berm. For each house, the geographic location, size ($ft^2$), and sales history (date and price of initial sale and any resales) were included in the data base. However, other attributes affecting house prices--such as decor, condition, air conditioning, swimming pools, and built-in appliances--were not observed. For this reason, comparisons have been made between groups of houses rather than between individual houses, although it has been assumed that the unobserved attributes did not vary systematically between the groups being compared.

Note that, in general, the prices in two different real estate transactions are not directly comparable. First, the houses may be of different sizes, and using cost/$ft^2$ only partially corrects for size because a large house is generally cheaper per $ft^2$ than a small house that is otherwise similar. Thus, a comparison of the desirability of two locations using cost/$ft^2$ would be biased if one of the locations had larger houses than the other. Second, two houses of the same size could differ in decor, appliances, and other attributes. Based on the apparent homogeneity of the houses at these sites, however, it appears reasonable to assume that the unobserved attributes do not vary systematically with location in a given subdivision. Finally, two transactions with different dates of sale require adjustments for inflation before a valid price comparison can be made.

The problems of comparing two different real estate transactions can be handled by treating the variable PRICE as a function of the explanatory variables SIZE, DATE, LOCATION, and ERROR using a different function for each subdivision. Here, SIZE is the square footage of the house, DATE and PRICE refer to the amount that the house would sell for at a given time, and LOCATION is a proxy for distance from the highway. The ERROR variable represents the unobserved differences between transactions, including the possible physical differences already mentioned, the desires and bargaining abilities of buyers and sellers, the input of agents and appraisers, and any other influences on the sale price that are not observed in this data base.

In the calculations in this paper, log(PRICE)

rather than PRICE itself will be used as the dependent variable. This has three advantages. First, if two differently priced houses were subject to the same, possibly time-varying, rate of price appreciation (such as during a period of inflation), the dollar gap between the prices would increase but the gap between their log prices would not change. Second, one of the simplest models for the effect of PRICE on DATE is that of exponential growth, under which log(PRICE) is a linear function of DATE. Finally, differences in log prices can easily be re-expressed as percentage price differences.

To summarize, log(PRICE) will be modeled as a linear function of the explanatory variables. The resulting regression coefficients can be interpreted in a way that relates the explanatory variables to percentage price differences; for example, if the coefficient for highway proximity was x units/m, each additional meter of distance would increase prices by 100[exp(x)-1] percent. Furthermore, if it was known that traffic sound decreased at about y dB of LEQ per extra meter of distance, it could be estimated that the NDSI [discussed by Nelson (1)] equals 100[exp(x)-1]/y percent/dB at this site. Estimating the regression coefficients and their standard errors requires that the standard assumptions of regression analysis be made. Also, the data base will be considered as if it were a random sample from some superpopulation of houses.

There is one final assumption made in the calculations in this paper unrelated to those discussed in the preceding paragraph. Since some resale buyers may have taken over the liability of paying the annual assessments for construction of the berm, their willingness to pay might not have been accurately represented by the prices they paid. Note, however, that the assessments (shown in Table 2) are probably too small to be significant, especially if paid monthly along with a mortgage payment. Also, unless the assessment effect varies systematically with location, it will not bias the analysis.

## CONFIRMATORY FINDINGS OF PROXIMITY EFFECTS

As noted in the opening section, the evidence in the literature suggests that people will pay extra to locate away from a highway abutting their neighborhood. The disadvantage of highway proximity is usually identified with traffic noise, although visual and other stimuli are also involved. Traffic sound differentials sufficiently large to cause differences in reported annoyance were observed in the two unshielded situations, that is, in Lakewood and in Troy Meadows before the berm was constructed. Therefore, these unshielded situations should be examined to determine whether proximity-induced traffic sound differences affected real estate prices.

In the Lakewood subdivision, after excluding one exceptionally large house and one exceptionally small house, there remain 57 houses in the data base; these houses range in size from 1,300 to 1,920 $ft^2$. All of these except three were built during the period 1968-1971. Recall that in Lakewood there are many rows (12) with only a few houses (3 to 6) in each row. The large number of rows makes it reasonable to treat ROW as an interval-scale explanatory variable.

The model

$$\log(\text{PRICE}) = A + (B)(\text{DATE}) + (C)(\text{ROW}) + (D)(\text{SIZE}) \quad (1)$$

has been estimated for the houses in the Lakewood subdivision (57 initial sales plus 32 resales). The fit is quite good ($R^2$ = 0.924), and all three explanatory variables are significant at the 1 percent significance level, indicating the existence of a proximity effect. The parameter values and their standard errors (in parentheses) are: A = 10.053 (0.047), B = 0.066 (0.002) per year, C = 0.00766 (0.00198) per row, and D = 0.00016 (0.00003) per $ft^2$. It is implied by these estimates that a 1 percent increase in size yielded roughly a 0.25 percent increase in the price of an average Lakewood home, that prices were increasing at about 6.8 percent/yr during the period 1968 to 1977, and that prices increased by 0.77 percent (standard error = 0.20 percent) per row as one proceeds away from the highway. This last value makes the expected price of a house located in the center of Lakewood subdivision about 5 percent higher than it would be if it were located in Row 1.

During the research for what eventually became the Troy Meadows berm effectiveness study (4), sound contours were obtained for Lakewood as well. When the sound difference between Row 1 and the middle of the subdivision is combined with the 5 percent price difference estimated in the preceding paragraph, an NDSI of roughly 0.4 percent/dB is obtained for Lakewood. This is in agreement with the NDSI estimates cited in Nelson (1) and Taylor et al. (2).

A proximity effect in the neighboring Troy Meadows subdivision during the unshielded pre-berm period was also looked for. Because 47 of the 65 houses in Troy Meadows are of the same style and size (2,262 $ft^2$) and are scattered among all five rows, one can control for house size by restricting attention to these comparable houses. In this group, there were 47 initial purchases during a 2-yr period from 1971 to 1973, and only 8 resales before the berm was built; therefore, little is lost by ignoring the resales and restricting attention to the 47 initial sale transactions. Hence, it is the market for new, nearly identical houses that is being examined.

The observed prices were lowest in Row 1, highest in Row 5, and took intermediate (and essentially equal) values in Rows 2 to 4. The houses were built during a 2-yr period and, generally speaking, Rows 1 and 4 were sold first, followed by Rows 2, 3, and 5, respectively. In a linear regression of log(PRICE) on ROW and DATE, both explanatory variables were significant, so there does appear to be a proximity effect in Troy Meadows. Recall that, while the distance of one row from the highway is a small increment in Lakewood, in Troy Meadows there are only five rows with many houses in each row (see Figure 1). This means that it would be more appropriate to use a dummy-variable approach to represent the row effect in Troy Meadows.

The following statistical model was fit to the 47 data points:

$$\log(\text{PRICE}) = A + (B)(\text{DATE}) + C_2R_2 + C_3R_3 + C_4R_4 + C_5R_5 \quad (2)$$

where $C_i$ is the premium in log(PRICE) that Row i commands over Row 1, and $R_i$ = 1 if the house is in Row i and $R_i$ = 0 otherwise. The estimates of $C_i$ suggest that there were really only three price levels: Row 1 was cheapest, Rows 2 to 4 were sold at intermediate prices, and Row 5 was the most expensive.

The following reduced model

$$\log(\text{PRICE}) = A + (B)(\text{DATE}) + C_{234}R_{234} + C_5R_5 \quad (3)$$

provides a slightly higher corrected $R^2$ (0.724 versus 0.716). Its parameter estimates and their standard errors (in parentheses) are: A = 10.659 (0.018), B = 0.019 (0.010) per year, $C_{234}$ = 0.039

(0.009) between Row 1 and Rows 2 to 4, and $C_5$ = 0.088 (0.013) between Row 1 and Row 5.

Are these values reasonable? It is suggested by the DATE coefficient that price increases for these new homes were 1.9 percent annually (around 1972). This figure appears slightly low, which perhaps is due to the short time period covered by the sample. A low figure would also result if the best houses sold first. If the builders increased their prices at all it was done only occasionally, not continuously. The estimated premium from Row 1 to Rows 2-4 is 4 percent, and from Rows 2-4 to Row 5 it is an additional 5 percent. While the latter difference probably has more to do with the presence of larger lots and cul-de-sacs than it does with highway proximity, it is suggested by the former difference that buyers of houses in Row 1 received discounts of about 4 percent (standard error = 1 percent) as compensation for having their backyards adjoin the highway. Taylor et al. (2,p.533) have also reported some evidence of a first-row discount.

The percentage discounts reported for Troy Meadows are similar to those reported for Lakewood. Because the sound-level difference between Rows 1 and 3 was about 7 dB (67 dB versus 60 dB) before the berm was built, the NDSI estimate is 0.6 percent per decibel for Troy Meadows. Hence, the analyses of Lakewood and of Troy Meadows before the berm was built both support the premise that highway proximity affects housing prices in the manner described by Nelson (1).

## DOES TRAFFIC SOUND REDUCTION CONFER ECONOMIC BENEFITS?

It is suggested by the evidence relating real estate values to sound levels that traffic sound abatement would confer monetary benefits on some homeowners by increasing their property values. However, all such evidence is essentially cross-sectional rather than the result of a before-and-after study of property values before traffic sound abatement versus values of these same properties after abatement. Taylor et al. (2) state that the "study of the effect of barrier construction on house prices is [thus] an important topic for inquiry." The study presented here is, to the knowledge of the authors, the first such before-and-after study. It should be noted that only a single site will be reported on and that the findings may not hold in general.

Recall that the Troy Meadows earth berm was built between a traffic sound source and an existing residential neighborhood, that it reduced sound levels in Rows 1 and 2 (previously the high-annoyance area) below the previously observed LEQ = 60 dB annoyance threshold, and that it reduced annoyance ratings in Rows 1 and 2 to essentially the same low level as in Rows 3 to 5. Note also that a price gradient with respect to distance from the highway existed in Troy Meadows before the berm was built. (A price gradient in the nearby Lakewood neighborhood persisted over time, so the price gradients are not merely artifacts of the developers' initial prices.) If sound-level differences due to traffic sound reduction confer the same economic benefits as do sound-level differences due to distance from the highway, then it would be expected that the Troy Meadows earth berm would eliminate, or at least reduce, the price premium for distance from the highway. It might also be possible to detect a house-price increase in Rows 1 and 2 coincident with the construction of the berm.

To test the hypothesis that traffic-sound abatement would confer monetary benefits on some homeowners by increasing their property values, methods discussed in the preceding section will be used to look for proximity effects in Troy Meadows during the post-berm period. Post-berm resales of houses with 2,262 ft² occurred between mid-1975 and early 1980 and were spread among Rows 1 (7 resales), 2 (9 resales), 4 (4 resales), and 5 (4 resales). The full model, which is Equation 2 with $C_3$ set to 0, revealed no statistically significant difference between $C_4$ and $C_5$. The reduced model with Rows 4 and 5 pooled is

$$\log(\text{PRICE}) = A + (B)(\text{DATE}) + C_2R_2 + C_{45}R_{45} \qquad (4)$$

This model gave an equally good fit ($R^2$ = 0.92) and produced the following estimates (and standard errors): A = 10.206 (0.070), B = 0.127 (0.008), $C_2$ = 0.041 (0.030), and $C_{45}$ = 0.089 (0.031).

The figures in the preceding paragraph suggest that in post-berm Troy Meadows, Row 2 sold for a 4 percent (standard error = 3 percent) premium over Row 1, while Rows 4 and 5 sold at a 9 percent (standard error = 3 percent) premium over Row 1. The DATE coefficient suggests an annual appreciation rate of 13.5 percent, which reflects the strong market for these houses in the late 1970s. Although these premium estimates are somewhat imprecise, they imply that proximity to the highway continued to affect prices even after the berm was built. Indeed, their similarity to their pre-berm counterparts indicates that the berm did little to reduce the existing price differentials between rows. Apparently, any effect of the berm on prices was too small to be detected in the presence of other variation.

## SUMMARY

The research reported in this paper concerns the effects of traffic sound and its reduction on house prices. It contains comparative analyses of two adjacent sites bordered on one side by an Interstate freeway. It differs from other such investigations in that the sound differentials arose not only from differences in proximity to the highway, but also from the construction of an earth berm shielding one of the sites.

The data are consistent with the generally accepted idea that, in the absence of shielding, proximity to a highway tends to reduce house prices. It is suggested by this idea that a barrier would confer economic benefits (higher resale prices) along with its acoustic and visual benefits. Accordingly, a test of this hypothesis was performed. However, no significant price effects were found associated with a demonstrably effective earth berm, which residents willingly paid to construct. This raises doubts about the use of hedonic real estate price models to quantify the benefits of sound reduction because these models are generally not based on true treatment-control data. It may be that sound differentials are capitalized into house prices differently depending on whether they arise from distance, from barriers, or from quieter traffic streams. To resolve this issue would require larger samples, perhaps analyzed with Palmquist's repeat-sale technique (3).

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# The One-Minute $L_{eq}$ Measurement Method

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ABSTRACT

A noise measurement method for energy-average sound level ($L_{eq}$) that provides more flexibility and information than most methods in use today is discussed. The one-minute $L_{eq}$ measurement method consists of a series of $L_{eq}$ measurements, each one minute in duration. This method requires an integrating sound level meter or portable noise monitor. Limitations of other commonly used methods and advantages of the one-minute method are discussed. An example of the $L_{eq}$ method's use is presented.

A method for the short-term measurement of the energy-average sound level ($L_{eq}$) of environmental noise is described. This method uses currently available integrating sound level meters (SLMs) or portable noise monitors. It consists of dividing the measurement period into a series of one-minute intervals. [A similar measurement technique has been described in Sirieys and Commins (1).] $L_{eq}$ is measured and recorded each minute and observations of significant noise events are made. The overall measurement period can be of any duration but is usually one hour or less and always consists of contiguous one-minute intervals. Overall $L_{eq}$ is determined by calculation of the energy average of the valid one-minute $L_{eq}$s.

The advantages of the one-minute $L_{eq}$ measurement method over more commonly used methods, such as the check-off method and continuous-monitoring method, include increased flexibility, complete sampling of the sound level, and diagnostic capabilities for contributions from various noise sources. In the following sections, limitations of these commonly used methods are discussed further and examples are presented.

## LIMITATIONS OF COMMONLY USED METHODS

### Check-Off Method

The check-off method (2,3) for measuring environmental noise levels has been in use for many years. Originally developed for statistical sampling of noise levels with hand-held SLMs, this method required reading the SLM instantaneously every 10 sec and checking off a box corresponding to the observed level on a data sheet, thereby creating a distribution of check marks. Statistical descriptors, such as $L_{10}$, $L_{50}$, and $L_{90}$, can readily be determined from such a distribution. $L_{eq}$ can also be determined, typically by using a scientific calculator. Statistical tests are then performed to determine the precision with which the descriptor is known. Described in "Fundamentals and Abatement of Highway Traffic Noise" are the procedure and the tests for determining $L_{10}$ in detail (2).

Although the check-mark method is a relatively straightforward procedure, it has some limitations:

- The method is a coarse sampling of the sound level (one sample every 5 or 10 sec), and therefore fairly long measurement periods are often required before $L_{10}$ or $L_{eq}$ can be determined with reasonable confidence. Determining confidence intervals on $L_{eq}$ requires some calculation and the intervals are often quite large.
- The method is subject to reading error.
- Significant loud events can be missed during attenuator switching. This problem is particularly significant when using the method to determine $L_{eq}$. $L_{eq}$ is critically dependent on maxima and, if one or more high-level samples are missed, $L_{eq}$ could be significantly underestimated.
- The measurement engineer's attention is often strongly focused on the mechanics of performing the method properly and little time is available for note-taking about noise sources, important events, or traffic conditions.
- Two individuals are required if simultaneous traffic counts are to be made even on a roadway having only a moderate level of traffic.