# TOWARD A COMMUNITY IMPACT MEASURE FOR ASSESSMENT OF TRANSPORTATION NOISE

Fred L. Hall, Department of Geography and Department of Civil Engineering, and
Brian L. Allen, Department of Civil Engineering, McMaster University

Despite improvements in techniques for measuring and predicting transportation noise, no one has yet developed a reliable method for identifying the total impact on a community of the noise generated by a proposed transportation facility. A procedure, the noise annoyance impact, is developed for measuring this total impact in a variety of units. In essence, the noise annoyance impact transforms noise measurements for a particular location into a number representing the average impact of such noise on people, multiplies this number by the number of people in that location, and sums this result over the full extent of the area. A sample application, based on two proposed highway alignments for an urban area, used the traffic noise index and the noise pollution level to represent the noise and the data from an earlier survey by the Building Research Station in England to specify the percentage of the population annoyed at a particular reading of a traffic noise index or noise pollution level. The resulting noise annoyance impact was thus expressed as the total number of people annoyed. The noise impact is easy to interpret and, therefore, provides a measure of the total areal impact of noise that can be used effectively in public participation efforts. In addition, the formulation of the noise annoyance impact is mathematically sound. It permits combination of all of the pertinent noise data for the full study area into a single number. Although further research is necessary to specify more accurately the relationship between noise and the percentage of population annoyed or any other measure of average noise impact, the principles of the noise annoyance impact can be applied now.

•RECENT concern about the noise produced by transportation facilities has led to improvements in techniques for measuring and predicting transportation noise. Unfortunately, there have not been similar advances in procedures for incorporating the information from these techniques into some overall assessment of the noise impact of a new facility. It is the aim of this paper to develop procedures that can assess the total community impact of transportation-produced noise.

An assessment technique for noise impact should make use of as much relevant information as possible, and the resulting assessment should be as succinct as possible (a single number would be best). In addition, the technique should be mathematically legitimate and should not multiply or add numbers that represent merely ordinal information. Furthermore, at extreme levels, noise can damage hearing or health; at slightly lower levels, noise remains a source of annoyance or irritation. Presumably, facilities whose noise would cause damage will not be built; therefore, the annoyance factor is of prime concern when noise produced by transportation facilities is assessed. What is needed, then, is a way to measure the total annoyance caused people by the noise from such a facility, over the full areal extent of the impact. A general form for such a measure, the noise annoyance impact (NAI), can be given as

$$\mathrm{NAI} = \int \int f\,[\mathrm{noise}\,(x, y)]\ \mathrm{pop}\,(x, y)\,dxdy \qquad (1)$$

where

noise (x, y) = appropriate measure of noise at a particular location (x, y);
pop (x, y) = density of people at that location; and
f (noise) = function that describes the annoyance effect of a given level of noise on people and that will change according to the units chosen to express NAI, e.g., total number of people annoyed, total monetary cost of the noise annoyance, or any other logical units.

For example, noise (x, y) might be measured as noise pollution level (NPL) (to be described later), and f (noise) could express the percentage of a population annoyed by a given NPL. Then,

$$a(x, y) = f[\text{noise}(x, y)]\ \text{pop}(x, y) \tag{2}$$

would be the number of people per unit area at a particular location (x, y) annoyed by the noise, and

$$\text{NAI} = \int\int a(a, y)\, dxdy \tag{3}$$

would be the total number of people in the area annoyed by noise.

One assumption is necessary for this approach: The sensitivity to noise of any small population group is similar to that for the full population. This is equivalent to assuming that the population does not self-select through residential locations so that those who are most sensitive to noise do not reside in noisy locations. It is not the same as assuming that all people respond identically to noise; we know the opposite to be true (1). However, since sensitivity does not appear to be related to socioeconomic characteristics but rather to personality traits (2), it is impossible to predict the noise sensitivity of particular groups given presently available population data. Hence it is necessary to assume that the composition of noise sensitivity in any sample population is similar to that of the whole population and that a single function f can be used to represent this. For obvious exceptions to this assumption, e.g., hospitals, a separate noise response function should be used.

The remainder of this paper develops one approach for calculating the number for NAI, discusses several potential measurement scales for noise (x, y) and the function f (noise), demonstrates the use of the measure, and comments on the viability and possible extensions of the measure.

## NOISE MEASUREMENT

In this section our twofold purpose is to show that the majority of noise measurement techniques fit into the formula of equation 1 as noise (x, y) functions rather than as f (noise) functions and to discuss several available noise measures before they are introduced as elements of the domain of the function f. Because this is the purpose, we will review the noise measures. If one is to interpret what noise is and what effect it might have, two components must be considered: the acoustic or physical properties and the human reaction to those properties. Ascertaining the former by either direct measurement or calculation is not a problem, and a considerable number of acceptable methods are available. However, selection from among these properties and subsequent combination of them into a single measure that corresponds well to the way humans react to noise are more difficult.

Noise has been defined as unwanted sound, and as sound, direct measurement of its physical properties poses no difficulty. However, for the measurements to be of any value, they must include the intensity, frequency, and duration (or variability over time) of a sound. One commonly used method to establish intensity is the sound pressure level (SPL), expressed in units of decibels and computed by the relation

$$\mathrm{SPL} = 20 \log_{10}(p/p_0) \tag{4}$$

where

$p$ = average pressure of a measured sound in a specified frequency band, and
$p_0$ = reference pressure at the threshold of hearing [usually taken as 0.0002 μbar (0.00002 Pa)].

Thus, when $\mathrm{SPL}(p_0) = 0$ dB, sound pressure levels for various pressures may be easily computed. [SPL is not the only measure of noise intensity, but it is commonly used. In fact, Young (3) briefly discusses over 60 noise measurement scales, most of which are variations of the same form.]

The intensity or loudness characteristic depends not only on response to single frequency bands but also on response to wider ranges of frequency. Since sound waves generated by most noise sources do not consist of a single frequency, but rather a range of tones, computational techniques were developed to account for this variation. An early measure by Beranek (in 1936), the speech interference level (SIL), or a later version of it, the preferred speech interference level (PSIL), computed intensity as the arithmetic average of sound pressure levels in three predetermined frequency bands (3). For example, SIL is given as

$$\mathrm{SIL} = 10 \log_{10}[(p_1 p_2 p_3)^{2/3}/p_0^2] \tag{5}$$

where

$p_i$ = sound pressure levels in the three specified bands, and
$p_0$ = reference pressure.

Obviously SIL is identical in form to SPL and has the additional advantage of frequency weighting.

SIL was not the only method to incorporate the concept of frequency into the noise measure; there were at least six methods developed over a 30-year period (from 1930) that attempted to provide even better measures to simulate the response of the human ear to noise. It is not surprising then that this interest in frequency response also resulted in noise measurement instruments that provide direct readout of frequency-weighted noise. When electronic weighting circuits are used, the response of the human ear can be closely simulated if they discriminate against frequencies below 500 Hz and above 10,000 Hz. The most commonly accepted weighting is called the A-weighted scale. Decibel levels referred to in the remainder of this paper will use this weighting, i.e., dBa.

Although the majority of such measures acknowledge that human perception of sound depends on loudness as determined by some combination of frequency and intensity, Kryter argued that annoyance is different from loudness (4, 5). For a study of aircraft noise, he weighted each frequency band differently, thus developing the perceived noise level (PNL) as

$$\mathrm{PNL} = 33.2 \log_{10}\left[\sum_{i} \delta_i (w_i p_i/p_0)^{2/3.6}\right] \tag{6}$$

where

$p_i$ = sound pressure levels in three specified bands;
$p_0$ = reference pressure;
$\delta_i$ = 1 for maximum member in summation, 0.3 for octave bands, and 0.15 for third-octave bands; and
$w_i$ = weighting factor for frequency band i.

Equation 6 is quite appealing in its flexibility, particularly when compared with previously available measures. The $w_i$ could obviously be chosen for a wide range of frequency bands and presumably over a wide range of conditions. Unfortunately the data collection and reduction task would be formidable if the measure were to be developed fully. Additionally it still does not account for the third property of sound outlined at the beginning of this section, i.e., duration or time variability.

Almost all noises vary over time, particularly transportation noise. It is apparent that such variations affect the duration of any particular noise level and must be included in noise investigations if a comprehensive examination is to result. The composite noise rating (CNR) appears to be the first attempt at quantifying this effect into a single measure (3) and is given by

$$CNR = L_{eq} + C_{bk} + C_{other} \qquad (7)$$

where

$L_{eq}$ = value estimated by $L_{max} + 10 \log (t_e/T)$;
$L_{max}$ = maximum sound pressure in specified frequency band;
$t_e$ = effective duration of $L_{max}$;
$T$ = total sampling time;
$C_{bk}$ = correction for background (ambient) noise; and
$C_{other}$ = correction for other factors, such as time of day.

The CNR provides a measure of the amount by which a relatively steady noise exceeds the background noise, modified by time.

Two modifications have been made to PNL to incorporate the duration of noise. A complex modification resulted in effective perceived noise level (EPNL) (3, 5). A simpler noise and number index (NNI) (7) is given by

$$NNI = \overline{PNL} + 15(\log_{10} N) - 80 \qquad (8)$$

where

$\overline{PNL}$ = average peak PNL observed, and
$N$ = number of aircraft flights.

PNL, CNR, EPNL, and NNI dealt with aircraft noise. None correlated well with annoyance caused by traffic noise. The traffic noise index (TNI) was derived by Griffiths and Langdon (8) to better simulate responses to traffic noise as follows:

$$TNI = 4(L_{10} - L_{90}) + (L_{90} - 30) \qquad (9)$$

where $L_i$ is the noise level (dBA) exceeded i percent of the time. As was the case with the previous four measures, TNI is effective only for the explicit purpose for which it was designed; it does not correlate well with response to other types of noise (e.g., aircraft noise).

The most recent entry to account for variability over time is the noise pollution level (NPL) (9), given by

$$NPL = L_{eq} + (L_{10} - L_{90}) \tag{10}$$

where

$L_{eq} = L_{50} + (L_{10} - L_{90})^2/56$, and
$L_i$ = noise level (dBA) exceeded i percent of the time.

The NPL measure in equation 10 has proved to be the most acceptable measure to date. It provides an annoyance response to fluctuations of noise about a mean level (similar to CNR), is modified by time to account for duration, and appears to simulate response well to all forms of transportation noise.

Regardless of the acceptability of any of the previous measures, none explicitly incorporates the time of day. Obviously an NPL or NNI value will represent more annoyance at 3 a.m. than at 3 p.m. At least two measures have been developed to account for this variation: the noise exposure forecast (NEF), extended from the EPNL (10), and the community noise equivalent level (CNEL), derived for surface transportation noise (11). The formulations of the two are similar. For CNEL,

$$CNEL = L_{50} + 10 \log_{10} N_t - 49.4 \tag{11}$$

where

$L_{50}$ = average noise level of events;
$N_t$ = weighted number of events, e.g., $N_d + 3N_e + 10N_n$; and
$N_d, N_e, N_n$ = number of events during daytime (7 a.m. to 7 p.m.), evening (7 p.m. to 10 p.m.), and nighttime (10 p.m. to 7 a.m.) respectively.

Both CNEL and NEF can therefore represent more comprehensively those aspects of noise that lead to annoyance.

## ASSESSMENT OF COMMUNITY IMPACT

Not all recent work has been on measures of noise at one point. A few procedures have been used that attempt to identify the full impact of new facilities over an area. These have not explicitly taken the form of our equation but can be analyzed in terms of it, and the implicit function f(noise) can be identified.

### Previous Research

A procedure based on counting the number of households (or people) within a specified critical noise level contour has been used in several studies (12, 13). The noise levels have been measured as discussed earlier in the paper. This approach has the merit of being a concise measure that incorporates areal extent, but it has two major weaknesses. First, the choice of a critical contour must necessarily be arbitrary and may have an unintentionally large influence on relative outcomes, either because of the population distribution or the landscape features affecting noise propagation. For example, assume that one must compare two alternate routes for a roadway and that the contour of 87 NPL has been selected as critical. [This was the value used in the Rand study (12).] Route A is found to involve 100 households inside the 87 NPL contour, and route B involves 150. The choice is obvious. However, suppose that, for one or both reasons mentioned above, there are an additional 100 houses within the 85 NPL contour on route A and only 10 additional houses in the 85 to 87 NPL band on route B. Then, if 85 NPL had been set as the critical value, the decision would be reversed.

The second weakness relates to the form of the function f(noise). As implied by this procedure, it is a zero-one step function. For NPL readings below 87, $f = 0$, and hence the population affected by these noise levels does not contribute at all toward the final measure. For NPL $\geq 87$, $f = 1$, and every part of the population is counted. This seems to be an unrealistic form for the function to take and certainly is less justifiable than the assumption about the noise sensitivity of small groups made in the introduction to this paper.

The U.S. Environmental Protection Agency recognized these same kinds of shortcomings and suggested some possible remedies (11) that, to the best of our knowledge, have not been further developed. The Ontario Ministry of Transportation and Communications (MTC) has attempted to overcome these shortcomings with a modification of the same basic approach in which a number of different noise contours are mapped and the affected population in each interval or band is counted. Unless the choice is obvious, because of dominance in all the intervals, individual judgment must be used to combine the counts and their corresponding intervals so that a decision can be made. The modified approach does not fit our equation at all, because it does not result in only one number. The advantage of conciseness is lost, and the relative weighting of all these data becomes arbitrary and implicit.

## Proposal

This review of previous and current practice indicates that no one has yet produced a completely satisfactory traffic noise impact measure that incorporates the full areal effect. What is needed is a way to identify the total annoyance caused by a specific transportation project. The following discussion is organized around two questions:

1. What does total annoyance mean?
2. How can the annoyance caused by a specific project be isolated?

A meaningful measure of total annoyance should be grounded in reasonable notions of individual annoyance responses that can be aggregated legitimately and understandably. Two concepts of annoyance responses at the individual level are plausible:

1. Annoyance is a two-valued response, i.e., either one is annoyed or one is not annoyed.
2. Annoyance is a many-valued response, in which increasing degrees of irritation are possible. At the extreme, this concept includes a continuum of annoyance, with an infinite number of possible responses.

The ability to aggregate individual responses legitimately makes certain demands on the kinds of scale (nominal, ordinal, interval, or ratio) used to tally such responses. Aggregation also requires a function that, for a particular measure of noise, will define the impact on persons subjected to that noise. Because response or sensitivity to noise varies considerably for different people, the number given by the function will necessarily be an average or representative response.

Assuming a two-valued individual annoyance response, this average can be easily and legitimately obtained. At any reading of noise $(x, y)$, f(noise) will simply be the percentage of the total population that is annoyed by that noise. The individual response can be measured on a nominal scale, but f(noise), representing aggregate response, will provide a result on a ratio scale, permitting multiplication (by numbers of people) and addition quite legitimately.

The assumption of a many-valued individual annoyance response, although possibly more appealing intuitively, makes aggregation and subsequent calculation considerably more difficult. The standard procedures for collecting data on subjective human responses, such as annoyance caused by noise, rely on ordinal scales (e.g., a semantic differential scale). Arriving at the average response for a particular noise(x, y) reading demands caution when this scale is used. The only legitimate value to use is the median response; use of the arithmetic mean instead of the median response demands that the data be at least on an interval scale. Although ordinal numbers are treated as if they contained interval scale properties, this can be avoided, and a legitimate and representative or average f(noise) can be derived.

Unfortunately, the resulting function cannot be used in the kind of calculation involved in our equation. For such multiplications to be meaningful (much less legitimate), f(noise) must produce numbers on a ratio scale, but the median response values still represent only an ordinal scale. As constructed, our equation implies that 200 people experiencing degree 4 annoyance represent an equivalent impact to 400 people experiencing degree 2 annoyance or 800 people experiencing degree 1 annoyance. Doubling the annoyance measure must imply doubling the severity, or it is nonsensical to multiply populations by annoyance levels.

Although standard subjective response data are ordinal, other kinds of many-valued annoyance response data may be collected that would surmount this problem. For example, a monetary annoyance measure obviously meets the ratio scale requirement and has the additional advantage of being intuitively understandable to respondents. Although such monetary data might be harder to obtain than ordinal data, they seem the simplest way to implement the formula if one prefers to view individual annoyance responses as many valued.

We still have to identify the way in which the annoyance due to a specific project can be isolated. The item of interest is the change in total annoyance caused by the project $\Delta \mathrm{NAI}_j$, where j indexes the several alternative projects. Predicting the noise caused by the project alone and calculating NAI from that to represent $\Delta \mathrm{NAI}_j$ is wrong. Because of the logarithmic scale used to measure sound pressure (equation 4), on which all the noise(x, y) measures are based, noise levels are not directly additive. In fact, if the difference between the SPL produced by two sources is 6 dBA, the total dBA will only be 1 dBA greater than the larger of the two original levels. Noise from one source does not act alone but acts with all other noise sources in the area. Therefore, the project-produced noise must be superimposed on the background noise before NAI is calculated. However, because the background noise is constant for all projects, the impact of the background noise $\mathrm{NAI}_b$ need not be computed and subtracted from $\mathrm{NAI}_j$ so that the best alternative with respect to noise can be selected. That is, $\Delta \mathrm{NAI}_j$ can only be obtained by

$$\Delta \mathrm{NAI}_j = \mathrm{NAI}_j - \mathrm{NAI}_b \qquad (12)$$

but this calculation need not be performed so that a choice among the projects can be made; however, $\mathrm{NAI}_b$ would have to be calculated to obtain some sense of the absolute scale for $\mathrm{NAI}_j$ in each instance, for example, to compare noise reductions with the cost of achieving them.

In summary, the proposal, as given in equation 1, is a measure of the impact of noise based on the total number of people annoyed by a specific transportation project. The function f, the core of this proposal, transforms noise levels (which can be measured however desired) into a measure of the average response of population aggregations to that noise, based on the assumptions that (a) individuals differ with respect to their susceptibility to annoyance caused by noise and that (b) any small group of people can be treated as if their noise sensitivity were the same as that of the whole population. Two meaningful units for NAI are total number of people annoyed, based on the supposition that individual response is two valued, and total monetary value of the annoyance, if individual response is many valued.

## EXAMPLE OF APPLICATION OF NOISE IMPACT MEASURE

The following example is intended primarily to clarify the previous discussion and to demonstrate the practicability of the NAI measure. Some parts of the example, in particular the noise(x, y) measure used and the form of the function f, are not as strong as they could be and need better empirical evidence before they are used in an actual project.

### Study Area

The example is based on a 1.5-mile (2.4-km) section of the Queen Elizabeth Way through Burlington, Ontario, for which a feasibility study had recently been completed for the Ontario MTC (13). Two distinct alignments were considered in that study, as shown in Figure 1. The case study consisted of calculating the NAI of each of the two proposed routes during the peak hour.

The 1973 residential populations (Figure 1) are based on polling subdivisions (courtesy of the Burlington Planning Department). Although these were the smallest areal units for which population figures could be obtained, a rectangular grid of smaller unit area for noise prediction was desirable; therefore, land use maps were used to approximate the residential distribution. Most districts were almost uniformly built on; in these, the population was assumed to be evenly distributed and subdivision totals were divided accordingly. The largest subdivision, in the center of the study, consisted mostly of truck farms. Most of its population was allocated to the few grid rectangles containing housing, and the remainder of the district was given a very small population.

The major contribution to background noise in the area was assumed to come from the secondary streets in that there was no heavy industry nearby. The 1973 AADT data, obtained from the Burlington Traffic Department, were averaged along the several segments of each street shown to produce a uniform one-way volume for the road. The uniform volumes and the range of volumes on the segments of each road are given in Table 1. Peak-hour volumes were assumed to be 10 percent of the one-way AADT. These values will be conservative because flows in opposite directions were implicitly assumed to be zero. Using the uniform volumes simplified calculations considerably and introduced only minor errors except for two roads. Maple Avenue is both close to the Queen Elizabeth Way, so that its contribution to total noise is minor, and runs through the sparsely settled area, so that the error in NAI will be small. Traffic on Lakeshore Road increases from west to east. At the Queen Elizabeth Way interchange, the range is 5,379 to 9,109; therefore, the error is lowest at the most important location. Nevertheless, application of this technique should obviously use the more accurate volumes.

### Specific Functions for Noise Annoyance Impact

Two components of our equation need to be specified before it can be used: (a) the best measure for noise at a point and (b) the function for translating this noise measure into an annoyance measure. The earlier discussion of noise measures suggested that NPL was one of the best available, hence it was chosen for noise(x, y). In addition, TNI was also used for comparative purposes primarily because it was originally derived to give the best fit to annoyance data for traffic noise.

Identification of reasonable functions for f(NPL) and f(TNI) was difficult. The decision was finally made to measure NAI as total number of people annoyed primarily because the only remotely usable data were in this form. Therefore, use of that approach here does not mean we necessarily think that the two-valued concept of individual annoyance is better but simply that it is supportable, and data are available. Although the functions are based on the best available data, their derivation, and even some aspects of the original data, are questionable in places and certainly demonstrate the need for further research.

As shown in Figure 2, the functions represent an interpolation and transformation of a diagram (14) that appears to be based on the survey, undertaken by the Building Research Station (BRS) in England, and that led to the development of TNI (8, 15). That survey collected data on a seven-point scale of satisfaction or dissatisfaction with noise. It is not clear which point on such a scale should be considered to be the turning point for annoyance. In other words, data were collected assuming a many-valued concept of annoyance and were later interpreted assuming a two-valued concept. The transformation for getting from the first to the second assumption was not made known (if indeed it can be legitimate).

A further possible drawback to the function of Waller (14) and BRS is that the TNI is probably not mathematically legitimate. The data were collected on a seven-point ordinal scale but were then treated as at least interval-scaled data in the calculation of a regression equation. It is not clear, from available references, whether Waller's graph depends on the TNI calculation or goes back to original data. In either case the first objection definitely holds so that the specific results obtained in this example should not be taken too seriously; however, this is the best available data for such a function and is used here simply for demonstration purposes.

## Calculations

For calculation purposes, the study area was represented by a grid of 400 by 1,000-ft (122 by 305-m) cells. The grid orientation was chosen to coincide with the alignment of the majority of the secondary road system. Population was allocated to this grid as described previously.

Based on the traffic flows in Table 1 and known characteristics of the roadways and surroundings, NPL and TNI were predicted for each grid point as follows. The noise from each roadway was calculated by using an interactive computer program adapted at McMaster University from the Michigan version of the method used by Bolt Beranek and Newman, Inc. (16, 17). Possible output from the program included $L_{90}$, $L_{50}$, $L_{10}$, CNEL, TNI, and NPL. The first three of these were used as input to an additional program package, also developed at McMaster University, that added all the noise contributions at each grid point. This program then calculated NPL and TNI, estimated the percentage annoyed from a discrete representation of the curves (Figure 2), multiplied this by population, and summed this result over all grid points for the area. This was done for each of the two alternative alignments.

## Interpretation of Results

Although results of the case study are presented here, one must remember the shortcomings discussed earlier and not consider these particular numbers to be decisive for the study area. The final results indicate little real difference between the noise impacts of the two alignments. For the westerly alignment route A, NAI is 2,665 based on NPL as the measure of noise; $NAI_B$ is 2,636. The difference of 29 people is not particularly significant compared with the total study area population of almost 10,000. Astonishingly, when TNI was used as the noise measure, the difference between $NAI_A$ and $NAI_B$ was almost identical (1,842 versus 1,812), although the total numbers are quite different from those based on NPL.

Areal disaggregation of the total NAI is quite simple, based on the original grid representation of the data, and permits closer scrutiny of the locations most strongly affected. Figures 3 and 4 show disaggregated representations of $NAI_A$ and $NAI_B$ (based on NPL). In addition, representative intermediate results have also been plotted for route B: $L_{10}$ in Figure 5; NPL in Figure 6; and f(NPL), the percentage annoyed at each grid point, in Figure 7. Figures 3, 4, 5, 6, and 7 are shown as three-dimensional representations for ease of interpretation but could as easily have been presented in the standard contour format.

Some of the drawbacks of the approaches based on counting houses within critical

**Figure 1. Study area, showing population.**

**Table 1. 1973 AADT for roads in study area.**

| Road | AADT Average | AADT Range |
|---|---|---|
| King Road (Highway 2) | 2,625 | 1,833 to 3,599 |
| Francis Road | 1,069 | 856 to 1,320 |
| Queen Elizabeth Way | 48,270 | 47,350 to 51,050 |
| Maple Avenue | 3,383 | 990 to 7,604 |
| Brant Street | 7,797 | 6,630 to 9,250 |
| Plains Road | 7,459 | 6,620 to 9,569 |
| Lakeshore Road (Highway 2) | 7,594 | 4,371 to 11,550 |

**Figure 2. Functions of TNI and NPL.**

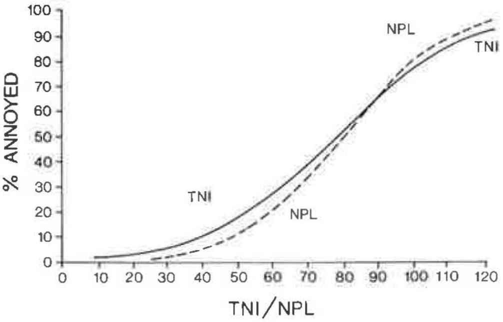

**Figure 3. Population annoyed based on noise pollution levels, route A.**

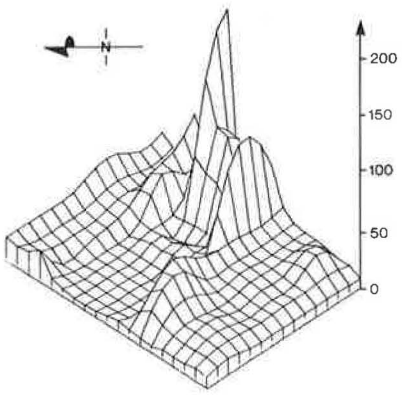

**Figure 4. Population annoyed based on noise pollution levels, route B.**

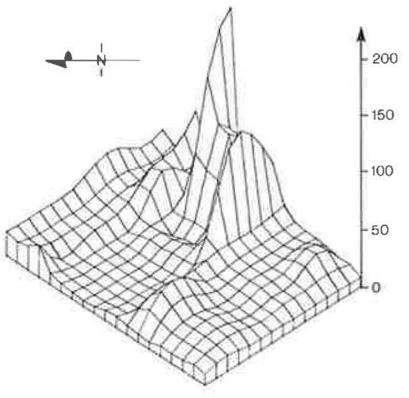

Figure 5. $L_{10}$ noise levels, route B.

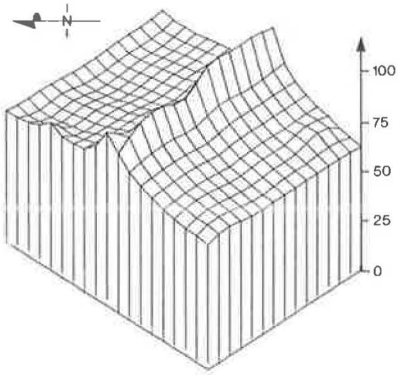

Figure 6. Noise pollution levels, route B.

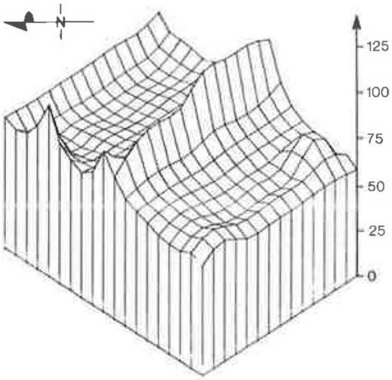

Figure 7. Percentage of population annoyed at each grid point based on noise pollution level, route B.

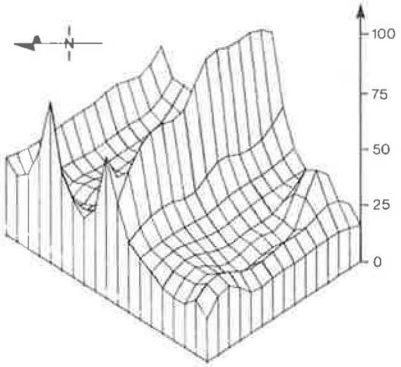

Table 2. Results for modified Ontario Ministry of Transportation and Communications approach.

| Range | Contour Interval (dBA for $L_{10}$) | People Affected Route A | People Affected Route B |
|---|---|---|---|
| Lowest | 70 to 74 | 332 | 442 |
| Intermediate | 75 to 79 | 229 | 12 |
| Highest | 80 and over | 358 | 365 |

contours can be demonstrated with these intermediate results in conjunction with the population data. The approach of the Ontario MTC referred to earlier used an $L_{10}$ of 70 dBA as the critical contour. Route A affects 919 persons within that contour; route B affects 819. If one is certain of the critical contour selection, then route B is obviously the better choice. However, if uncertainty exists about the critical contour, the modified Ontario MTC approach might be preferable (Table 2). The additional information (Table 2) appears to make the choice harder rather than easier. Using NPL data to draw the contours, as done in the Rand study, gives similarly confusing results. For a critical contour of 87 NPL (the value used by Rand) routes A and B affect similar numbers of people (370 and 365 respectively). If a different critical level is used, the choice of alternative will change. For example, at 80 NPL 436 and 378 people are affected (B is better); however, at 95 NPL 244 and 335 people are affected (A is better). Such potential ambiguity in a decision procedure provides a strong incentive for using a measure such as the NAI, which can incorporate the fact that different numbers of people are affected by different noise levels.

## CONCLUSIONS

The limitations of this particular example are obvious. We used 1973 population and traffic data for what are actually future roadways. The simplifying assumptions for traffic flow have probably distorted the results somewhat. The representations of f(NPL) and f(TNI) used here are not rigorous and might be different for different land uses or for different times of day. However, all of these limitations can be overcome with more time or personnel to carry out calculations, with additional research on people and noise response, or even with better use of existing data. If such problems cannot be overcome, particularly those relating to the function transforming noise measures into annoyance, any efforts to incorporate noise pollution into an evaluation procedure may be counterproductive or misleading because one is unlikely to be clear about what is being measured.

The general approach is nevertheless persuasive: It is well suited to visual display, easy to interpret, and intuitively meaningful. Additionally, the calculations involved are quite straightforward and easy to follow and permit the inclusion of such a measure in public participation meetings. In fact, it is probably easier to understand the significance of this measure than of any of the others currently in use. The final advantage is that the general approach is applicable to any kind of noise source and that this, in turn, permits comparison among different modes of transportation, a task for which few of the existing noise measures are reliable. However, one shortcoming of the discussion of this proposed community noise impact measure, in both the example and the theory, should be brought out. As presently defined, NAI is a static measure, concerned with noise during 1 hour of an average day of 1 year. This is inaccurate in several respects: Noise levels vary over the day; population varies over the day, in terms of physical presence of people; and, in the long run, both population and traffic are sure to change (and likely to increase). A more complete noise impact measure should probably be expressed as

$$\mathrm{NAI} = \sum_{t} n(t)\, d(t) \cdot \int\int\int f[\mathrm{noise}(x, y, h, t)] \cdot \mathrm{pop}(x, y, h, t)\, dx\,dy\,dh \qquad (13)$$

where

x and y = spatial coordinates;
h = hours of the day;
t = years into the future;
d(t) = some discounting factor, indicating that future noise is not equal in importance to present noise; and
n(t) = number of traffic days to be considered in the year, which may change if the workweek changes.

Obviously, several of the functions needed to carry out this complete analysis are not known and would be hard to specify. Some of them are not out of reach, however, and would be worth pursuing.

Consider, for example, what is needed to treat noise impacts over a full day rather than simply during the rush hours. The noise prediction techniques call for traffic volume and composition among other variables. Although a complete prediction of off-peak travel would be too much to expect, 24-hour volumes could be distributed over the day roughly as is currently done or in some other way to arrive at acceptable estimates. If the traffic can be estimated, then noise can be estimated as well. Population fluctuations over the day can also be estimated on the basis of generalizations about family behavior, e.g., work, school, and shopping trips. If this is done, it may well turn out that the noise impact of a particular road is less than anticipated because the population is smallest when the noise is worst. Thus, incorporating the fact that population fluctuates over the day may prove sufficiently important to warrant an investigation. A variable measuring the stage in the life cycle of adjacent populations may also be necessary to more clearly delineate likely daily population movements.

Even more information is needed to treat changing noise impacts over a span of years, and the effect may be more important than that of the daily cycle. Not only traffic will increase, but the population will change as well. Areas that were at one time open fields will contain housing, the density in single family areas may increase, and residential land may be converted to industrial activities. Even if traffic and noise levels were to remain constant, the impact would certainly change. The problems involved in predicting these data are not to be minimized. With a great deal of effort we can predict, without a great deal of accuracy, traffic levels 15 to 20 years from now. What the traffic will be during the intervening years is extremely hard to guess at, even if the terminal forecast is right. Should one use straight-line, exponential, or logistic interpolation? Likewise, we can produce a reasonable estimate of land use patterns in the terminal year; in fact, this was probably done as part of the traffic forecast. But when will certain land use changes occur during the intervening period?

These problems, however, are not unique to noise impact measurement. They are the same problems that still face any transportation planning effort. When solutions to them are found, they can be used to extend our ability to evaluate transportation noise. It is not necessary to wait for these developments, however. The principles of the noise annoyance impact measure developed in this paper can be applied now to bring noise impact measurement to the same state as the more advanced parts of transportation planning.

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