where X is the weighting factor and Y is the cost per dwelling to abate. The values produced from this formula were rounded to the nearest fifth increment so as to ease computation and not overstate the level of significance of the answer.

Existence Before or After Highway

Whether the dwelling was in existence before or after the highway was built was also an important factor. This factor considered the intrusiveness of the highway noise as well as the noise increase experienced by a receptor because of the highway. High noise increases and intrusiveness are associated with new-alignment highways. Persons who build adjacent to an existing facility move into a noise environment and usually become accustomed to it. New highways, however, invade an existing environment and usually cause sharp noise increases in a short time. Therefore, those receptors in existence prior to the building of the highway deserve greater consideration for abatement than do those that were built adjacent to an existing highway. A weighting value of either 0 or 50 was assigned this consideration; 0 was assigned to those sites developed adjacent to an existing highway and 50 was assigned to those in existence prior to the highway.

Public Involvement

The final weighting factor considered was public involvement. This factor is equal to either 0 or 25, based on correspondence and contacts by citizens with the department. This factor was determined important because those communities that made contact had reached an annoyance level that caused them to take action.

It is apparent that the above factors were not given equal importance. The total weighting value (or priority number) can now be calculated as the sum of the four factors above. The lowest value would be 0 and the highest value would be 250, for example:

Noise level (100) + cost per unit (75) + existence before or after highway (50) + public involvement (25) = 250.

Table 1 provides a complete summary of the data for this analysis. The priority categories and the sites that fall into each are listed below:

Category	Site
1	11, 12, 13, 14, 15, 27, 37, 38, 39, 47
2	16, 17, 25, 26, 29, 30, 31, 35, 36, 40
3	4, 7, 19, 21, 28, 32, 34, 45, 46, 48
4	3, 6, 9, 20, 22, 24, 33, 41, 43, 44
5	1, 2, 5, 8, 10, 18, 23, 42

The relative importance assigned each area above was a subjective decision of GDOT. However, the department felt that these weightings were reasonable based on past experiences and experiences of other states.

CONCLUSIONS

This paper provided a relative priority listing of potential type II abatement sites for the state of Georgia. The list was not intended to set a rigid priority but rather to serve as a guide for further considerations. The total cost of abatement ($17 686 000) prohibited the implementation of noise abatement for all sites.

The priority list will be updated on a continuous basis as warranted. This may result in the addition, deletion, or shift in priority of a site.

Any request for type II abatement funding will be accompanied by a design noise study report that justifies the site choice and refers to this paper.

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Simplified Traffic-Noise-Prediction Model for Transportation and Land Use Planning

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An empirical model for the estimation of Leq noise levels along urban and suburban streets has been developed. The only required data inputs are classified traffic counts, and the computational technique is appropriate for a hand calculator. In addition to a description of the model, a brief history of its development and experimental verification is included. Advantages and limitations of the model are depicted. Suggested applications by land use and transportation planning staffs are described.

Planners and engineers who work in small cities are continuously faced with the need to understand and to analyze large amounts of data for a multitude of different purposes. Data will flow into offices from applicants who seek to develop a housing site, petitioners who desire to widen a street, and residents who are lobbying to relocate an industrial plant or move the offending access road. If there are enough staff, time, funds, and the proper tools, a considered analysis of requests can be made. However, there never seems to be adequate funds, staff, or time. Coupled with this inflow are the professionals' other duties, which include the fulfillment of state and federal data requests and the submission of applications for federally funded programs. Requests for zoning variances, reviews of environmental-assessment forms, and attendance at community meetings consume other portions of the professional's time. Because of the diversity of functions, the planner often becomes a jack of all trades who is master of none.

It is difficult for a planner or an engineer in a small community to become a specialist in any one sphere, although a better understanding of one subject over another may be gained. The noise emitted by urban traffic has long been recognized as a significant source of annoyance in residential neighborhoods. Yet, for the reasons mentioned, engineers and planners do not become specialists in acoustics or in community noise. That knowledge is left to the large city and state agencies that can afford the expertise. The state agencies that have large computers have responded to the needs of the small cities regarding road designs or capacity projections. Unfortunately, truck problems in residential neighborhoods that have low traffic volumes occur in small and large cities. The state agencies cannot appropriately assist the small cities here. Thus, in cities that have limited resources, traffic-noise-control strategies have been adopted without adequate study and planning. The results are often less than satisfactory.

The most commonly used approach to traffic noise reduction has been the use of traditional traffic-management schemes in which traffic has been redirected to streets that pass through more-compatible land uses. To adequately address conflicts with compatible land use and truck traffic noise, the planners and engineers must understand what transportation noise is, what is annoying and intrusive in urban environments, and what the importance of the different sources is in contributing to the traffic noise. There is rarely sufficient time or funds to call in a consultant for a one-street issue. Yet there is a desire to address constituents' needs.

Once the problem has been grasped, there is a need for a simple tool that aids the professional in comparing alternatives by seeing the implications of one suggestion versus an alternative. The noise-prediction model described in this paper does that. It is a tool that may be used in planning for compatible land uses and in responding to changes in street functions and uses over time. It is a tool for those who have too little time, insufficient funds, and a lack of in-depth knowledge of a specialized field.

BACKGROUND

The impetus in developing the noise-prediction model resulted from a study by the U.S. Environmental Protection Agency (EPA), the objective of which was to evaluate the effectiveness to communities of several vehicular noise-control strategies. A portion of the work has been directed at the acoustic impacts of traffic-management schemes in urban residential areas that have stop-and-go vehicular flow at speeds less than 55 km/h (35 mph).

Although models for the prediction of noise from freely flowing traffic at speeds more than 50 km/h (31 mph) have been in existence for some time (for example, those of the Federal Highway Administration, the National Cooperative Highway Research Program, and the U.S. Department of Transportation), efforts have only recently been undertaken to predict noise levels for accelerating traffic on residential and urban streets (1,2). Previously existing models for urban traffic noise were complicated by site specificity, in which questions of noise propagation come into play. They were further weakened by an examination of noise-source characterizations of the various traffic components that was less than rigorous. Thus, our model was developed to meet two criteria. First, a means was needed of evaluating the noise-reduction benefits that accrue to communities that adopt one traffic-management strategy rather than another by using easily collectible and statistically reliable data. Second, the model had to be simple to use and to understand by city staff unfamiliar with acoustics. The model was designed to meet the following objectives:

1. To predict maximum traffic Leq noise levels along urban and suburban residential streets,
2. To identify those components of traffic noise that are most important acoustically, and
3. To permit comparisons of noise levels before and after implementation of area and time restrictions.

The primary purpose of the model as originally conceived was to compare differences in noise levels rather than to predict absolute levels. Consequently, a noise model that is not site specific was chosen for computational simplicity. The progagation paths are assumed to remain relatively constant and only the source characteristics are variable. This is the scenario that planners most often face.

The acceleration model predicts the Leq of traffic noise for speed zones posted at 55 km/h or less that have stop-and-go traffic. All vehicles are assumed to accelerate past a microphone 7.5 m (25 ft) from the vehicle path. This condition for maximum acceleration noise exists in the field downstream of a stop sign on a single-lane road or on a hill. For multilane roads, roads that have single intersections, or measurement positions so far downstream that vehicles have reached cruising speed, noise levels measured would be expected to be somewhat below those predicted. The relative differences in noise levels that result from change in traffic flow would not be affected by these considerations since the site and road characteristics do not change. Because only the source condition is altered, these differences in noise level (unlike absolute level) do not require specifications of measurement position.

Verification that the model does predict absolute Leq within reasonable tolerances is important. This is one reason why a measurement distance of 7.5 m was chosen. In urban and suburban environments, large areas free from reflective surfaces are rare. Ground and terrain effect, even at 15 m (50 ft), can be important. The choice of 7.5 m permits the selection of a greater number of sites for model verification and correlates with 7.5-m measurements used in enforcement.

The one complicating feature of the model is that it requires classified traffic counts since trucks and motorcycles are generally noisier than automobiles. Classified counts for many local and collector streets in communities are rare but not so rare as meaningful noise-monitoring data.

MODEL DEVELOPMENT

The model is divided into two major components: (a) continuous noise, or the general hubbub associated with automobile flow, upon which is superimposed (b) discrete events, or the isolated passing of noisy vehicles (trucks, buses, motorcycles, etc.).

The data for the continuous-noise component of the model came from a 1978 EPA study (3). Measurements of automobile noise were made at 20 urban and suburban sites. The roadside measurement locations were generally 30-38 m (100-125 ft) downstream of intersections at which automobile acceleration is typically at its maximum. The following equation summarizes the findings:

$$\mathrm{Leq(cars)} = 10.5 \log N + 23 + 10 \log 24/T \qquad (1)$$

where N is automobile flow during observation time T (in hours).

To calculate the effects of discrete events on Leq, a triangular noise time history is assumed (Figure 1).

The single-event contribution to daily Leq may be calculated as follows:

$$\mathrm{Leq(24\ h)} = L_{max} - 4 + 10 \log t - 49 \qquad (2)$$

where L_{max} is the peak noise level of the event and t is the time (in seconds) between points on the event time history at which the sound-pressure level is equal to L_{max} - 10 dB(A) (event duration).

A typical event duration 30 m (100 ft) downstream of an intersection is 4 s (from observations and calculations based on a measurement position 7.5 m from the centerline of the travel lane). If we assume that t = 4 s, the contribution of N single events to the Leq of a sample duration T (in hours) is as follows:

$$\mathrm{Leq(single\ events)} = L_{max} + 10 \log N - 47 + 10 \log 24/T \qquad (3)$$

It is the elimination of discrete events that most area and time vehicular restrictions attempt to achieve. Thus, energy-averaged values of L_{max} are desired for the following vehicle classifications: two-axle trucks, three-axle trucks, trucks that have more than three axles, motorcycles, and buses.

Figure 1. Time history of discrete event.

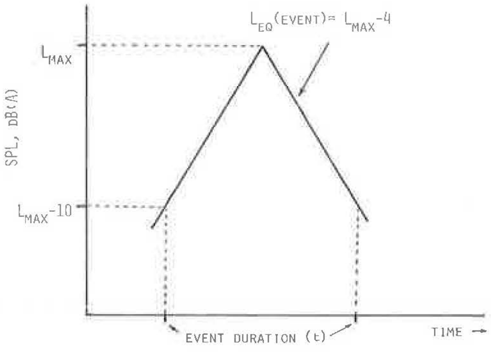
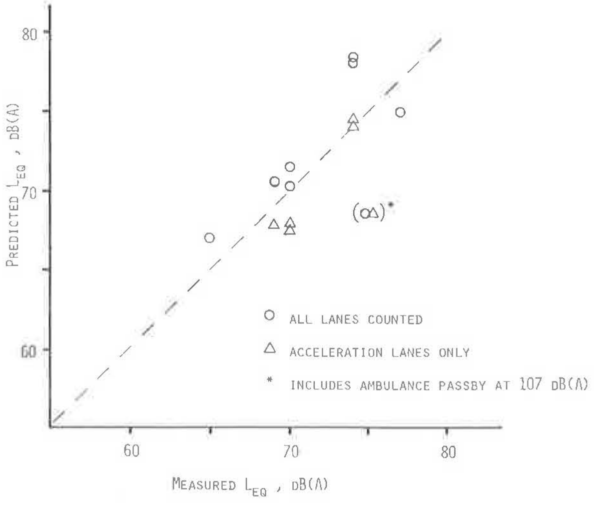


Figure 2. Comparison of predicted and measured Leq.



Noise data from acceleration tests of various classes of trucks were available from a 1974 study of several hundred vehicles conducted by Wyle Research Laboratories (4). The energy-averaged L_{max} for the desired vehicle classifications was calculated from histograms of these data. L_{max} at 7.5 m equals 83.2 dB(A) for two-axle trucks, 88.5 dB(A) for three-axle trucks, and 90.5 dB(A) for trucks that have more than three axles. Now that EPA truck-noise regulations are in effect, it is anticipated that these fleet-averaged levels will be reduced as older vehicles are retired.

For motorcycles, acceleration data from 429 unmodified vehicles were used to calculate energy-averaged L_{max}. The source for these data is the EPA background document on motorcycle noise. At 7.5 m, L_{max} (motorcycles) = 91.2 dB(A).

When this model was developed, insufficient data on bus-acceleration noise were available; consequently, buses were modeled as two-axle trucks. This assumption may, in some cases, result in the underestimation of the noise impact of buses. As new data become available, L_{max} descriptors for the various vehicle classifications may be updated and refined.

Once traffic-count data have been obtained, the Leq contributions of the various traffic components are calculated individually by using Equation 1 for cars, vans, etc., and Equation 3 for the various classifications of trucks, motorcycles, etc. A composite Leq of traffic noise may be calculated by logarithmically summing these Leq contributions by using Equation 4:

$$\mathrm{Leq(composite)} = 10 \log \sum_{i=1}^{n} 10^{[\mathrm{Leq}(i)/10]} \qquad (4)$$

where there are n different traffic components (i).

MODEL ACCURACY

Although the original purpose of this model was to assess changes in noise level due to various traffic-management schemes, its utility to planners and traffic engineers was seen to be limited unless the model performed reasonably well in predicting absolute Leq levels. Consequently, a limited series of simultaneous traffic counts and Leq measurements was undertaken in Des Moines, Iowa; Cambridge, Massachusetts; and Manchester, New Hampshire.

The sophistication of the Leq data collection ranged from manual readings taken every 10 s for 17 min to automatic community-noise analyzers that printed out hourly readings. The types of road encountered included two-lane, four-lane (two-way), four-lane (one-way), and divided four-lane. Road segments on hills and upgrades were included as well as level roads.

Figure 2 shows a comparison of predicted and measured Leqs at the various sites by using two computational techniques. The simplest method of composite Leq calculation is to assume that all traffic flow is in the nearest travel lane. This procedure will generally lead to overprediction of noise levels, as shown by the circles in the figure. Another possible method is to ignore deceleration lanes and count only traffic in acceleration lanes. The triangles show that this method tends to underpredict the levels. Further refinement of the calculation technique, such as adjustments for the various lane distances in multiple-lane roads, is possible but it is probable that, for roads up to four lanes in width, the accuracy of either of these two simple techniques is adequate for a first-cut estimation of traffic noise strength.

MODEL ADVANTAGES

The predictive model has several advantages in the general and in the more-technical spheres. First, it uses traffic classification data that are available or may be easily obtained. Second, the costs to the traffic engineering office in collecting the needed data are low. A third general advantage of the model is that the calculations may be performed by using a hand calculator. The equations are simple and understandable by those who have not dealt extensively with acoustics but who may be in positions that necessitate analysis of the traffic noise.

Technically, the model possesses advantages over measurement programs in addition to the obvious cost factor. The accuracy of short-duration Leq measurements can be seriously compromised by the passing of a single excessively noisy vehicle, and these measurement errors are compounded when two scenarios are compared. The use of vehicle noise classifications and average daily counts results in a statistically more-meaningful characterization of the street as a noise source, and the 7.5-m noise levels calculated for various street segments may be conceptualized as traffic noise strength and recorded by using single-number descriptors on a planner's map.

Noise-emission characteristics of traffic components change from year to year. This model has the advantage of flexibility to these changes in that the data-base input (L_{max}) for discrete events is accessible and easily changed to reflect changing fleet conditions without altering the format of the equations.

Another advantage of this model over measurement and other currently available noise-prediction models is that the contributions of noisy vehicles retain their identity. This is particularly important since recent studies have shown that people react differently to noise sources of equal Leq but differing time histories (5). A percentage of noisy events may be derived from the required input to the model, and this information can be very useful in supplementing and interpreting the Leq predictions calculated by using the model.

A few caveats concerning the use of Leq (also Ldn and other energy-averaging tools) in predicting community response to noise are appropriate here. Leq is a reasonable metric to use in evaluating community response to noise of similar time history. However, area and time restrictions are designed to eliminate noisy events and the annoyance that results from interrupted sleep, speech, and other such irritations that they cause. By elimination of a significant percentage of noisy events, the time history of the noise changes to a more-constant one. A 50 percent decrease in trucks will result in a maximum reduction in Leq of only 3 dB(A).

For traffic scenarios in which the noise is more consistent in terms of time history (i.e., a highway several hundred feet away from the receiver), a 3-dB(A) reduction in Leq would be considered modest. But in a situation in which every truck that passes is an intrusion (e.g., on residential streets), the percentage of reduction in truck traffic may be a more-meaningful metric than Leq in evaluating the effectiveness of a restriction of this kind.

MODEL LIMITATIONS

This model is a source descriptor. The absolute levels are predicted at a distance of 7.5 m from the center of the nearest traveled lane and are meant to represent traffic in an accelerating mode. Thus the predicted levels will tend to overestimate the noise for road segments on which traffic is at cruising speeds, on downhill segments, and on divided or exceptionally broad streets.

To predict levels at a particular observer site, acoustic propagation-path corrections must be made either by measurement or by calculation. If the propagation paths are complex, as they often are in urban environments, it may be necessary to perform simultaneous noise measurements at 7.5 m (the prediction standard distance) and at the observer location in question. For less-complicated paths, simple mathematical corrections of 3-4 dB(A) per doubling of distance are adequate.

MODEL APPLICATIONS

Two potential applications are described. The first pertains to programs that are federally funded and must therefore meet specific requirements. The U.S. Department of Housing and Urban Development (HUD) will be used as an illustration. The second application considers local problems and their resolution.

HUD encourages land-use patterns suitably separated from major noise sources. Its environmental criteria are used for the department's funding programs in assistance for comprehensive planning, block grants for community development, new construction, modernization, and rehabilitation (HUD Environmental Criteria and Standards, Code of Federal Regulations, Part 51, August 13, 1979). The department has recently published its Noise Assessment Guidelines (2) to aid in assessing the noise produced by highway, airport, and rail operations. There are several adjustments required by the guidelines for streets that have stop-and-go traffic, road gradients, volume, and traffic types.

Our model, however, may be used to provide a simple first-cut determination of planned project compliance with HUD regulations. The model specifically addresses urban street situations in which the traffic is moving slowly and passes close to structures. The model is a potential tool that may assist the planner in determining whether there may be major difficulties or no difficulties in a proposed project.

The second sphere concerns local projects. The developed area of a city consists of 20-30 percent streets. A prime consideration for planners and engineers is the appropriateness of the traffic volume and type on the land uses that abut on these streets. Local streets provide access to residents, visitors, and delivery trucks. Low volume and low mobility induce social interactions and a sense of privacy and safety (6). When streets satisfy user needs for greater mobility, increased speeds, and better road geometry, higher numbers of vehicles that pass through may be found. The function of these designed collector and arterial streets is to carry both through and local traffic. Conflicts may occur when through and local traffic uses the same road in residential neighborhoods. These conflicts arise for several reasons, which include changing street functions and changing land use patterns upstream from the affected streets.

To resolve the conflicts, a number of traffic-management schemes may be considered. Examples are area restrictions, curfews, and traffic-free zones. The objective sought is a more-livable environment without the inappropriate traffic intrusions.

The noise-prediction model described earlier may be applied in determining the compatibility of existing land uses with changing traffic and classification types. This tool may serve as one measure to assist the decision makers in selecting one traffic-management scheme over another.

For example, it may be desired to predict the noise levels along a collector street that runs through a residential zone. If the average daily traffic volume is 10 000 vehicles, 10 percent of which is trucks, the Leq noise levels 7.5 m from the centerline of the nearest lane of travel might be as follows:

Vehicle Classification	Vehicles per Day	Leq [dB(A)]	Equation Used
Automobiles, vans, etc.	9000	64.5	1
Two-axle trucks and buses	600	64.0	3
Three-axle trucks	200	64.5	3
Trucks that have more than three axles	200	66.5	3
Total		71	4

Let us assume that a through-truck ban is being considered for this street. The traffic engineer wishes to estimate the traffic noise reduction from such a ban. If the ban is 50 percent effective for two-axle trucks and buses and 90 percent effective for larger vehicles, the Leq noise levels (at 7.5 m) would be as follows (by using the same equations):

Vehicle Classification	Vehicles per Day	Leq [dB(A)]
Automobiles, vans, etc.	9000	64.5
Two-axle trucks and buses	300	61.0
Three-axle trucks	20	54.5
Trucks that have more than three axles	20	56.5
Total		67

Thus, the Leq noise reduction achieved along this street would be 4 db(A).

Variations in the effectiveness of the ban could be modeled and presented before the residents and appropriate committees. The alternatives could then be compared and appropriate actions taken.

In conclusion, the noise-prediction model is a tool that provides the planners, the engineers, and the public with an easily understandable assessment of a complex problem. Its use in a decision-making process may ensure a more-balanced consideration of the traffic noise levels in residential neighborhoods.

ACKNOWLEDGMENT

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