Estimating Traffic Noise Levels and Acceptability for Freeway Design

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Noise generation by freeway traffic is an aspect of the urban environment that has received little consideration in highway location and design procedures because of a lack of suitable data. A survey of realtors in Toledo, Ohio, showed that the immediate proximity of a freeway could reduce the sale price of a typical residential property by 20 to 30 percent. The realtors considered noise as the most important cause of this loss in value. Home interviews with 138 residents in the vicinity of a depressed section of the Detroit-Toledo Expressway showed that, of those who live immediately adjacent to the right-of-way, two out of three would not choose such a location again. Less than half of the residents who live within 1,200 feet of the expressway expressed such sentiments, and analysis of survey results indicates that neighborhood factors not related to the expressway were important considerations to these respondents. Thus, any economic effect of traffic noise on residential property seems to attenuate within less than a block from a depressed freeway. Results of the home interviews are used in connection with measurements of perceived noise level in an attempt to develop an acceptability index for traffic noise. A simple probability model for traffic noise generation is proposed by which the highway designer can estimate noise levels by using design traffic volume and percentage of trucks together with the mean noise level for a single truck either estimated or measured at a similar location. This model is used to predict maximum noise levels in a residential area, and the results are compared with observed values.

•CONTROLLING the quality of the urban environment is surely one of the greatest problems faced by modern industrial society. Production, consumption, and disposal of an ever-increasing store of material culture have come to be recognized as potential agents of destruction not only to the beauties of nature but also to the psychic and physical well-being of urban dwellers.

Not the least of the environmental problems in the modern city is the production of noise. One can hardly think of an activity that does not result in some kind of unwanted sound or noise. In fact it seems fair to say that the higher the level of economic activity in a factory, an office, or a city, the higher the noise level will generally be. If this is so, then noise can be regarded as a price paid for productivity in an industrial society. Solving the noise problem is not simply a matter of eliminating noise from the urban environment. The real problem is to determine what types and levels of noise are physically and psychologically acceptable to the typical human being and to provide the necessary technology and legal machinery to maintain urban noise below the allowable limits.

The term "noise pollution" has been used in numerous articles by the press, which has given increasing attention in recent years to urban noise. One of the principal

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noise sources that the press has singled out is the urban transportation system in general and the highway system in particular. It is beside the point to contend that other noise generators, including some other transportation modes, can far exceed the ability of street and highway traffic to assault the ears of innocent bystanders. The point is that street and highway traffic is a noise generator and one that is ubiquitous, easily identifiable, and outside the control of the hearer. Such a familiar and widespread source of noise can easily become established in the public mind as a target on which to direct its dissatisfaction with the increasing rarity of peace and quiet.

Controversies generated by proposed freeway locations can delay specific projects and also retard development of an entire metropolitan transportation program. Reactions of potentially affected homeowners can be quite emotional. Such reactions often result from fear of the effects of noise or other environmental aspects of the proposed facility. To be able to estimate the probable effect of a proposed project on a neighborhood, highway officials need to have some knowledge of the mechanics of the generation and propagation of traffic noise as well as its effects on people.

Insofar as it may affect the prices of nearby property, traffic noise has a negative economic value. If noise control features of highway design and location are to be justified from the standpoint of cost effectiveness, this negative value must be determined.

The purpose of this paper is to explore the effect of urban freeway traffic noise on the inhabitants of nearby residential property. A simple model will be proposed by which traffic noise levels may be estimated from traffic parameters, and a noise acceptability index will be described.

A SURVEY OF THE ATTITUDE OF REALTORS TOWARD EXPRESSWAY TRAFFIC NOISE

Professional realtors are probably the most concerned and best informed of those in the business world about the factors that influence sales of residential property. They are, therefore, likely to have some explanation for the relative undesirability of lots near an urban expressway. A mail questionnaire was employed to survey their opinions regarding expressway noise because time and resources were limited. There were approximately 280 listings in the 1967 Toledo telephone directory under the heading "Real Estate." A questionnaire was sent to every second name under this heading. The actual number of replies received was 44, which represents a response rate of about 31 percent. The data provided by the respondents therefore constitute about a 15 percent sample of the realtors in the Toledo metropolitan area.

The questionnaire first established whether or not the realtor regarded the presence of an expressway right-of-way along a lot line of a single-family residence to be a deterrent to a prospective buyer. All but one respondent replied in the affirmative. If the answer to this question was "yes," the realtors were then asked which of the following they regarded as the most important single reason for this condition: fumes, vibration, headlight glare at night, noise, or something other than these. More than one of these 5 choices were marked by many of the respondents. A few indicated the relative importance of choices by numerical ranking, but most of those who gave multiple answers to this question simply marked 2 or more conditions. All of the respondents who indicated an affirmative answer to question 1 specified noise as at least a contributing reason for the comparative unattractiveness of a lot contiguous to an expressway (Table 1).

The final question is admittedly naive; however, only 6 respondents did not give quantitative answers. The realtors were asked to state how much more they felt an otherwise identical residence might sell for than a property next to the expressway if the latter is worth $10,000, $15,000, or $30,000. They were to assume that lot sizes were typical of a city or suburban area and that properties had city water and sanitary sewers. All responses have been converted to percentage decrements, which can be interpreted as the proportion of market value that a property in a given price range might lose as a result of being located next to an expressway as compared to an otherwise identical parcel not so located (Table 2).

Many of the respondents took advantage of the invitation to add their own comments to the formal questionnaire. A review of these comments lends support to the conjecture that complaints about noise or other environmental conditions really stem from effects of highway proximity on social values such as prestige. One such statement is typical: "Location value is an important factor in the purchase of a residence and public reaction to a location near an expressway is loss of prestige. The loss of value is proportionately more for higher priced residences."

The results of the mail questionnaire indicate clearly that proximity of an expressway right-of-way is considered a definite detriment to the value of a single-family residential property. Traffic noise was not only the most cited single cause but also a condition that was almost unanimously regarded at least as a contributing factor. It would seem, then, that expressway traffic noise does have a distinctly negative value in the minds of professional realtors.

TABLE 1

REASONS GIVEN BY REALTORS FOR PROSPECTIVE BUYERS BEING DETERRED FROM BUYING SINGLE-FAMILY RESIDENCE ALONG EXPRESSWAY

Reason	Number of Times Selected[a]	Percent
Noise	19	44.19
Noise and fumes	4	9.30
Noise and glare	1	2.33
Noise and vibration	6	13.95
Noise and other	2	4.65
Noise, fumes, and vibration	2	4.65
Noise, fumes, vibration, and glare	7	16.28
All factors, including other	2	4.65
Total	43	100.00

[a]Does not include one respondent who did not regard freeway presence as being a deterrent.

MEASUREMENT AND EVALUATION OF TRAFFIC NOISE

A basic requirement in any attempt to evaluate the effects of traffic noise is some parameter that can characterize the "loudness" or "noisiness" of a given sound. Unfortunately, the selection of such a parameter is far from a simple problem.

The loudness of a sound is by no means a directly measurable, physical quantity. The loudness of a sound and its potential annoyance is really a psychological reaction by an individual to a number of physical and physiological factors. The best that can be done in comparing the relative loudness of 2 or more sounds is to measure a selected physical quantity or group of quantities that have been shown by some reliable experiments to have a high correlation with subjective estimates of loudness by a large number of people.

Perceived noise level (PNL) is one fairly complex criterion based on experimentally determined "equal-annoyance contours." PNL is defined as the sound pressure level in decibels of a band of noise from 910 to 1,090 cycles per second (cps) that sounds as "noisy" as the noise being rated. It has been found that PNL predicted the acceptability of jet and piston aircraft noises more accurately than did a number of other psychoacoustical criteria. PNL can be computed by means of certain formulas and a conversion table such as the one presented by Beranek (1). Beranek and others also give a definition of the decibel.

Contours of perceived noise level are shown in Figure 1 for a residential area in Toledo, Ohio. A disadvantage in the use of PNL is that it requires not only a set of octave band frequency data but also a certain amount of computation. However, it was found that there was a very high correlation between the computed PNL and the sound pressure level in the 600 to 1,200 cycle octave band. For the Toledo data, the correlation coefficient was 0.999, and the standard error of estimate was 1.00 PNdb.

With a portable instrument such as the General Radio Company Type 1558-A Octave Band Analyzer it is possible to obtain direct instantaneous field readings of the 600 to 1,200 cycle band and then to estimate PNL from a curve like that

TABLE 2

REALTORS' ESTIMATE OF LOSS IN VALUE OF RESIDENTIAL PROPERTY CONTIGUOUS TO EXPRESSWAY

Approximate Dollar Value of Property Next to an Expressway	Median Estimated Percent Loss in Value	Median Estimated Dollar Loss in Value
10,000	27.7	2,770
15,000	24.3	3,650
30,000	20.0	6,000

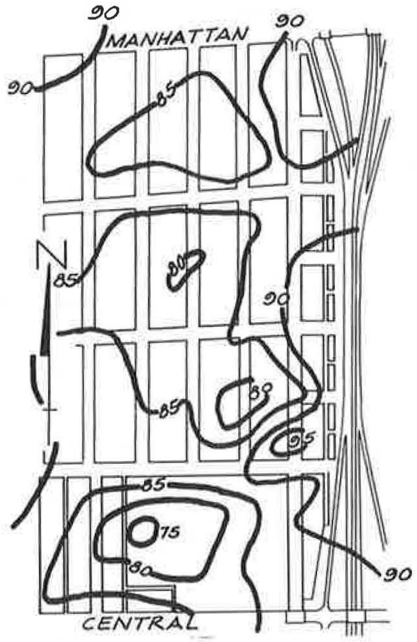

Figure 1. Sound pressure level contours—maximum perceived noise level during 3-minute sampling.

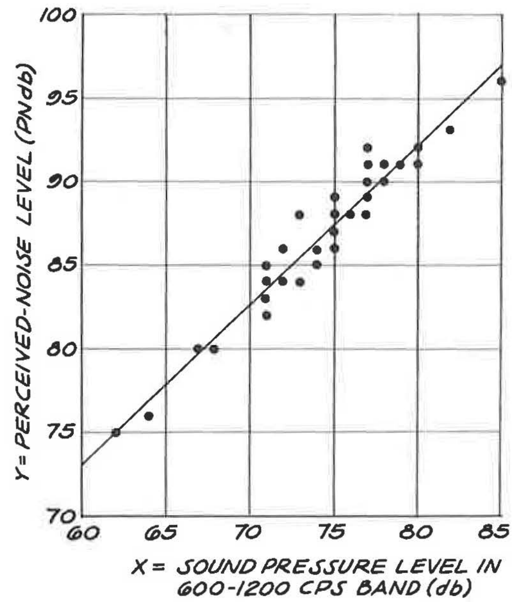

Figure 2. Perceived noise level as a function of sound pressure level in 600- to 1,200-cps octave band.

shown in Figure 2. It would therefore appear that the existence of a short, practical method for approximating PNL might well make this criterion an attractive one to use for evaluating the subjective effects of highway traffic noise.

COLLECTION AND ANALYSIS OF TRAFFIC NOISE DATA

A minimum of 6 readings of the sound level meter were taken at each of 340 survey stations along the Detroit-Toledo Expressway. All such readings were made on the C-scale and consisted of the highest value observed during a 3-minute sampling interval.

In addition to this basic set of sound level readings, one area was selected for more intensive study. Three-minute samples of traffic noise were recorded on tape by the use of an Ampex Model 602-2 recorder. Power for the tape recorder was supplied by a 12-volt automobile battery connected to an inverter. The taped noise samples were later used in the laboratory as input to an octave band analyzer in order to obtain data for computation of perceived noise level.

The residential area selected for the more intensive field work contained 36 noise survey stations. It was possible to occupy all 36 stations in one afternoon, and most readings were made on Friday afternoons between 1:00 and 5:00. A set of 10 noise samples was obtained for each survey station over a 10-week period. The time of occupying each station was approximately the same each week. For those noise survey stations that afforded a view of the expressway, a count of southbound vehicles was recorded for each 3-minute sampling period. The southbound roadway is the one closest to the study area.

In obtaining sound level readings for an individual vehicle, we had to select vehicles for measurement that were not part of a platoon of traffic and that passed the survey station at an instant when traffic in the opposite lanes was not a disturbing influence. It was thus practically necessary to obtain single vehicle readings during intervals other than peak traffic periods. Because vehicle speeds tend to be higher in light traffic than in heavy, noise level readings for individual vehicles are probably somewhat higher than what they would have been had it been possible to obtain them during the peak hours.

AN INVESTIGATION OF RESIDENT REACTION TO EXPRESSWAY TRAFFIC NOISE

A total of 138 home interviews were conducted for the purpose of determining the reactions of the local residents to traffic noise emanating from the expressway. These interviews were all conducted in the same residential area utilized for the survey of traffic noise.

Selected statistics, given in Table 3, are considered reasonable inferences from the survey findings. The range of percentage given may be considered in each case to include the true population percentage with a 95 percent level of confidence. Results of the home interviews seem to indicate the following:

1. Although the respondents are aware of the expressway traffic noise, it does not, in general, disturb them very much.
2. Relatively few residents have taken action to reduce noise level in their homes.
3. With the exception of the highest category, no marked difference appeared when the data were segregated by sound pressure levels into 4 categories: 70 and under, 71 to 75, 76 to 80, and 81 to 85 decibels. No coherent relationship could be found between degree of disturbance and distance from the freeway even though sound pressure levels decrease with distance.
4. The main source of the noise emanating from the expressway is trucks.
5. None of the respondents had ever lodged a complaint about traffic noise with any public authority. Several of those interviewed, however, indicated that an important reason for not complaining was a feeling that little relief could be expected anyway.
6. Awareness of the traffic noise seems to increase with greater length of residence in the area. This is quite possibly because those with longer residence are older and sensitivity is merely a function of age.

The data given in Table 3 might give the impression that the attitudes of residents living near the expressway are in conflict with those of the realtors. That is, the general impression to be gained from the home interview data is that the noise problem is not particularly important to the residents in the vicinity of an expressway. The realtors, however, were asked only to estimate the economic effect of expressway noise on property contiguous to the right-of-way, and the local residents who were interviewed lived within an area extending 1,100 or 1,200 ft from the right-of-way line. If we are to compare the results of the 2 studies, we must consider only those residents whose properties are contiguous to the right-of-way line. For practical purposes, this group is the same as the group in the 81 to 85 decibel range of sound pressure levels. Table 4 gives the responses of this group. The proportion of those on contiguous lots who rate

TABLE 3

ATTITUDE REGARDING EXPRESSWAY NOISE OF LOCAL RESIDENTS WHO LIVE 1,200 FEET OR LESS FROM EXPRESSWAY AS REPORTED IN HOME INTERVIEWS

Attitude	Percent of Interviewees
Have experienced a disturbance	38 to 54
Rated noise as very severe	10 to 16
Feel trucks are main cause of the noise	79 to 85
Rated overall effect of noise as not noticeable	54 to 70
Have taken action to reduce noise level in home	8 to 14
Would not live in similar location again	38 to 54

TABLE 4

ATTITUDE REGARDING EXPRESSWAY NOISE OF LOCAL RESIDENTS WHO LIVE IN 81 TO 85 DECIBEL RANGE OF SOUND PRESSURE LEVEL AS REPORTED IN HOME INTERVIEWS

Attitude	Percent of Interviewees
Have experienced a disturbance	50
Have experienced a disturbance and rated noise as very severe	37
Rated overall effect of noise disturbance as annoying or objectionable or highly objectionable	75
Would not buy, build, or rent this close to an expressway again	63

noise as very severe is on the order of 3 times the corresponding percentage for the area as a whole. Nearly 2 out of 3 respondents who experienced a disturbance from noise indicated that they would not choose to live as close to an expressway as at present. Analysis of survey data not presented here shows that this attitude on the part of respondents in the highest sound level category is probably due to noise, although an apparently similar trend in the quieter regions seems to stem from neighborhood factors not necessarily attributable to the expressway.

If this expressed reluctance to relocate next to a freeway is translated into economic terms, one can infer that a substantial price reduction would have to be offered to those who have so expressed themselves if they were to be induced to rent or purchase another dwelling similarly situated. Thus, the attitudes of residents who actually live in close proximity to an expressway right-of-way line is in qualitative agreement with the opinions of professional realtors.

A CRITERION FOR ESTIMATING THE DISTURBANCE CREATED BY TRAFFIC NOISE

An attempt was made to use data obtained from the home interviews to develop a criterion for estimating the attitude of nearby residents toward noise generated by an expressway. Respondents were requested to give their general reaction to expressway traffic noise in 5 categories ranging from highly objectionable to no disturbance. Table 5 gives the number of responses in each category. One way of assigning weights to each category is to assume that responses to an interview question of this type are normally distributed.

The responses of people who rated the overall effect of noise as highly objectionable are about 4.4 percent of the total responses. If the distribution is normal, these people represent the highest "tail" of the curve. The highest 4.4 percent of the area under a normal curve has a centroid of about 2.16 standard deviations above the mean. The next 3.7 percent in the objectionable category has a centroid about 1.56 standard deviations from the mean. The other categories are similarly determined. The standard score, called the acceptability index, is computed by arbitrarily assigning a value of 50 to the mean and 10 to the standard deviation. If the normal probability curve is considered to extend 3 standard deviations above and below the mean, then the maximum standard score is 80 and the minimum is 20.

Figure 3 shows a graphical extrapolation of the relationship between perceived noise level and acceptability index. The maximum scale value of 80 is attained at about PNdb = 131, which is a fairly reasonable value, about halfway between the discomfort and the pain thresholds. The curve has a minimum point at PNdb = 78, which corresponds to an index of about 47. Below this value the index is of little significance anyway because 47 is the top of the no disturbance range.

The acceptability index, as it has been described, seems to fit the available data very well, including logical limitations on its maximum value. We suggest, therefore, that further study would be useful to develop this index as a working tool for evaluating through the use of perceived noise level the subjective effects of expressway traffic noise in residential areas.

TABLE 5

ACCEPTABILITY INDEX FOR RESPONSE CATEGORIES RELATING TO EXPRESSWAY NOISE

Category	Number of Responses	Percent Total Responses	Standard Deviation	Acceptability Index
Highly objectionable	6	4.41	2.16	72
Objectionable	5	3.68	1.56	66
Annoying	11	8.09	1.18	62
Not noticeable	39	28.67	0.53	55
No disturbance	75	55.15	-0.72	43

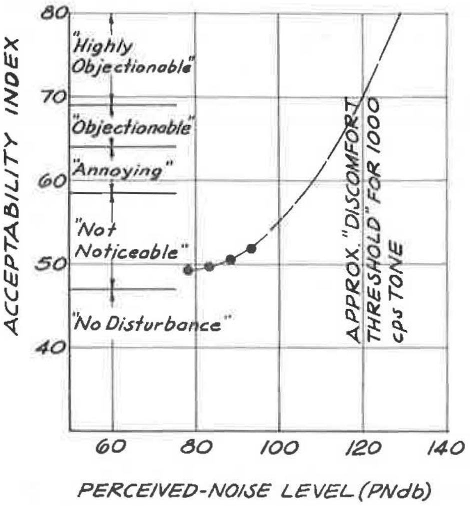

Figure 3. Relationship between acceptability index and perceived noise level.

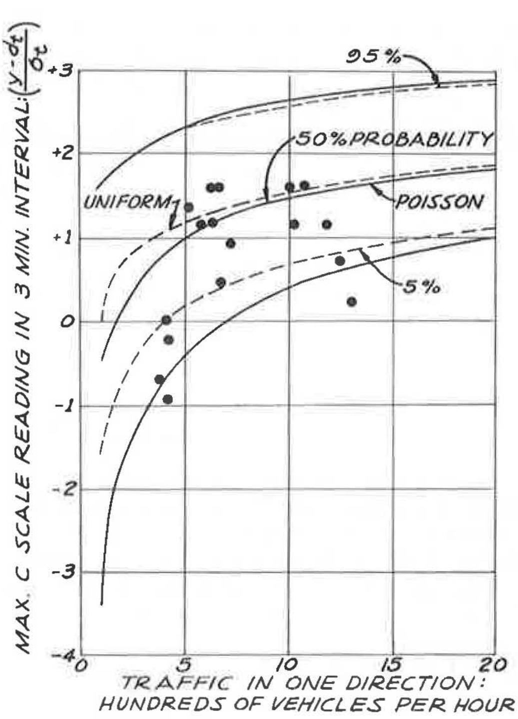

Figure 4. Sound level versus traffic volume in which 20 percent of vehicles are trucks.

ESTIMATING TRAFFIC NOISE LEVELS

If noise propagation is to be considered in freeway location and design, a method for estimating traffic noise and a criterion for evaluating its effect must be developed. Traffic noise data from the Toledo study were used to develop a simple model based on probability considerations. The model depends on the fact that noise levels from individual vehicles are normally distributed. Sounds generated by over 400 passenger cars and an equal number of trucks were measured at a point on the Detroit-Toledo Expressway. The probability that a single vehicle will not exceed a given sound level can readily be found from tables of the normal probability distribution. In a given time period, n cars and m trucks will pass a fixed point on the road.

Let the probability that a single car will not exceed a given sound level be P_p and let the corresponding value for a single truck be P_t. If q is the average number of trucks in a time interval Δt and s is the average number of cars during the same interval, then the probability that no vehicle will exceed a given sound level x during Δt is

$$A = \left(\frac{q^m e^{-q}}{m!}\right) \left(\frac{s^n e^{-s}}{n!}\right) P_t^m P_p^n \quad (1)$$

The values of m and n can vary independently for a given q and s, and the estimation of A requires the summation of mutually exclusive probabilities resulting from many pairs (m, n). By performing this computation for a series of hourly traffic volumes, a range of sound levels, and a given proportion of trucks, we can determine graphically the sound level that has a given probability of being maximum for a particular average hourly volume. Figure 4 shows the results of one such computation for traffic in which 20 percent of the vehicles are trucks.

If vehicles are considered to be moving at a uniform headway and trucks are uniformly spaced in the traffic stream, then

$$A = P_t^m P_p^n \quad (2)$$

where m and n are fixed for a given average volume and percentage of trucks.

Sound levels are expressed in terms of the number of standard deviations above or below the mean individual truck sound level in order to make the model applicable to other sites. If the mean individual truck sound level is determined for any site, a series of charts similar to Figure 4 can be used to estimate sound level as a function of traffic parameters.

This technique was utilized to prepare a map of computed sound level contours for the study area adjacent to the Detroit-Toledo Expressway. Mean truck noise levels were obtained and traffic counts were used to compute sound pressure levels along the expressway and along the major streets bordering the area. Sound levels in the interior of the area were computed by combining the sound levels from the 3 traffic arteries with an "ambient" noise level estimated from readings taken in a residential area remote from any arterial streets. We assumed that sound levels diminished with distance from the source at the rate of 6 decibels for each doubling of distance. The correlation coefficient between computed and observed sound levels was found to be 0.998.

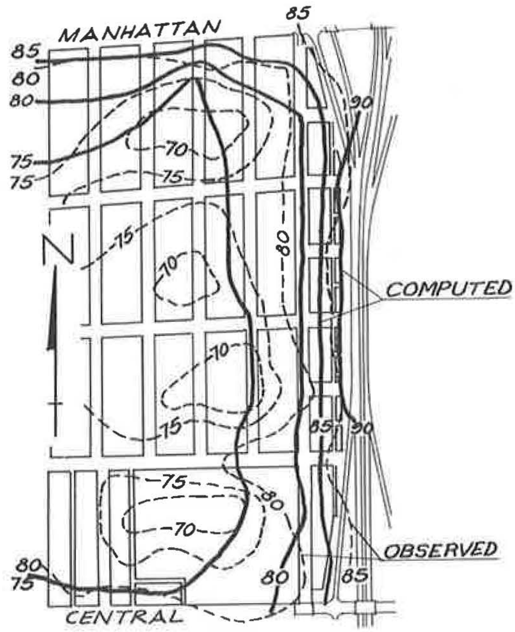

Figure 5. Computed versus observed perceived noise level.

Computed and observed sound level contours are shown in Figure 5. The computed contours lack the detail exhibited by the observed contours, but this is to be expected because there is a pocket of relatively low noise level between each pair of east-west streets. The east-west streets function as channels for the sound waves from the expressway, and the buildings between tend to absorb and attenuate the sound. Because the computation of estimated sound levels contained no allowance for such excess attenuation, these low-level areas could not have been predicted. If the 70-decibel contour lines and the larger irregularities in the 75-decibel line are disregarded because they probably result from the condition just described, the agreement between observed and computed noise level contours is fairly good.

We believe that the techniques described in this paper can be used to estimate with a reasonable degree of precision the configuration of sound level contours within an area and that a practical acceptability index can be developed by pursuing further study along the lines indicated. The techniques outlined could become working tools for the highway designer.

ACKNOWLEDGMENT

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