SOCIOECONOMIC AND SITUATIONAL FACTORS
IN URBAN TRAFFIC NOISE ANNOYANCE LEVELS

by

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ABSTRACT

Traffic noise is having an increasingly adverse impact on the quality of urban life. As a result it is necessary for community planners and engineers to develop better traffic management criteria and study techniques to keep the level of community traffic noise to socially desirable levels. In the recent past substantial research has been done to help understand the physical properties of traffic noise and indices of community noise perception. However, little is understood about the perception and annoyance levels of specific groups toward traffic noise. Complete knowledge of all dimensions of traffic noise annoyance is necessary for the further development of community traffic management criteria and neighborhood planning techniques.

The purpose of this research is to investigate the dimensions of public annoyance to traffic noise in a large city. Specifically, the study objective is to investigate the relationship between noise annoyance in several urban neighborhoods and the socioeconomic and situational variables which have some impact on attitudes about traffic noise.

Following a preliminary noise annoyance survey of 3500 households in Vancouver, British Columbia, a discriminant-classification statistical technique was used to analyze a follow-up, in depth,

attitudinal survey of 331 households in several neighborhoods.

Three categories of information were obtained in the survey:

- 1) a household survey of attitudes to noise using a semantic differential scaling technique;
- 2) measures of the socioeconomic and cultural profiles of each household surveyed, and
- 3) measures of the physical and situational neighborhood variables which would likely have some effect on the noise environment of the household.

The statistical model was used to investigate the dimensions of socioeconomic, cultural, and physical variables on separating those social groupings which were highly sensitive to traffic noise from those who were less sensitive.

Results show that the respondent's high socioeconomic status is the major factor in noise annoyance followed by the distance the respondent lives from major traffic arteries. Particularly, it appears that education levels are the dominant factor in traffic noise annoyance. The implication of the results of this research is that traffic management criteria must include consideration of the socioeconomic and cultural environment as well as accepted traffic planning criteria to meet publicly acceptable traffic noise levels.

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CHAPTER I

INTRODUCTION

Statement of Problem

An increased awareness of the problems of noise has been one of the major aspects of a new concern over the environment. Past investigations have revealed that, not surprisingly, the prime "disturber" or source of noise in residential areas and communities appears to be traffic. As the standard of living rises and an increasing number of vehicles moves along our roadways this problem will only become greater; therefore, in order to deal with traffic noise and its management in residential areas, it becomes necessary for traffic managers and planners to understand as completely as possible all aspects of traffic noise from its generation to its perception by the public.

In the past, any undertaking in the form of new or improved roads on the part of government or planning agencies had only to be concerned with traditional traffic engineering considerations, e.g. the speed and road capacity desired. More recently, in the U.S., environmental impact statements have been required as part of the planning process to estimate the adverse effects, if any, on the environment. It is new efforts along these lines to understand and deal with traffic noise which will need to be made before progress can be attained in reducing the traffic noise or alleviating

the problems caused by it. Traffic planners must now be concerned with the overall impact of any new facilities and this must, therefore, include consideration of the noise impact.

In the recent past, substantial research has been done to help understand the physical properties of traffic noise and compile and develop indices of community noise perception. However, little is understood about the perception and annoyance levels of specific groups toward traffic noise. As a result, it has become necessary for engineers and planners to develop newer and better traffic management criteria and study techniques to attain and keep the level of traffic noise in the community to socially acceptable levels. It is hoped that this thesis may shed some light on one aspect of the above, viz. a better understanding of those factors which contribute to a community's or individual's awareness of noise. Therefore, the purpose of this research is to investigate the dimensions of annoyance with traffic noise in a large city, Vancouver, B.C. Specifically, the study objective is to investigate a number of urban characteristics or factors and to establish their effect upon the individual's perceived levels of annoyance.

Hypothesis

An individual's perception of noise depends upon many circumstances and factors. In the relative quiet of the evening,

the passage of a single car may become a major "disturber" of the peace. On the other hand, several motorcycles may drive by and be hardly noticed in the vicinity of a noisy construction site. One member of a family may be much more susceptible to the same noise than another member and, finally, the same individual may give quite different responses to the same noises if they happen to occur at different times or under different circumstances.

Practicality and time considerations in this thesis dictated against elaborate attempts to investigate the responses to noise under varying circumstances, e.g. traffic noise occurring late in the evening vs. that during rush hour. Rather, attention was focused on the examination of those factors which were felt could affect or contribute to an individual's perception of noise in a fairly direct manner.

These factors or variables are of many forms; a socio-economic characteristic such as high income may make an individual more aware of his greater expectations with respect to his environment, thus leading him to a greater awareness of and sensitivity to noise intrusions. Similarly, an older person may have become accustomed to a particular noise pattern and thus be less sensitive to the noise environment. Demographic data such as home or vehicle ownership may also affect one's perception of traffic noise, e.g. the owner or driver of a motorcycle or truck may be far less prone to perceive traffic noise as annoying than one who does not

own any vehicles.

The physical environment and traffic characteristics themselves may also play a role in determining one's perception of noise; the easily visible presence of a large stream of traffic moving past one's residence may alter the perception of noise so that the noise from the traffic stream seems to be louder than it actually is. The presence of even a few motorcycles or large trucks usually contributes greatly to the perceived annoyance no matter how large the continuous flow of automobile traffic may be. Finally, the traffic noise itself, as measured objectively by a calibrated measuring device, would certainly seem to be a factor; the greater the measured traffic noise, the greater should be the annoyance indicated.

It is obvious, then, that many factors exert some influence on the individual's perception of traffic noise. Therefore, the following hypothesis has been developed as a focus for this research:

"The individual's stated annoyance level is a function of the socioeconomic characteristics of the individual and of the physical characteristics of the traffic situation."

Thus, the study objective is to investigate the relationship between noise annoyance in several urban neighborhoods and the socioeconomic and situational variables which have some impact on attitudes about traffic noise.

Assumptions and Limitations

Several assumptions and limitations should be made explicit before continuing. The assumptions are made both to limit the factors under consideration and to be able to analyze the data in the form in which it was collected. These assumptions, of necessity, put certain constraints on the analysis and limit the scope of the investigation and, to a certain extent, this is desirable as it enables a tighter focus to be brought upon the topic and the specific factors under consideration.

The following is a summary of the assumptions made and the limitations encountered:

- 1) The perceived annoyance can be described and measured on a semantic differential Likert scale rating system. This is an ordinal rating system indicating "levels of perceived annoyance" (e.g. mildly annoying, very annoying etc.) and no presumption is made that a particular level of annoyance is any fraction or multiple of another level of annoyance. The subjective rating given is a particular individual's response to a particular question.
- 2) The factors under consideration (socioeconomic and traffic related) were restricted to those variables which were felt would contribute reasonably simply and directly to explaining the perception of noise annoyance and to the

development of a simple "metric" which could be used to indicate and describe noise annoyance. Other factors could have been brought into consideration after more extensive work in data gathering had taken place or if more complex variables were considered, but it was decided to limit the scope of the investigation by restricting the factors to those variables which could be relatively easily obtained and measured.

- 3) In the process of data collection, measurements of variables took several general forms. Traffic noise, of its nature, is continuous and can be measured as such. Variables such as age were more easily grouped into discrete segments, e.g. 20-29 years old. Characteristics such as the respondent's sex were coded in a purely discrete fashion. Finally, noise perception or annoyance can be described by the respondent along a continuum, but is conveniently represented by discrete numbers which are ordinal in nature and convey only the relative order or ranking of the perception. It was assumed that all of these various forms of factor representations could be used together in an analysis.
- 4) The sample study areas were city streets in residential areas. It was recognized that these streets were not homogeneous in nature, i.e. there were in the sample

both arterials and side streets. These locations are shown on maps in chapter 3.

- 5) The traffic characteristics, as measured, were assumed to be representative of the traffic situation in the given area. This qualification and its limitations are more fully discussed in the appendix on data collection.

Research Approach

The problems involved in the analysis of perceived annoyance are in determining which factors exert the greatest influence: socioeconomic characteristics, traffic characteristics or measured noise. As it was already known through the surveys and interviews who was annoyed and their relative level of annoyance, it was decided to use discriminant-classification analysis as the statistical technique for deciding which of the variables or characteristics were most significant in assigning an individual to a particular group characterized by a given level of annoyance. In this way two results would be obtained: first, only those factors which contributed most to the classification and assignment of individuals to their correct group would be included (thus establishing these factors as dominant over the others in influencing the perception of traffic noise) and, secondly, some general idea of how important the variables under consideration are can be gained by ascertaining what percentage of individuals are correctly classified, a posteriori,

by the discriminant-classification scheme. A high percentage of correct classification and assignment would tend to support the hypothesis that those socioeconomic and traffic characteristics did influence the individual's expressed annoyance with traffic noise. A small percentage of correct classifications would indicate that either the variables under consideration are not those which influence annoyance with traffic noise or else that the entire hypothesis of annoyance being influenced by such factors is wrong. A third alternative may exist in that errors may have provided an inappropriate or inadequate data base on which to perform the analysis.

Preview

Chapter Two will offer a brief summary of the literature on the subject. Chapter Three will be concerned with the data collection and reduction and the research methodology. A summary of the analysis will be presented in Chapter Four and the results of the analysis given in Chapter Five. In addition to the research findings, Chapter Five contains some implications of the results and suggestions for further research. Further aspects of data collection and information on noise measurement and indices are to be found in two appendices.

CHAPTER II

LITERATURE SURVEY

Research in the area of traffic noise and its implications for traffic management and control has been focused in approximately three main areas: the control of noise, the relation of measured traffic noise to traffic composition and characteristics, and the relation of measured traffic noise (as characterized by the establishment of some index) to the perceived annoyance. This study is an offshoot of the last area, viz. an attempt to relate the perceived annoyance on the part of individuals not primarily to the disturbing noise but to both the physical environment and social characteristics of the individual.

Control of Noise

Noise control measures may be classified into three categories: noise reduction and/or control at the source, control of transmission path, and protective measures taken at or by the receiver.

The two important areas of noise generation associated with the vehicle are the power plant (gears, intake and exhaust processes, fans, blowers, superchargers) and the contact with the road surface (tire whine, brake squeal). For most motor vehicles the primary noise sources are exhaust noises (low frequency) and tire noise (higher frequency), the tire noise being dominant above 50 mph.

Exhaust noise, however, is dominant for diesel trucks, buses and motorcycles.

The following list summarizes the primary methods of noise reduction at the source:¹

- a) design of the device to produce little or no noise.
- b) inhibition of noise radiators by absorption material.
- c) alteration of frequency characteristics by changing stiffnesses or adding weights to certain portions of the structure.
- d) enclosure or baffling.
- e) changes in operating procedures.
- f) proper alignment, maintenance, and lubrication.

Short of forcing vehicles to be quieter there are other methods of reducing noise, i. e. by effectively controlling or eliminating the access of vehicles (especially trucks) to certain areas or at certain times. Often this is done, not for reasons of reducing noise, but to relieve congestion. Europe has been far ahead of North America in this regard. Alexandre notes that the Common Market countries have adopted common maximum permitted noise levels for motor vehicles and other countries have been following the example.²

In addition, vehicles are tested before they are ever put on the market for sale and noise testing has become part of the regular maintenance and safety testing procedures. In some instances separate traffic noise patrols have also been instigated whose job

it is to apprehend, fine, and insure compliance of repair orders to any vehicle which appears to be too noisy. If the patrol feels that the vehicle is excessively noisy (a subjective appraisal as no measuring devices are carried) the vehicle is taken to a testing station for objective testing and is not allowed back on the road unless any deficiencies are corrected.

Control of the transmission path may be accomplished in a number of ways:³

- a) Increasing distance: Increasing the distance between the noise source and receiver will reduce noise levels at the receiver.
- b) Path deflection: Barriers can be effective under certain conditions in deflecting noise away from the receiver.
- c) Enclosure: Attenuation may be attained by the use of a properly designed enclosure around either the noise source or the receiver.
- d) Absorption: Absorbing materials in the path of the noise effectively limit the noise reaching the receiver.

In most cases the primary and often only relief is through path deflection of the noise. This is usually accomplished with the use of either acoustic barriers, cut and fill sections, or landscaping. Effective sound barriers should be solid, dense,

impermeable, not liable to vibrate, and have considerable mass.⁴

Earth mounds and various wall barriers are the usual types.

Barriers are of greatest effect if installed close to either the source or receiver and should be in the order of 10 feet in height.

Theoretical studies of barriers by Maekawa⁵ and Moore⁶ have led to the development of curves of noise reduction by a barrier in terms of its effective height (height above the source), the diffraction angle over the barrier (the greater the angle, the greater the noise reduction), and the frequency of the noise (higher frequencies are more effectively stopped by the barrier). These theoretical curves have been modified by Galloway⁷ for practical use in highway design. Barriers are, in general, more effective in reducing automobile noise since the source of this noise, pavement-tire interaction, is of high frequency and is essentially at ground level, thus maximizing the effective height of the barrier. The theoretical maximum effective barrier reduction is about 15 dB for cars and 10 dB for trucks.⁸

More recent practical studies by Harmelink⁹, however, have indicated that barriers are not substantially effective. Investigations into the performance of barriers along freeways in Ontario indicated that only moderate (2-4 dBA) reductions in noise occurred at homes near the freeway after the installation of several types of barriers, and no relief at all was found for those living above the ground level of a house. It was concluded that effective barriers (i.e. a 8-10 dBA

reduction in measured noise) would have to be over 20 feet high and would be prohibitively expensive.

The vertical displacement of a road to a position below ground produces acoustic shielding in much the same manner as a barrier.¹⁰ Although sections with vertical retaining walls achieve greater attenuation than cut sections with sloped embankments, the latter usually have several advantages in having greater right-of-way, being cheaper, and being better sound absorbers (sound would be reflected from a retaining wall back into the traffic stream).

The use of bushes, trees, and other foliage is virtually useless in the reduction of noise, it being necessary to provide roughly 100 to 200 feet of 15 foot high trees to achieve a 4 to 5 dB reduction. Their chief value lies in screening the offending noise from view and offering psychological screening.¹¹

Examples of attempts to reduce noise at the receiver consist of the installation of building insulation, the use of double windows, acoustic paneling, or the employment of self generated internal sounds to mask extraneous noises. The above apply primarily to facilities which already exist in the vicinity of noise; if new facilities are to be located in a similar noisy area, care can be taken to see that areas of particular sensitivity to noise be located on the far side of the building away from the noise source. In addition, improved building and housing layouts might be designed to minimize noise by facing them away from an existing freeway

and locating bedrooms on the far side of the structure.

Traffic Noise and Traffic Characteristics

The second major area of current investigation is that of relating measured traffic noise to the traffic characteristics, with two major studies by Johnson and Saunders¹² and Galloway¹³ et. al., being prime contributions in this area. In a study of free flowing traffic in Great Britain, Johnson and Saunders took roadside noise measurements and empirically derived a model of the noise based on measured characteristics. Noise levels were measured in dBA and analyzed using a statistical distribution analyzer to determine the true distribution. Not unexpectedly, results indicated that, at distances close to the roadway or at sufficiently low traffic densities, it is the noise of individual vehicles that is observed and that noise levels decrease at 6 dB per doubling of distance as is expected for point sources. At greater distances from the roadway and higher traffic densities, the noise due to individual vehicles tends to smear into a line source from which both mean and peak noise levels decrease at 3 dB per doubling of distance. It was also found that the highest and lowest noise levels were controlled by individual noisy vehicles and by background noise respectively.¹⁴

Through analysis of these and other factors, Johnson and Saunders produced an empirical expression for the mean noise levels, in dBA, for free flowing traffic:

$$L_{50} = 3.5 + 10 \log V - 10 \log D + 30 \log S$$

where V = traffic volume (vph)

S = speed (mph)

D = distance from roadway center line to
observer (feet).

L_{50} = median noise level (dBA).

The above equation was derived for a traffic composition consisting of 20% trucks but was assumed valid ± 1 dBA for up to 40% trucks. The speed range considered was from 35 to 55 mph and the above equation obtained by normalizing to 40 mph. The noise source strength of individual vehicles was assumed to vary as the fourth power of the speed.

Analytical models of both a continuous line source and a discrete source have also been developed and analyzed by Gordon et. al.¹⁵ For flow rates in excess of 1000 vehicles per hour the noise level due to an infinite line source is predicted by

$$L_{50} = 20 + 10 \log V - 10 \log D + 20 \log S$$

The above equation is one of steady state, i.e. there is no statistical time distribution of the noise levels.

The discrete source model (individual vehicles) predicts a mean noise level of

$$L_{50} = 40 \log S - 10 \log D + 10 \log p + 10 \log \left[\tanh (1.19 \times 10^{-3} p D) \right] + K$$

where ρ = traffic density in vehicles/mile

K = a constant

The discrete source model approaches the continuous line source model as ρ increases.

In contrast to the empirical and analytical models above, Galloway et. al.¹⁶ have developed a probabilistic simulation model in an effort to overcome drawbacks of the above methods (e.g. presence of only uniform vehicle spacing, lack of a "single lane equivalent" for multiple lanes, inability to handle a varied composition of vehicles), and also to avoid the necessity of being tied to data observations for every situation or phenomenon which was to be investigated.

Input data consisted of information on roadway characteristics (number of lanes, lane width), distance to observation point, traffic flow characteristics (mean speed, traffic mix, volume), and noise levels produced by individual vehicles (defined by octave band noise spectra). The set of noise sources (vehicles) arrayed along a line for which the observed noise level was calculated is termed a snapshot of highway noise conditions, i.e. a picture at that point in time. Successive snapshots were independent samples from a particular distribution of noise levels characteristic of the given flow and speed conditions.¹⁷

Vehicles were considered as noise sources along a roadway with a specific flow rate. The assumption of a Poisson distribution

of vehicle inter-arrival times along the roadway (a good approximation for free flowing traffic) allows the programmer to sample randomly from this distribution thus obtaining, after conversion, a set of headways or vehicle spacings approximating that of free flowing traffic. The positioning of vehicles along the lanes also takes into effect the position of the roadway center-line and the relative location of other lanes. The vehicle mix is obtained by selecting at random from the distribution representing the proportions of different vehicles in the total traffic mix for that lane.

The noise source for the model was obtained by sampling from three reference spectra, one each for autos, heavy diesel trucks, and light trucks. Slight modifications in these three basic spectra enable the model to account for variations in noise level due to different operating conditions, e.g. for accelerating cars producing more noise than those at constant velocity a noise spectrum slightly above the normal reference spectrum might be used. Propagation losses used were the 6 dB per doubling of distance appropriate for a single source plus small corrections for attenuation due to absorption and scattering.

The octave band reference spectrum for each noise source was adjusted according to speed and the distance from the observer. These adjusted spectra for each vehicle are then summed by frequency band to give that composite spectrum which would be

obtained at the observation point at that instant. Finally, the mean noise level in dBA and other summary statistics are computed to characterize the noise level for the given situation.¹⁸ The linearized approximation of the mean noise level is the same as that derived analytically for the line source:

$$L_{50} = 20 + 10 \log V - 10 \log D + 20 \log S$$

In comparison with measured conditions, Galloway obtained very good agreement using the above model; so successful, in fact, were the results that a design guide or "cookbook" for computing noise from given conditions has been developed as an outgrowth of the original simulation model.

Noise Indices and Annoyance

Central to all efforts at noise abatement is the need to relate subjective response to the noise environment to some readily measured aspect of that environment. Progress can only be made after the selection of an appropriate criterion for assessing the severity of the noise exposure.¹⁹ This involves the measuring, scaling, and indexing of the noise.

The earliest systematic sound measurements carried out in the United States were of city noise in New York in 1929, most of the data being taken in the form of masking experiments, i. e. to what extent was one sound interfered with or overwhelmed by

another. A second type of observation was also made, however, independent of an observer's ear and yielding a physical measurement of the sound. The acoustimeter, or noise meter, used was similar to the modern sound level meter but employed only one frequency weighting network which was adjusted to match the Fletcher-Munson²⁰ equal loudness contours which closely resemble the A-weighting subsequently adopted in the first American standard sound level meter.

" if a certain meter reading results when a pure tone of 1000 HZ at a sensation level of 30 units agitates the microphone, then the same meter reading will be obtained for any other pure tone of equal loudness. Starting with any single frequency tone at the intensity just defined, if the level of the tone is altered by a chosen amount, say 10 dB, the reading of the noise meter changes 10 dB. It is well known, however, that a change of 10 dB in intensity produces unequal changes in loudness at different frequencies; hence the noise meter cannot be said to measure the loudness of a pure tone at other levels than that for which the weighting network was adjusted. The meter does, however, if calibrated accordingly, measure approximately the sensation level of a pure tone in the frequency region from 1000 to 5000 HZ, where the [weighting curve] . . . is substantially flat.

"The interpretation of the meter reading for a complex applied wave is more involved than for a pure tone. The rectifier is not a linear device; the noise meter [does not]

sum up the components of a complex wave in the same manner as does the ear in producing loudness. Hence, if two successive complex waves differ greatly in composition, the corresponding meter readings will not compare the waves as they are compared by the ear. There is thus a definitely arbitrary element involved in the use of a noise meter employed in any particular survey; another noise meter, having a different single frequency characteristic...and employing a different integrating device, would, in general, yield different measurements. The arbitrary feature is inevitable, however, as no known apparatus has been constructed capable of imitating the ear in the integration of the components of a complex wave."²¹

It has long been the goal to produce a device that would respond to noise signals with readings closely corresponding to subjective human response. The difficulty of this has been such that the A-weighted level, first introduced in 1935, persists in correlating as well with subjective evaluations of many varieties of noise as the most sophisticated scales and procedures.²² For further discussion of the A-weighted system, see Appendix B.

Further confirmation of the accuracy of the A-weighted network came in 1960 when Robinson, Copeland and Rennie²³ performed roadside experiments outside London in which noisiness judgements on passing vehicles were related to the objective readings of sound level meters with different frequency weighting networks. Listeners were stationed at roadside and asked to judge the noisiness of selected passing vehicles on a six step scale (from quiet to excessively noisy). The noise was also measured and recorded at the same spot as the listeners and analyzed in the lab by playing it

back through both A and B weighted networks. (The B weighted network is similar to the A weighted one but more sensitive to frequencies below 500 HZ). When all vehicle classes were grouped together, attempts to find relationships between the subjective noisiness rating given by listeners and the measured value of the noise gave poor results for both the A and B weighted networks. Grouping the vehicles into classes (private cars and commercial vehicles), however, brought out a clear relationship between measured noise levels and individual assessments of noise for each class. It was found that for both vehicle classes the A-weighted network outperformed the B weighted network with correlations of $\sim .9$ for the A-network versus $\sim .8$ for the B network. These results compared favorably with earlier work of a similar nature performed in Switzerland²⁴ and the U.S.²⁵

Young,²⁶ in several articles, and Galloway et. al.²⁷ have also attested to the use of the A-weighted network both because of its consistently respectable correlations with subjective response and its ease and simplicity in use.

Stevens, Zwicker, and Kryter²⁸ have all developed more sophisticated but similar methods for dealing with complex noise, i. e. realizing that sound, particularly traffic noise, is broadband in nature and that the intensity of this noise is not uniform across the frequency band. All methods take into account the masking of one component of a complex noise by the other components.

Frequency band analysis of the noise is performed and loudness indices determined for each band. These contributions are added together to obtain the total loudness with various weightings being used for each band depending on the particular method. Attempts to compare the various indices with subjective response have met with varied success. Modifications of the basic procedures are continually being developed and increased accuracy has been slowly forthcoming over the years. Kryter's Perceived Noise Level (PNL), used primarily in connection with aircraft noise, and a Robinson modification of Stevens' Mark VI calculations appear to give better results than most others but,²⁹ in general, appear only marginally better than the must simpler A-weighted rating. Further information on these rating schemes may be found in Appendix B.

Griffiths and Langdon³⁰ conducted a study in 1967 with the object of developing acceptability criteria for traffic noise in residential areas. Acoustic measurements were taken at 14 sites in the greater London area and 1200 interviews conducted among the residents of these areas. Insofar as it was possible care was taken to insure uniformity of the areas with respect to physical characteristics, i. e. straight road, uninterrupted traffic flow, no other major noise sources. As it was also desired to sample different elements of the population, residents from two local housing projects were among those interviewed. Here the primary purpose was to insure that both owners and renters were represented in the sample. No

other socioeconomic data was gathered because internal tests had indicated they made no different to levels of satisfaction with one exception; respondents of less than six months residence were more satisfied with noise levels than respondents who had been at the site longer.³¹

A-weighted sound level measurements were taken over a 24 hour period outside the house of each interviewee and L_{10} , L_{50} , and L_{90} sound levels were computed where

L_{10} = noise level (dBA) exceeded 10% of the time

L_{50} = median noise level (dBA)

L_{90} = noise level (dBA) exceeded 90% of the time.

Interview responses to certain questions or statements consisted of indicating a level of satisfaction or dissatisfaction along a seven point scale. Attempts were then made to correlate the L_{10} , L_{50} and L_{90} levels with the median dissatisfaction scores as obtained from the interviews. Overall results were relatively poor. Multiple correlation attempts were then undertaken with the hope of improving the results. The most significant correlations resulted from the comparison of median dissatisfaction scores with the mean 10% noise level (L_{10}) minus .75 of the mean 90% (L_{90}) level. Griffiths and Langdon then modified this expression as per below and termed it the Traffic Noise Index (TNI):

$$TNI(dBA) = 4(L_{10} - L_{90}) + L_{90} - 30$$

The parameter includes a measure of the variability of the noise

environment, $(L_{10} - L_{90})$, and a contribution from the background level, (L_{90}) . It is often useful to think of the L_{90} level coming from the whole stream of traffic and the L_{10} level from individual noisy vehicles. Pearson correlation coefficients between median dissatisfaction scores and the above mentioned indices are shown in Table 1.

When the correlation was between the Traffic Noise Index and the individual scores as opposed to median scores the above correlation fell to .29. Other results of the study were that the traffic noise was considered to be worse in bad weather and that the major noise offenders were, in descending order; motorcycles, trucks and buses, and sports cars. Like the A-weighted level, the TNI has maintained support in traffic noise studies because it offers ease of application in addition to correlating well with subjective response.

Johnston and Carothers³², in 1973, conducted studies to verify the use of the Noise Pollution Index (NPI) as an acceptable measure of subjective annoyance due to traffic noise heard indoors. Their experiment was a controlled one, occurring indoors, and consisted of having volunteers, while in a leisure environment, listen to a series of six minute tapes of traffic noise (of known characteristics, in dBA) and indicate their response to the particular noise on a "not annoying" to "very annoying" scale (index numbers 1 to 9). Attempts at correlation were then made between the dissatisfaction

TABLE 1

PEARSON CORRELATION COEFFICIENTS BETWEEN
SELECTED INDICES AND
MEDIAN DISSATISFACTION SCORES

	<u>Selected Index</u>			
	<u>L₁₀</u>	<u>L₅₀</u>	<u>L₉₀</u>	<u>TNI</u>
Median Dissatisfaction Score	.51*	.35	.19	.81**

* p .05

** p .001

Source: Griffiths and Langdon, p. 5.

scores and the NPL, where NPL was defined as

$$NPL = L_{eg} + k\sigma$$

where the energy mean

$$L_{eg} = 10 \log \left[\frac{\int_0^T 10^{L(t)/10} dt}{T} \right]$$

and $L(t)$ = the noise level in dBA as a function of time

T = the length of the particular tape run (6 minutes)

σ = the standard deviation of the noise level in dBA

k = a constant designed to obtain maximum correlation with subjective response (thought by Robinson to be about 2.6)

In attempting to find an optimal value of k to maximize the correlation coefficient several apparently conflicting results were obtained as, for different trials, very different values of k were found to give optimum correlation (correlation coefficients ranged from .77 to .96). The high value of optimum k was 10.5 while the low value, obtained in several trials, was zero.

Upon examination of the data, the authors offered the explanation that, in considering annoyance responses to traffic noise where the standard deviations are of the order of 10 dB or less, there exist three regions governed by the mean noise level (L_{eg} in this case). In the two extreme regions (L_{eg} above 75-80 dBA or below 40-45 dBA) annoyance is either constantly very high or else minimal and would be independent of standard deviations,

i.e. of the $k\sigma$ term. In the center region, however, annoyance would depend both on the mean noise and the measure of the standard deviation. Johnston and Carothers concluded that the NPL worked as well as any other index in relating to subjective response, but that more research was needed into the variability of the "constant" k .

These indices and others not mentioned above are discussed briefly in Appendix B on the measurement of noise and the formulation of indices. The Appendix covers several of the main indices but is by no means exhaustive as there are almost as many indices as there are researchers.

FOOTNOTES

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² A. Alexandre, "European Efforts to Reduce the Impact of Traffic Noise", Inter-Noise 72 Conference Proceedings, Washington, D.C., October 1972, pp. 205-209.

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⁵ Z. Maekawa, "Noise Reduction by Screens", Applied Acoustics, Vol. 1, 1968, pp. 157-173.

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⁷ W. J. Galloway, W. E. Clark, and J. S. Kerrick, "Highway Noise: Measurement, Simulation, and Mixed Reactions", National Cooperative Highway Research Program Report No. 78., Highway Research Board, Washington, D. C., 1969.

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⁹ M. D. Harmelink, and J. J. Hajek, "Highway Noise Control", Traffic Engineering, Vol. 43, No. 12, September 1973, pp. 47-53.

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¹¹ Harmelink, loc. cit.

¹² D. R. Johnson, and E. G. Saunders, "The Evaluation of Noise from Freely Flowing Road Traffic", Journal of Sound and Vibration, Vol. 7, No. 2, 1968, pp. 287-309.

¹³ Galloway, op. cit.

¹⁴C. G. Gordon, W. J. Galloway, B. A. Kugler, and D. L. Nelson, "Highway Noise: A Design Guide for Engineers", National Cooperative Highway Research Program Report No. 117., Highway Research Board, Washington, D. C., 1971.

¹⁵Ibid.

¹⁶Galloway, op. cit.

¹⁷Ibid., p. 43.

¹⁸Ibid., p. 44.

¹⁹Theodore Schultz, Community Noise Ratings, Applied Science Publishers Ltd., London, 1972, p. 2.

²⁰H. Fletcher, and W. A. Munson, "Loudness, its Definition, Measurement, and Calculation", Journal of the Acoustic Society of America, Vol. 5, 1933, pp. 82-108.

²¹R. H. Galt, "Results of Noise Surveys: Part 1: Noise out-of-doors", Journal of the Acoustic Society of America, Vol. 2, 1930, pp. 32-33.

²²Schultz, op. cit., p. 15.

²³D. W. Robinson, W. C. Copeland, and A. J. Rennie, "Motor Vehicle Noise Measurement", The Engineer, Vol. 211, March 1961.

²⁴Gernaldirektion PTT, Switzerland, "Forschungs und Versuchsamwalt", Report No. 22, 637, and Appendix, October 1959.

²⁵B. Andrews, and D. M. Finch, Proceedings, Highway Research Board, Washington, D. C., December 1951, p. 456.

²⁶R. W. Young, in many studies listed in Schultz, op. cit., p. 13, repeatedly reminds the reader that the A-weighted level persists in correlating almost as well with subjective evaluations

of many varieties of noise as the most sophisticated scales and procedures. See also R. H. Parkin, "On the Accuracy of Simple Weighting Networks for Loudness Estimates of Some Urban Noise", Journal of Sound and Vibration, Vol. 2, 1964, pp. 86-88.

²⁷Galloway, op. cit., p. 25.

²⁸For a fuller description of the various indices developed by Stevens, Zwicker, and Kryter over the years and a partial list of their various publications, see Schultz, op. cit., pp. 16-21, 30-34.

²⁹Schultz, op. cit., p. 21.

³⁰I. D. Griffiths, and F. J. Langdon, "Subjective Response to Road Traffic Noise", Building Research Station Current Paper 37/68, April 1968.

³¹Ibid., p. 3.

³²G. W. Johnson, and R. Carothers, "Annoyance Measurements Related to Urban Traffic Noise Exposure", University of Toronto--York University Joint Program in Transportation, Research Report No. 13, 1973.

CHAPTER III

DATA REDUCTION AND METHODOLOGY

Data Reduction

The purpose of the study is to investigate the relationship between noise annoyance and the socioeconomic and situational variables which have some impact on attitudes about traffic noise. In this manner characteristics or patterns of characteristics can be used to explain or distinguish between the various groups who are affected differently by traffic noise. The structure of this chapter will be to explain briefly the collection and organization of data, the methodology adopted, and the principles behind those methods used.

Three areas of Vancouver were chosen for the study on the basis of results of a previous survey.¹ The noise climate in these areas (see Map 1) had been indicated to be fairly bothersome, and it was felt that respondents in the three areas (West End, Kitsilano, Fairview/East End) would be representative of the range of socioeconomic variables to be investigated. The interview locations (a one block section) in each area numbered about twenty and were selected to simulate as closely as possible the average conditions within the area. A total of 331 sets of socioeconomic and annoyance data were gathered while traffic and noise data were obtained for each measurement location associated with the particular interview block. Both interview and noise measurement locations are shown

on maps 2 through 9. All data were collected during the mid-day hours of weekdays in August, 1973.

The data used for this study can be divided into two general categories; those variables associated with the individual and those associated with the physical environment.

Socioeconomic variables

The eight variables associated with the individual respondent are socioeconomic in nature and are shown in Table 2.

Age and sex are basic variables used in the analysis to determine if there occurs any marked difference in perception of noise either on the basis of sex (e.g. the housewife, who may be home all day, as opposed to the businessman, who may experience the mid-day residential noise climate only occasionally), or on the basis of age (e.g. are the young, perhaps used to a faster pace of life and its accompanying distractions, less susceptible to noise than their elders?). The following categories were used to obtain data on the age and sex of the respondent.

<u>Sex:</u>	Male ☐	or	Female ☐
<u>Age Group:</u>	Under 20 ☐	50 - 59	☐
	20 - 29 ☐	60 - 69	☐
	30 - 39 ☐	70 or older	☐
	40 - 49 ☐

MAP 1

Areas Under Study

- I - West End
- II - Kitsilano
- III - Fairview

MAP 4
KITSILANO
INTERVIEW LOCATIONS
IN KITSILANO

MAP 6
Fairview - East
Interview Locations
in Fairview - East

MAP 8
Fairview - West
INTERVIEW LOCATIONS
IN FAIRVIEW - WEST

Noise and Traffic
Volume Measurement
Locations in Fairview-West

MAP 9

TABLE 2

SOCIOECONOMIC VARIABLES

AGE:	age of the respondent
INCOME:	yearly income of the respondent
SEX:	sex of the respondent
EDUC:	education level of the respondent
CAROWN:	number of cars owned in the household
OWN/RNT:	indication of whether the respondent owns or rents
HOWLNG:	indication of respondent's length of residency at his present address
JOB:	indication of the type of occupation in which the respondent is employed.

Education, income and occupation often correlate highly with one another, so, to a certain extent, these three variables are somewhat redundant. All are used, however, because of the differences involved in an individual's expectations based on these variables. Occupations which pay roughly the same can vary considerably in their noise environment, e.g. an office job as opposed to a field job in construction. It would then be expected that if differences on the perception of noise arise, all other things being equal, this difference could be attributed to tolerances or frustrations affiliated with working at the particular job. Those with high incomes or more education may feel they have earned the right to a quiet environment and thus be quite distressed at moderate or loud noise levels in their home environment. Galloway², in a study of susceptibility to freeway noise, found that those who were more annoyed tended to be better educated, somewhat older, and did not use the freeway for work (no element of necessity was perceived with respect to the freeway). The above three variables were broken down according to the categories given below.

Income (in dollars):

☐ Under 2000	☐ 10,000-11,999
☐ 2000-3999	☐ 12,000-13,999
☐ 4000-5999	☐ 14,000-15,999
☐ 6000-7999	☐ 16,000-20,000
☐ 8000-9999	☐ Over 20,000

Education Level Attained:

☐ Public School Diploma	☐ Junior College
☐ High School Diploma	☐ University Degree
☐ Professional Training	☐ Post Graduate Degree

Occupational Category:

☐ Professional	☐ Homemaker
☐ Managerial	☐ No Employed
☐ Craftsman	☐ Part-time Employee
☐ Sales, Clerical	☐ Student
☐ Secretarial	☐ Unskilled

Car owners, because of their owning a car themselves, may be more inclined to tolerate the traffic noise of others. In a similar fashion, those who do not own cars and thus do not contribute to the noise pollution may be inclined to be quite sensitive.

Length of residency in the present dwelling and the ownership status of the individual (do they own or rent) also may be expected to affect the perception of noise. Certain acclimatization may occur after an individual has been exposed to a particular noise environment for a period of time; on the other hand it is possible that if the individual has not adjusted or accommodated himself to the noisiness, he may become even more susceptible and hypersensitive over time. Ownership of the dwelling may lead to increased annoyance because

of the implied decrease in value or comfort of the home in the presence of a noisy environment. A renter may not become as annoyed because, in theory at least, he has the option of moving without a great deal of difficulty or possible loss of equity in the home. Vehicle and home ownership status and length of residency were obtained according to the format below.

Home Ownership Status:

☐ Own ☐ Rent

Length of Residency (in years):

☐ Less than 1	☐ 5 - 10
☐ 1 - 2	☐ 10 - 15
☐ 3 - 5	☐ over 15

Number of Vehicles Owned:

The appropriate number was entered.

Situational Variables

The characteristics associated with the physical environment are listed in Table 3. These characteristics describe the noise environment in the area, at the time measured, and the presence of factors which may alter the perception of noise by the individual.

L_{10} and L_{50} are the sound levels exceeded 10% and 50% of the time respectively, as measured in the A-weighted system (units of

TABLE 3

SITUATIONAL VARIABLES

TNI:	traffic noise index
L ₁₀ :	noise level exceeded 10% of the time (indicative of peaks)
L ₅₀ :	median noise level
DIST:	distance between the listener and the street the respondent indicated was noisiest
TOTVEH:	total number of vehicles past the measuring apparatus during the hour of measurement
TREES:	indicates presence or absence of large trees in the area
BLDGS:	indicates presence or absence of large buildings in the area
FLOW:	indicates whether traffic flow is interrupted or free flowing.

dBA). L_{10} is indicative of the "peak" sound levels and L_{50} of the median or average sound level. The Traffic Noise Index (TNI) is a composite index formed using the values of L_{10} and L_{90} (the sound level exceeded 90% of the time) and is more fully described in Chapter II and Appendix B. A sample hardcopy of the continuous noise level as output on a chart recorder is shown below.

The distance involved is that approximate distance, in feet, from the center line of the roadway upon which the noise was measured to the house where the interview was made. Distances were estimated using large scale street maps of the city (scale 1" = 200'). The number of vehicles was the total number of cars, trucks, buses and motorcycles to have passed the measuring apparatus in both directions during the hour in which noise measurements were taken. The ranges of noises and volumes of traffic encountered during the measurement hour are given in Tables 4 through 6. The locations indicated refer to those illustrated on maps 3, 5, 7 and 9. Figures 1 through 3 illustrate the range of noise levels encountered for various traffic volumes. The flow characteristic of the traffic stream was a two valued index to differentiate between uninterrupted flow and that which was regularly stopped because of lights, stop signs or frequent pedestrian crossings. The presence of large trees or buildings which could affect the noise path in the area of noise transmission under concern (either through shielding or reflection effects) was

16th near
Oak

16th Ave between Oak and Richelieu
obtained 10:15 - 11:15 A.M.
Friday in August

TABLE 4

TRAFFIC VOLUMES AND NOISE LEVELS - WEST END

(all figures are for the one hour measurement period)

Location	Traffic Composition					Measured Noise Levels	
	Number of cars	Number of pickups/vans	Number of trucks	Number of buses	Number of motorcycles	L ₅₀	L ₁₀
1	297	29	17	4	--	65.0	75.0
2	64	4	8	--	--	64.0	70.0
3	985	107	42	18	4	72.4	79.5
4	241	25	16	--	--	65.6	74.3
5	36	2	3	--	--	57.7	64.7
6	945	107	37	24	8	75.1	82.5
7	710	66	32	1	6	71.7	81.1
8	695	62	26	23	11	70.2	79.2
9	1055	128	41	10	15	71.0	79.5
10	1015	106	35	3	16	71.3	79.3
11	235	26	20	7	6	65.0	76.8
12	1446	193	60	17	5	73.5	82.4

TABLE 5

TRAFFIC VOLUMES AND NOISE LEVELS - KITSILANO

(all figures are for the one hour measurement period)

Location	Traffic Composition					Measured Noise Levels	
	Number of cars	Number of pickups/vans	Number of trucks	Number of buses	Number of motorcycles	L ₅₀	L ₁₀
1	670	118	28	12	8	70.2	79.7
2	540	31	7	1	7	64.0	75.3
3	1185	177	52	13	18	67.2	74.6
4	1048	117	61	53	16	64.7	73.0
5	763	88	27	--	9	61.6	71.6
6	637	74	18	19	13	64.0	75.0
7	1070	139	36	15	17	65.8	75.1
8	665	70	14	49	7	64.0	74.4
9	925	93	21	17	13	67.6	76.7
10	740	52	13	15	5	59.2	72.3
11	1070	96	44	1	9	60.1	67.3
12	1040	108	34	66	18	66.5	74.7
13	558	52	14	16	9	63.2	74.8
14	435	47	12	--	2	59.3	70.4

TABLE 6

TRAFFIC VOLUMES AND NOISE LEVELS - FAIRVIEW/EAST END

(all figures are for the one hour measurement period)

Location	Traffic Composition					Measured Noise Levels	
	Number of cars	Number of pickups/vans	Number of Trucks	Number of buses	Number of motorcycles	L ₅₀	L ₁₀
1	266	47	15	--	3	56.1	68.2
2	1348	289	221	--	11	73.6	79.7
3	1200	168	37	--	22	70.7	78.8
4	560	128	66	24	5	66.0	74.2
5	935	124	40	--	17	66.1	75.5
6	717	213	179	3	8	71.8	81.8
7	1005	125	54	17	13	63.6	70.4
8	940	146	28	1	9	69.3	78.9
9	1665	244	138	31	31	66.3	73.9
10	397	84	32	--	5	60.2	72.2
11	1170	287	197	2	15	70.0	76.8
12	790	105	45	14	6	64.1	73.0
13	883	155	45	1	5	76.1	84.9
14	547	97	30	17	6	54.8	64.1
15	217	28	17	--	2	61.0	75.0

Figure 1.
Measured Noise and Traffic Volumes
West End. (5.6% trucks)

Range displayed is from median noise level (L₅₀)
to the 10th percentile level (L₁₀).

Figure 2.

Measured Noise and Traffic Volumes

Kitsilano (6.1% trucks)

Range displayed is from median noise level (L_{50})
to the 10th percentile level (L_{10}).

Figure 3.

Measured Noise and Traffic Volumes

Fairview (8.6% trucks)

Range displayed is from median noise level (L_{50})
to the 10th percentile level (L_{10}).

also taken into account by distinguishing between those situations in which large buildings and trees were present and those in which they were not.

Lastly, attitudes toward traffic noise were collected as part of the same interviews in which the socioeconomic data was obtained. These were obtained by asking the interviewee to respond with varying degrees of agreement or disagreement with a statement on traffic noise (see questionnaire in Appendix A). Through the use of semantic differential Likert scale rating it was possible to attach a number index to an individual's stated annoyance with traffic noise. This number index would then categorize the individual as belonging to a group which was annoyed or unannoyed by traffic noise to a particular extent. A summary of these responses is given in Tables 7 through 10. In addition, Figure 4 presents a scale of noise relating various sound sources and the general response to them.

All the above data were collected during the mid-day hours, 10 A.M. to 4 P.M., during August, 1973. Noise and traffic data were collected simultaneously at locations indicated in the interviews to be the principal sources of traffic noise in the area. Errors in the collection and organization of data are further discussed in Appendix A.

TABLE 7
RESPONSE TO ANNOYANCE QUESTION
WEST END

Response to statement that "traffic noise in the neighborhood is annoying":

	<u>Number</u>
Strongly Agreed	39
Mildly Agreed	45
Indifferent	8
Mildly Disagreed	18
Strongly Disagreed	<u>19</u>
	119

TABLE 8
RESPONSE TO ANNOYANCE QUESTION
FAIRVIEW

Response to statement that "traffic noise in the neighborhood is annoying".

	<u>Number</u>
Strongly Agreed	42
Mildly Agreed	21
Indifferent	13
Mildly Disagreed	14
Strongly Disagreed	11
No Reply	<u>1</u>
	102

TABLE 9
RESPONSE TO ANNOYANCE QUESTION
KITSILANO

Response to statement that "traffic noise in the neighborhood
is annoying. "

	<u>Number</u>
Strongly Agreed	30
Mildly Agreed	40
Indifferent	6
Mildly Disagreed	26
Strongly Disagreed	<u>8</u>
	110

TABLE 10

RESPONSE TO ANNOYANCE QUESTION
(COMPOSITE ALL THREE AREAS)

Response to statement that "traffic noise in the neighborhood is annoying".

	<u>Number</u>	<u>%</u>
Strongly Agreed	111	33.6
Mildly Agreed	106	32.0
Indifferent	27	8.2
Mildly Disagreed	58	17.5
Strongly Disagreed	28	8.4
No Reply	<u>1</u>	<u>.3</u>
	331	100.0

*Typical A-Weighted sound levels taken with a sound-level meter and expressed as decibels on the scale. The "A" scale approximates the frequency response of the human ear.

Figure 4. Weighted Sound Levels and Human Response

Source: U.S. DOT "Recommendations for Northeast Corridor Transportation, Final Report", NTIS, Sept. 1971, pp. 62-63.

Methodology

The basic purpose of the study was to determine what characteristics, if any, could be used to understand and distinguish among various attitudes toward traffic noise. Two statistical methods were used in the investigation, factor analysis and discriminant classification analysis. Discriminant analysis was employed initially in an attempt to use the variables discussed above to classify individuals into groups based on their stated annoyance toward noise and to distinguish between these groups on the basis of the given characteristics. Later, factor analysis was used in an attempt to group similar variables into a single factor and thus reduce the effective number of variables. Discriminant analysis was then used again using these factors as the new "variables".

Discriminant-classification analysis

Discriminant analysis is a statistical technique to facilitate the classification of things or persons. Given two or more classes of persons and a set of measurements made on each person we seek an index number derived from these measurements which, when applied to some newly observed and unclassified person, will assign him to one or another of the classes with the smallest probability of error.³ For the simplest case of classification into two groups the procedure for discriminating consists in finding a

critical value of the index such that any individual whose computed index value on the discriminant function fell below the critical value would be classified as belonging to one class, otherwise to the other class.

The principal difference between a discriminant function and an ordinary linear regression function arises from the nature of the dependent variable. A linear regression function uses values of the dependent variable to determine a linear function of independent variables that will estimate the values of the dependent variable, whereas the discriminant function possesses no such values or variable, but instead uses a two-way classification of the data to determine the linear function.⁴

Consider a set of k variables $X_1, X_2, \dots, X_k$ by means of which it is desired to discriminate between two groups of individuals. Let

$$Z = \lambda_1 x_1 + \lambda_2 x_2 + \dots + \lambda_k x_k$$

be a linear combination of these variables. The problem then is to determine the λ 's by means of some criterion that will enable Z to serve as an index for differentiating between members of the two groups. By adjustments to the λ 's the discriminating hyper-plane, Z , can be aligned in space such that values of Z corresponding to the two groups will assume increasingly divergent values, i.e. the difference between the values of Z for the two groups will

become greater. At the same time, however, variations of the values of Z within a group also become increasingly large for both groups; consequently the increase in the separation of the values of Z for the two groups occurs at the expense of an increase in the separation of the values of Z within each group. This situation corresponds to that in which the means of the two distributions are separating but for which the standard deviations are increasing to such an extent that greater discrimination between the two distributions does not necessarily result. It would be desirable to choose a plane that separates the values of Z for the two groups as widely as possible relative to the variation of the values of Z within the two groups. As a measure of the separation of the two groups, it is convenient to use $(\bar{Z}_1 - \bar{Z}_2)^2$, where $\bar{Z}_1$ and $\bar{Z}_2$ are the means of the two groups. As a measure of the variation of the values of Z within the two groups, it is convenient to use

$$\sum_{i=1}^2 \sum_{j=1}^{n_i} (z_{ij} - \bar{z}_i)^2$$

where z_{ij} denotes the Z value of the j^{th} individual in the i^{th} group and n_i the number of individuals in group i . Then the desired plane will be that for which the λ 's are determined to maximize the function

$$G = \frac{(\bar{Z}_1 - \bar{Z}_2)^2}{\sum_{i=1}^2 \sum_{j=1}^{n_i} (z_{ij} - \bar{z}_i)^2}$$

Set up in this way, the problem then can be solved mathematically to obtain the values of λ and, consequently, the discriminant function, Z .⁵

Having determined the discriminant function, we measure the values of the characteristic variables of a new subject and calculate his score using the discriminant function. If his score exceeds a certain cutting score, usually halfway between the means of the two groups, he is assigned to that group which had the highest mean score on the discriminant function. This cutting score will vary depending on the a priori probabilities of actually belonging to one of the groups. By a suitable choice of cutting point, the overall possibility of misclassification may be minimized.⁶

In multiple discriminant analysis (more than two groups), weighting factors (λ 's) are calculated for each group entering the analysis and a discriminant function formed for each group. The values of variables for a new subject are then measured and applied to each discriminant function and the subject assigned to the group for which he attains the highest weighted score.

In the present case discriminant analysis was used not specifically to classify new subjects, but rather to discover what variables proved most useful in characteristics or predicting, a posteriori, the relative noise annoyance felt by individuals.

Factor analysis

Factor analysis is a statistical method of analyzing the intercorrelations within a set of observations of variables to determine whether the variations represented can be adequately accounted for by a smaller number of basic factors than was used at the start of the investigation. The problem is to find a small as possible orthogonal set of basis vectors (factors with zero correlation between each pair) which accounts for most of the variance in the original set of variables. Factor analysis enables one to group some variables together because these new factors hopefully reflect some more basic characteristics of the original variables.⁷

The first step in the more common R-factor analysis involves the calculation of a correlation matrix for the set of initial variables. The second step is to reduce the data by constructing a new set of variables on the basis of the interrelations exhibited in the data. Two methods are available for accomplishing this: common factor analysis and principal component analysis. Since principal component analysis was used in the present case it will be described further.

Principal component analysis is a method of transforming a given set of variables into a new set of composite variables or principal components that are orthogonal or uncorrelated to each other. No particular assumption about the underlying structure of the variables is made as there is in common factor analysis. One determines the best linear combination of variables which accounts

for more variance in the data than any other linear combination of variables. The first principal component is the single best summary of linear relationships exhibited in the data. The second component is that linear combination of variables that accounts for the most residual variance after the effect of the first component is removed, and so on for subsequent components.⁸ Each component must also be orthogonal (have zero correlation) to every other component. Since each component is the best linear summary of variance left in the data after the previous components are taken care of, the first several components will hopefully explain most of the variance in the data.

The final step in factor analysis is factor rotation. By means of this rotation each factor is made as simple and as interpretable as possible, the ultimate goal of any rotation being to obtain some theoretically meaningful factors and the simplest factor structure. There are two types of rotation: oblique rotation, in which the factors are not kept orthogonal, and orthogonal rotations. Varimax rotation, the type used in this situation, centers on simplifying the columns of a factor matrix, equivalent to maximizing the variance of the squared loadings in each column. As an example consider Table 11 below.

After rotation, variables A, B, and C load quite largely on factor II and very little on factor I while the reverse is true for variables D and E. The loadings or numbers in a given row

TABLE 11

EXAMPLE OF FACTOR LOADINGS

Variable	Unrotated Factor Matrix		Rotated Factor Matrix	
	Factor I	Factor II	Factor I	Factor II
A	.75	.63	.14	.95
B	.69	.57	.14	.90
C	.80	.49	.18	.92
D	.85	-.42	.94	.09
E	.76	-.42	.92	.07

represent regression coefficients of factors in describing the variables. The total variance of a variable accounted for by the combination of all factors is called the communality of the variable. The communality of a variable is thus that proportion of its total variance which is represented in the factor space. The communality of variable A is

$$(.14)^2 + (.95)^2 = .922$$

and $(.95)^2$ or .903 of this is explained by factor II. In principal component analysis the importance of a given factor in terms of the amount of total variance in the data it accounts for may be obtained by adding the squares of the loadings in each column. For factor II, this becomes

$$(.95)^2 + (.90)^2 + (.92)^2 + (.09)^2 + (.07)^2 = 2.572$$

This number is called the eigenvalue for factor II and since, using principal component analysis, the sum of all eigenvalues is equal to the original number of variables, we have the proportion of the total variance accounted for by factor II is

$$\frac{2.572}{5} = .515$$

A more detailed discussion of the various types of factor analysis may be found in either Rummel⁹ or the Statistical Package for the Social Sciences (SPSS) computer program manual.¹⁰

FOOTNOTES

¹A. J. Price, "A Community Noise Survey of the Greater Vancouver Regional District", Engineering Report, Barron and Strachan, Consulting Acoustical Engineers, Vancouver, B.C.

²W. J. Galloway, W. E. Clark, and J. S. Kerrick, "Highway Noise: Measurements, Simulation, and Mixed Reactions", National Cooperative Highway Research Program Report No. 78, Highway Research Board, Washington, D. C., 1969, p. 70.

³Keith Hope, Methods of Multivariate Analysis, University of London Press Ltd., London, 1968, p. 102.

⁴Paul G. Hoel, Introduction to Mathematical Statistics, John Wiley and Sons Inc., New York, 1954, p. 180.

⁵Ibid., p. 181.

⁶Hope, op. cit., p. 106.

⁷For a more comprehensive discussion of factor analysis see either R. J. Rummel, "Understanding Factor Analysis", Journal of Conflict Resolution, Vol. II, No. 4, December 1967, pp. 444-480, or Norman Nie, Dale Bent, and C. Hadlai Hull, Statistical Package for the Social Sciences (SPSS), McGraw-Hill Book Company, New York, 1970, pp. 208-244.

⁸Nie, op. cit., p. 210.

⁹Rummel, op. cit.

¹⁰Nie, op. cit.

CHAPTER IV

ANALYSIS

All analyses discussed in this chapter took place at the University of British Columbia computing center and two programs of the University were used in the analysis (UBC FACTO, the factor analysis program, and BMD 07M, the discriminant analysis program). The analyses of the data occurred in several phases. Initially, discriminant analysis was run using only a few test variables to obtain some preliminary information as to how the process was working. These variables are listed in Table 12 and the results of the above analysis were inconclusive. Two separate attempts at discriminant-classification were made, one into five groups and the other into three groups as per Tables 13 and 14. The actual number in each classification was known on the basis of the response to the statement "The noise from traffic in this neighborhood is annoying", and these are given in Tables 7 through 9 of Chapter III.

As can be seen from Table 10 in Chapter III, the majority of respondents indicated annoyance with traffic noise in the community to some extent. This weighting in favor of those annoyed reflects a basic assumption of the investigation in choosing as study areas those sections which had indicated in previous surveys that traffic noise was a problem. Accordingly, the annoyance responses were accepted as representing a valid sample of opinion in those particular

TABLE 12

FIVE TRIAL DISCRIMINATING VARIABLES

OWN/RNT

HOWLNG

AGE

TNI

INCOME

definitions of the above variables may be found in

Tables 2 and 3.

TABLE 13

FIVE GROUP CLASSIFICATION CATEGORIES

-
-
1	=	strongly disagreed
2	=	mildly disagreed
3	=	neither agreed nor
disagreed (indifferent)
4	=	mildly agreed
5	=	strongly agreed
-

TABLE 14

THREE GROUP CLASSIFICATION CATEGORIES

A = disagreed = 1 and 2

B = indifferent = 3

C = agreed = 4 and 5

areas. Had there been a priori knowledge that the responses obtained were unrepresentative of opinion in the area, weighting factors could have been applied to the sample number in each group to reflect this prior knowledge. Since it was felt that the sample numbers were representative, a weighting of unity for each group was assumed.

In the attempts at classifying individuals into five groups none of the five variables in Table 12 was significant at the 5% level of significance, and at the 10% level of significance AGE and TNI together were able to classify correctly only 14.9% of the subjects. Greatest success was in classifying those who were indifferent or strongly disagreed, where almost 50% were correctly classified. Results are shown in Table 15.

It was then decided to attempt classifications into only three groups by combining those groups which basically agreed or disagreed with the statement on noise as indicated in Table 14. At the 5% level of significance AGE was the first to enter as a discriminating variable resulting in 19.4% correct classifications and being most successful in classifying those who were either not annoyed (disagreed with the statement) or indifferent. Less than 1% of those annoyed were correctly classified, however. The addition of the variable OWN/RNT to the discriminant function increased the percentage of correct classifications to 28.5%, increasing the percentage of those annoyed who were correctly classified to 24%

TABLE 15

CORRECT CLASSIFICATION MATRIX - FIVE GROUP TRIAL

Number of cases classified into groups -

NOTANY MLDNOT INDIFF MLDANY VERYAN

Group					
NOTANY	14	6	7	0	1
MLDNOT	22	12	17	6	11
INDIFF	6	4	12	4	1
MLDANY	27	27	38	11	3
VERYAN	30	20	61	0	0

% of cases classified into each group -

NOTANY MLDNOT INDIFF MLDANY VERYAN TOTAL

Group						
NOTANY	50.00	21.43	25.00	00.00	3.57	28.00
MLDNOT	37.93	20.69	29.31	10.34	1.72	58.00
INDIFF	22.22	14.81	44.44	14.81	3.70	27.00
MLDANY	25.47	25.47	35.85	10.38	2.83	106.00
VERYAN	27.03	18.02	54.95	00.00	0.00	111.00

Correct classification matrix: 5 groups

Discriminating variables: AGE, TNI

Level of significance: 10%

14.85% of the cases were correctly classified

but declining in the ability to classify the indifferent and those who professed not to be annoyed. Changing the level of significance to 10% and 20% did not result in any change in the discriminant function or the percentage correctly classified. Tables 16 and 17 illustrate the above.

Discriminant-Classification Analysis

At this stage it was decided to increase the number of variables under consideration. This was done in stages from 5 to 11, 12, 15 and finally 16 variables. The complete list in the order of addition is shown in Table 18.

Five Group Case

In running the discriminant analysis again using the increased number of variables and five groups, the first three variables to enter the discriminant function and the percentage of correct classifications were always the same at the 5% level of significance. Education was the first variable to enter and, by itself, was able to correctly classify 23.6% of the subjects, the greatest success being in classifying those who either strongly agreed or strongly disagreed with the noise statement (were either very annoyed or not at all annoyed). Almost no one was categorized to be of moderate or "mild" opinion (see Table 19). The next two variables to enter the discriminant function were the distance and

TABLE 16

CORRECT CLASSIFICATION MATRIX - THREE GROUP TRIAL

Number of cases classified into groups -			
Group	NOTANN	INDIFF	ANOYED
NOT ANN	42	44	0
INDIFF	6	21	0
ANOYED	86	130	1

% of cases classified into each group -				
Group	NOTANN	INDIFF	ANOYED	TOTAL
NOT ANN	48.34	51.16	0.00	86.00
INDIFF	22.22	77.78	0.00	27.00
ANOYED	39.63	59.91	.46	217.00

Correct classification matrix: 3 groups

Discriminatory variables: AGE

Level of significance: 5%

19.38% of the cases were correctly classified

TABLE 17

CORRECT CLASSIFICATION MATRIX - THREE GROUP TRIAL

Number of Cases classified into group -				
Group	NOTANN	INDIFF	ANOYED	
NOT ANN	26	38	22	
INDIFF	5	15	7	
ANOYED	53	111	53	

% of cases classified into each group -				
Group	NOTANN	INDIFF	ANOYED	TOTAL
NOT ANN	30.23	44.19	25.58	86.00
INDIFF	18.52	55.56	25.93	27.00
ANOYED	24.42	51.15	24.42	217.00

Correct classification matrix: 3 groups

Discriminating variables: AGE, OWN/RT

Level of significance: 5%

28.48% of the cases were correctly classified

TABLE 18

SUMMARY OF DISCRIMINATING VARIABLES CONSIDERED

OWN/RT	)	
AGE	)	
	)	
HOWLNG	)	initial 5 test variables
TNI	)	
	)	
INCOME	)	
SEX	)	
EDUC	)	
	)	
DIST	)	next group of 6 variables added to increase
TOTVEH	)	total number of variables to 11
	)	
L10	)	
	)	
L50	)	
JOB	)	12th variable added
	)	
FLOW	)	
	)	
TREES	)	13th through 15th variables added
BLDGS	)	
CAROWN	)	16th and last variable added

TABLE 19

CORRECT CLASSIFICATION MATRIX - FIVE GROUPS

Group	Number of cases classified into group -				
	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN
NOT ANY	22	0	2	0	4
MLDNOT	37	0	8	0	13
INDIFF	14	0	4	0	9
SOMANY	50	0	12	2	42
VERYAN	44	0	17	0	50

Group	% of cases classified into each group -					
	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	TOTAL
NOT ANY	78.57	0.0	7.14	0.0	14.29	28.00
MLDNOT	63.79	0.0	13.79	0.0	22.41	58.00
INDIFF	51.85	0.0	14.81	0.0	33.33	27.00
SOMANY	47.17	0.0	11.32	1.89	39.62	106.00
VERYAN	39.64	0.0	15.32	0.0	45.05	111.00

Correct classification matrix:

5 groups

Discriminating variables:

EDUC

Level of significance:

5%

23.64% of the cases were correctly classified

the total number of vehicles which increased the percentage of correct classifications to 28.5% and 30.3% respectively. This increase in overall classification ability came about through increasing the percentage of those correctly classified in the middle groups (those of mild or no opinion) and decreasing the correct percentages of those who were definitely not annoyed. See Tables 20 and 21 for the exact figures.

Three additional variables, the indicator of the presence of trees, the car ownership index and the L_{10} noise level also entered the discriminant function raising the overall percentage of correct classifications to 32.7%; the largest increases occurred in the percentage of correct classifications of those who were indifferent or very annoyed. At the 10% level of significance the length of residency variable, HOWLNG, entered the discriminant function and raised the correct classification percentage to 33%. At the 20% level of significance the percentage of correct classifications declined since HOWLNG was removed as a discriminating variable and replaced by others. Thus, the "best" results were obtained at the 10% level of significance with seven variables in the discriminant function (EDUC, DIST, TOTVEH, TREES, CAROWN, L_{10} , and HOWLNG). Tables 22 and 23 illustrate the above.

TABLE 20

CORRECT CLASSIFICATION MATRIX - FIVE GROUPS

Number of cases classified into group					
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN
NOTANY	11	5	1	6	5
MLDNOT	23	0	8	15	12
INDIFF	9	0	2	6	10
SOMANY	24	1	21	26	34
VERYAN	23	0	12	21	55

% of cases classified into each group						
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	TOTAL
NOTANY	39.29	17.86	3.57	21.43	17.86	28.00
MLDNOT	39.66	0.0	13.79	25.86	20.69	58.00
INDIFF	33.33	0.0	7.41	22.22	37.04	27.00
SOMANY	22.64	0.94	19.81	24.53	32.08	106.00
VERYAN	20.72	0.0	10.81	18.92	49.55	111.00

Correct classification matrix: 5 groups

Discriminating variables: EDUC, DIST

Level of significance: 5%

28.48% of the cases were correctly classified

TABLE 21

CORRECT CLASSIFICATION MATRIX - FIVE GROUPS

Number of cases classified into group					
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN
NOTANY	13	4	1	2	8
MLDNOT	20	12	8	7	11
INDIFF	7	6	11	3	10
SOMANY	23	20	20	18	35
VERYAN	17	11	10	17	56

% of cases classified into each group						
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	TOTAL
NOTANY	46.43	14.29	3.57	7.14	28.57	28.00
MLDNOT	34.48	20.69	13.79	12.07	18.97	58.00
INDIFF	25.93	22.22	3.70	11.11	37.04	27.00
SOMANY	21.70	18.87	9.43	16.98	33.02	106.00
VERYAN	15.32	9.91	9.01	15.32	50.45	111.00

Correct classification matrix:

5 groups

Discriminating variables:

EDUC, DIST, TOTVEH

Level of significance:

5%

30.30% of the cases were correctly classified

TABLE 22

CORRECT CLASSIFICATION MATRIX - FIVE GROUPS

Number of cases classified into group						
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	
NOTANY	14	2	3	3	6	
MLDNOT	13	10	17	7	11	
INDIFF	5	6	3	6	7	
SOMANY	200	15	19	18	34	
VERYAN	17	12	6	13	63	

% of cases classified into each group						
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	TOTAL
NOTANY	50.00	7.14	10.71	10.71	21.43	28.00
MLDNOT	22.41	17.24	29.31	12.07	18.97	58.00
INDIFF	18.52	22.22	11.11	22.22	25.93	27.00
SOMANY	18.87	14.15	17.92	16.98	32.08	106.00
VERYAN	15.32	10.81	5.41	11.71	56.76	111.00

Correct classification matrix: 5 groups 5 groups

Discriminating variables: EDUC, DIST, TOTVEH, TREES,
CAROWN, L10

Level of significance: 5%

32.73% of the cases were correctly classified

TABLE 23

CORRECT CLASSIFICATION MATRIX - FIVE GROUPS

Group	Number of cases classified into group				
	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN
NOTANY	13	5	4	2	4
MLDNOT	13	13	16	6	10
INDIFF	5	3	9	4	6
SOMANY	19	15	27	14	31
VERYAN	21	16	8	6	60

% of cases classified into each group

Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	TOTAL
NOTANY	46.43	17.86	14.29	7.14	14.29	28.00
MLDNOT	22.41	22.41	27.59	10.34	17.24	58.00
INDIFF	18.52	11.11	33.33	14.81	22.22	27.00
SOMANY	17.92	14.15	25.47	13.21	29.25	106.00
VERYAN	18.92	14.41	7.21	5.41	54.05	111.00

Correct classification matrix: 5 groups

Discriminating variables: EDUC, DIST, TOTVEH, TREES,
CAROWN, L10, HOWLING

Level of significance: 10%

33.03% of the cases were correctly classified

Three Group Case

The same procedure as described above was also followed for the three group case, the variables being increased to 11, 12, 15 and 16 in number. Education and distance were again the first two variables to enter. At the 5% level of significance, the education variable was able to classify correctly 47.6% of all cases and education and distance together 52.4%. Car ownership was the third variable to enter the discriminant function, bringing the correct classifications to 56.1%. 43% of those not annoyed and 65% of those who were annoyed were correctly classified but only 22% of those who professed to be indifferent. This is shown in Tables 24, 25, and 26.

Age also entered at the 5% level of significance but its overall effect was to reduce the percentage of correct classifications to 49% (increasing the percentage of indifferent correct classifications at the expense of the percentage of those annoyed and unannoyed who were correctly classified). Several other variables also entered the discriminant function at the 20% level of significance but in no case was the overall percentage of correct classifications as high as by just using education, distance and car ownership. It should be pointed out, however, that as the number of variables in the discriminant function increased, the percentages of correct classifications in each group tended to become more equal even though the overall percentage correctly classified declined. As an example,

TABLE 24

CORRECT CLASSIFICATION MATRIX - THREE GROUPS

Number of cases classified into group			
Group	NOTANY	INDIFF	VERYAN
NOTANY	59	10	17
INDIFF	14	4	9
VERYAN	94	29	94

% of cases classified into each group				
Group	NOTANY	INDIFF	VERYAN	TOTAL
NOTANY	68.60	11.63	19.77	86.00
INDIFF	51.85	14.81	33.33	27.00
VERYAN	43.32	13.36	43.32	217.00

Correct classification matrix: 3 groups

Discriminating variables: EDUC

Level of significance: 5%

47.58% of the cases were correctly classified

TABLE 25

CORRECT CLASSIFICATION MATRIX - THREE GROUPS

Group	Number of cases classified into group		
	NOTANY	INDIFF	VERYAN
NOTANY	38	10	38
INDIFF	9	2	16
VERYAN	47	37	133

Group	% of cases classified into each group			
	NOTANY	INDIFF	VERYAN	TOTAL
NOTANY	44.19	11.63	44.19	86.00
INDIFF	33.33	7.41	59.26	27.00
VERYAN	21.66	17.05	61.29	217.00

Correct classification matrix: 3 groups

Discriminating variables, EDUC, DIST

Level of significance: 5%

52.42% of the cases were correctly classified

TABLE 26

CORRECT CLASSIFICATION MATRIX - THREE GROUPS

Number of cases classified into group			
Group	NOTANY	INDIFF	VERYAN
NOTANY	37	16	33
INDIFF	13	6	18
VERYAN	50	25	142

% of cases classified into each group				
Group	NOTANY	INDIFF	VERYAN	TOTAL
NOTANY	43.02	18.60	38.37	86.00
INDIFF	48.15	22.22	29.63	27.00
VERYAN	23.04	11.52	65.44	217.00

Correct classification matrix: 3 groups

Discriminating variables: EDUC, DIST, CAROWN

Level of significance: 5%

56.06% of the cases were correctly classified

ten variables were entered for the three group case at the 20% level of significance and the percentages of correct classification for those not annoyed, indifferent and annoyed were 44%, 41% and 57% respectively. The overall percentage correctly classified, however, was only 52%. This last case is shown in Table 27.

Two Group Case

The last attempt at classification using all the variables was an attempted two group classification with those who were indifferent being removed from the sample subjects, the reduction in sample size being less than 10%. Again education and distance were the two most important variables, together correctly classifying 65.7% overall at the 5% level of significance (54% of those not annoyed and 71% of those annoyed). Both the OWN/RT and TOTVEH variables also entered at this level of significance but reduced the overall accuracy to 63%. Both the unannoyed and annoyed were now correctly classified with over 60% accuracy (60.5% and 64.0% respectively). The OWN/RT variable did not pass the tolerance test at the 10% and 20% significance levels but several other variables were added which boosted the overall correct classification to 66.7% for five variables (EDUC, DIST, TOTVEH, BLDGS, TREES) at the 10% level of significance. 62.8% of those who were not annoyed and 68.2% of those who were had been correctly classified. Tables 28 through 31 give the classification matrices for the two group case.

TABLE 27

CORRECT CLASSIFICATION MATRIX - THREE GROUPS

Number of cases classified into group			
Group	NOTANY	INDIFF	VERYAN
NOTANY	38	22	26
INDIFF	7	11	9
VERYAN	51	43	123

% of cases classified into each group				
Group	NOTANY	INDIFF	VERYAN	TOTAL
NOTANY	44.19	25.58	30.23	86.00
INDIFF	25.93	40.74	33.33	27.00
VERYAN	23.50	19.82	56.68	217.00

Correct classification matrix: 3 groups

Discriminating variables: EDUC, DIST, CAROWN, AGE,
TOTVEH, TREES, BLDGS,
L10, L50, TINI

Level of significance: 20%

52.12% of the cases were correctly classified.

TABLE 28

CORRECT CLASSIFICATION MATRIX - TWO GROUPS

Number of cases classified into group		
Group	NOTANY	VERANY
NOTANY	59	27
VERANY	94	123

% of cases classified into each group			
Group	NOTANY	VERANY	TOTAL
NOTANY	68.60	31.40	86.00
VERANY	43.32	56.68	217.00

Correct classification matrix: 2 groups

Discriminating variables: EDUC

Level of significance: 5% $R^2 \sim .042$

60.07% of the cases were correctly classified

TABLE 29

CORRECT CLASSIFICATION MATRIX - TWO GROUPS

Number of cases classified into group		
Group	NOTANY	VERANY
NOTANY	46	40
VERANY	64	153

% of cases classified into each group			
Group	NOTANY	VERANY	TOTAL
NOTANY	53.49	46.51	86.00
VERANY	29.49	70.51	217.00

Correct classification matrix: 2 groups

Discriminating variables: EDUC, DIST

Level of significance: 5% $R^2 \sim .076$

65.68% of the cases were correctly classified

TABLE 30

CORRECT CLASSIFICATION MATRIX - TWO GROUPS

Group	Number of cases classified into group	
	NOTANY	VERANY
NOTANY	52	34
VERANY	78	139

Group	% of cases classified into each group		
	NOTANY	VERANY	TOTAL
NOTANY	60.47	39.53	86.00
VERANY	35.94	64.06	217.00

Correct classification matrix: 2 groups

Discriminating variables: EDUC, DIST, OWN/RT,

TOTVEH

Level of significance: 5% $R^2 \sim .11$

63.04% of the cases were correctly classified

TABLE 31

CORRECT CLASSIFICATION MATRIX - TWO GROUPS

Number of cases classified into group		
Group	NOTANY	VERANY
NOTANY	54	32
VERANY	69	148

% of cases classified into each group			
Group	NOTANY	VERANY	TOTAL
NOTANY	62.79	37.21	86.00
VERANY	31.80	68.20	217.00

Correct classification matrix: 2 groups

Discriminating variables: EDUC, DIST, TOTVEH,
BLDGS, TREES

Level of significance: 10% $R^2 \sim .12$

66.67% of the cases were correctly classified

Factor Analysis

Lastly, because of the large number of variables considered, it was decided to attempt a factor analysis of the first fifteen variables in an effort to obtain a few composite variables or factors which reflected the basic qualities of the original variables. Two factor analyses were performed, one on the original data set and a second on a revised data set obtained by the removal of those subjects who professed indifference toward the traffic noise. The results of both analyses are discussed below.

Only six (OWN/RNT, HOWLNG, BLDGS, L_{50} , L_{10} , TNI) of the original variables had communalities greater than .70. In both analyses, five factors with eigenvalues greater than 1.0 were retained. 66.3% of the total variance of the original data was explained by these five factors, and 67.1% of the total variance of the revised data was explained by its five factors. The rotated factor matrices and communality checks for each data set are presented below in Tables 32 and 33. Although numbered differently, the five factors produced in each case may be interpreted in terms of the same variables.

Factor I (both data sets)

This factor, which serves as a disturbance and separation index, accounts for 24.9% of the total variance in the original data and 24.8% in the revised data. It has high loadings, positive or

TABLE 32

ROTATED FACTOR MATRIX (3 AND 5 GROUP CASES)

Variable	F 1	F 2	F 3	F 4	F 5
OWN/RT	-0.08174	0.79249	-0.07466	0.21041	-0.17823
HOWLNG	-0.00315	-0.82994	0.01479	-0.09511	-0.17751
SEX	-0.08119	0.08225	0.78950	-0.06293	-0.12970
AGE	-0.12776	-0.65600	-0.07373	0.10234	-0.40440
JOB	0.06131	-0.10908	0.81196	0.07646	-0.10240
EDUC	-0.00911	0.21538	-0.25516	0.05730	0.67841
INCOME	-0.05252	-0.00273	-0.05410	0.01580	0.72126
FLOW	-0.00908	-0.04212	-0.01158	-0.52216	-0.03675
TREES	0.44808	-0.02880	-0.22516	-0.53811	-0.26694
BLDGS	-0.06275	-0.22694	0.10403	-0.79750	0.15284
TOTVEH	0.52038	0.12925	-0.03777	-0.61210	-0.13320
L50	0.97499	0.04716	-0.00511	-0.01420	-0.00971
L10	0.91511	-0.06289	0.05431	-0.08864	0.04852
DIST	0.61972	-0.08380	0.03491	-0.13979	0.00721
TNI	0.92779	0.14078	0.00561	0.14838	-0.08347

Check On Communalities

Variable	Before Rotation	After Rotation	Difference
OWN/RT	0.71634	0.71634	0.00001
HOWLNG	0.72959	0.72958	0.00001
SEX	0.65746	0.65745	0.00000
AGE	0.62611	0.62611	0.00001
JOB	0.69127	0.69126	0.00000
EDUC	0.57510	0.57510	0.00000
INCOME	0.52616	0.52615	0.00000
FLOW	0.27600	0.27599	0.00000
TREES	0.61313	0.61313	0.00001
BLDGS	0.72563	0.72563	0.00001
TOTVEH	0.68134	0.68134	0.00001
L50	0.95315	0.95315	0.00001
L10	0.85423	0.85423	0.00001
DIST	0.41189	0.41188	0.00000
TNI	0.90964	0.90963	0.00001

Rotated factor matrix and communalities for 3 and 5 group case.

TABLE 33

ROTATED FACTOR MATRIX (2 GROUP CASE)

Variable	F 1	F 2	F 3	F 4	F 5
OWN/RT	-0.05632	0.02231	-0.06803	-0.78137	-0.17398
HOWLNG	-0.02334	-0.11026	0.03869	0.83251	-0.14722
SEX	-0.07096	-0.08219	0.79815	-0.08105	-0.10889
AGE	-0.11160	0.08958	-0.08102	0.69950	-0.35888
JOB	0.03316	0.08498	0.80780	0.10929	-0.09158
EDUC	0.00146	0.03160	-0.29013	-0.25966	0.65284
INCOME	-0.07363	0.01063	-0.03596	-0.00029	0.78323
FLOW	-0.01645	-0.55055	-0.02414	0.05531	-0.00625
TREES	0.47607	-0.52732	-0.19115	0.06503	0.24782
BLDGS	-0.05750	-0.80591	0.12100	0.20747	0.11003
TOTVEH	0.53228	-0.60363	-0.03286	-0.12747	-0.14585
L50	0.97726	0.01480	0.00938	-0.04806	0.01834
L10	0.92123	-0.06173	-0.02302	0.06637	0.07898
DIST	0.59462	-0.16350	-0.01035	0.02887	-0.06235
TNI	0.93004	0.17640	0.00483	-0.13779	-0.05840

Check on Communalities

Variable	Before Rotation	After Rotation	Difference
OWN/RT	0.70206	0.70205	0.00001
HOWLNG	0.72895	0.72894	0.00001
SEX	0.66726	0.66725	0.00001
AGE	0.64515	0.64514	0.00001
JOB	0.68120	0.68120	0.00001
EDUC	0.57881	0.57880	0.00001
INCOME	0.62028	0.62027	0.00001
FLOW	0.30706	0.30705	0.00000
TREES	0.60690	0.60689	0.00001
BLDGS	0.72260	0.72259	0.00001
TOTVEH	0.68629	0.68629	0.00001
L50	0.95800	0.95799	0.00001
L10	0.86365	0.86364	0.00001
DIST	0.38514	0.38514	0.00000
TNI	0.91852	0.91851	0.00001

Rotated factor matrix and communalities for 2 group case.

negative, on the variables indicated in Table 34.

Factor II (original data) and Factor IV (revised data)

This factor could best be described as a time adaptability factor and is reflected by the high loadings on the variables in Table 35. The amount of variance accounted for is 15.4% in the original data and 8.8% in the revised data.

Factor III (both data sets)

This factor accounts for 10.7% of the variance in the original data and 10.6% in the revised data. The high loadings on the two variables in Table 36 indicate this factor is an index of position or status in life.

Factor IV (original data) and Factor II (revised data)

This factor is an index of the physical environment and particular scenario. The amount of variance accounted for is 8.5% in the original data and 16.2% in the revised data. High loadings are present on the variables listed in Table 37.

Factor V (both data sets)

This factor is an indicator of well being and expectations. It accounts for 6.8% of the total variance of the original variables and 6.7% of that of the revised data and is characterized by high loadings on the variables in Table 38.

TABLE 34

FACTOR LOADINGS

		<u>Original data</u>	<u>Revised data</u>
11.	TOTVEH	(.52038)	(.53228)
12.	L50	(.97499)	(.97726)
13.	L10	(.91511)	(.92123)
14.	DIST	(.61972)	(.59462)
15.	TNI	(.92779)	(.93004)

The figures in parentheses show the loadings on each variable and are obtained from the rotated factor matrix.

TABLE 35

FACTOR LOADINGS

		<u>Original data</u>	<u>Revised data</u>
1.	OWN/RT	(.79249)	(-.78137)
2.	HOWLNG	(-.82994)	(.83251)
4.	AGE	(-.65600)	(.69950)

TABLE 36

FACTOR LOADINGS

		<u>Original data</u>	<u>Revised data</u>
3.	SEX	(.78950)	(.79815)
5.	JOB	(.81196)	(.80780)

TABLE 37

FACTOR LOADINGS

		<u>Original data</u>	<u>Revised data</u>
8.	FLOW	(-.52216)	(-.55055)
9.	TREES	(-.53811)	(.52732)
10.	BLDGS	(-.79750)	(-.880591)
11.	TOTVEH	(-.61210)	(-.60363)

TABLE 38

FACTOR LOADINGS

		<u>Original data</u>	<u>Revised data</u>
6.	EDUC	(.67841)	(.65284)
7.	INCOME	(.72126)	(.78323)

Discriminant Analysis Using Factor Scores

Having established that the above five factors moderately effectively spanned the space of the original variables, we may then compute factor scores for each subject using the regression equations (of which each loading is a coefficient). These factor scores are used in lieu of the original variables in another attempt at discriminant-classification analysis. This analysis was run using the five factors to attempt classifications of subjects into five, three, and two groups as before. In all cases the time adaptability factor was dominant. For classification into five groups the time adaptability factor entered at the 5% level of significance but was able to classify correctly only 16.1% of the subjects. The disturbance-separation factor was entered and raised the percentage of correct classifications to 20.0%. The combination of factors performed fairly well in classifying those who were indifferent or not annoyed but extremely poorly for the very annoyed. No further factors were entered at the 10% and 20% levels of significance. See Tables 39 and 40 for the above results.

The time adaptability factor was the only one entering the discriminant function in the three group discrimination analysis. As seen in Table 41, however, this factor was only able to classify 22.4% of the cases correctly at the 5% level of significance. Over 50% of both the unannoyed and indifferent were correctly classified

TABLE 39

CORRECT CLASSIFICATION MATRIX USING FACTORS
- 5 GROUPS

Number of cases classified into group						
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	
NOTANY	1	12	12	2	1	
MLDNOT	3	27	25	2	1	
INDIFF	2	5	16	2	2	
SOMANY	10	31	56	5	4	
VERYAN	9	32	64	2	4	

% of cases classified into each group						
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	TOTAL
NOTANY	3.57	42.86	42.86	7.14	3.57	28.00
MLDNOT	5.17	46.55	43.10	3.45	1.72	58.00
INDIFF	7.41	18.52	59.26	7.41	7.41	27.00
SOMANY	9.43	29.25	52.83	4.72	3.77	106.00
VERYAN	8.11	28.83	57.66	1.80	3.60	111.00

Correct classification matrix: 5 groups

Discriminating factors: TIME ADAPTABILITY

Level of significance: 5%

16.06% of the cases were correctly classified

TABLE 40

CORRECT CLASSIFICATION MATRIX USING FACTORS
- 5 GROUPS

Number of cases classified into group					
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN
NOTANY	13	4	5	6	0
MLDNOT	20	16	8	14	0
INDIFF	8	2	7	10	0
SOMANY	22	21	32	30	1
VERYAN	24	20	50	17	0

% of cases classified into each group						
Group	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	TOTAL
NOTANY	46.43	14.29	17.86	21.43	0.0	28.00
MLDNOT	34.48	27.59	13.79	24.14	0.0	58.00
INDIFF	29.63	7.41	25.93	37.04	0.0	27.00
SOMANY	20.75	19.81	30.19	28.30	0.94	106.00
VERYAN	21.62	18.02	45.05	15.32	0.0	111.00

Correct classification matrix: 5 groups

Discriminating factors: TIME ADAPTABILITY,
DISTURBANCE-SEPARATION

Level of significance: 5%

20.00% of the cases were correctly classified

TABLE 41

CORRECT CLASSIFICATION MATRIX USING FACTORS
- 5 GROUPS

Number of cases classified into group			
Group	NOTANY	INDIFF	VERYAN
NOTANY	43	37	6
INDIFF	7	16	4
VERYAN	81	121	15

% of cases classified into each group				
G	NOTANY	INDIFF	VERYAN	TOTAL
Group				
NOTANY	50.00	43.02	6.98	86.00
INDIFF	25.93	59.26	14.81	27.00
VERYAN	37.33	55.76	6.91	217.00

Correct classification matrix: 3 groups

Discriminating factors: TIME ADAPTABILITY

Level of significance: 5%

22.42% of the cases were correctly classified

but less than 7% of the annoyed were so classified. No improvement was forthcoming at the 10% or 20% levels of significance.

Attempts to use factor scores in two group analysis proved moderately more successful. The time adaptability factor was the only significant factor at the 5% level of significance and was able to classify 60.1% of all cases correctly (51.1% of the unannoyed and 63.6% of the annoyed). At the 10% and 20% levels the disturbance-separation and physical environment factors entered the discriminant function but lowered the overall correct classifications to 58.4% without markedly improving the balance between the percentages of annoyed and unannoyed correctly classified. This can be seen in Tables 42, 43, and 44.

In general, the factors did not prove as fruitful in classifying individuals correctly as did the raw variables.

TABLE 42

CORRECT CLASSIFICATION MATRIX USING FACTORS
- 2 GROUPS

Number of cases classified into group		
Group	NOTANY	VERYAN
NOTANY	44	42
VERYAN	79	138

% of cases classified into each group			
Group	NOTANY	VERYAN	TOTAL
NOTANY	51.16	48.84	86.00
VERYAN	36.41	63.59	217.00

Correct classification matrix: 2 groups

Discriminating factors: TIME ADAPTABILITY

Level of significance: 5% $R^2 \sim .03$

60.07% of the cases were correctly classified

TABLE 43

CORRECT CLASSIFICATION MATRIX USING FACTORS
- 2 GROUPS -

Number of cases classified into group			
Group	NOTANY	VERYAN	
NOTANY	45	41	
VERYAN	82	135	

% of cases classified into each group			
Group	NOTANY	VERYAN	TOTAL
NOTANY	52.33	47.67	86.00
VERYAN	37.79	62.21	217.00

Correct classification matrix: 2 groups

Discriminating factors: TIME ADAPTABILITY,
DISTURBANCE-SEPARATION

Level of significance: 10% $R^2 \sim .038$

59.41% of the cases were correctly classified

TABLE 44

CORRECT CLASSIFICATION MATRIX USING FACTORS
- 2 GROUPS

Number of cases classified into group		
Group	NOTANY	VERYAN
NOTANY	45	41
VERYAN	85	132

% of cases classified into each group			
Group	NOTANY	VERYAN	TOTAL
NOTANY	52.33	47.67	86.00
VERYAN	39.17	60.83	217.00

Correct classification matrix: 2 groups

Discriminating factors: TIME ADAPTABILITY,
DISTURBANCE-SEPARATION,

Level of significance: 2²PHYSICAL ENVIRONMENT

Level of significance: 20% $R^2 \sim .043$

58.42% of the cases were correctly classified

CHAPTER V

RESULTSResearch Findings

The results of the discriminant analyses of both the original variables and composite factors are both encouraging and confusing. When using the raw data scores, the education level is clearly the more useful single variable in discriminating among groups, with the distance variable being next in importance; but, in combination with the education variable, the addition of distance to the discriminant function offers generally slight improvement in the percentage of correct classifications. Other variables enter the discriminant function, although frequently only at the 10% and 20% levels of significance, but usually do not improve the overall classification capabilities. Rather, they often decrease this overall capability but offer greater balance in the percentages of correct classification in each group.

Factor analysis on the original variables revealed that five factors were able to explain roughly $2/3$ of the total variance of the original fifteen variables. Because of the dominance of the education level in the earlier discriminant analysis, it might have been expected that the well being-expectation factor (which included education) would be that factor most likely to enter the discriminant function when the five factors were used as possible discriminating

variables. At no point, however, even at the 20% level of significance, did this factor enter the discriminant function; rather the single most important factor in discriminating was the time adaptability factor whose variables (OWN/RNT, AGE, HOWLNG) most often did not enter the discriminant function when the analysis was performed using the original variables.

Based on the percentages of correct classifications obtained using each method, it is apparent that only in the case of two group discrimination does use of factors give correct classification percentages close to those obtained using the original variables. A brief summary of "best" results is shown in Table 45. All percentages shown below occur at the 5% level of significance. These results indicate that, for predictive accuracy in this case, one is, in general, much better off using the raw variable data than composite factor scores.

Below are the means and standard deviations of the 16 original variables for the five and three group cases. From investigation of these means and standard deviations and knowledge of the coding of the variables, observations can be made with respect to the variables and the way in which they might contribute toward classifying the subjects into the particular groups. See Tables 46 and 47.

TABLE 45

SUMMARY OF "BEST" RESULTSOverall % of correct classification

	<u>Using original variables</u>	<u>Using factors</u>
5 group case	32.7%	20.0%
3 group case	56.1%	22.4%
2 group case	65.7%	60.1%

TABLE 46

MEANS AND STANDARD DEVIATIONS OF VARIABLES - 5 GROUP CASE

Means (the last column contains the weighted grand means over the groups used in the analysis)

Variable	Group					
	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	
OWN/RT	1.5714	1.5862	1.6667	1.7453	1.7477	1.6970
HOWLNG	2.4643	3.0000	2.0000	2.5000	2.5135	2.5485
CAROWN	1.2667	1.2632	1.3750	1.2048	1.1111	1.2027
SEX	1.5000	1.5862	1.5185	1.5755	1.5315	1.5515
AGE	3.8214	3.7544	2.7037	3.3619	3.2973	3.3943
JOB	3.5417	4.1190	3.8636	4.0562	3.5543	3.8390
EDUC	2.2692	2.6724	3.0000	3.0577	3.3486	3.0162
INCOME	4.7826	4.5532	4.7143	4.7791	4.6667	4.6966
FKOW	1.7857	1.8103	1.6667	1.6698	1.6667	1.7030
TREES	1.8571	1.8448	1.8889	1.7642	1.7387	1.7879
BLDGS	1.6429	1.6379	1.5926	1.4906	1.5586	1.5606
TOTVEH	992.00	766.26	834.04	826.78	972.05	879.62
L50	69.175	65.947	66.141	65.378	66.537	66.252
L10	78.011	75.429	74.874	74.528	75.650	75.388
DIST	205.36	166.64	168.70	130.71	108.29	138.92
TNI	59.561	56.414	57.452	56.480	57.223	57.059

cont'd/

TABLE 46 (cont'd)

Standard Deviations (the last column contains the weighted grand standard deviations over the groups used in the analysis)

Variable	Group					
	NOTANY	MLDNOT	INDIFF	SOMANY	VERYAN	
OWN/RT	0.50395	0.49681	0.48038	0.43777	0.43627	0.46027
HOWLNG	1.7317	1.8353	1.3868	1.5931	1.6396	1.6592
CAROWN	0.57521	0.48429	0.54596	0.38444	0.34524	0.42968
SEX	0.50918	0.49681	0.50918	0.49662	0.50127	0.49809
AGE	1.8470	1.7600	1.3535	1.5984	1.8320	1.7262
JOB	2.1253	1.9395	2.0624	2.1218	2.0242	2.0565
EDUC	1.2926	1.3687	1.5689	1.3995	1.5158	2.4682
INCOME	2.2601	2.2463	2.0966	1.7803	2.3264	2.1139
FLOW	0.41786	0.39545	0.48038	0.47252	0.47354	0.45762
TREES	0.35635	0.36523	0.32026	0.42655	0.44131	0.40943
BLDGS	0.48795	0.48480	0.50071	0.50229	0.49881	0.49707
TOTVEH	438.60	410.06	568.39	518.20	552.34	515.22
L50	6.3858	5.6263	5.8310	5.0497	4.2979	5.1817
L10	5.9928	5.3288	5.7600	5.0502	3.7821	4.9275
DIST	216.87	160.73	186.26	131.51	109.42	146.70
TNI	6.6123	5.8236	5.8333	5.1056	4.6908	5.3446

TABLE 47

MEANS AND STANDARD DEVIATIONS OF VARIABLES - 3 GROUP CASE

Means (the last column contains the weighted grand means over the groups used in the analysis)

Variable	Group			
	NOTANY	INDIFF	VERYAN	
OWN/RT	1.5814	1.6667	1.7465	1.6970
HOWLNG	2.8256	2.0000	2.5069	2.5485
CAROWN	1.2642	1.3750	1.1613	1.2056
SEX	1.5581	1.5185	1.5530	1.5515
AGE	3.7765	2.7037	3.3287	3.3943
JOB	3.9091	3.8636	3.8011	3.8344
EDUC	2.5476	3.0000	3.2066	3.0179
INCOME	4.6286	4.7143	4.7225	4.6974
FLOW	1.8023	1.6667	1.6682	1.7030
TREES	1.8488	1.8889	1.7512	1.7879
BLDGS	1.6395	1.5926	1.5253	1.5606
TOTVEH	839.76	834.04	901.09	879.62
L50	66.998	66.141	65.971	66.252
L10	76.270	74.874	75.102	75.388
DIST	179.24	168.70	119.24	138.92
TNI	57.438	57.452	56.860	57.059

cont'd/

TABLE 47 (cont'd)

Standard Deviations (the last column contains the weighted grand standard deviations over the groups used in the analysis)

Variable	Group			
	NOTANY	INDIFF	VERYAN	
OWN/RT	0.49622	0.48038	0.43600	0.46027
HOWLNG	1.8097	1.3868	1.6134	1.6592
CAROWN	0.51223	0.54596	0.36621	0.42888
SEX	0.49952	0.50918	0.49833	0.49809
AGE	1.7781	1.3535	1.7182	1.7263
JOB	2.0043	2.0624	2.0804	2.0537
EDUC	1.3496	1.5689	1.4639	1.4675
INCOME	2.2396	2.0966	2.0735	2.1137
FLOW	0.40058	0.48038	0.47195	0.45762
TREES	0.36031	0.32026	0.43335	0.40943
BLDGS	0.48295	0.50071	0.50051	0.49707
TOTVEH	430.34	568.39	539.63	515.22
L50	6.0412	5.8310	4.7053	5.1817
L10	5.6507	5.7600	4.4719	4.9275
DIST	180.54	186.26	120.96	146.70
TNI	6.2314	5.8333	4.9006	5.3446

1) OWN/RT

Code: 1 = own 2 = rent

Renters tend to be somewhat more annoyed than owners, a fact which appears in contrast to what might be expected.

2) HOWLNG

Code: higher numbers indicate longer residency at the address

Subjects who have lived the shortest time in their particular location are most indifferent toward traffic noise. As they remain in the same location they tend to become more annoyed with the noise until, finally, after they have been there even longer, they apparently become acclimated to the noise.

3) CAROWN

Code: the number is the average number of cars owned per household for the group

The very annoyed are marginally less likely to own a car than other groups.

4) SEX

Code: 1 = male 2 = female

Sex appears to play no role in the discrimination.

5) AGE

Code: higher numbers indicate older subjects

The age variable follows the same pattern as the length of residency. The youngest are indifferent, then become annoyed as they grow older, and apparently become acclimated and notice the noise less as they become older still.

6) JOB

Code: the lower the number, the greater the tendency toward a professional or managerial occupation
No pattern is discernible.

7) EDUC

Code: higher numbers indicate a higher level of education
There are strong indications present that those who have attained a higher level of education tend to be more annoyed.

8) INCOME

Code: higher numbers indicate greater incomes
No pattern is discernible.

9) FLOW

Code: 1 = interrupted 2 = free flowing

A very mild tendency shown is for a free flowing traffic situation to be more likely in the case of those who are relatively unannoyed.

10) TREES

Code: 1 = large trees in area 2 = no large trees

The absence of large trees is more characteristic of areas where respondents are not annoyed. Again this is contrary to what might be expected.

11) BLDGS

Code: 1 = large buildings in area 2 = no large buildings

No pattern is discernible.

12) TOTVEH

Code: numbers are the total number of vehicles past the noise measuring apparatus during the one hour measurement for the particular area.

A strange occurrence is noted here in that both the very annoyed and those who are not at all annoyed are characterized by the highest number of vehicles in the five group case. The variation in the number of vehicles is much greater, however, for those who are very annoyed. For the three group case, those who are annoyed are characterized by higher numbers of vehicles.

13, 14, 16) L₅₀, L₁₀, TNI

Code: numbers are the value of the noise index in dBA.

The higher the number, the greater the objectively measured noise.

No pattern is discernible. This is primarily due to

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the fact that the measured noises at roadside were not markedly different in most cases, probably because no rush hour measurements were made. This rough equality of measured noise manifests itself in that noise variables do not directly enter the set of discriminatory variables; rather, the separation of source and receiver becomes important in that it reflects the attenuation of noise over distance. Appendices A and B discuss further the various indices and the collection of data.

15) DIST

Code: numbers are approximate distances, in feet,
from source to receiver

There is a strong tendency for the distances involved to be greater for those who are not annoyed or are indifferent.

Several suggestions can be made as to why the education level is not part of the composite factor which proved most useful in classifying subjects into groups. First, the communality or percentage of total variance of the education variable explained by all given factors is fairly low at 58%; and, of this 58%, only the square of its factor loading or about 46% is explained by the well-being/expectation factor. Also, the variable with which education is associated in its factor is income which, by itself, was of no importance in classifying subjects into the correct groups.

On the other hand, the most successful factor in terms of correct classifications was the time adaptability factor composed of OWN/RT, AGE and HOWLNG, two of whose communalities were greater than .70. In addition, all three variables displayed a definite directional pattern in the description of group means. There was a positive indication that the more likely a subject was to be a renter, the more likely he also was to be annoyed by the traffic noise. Both the age and the length of residency of the subject followed a very similar time pattern; at an early stage (agewise or in length of residency) the subject appears relatively indifferent to traffic noise; as time passes the noise becomes annoying and, still later, the individual either becomes acclimated or chooses to ignore it.

As to why the results in general are not better, there are several possibilities. Of primary importance in this regard is the data base. In both its collection and sufficiency there are weaknesses. These weaknesses are discussed more fully in Appendix A but the main points are stressed here. The data was initially collected for a purpose other than for what it was put to use. Had there been greater foresight, a more complete and appropriate set of data would have been collected. Both noise and traffic measurements were taken for a very limited time and, in some cases, at inappropriate places. The purpose of the questionnaire administered to interviewees was not sufficiently

disguised, therefore it is quite possible that a certain bias on the part of the respondent has entered. Partially due to both the manner of collection and the coding of data, both cardinal and ordinal data were used in the factor and discriminant analyses. This mixture of data types has undoubtedly led to some errors in the accuracy and, consequently, the predictive ability of the analyses. Ideally, all variables which can be should be expressed cardinally with ordinal status being used only where necessary, e.g. the rating of noise annoyance or the distinction between male and female.

It is also highly probable that other variables, data which was not collected, are important in determining susceptibility to traffic noise, e.g. the number of peak noise occurrences in the time period. Lastly, attempts at perceiving and understanding relationships among variables based on analyses of individual scores rather than of means invariably leads to poorer results than if the means were used because of the greater stability of mean scores.

Conclusions

At least for the variables under consideration in this study, raw variable scores offer greater predictive accuracy than composite factor scores in the correct classification of individuals into groups based on the perceived annoyance toward traffic noise.

Education is the single most significant socioeconomic variable in classification and the physical separation (distance) between noise source and receiver appears to be second in importance. The time adaptability factor is the most important composite index in classification but does not fare as well as education. Finally, greater care in the selection and collection of data would seem to insure an improvement over the moderately successful results of this study.

Suggestions for Further Research

"A large number of data have indicated that the response of the individual to a stimulus of a given magnitude depends not only on the intensity of the stimulus, but also on the state of the organism as determined by its previous history. It follows that no scale which predicts a fixed relation between stimulus and response can be justified."¹ Despite what the generally acceptable and available results may indicate, a good sized group of individuals will continue to be annoyed when it appears they should not be and vice versa. A new approach toward analysis in these cases might be termed 'situation' or 'incident' analysis; i. e., in addition to the collection of the 'normal' socioeconomic and physical data, attention should be focused as closely as possible on just what is the annoying factor in each case; e. g. the single drive-by of a motorcycle late at

night (an isolated peak noise), the steady drone of heavy trucks along a main road (continuous loud noise), or the acceleration of a bus from a stop (intermittent peak noises above the ambient). The presence or absence of various incidents, as they become known, may then be used in analysis much the same as other variables.

More effort and attention should be focused on an individual's expectations with regard to noise and ways to characterize these expectations. Oftentimes, a measured noise environment which should not be offensive or annoying is found to be so by some because, for one reason or another, they expect or visualize a certain atmosphere of quiet or privacy which is most often not met; thus, they often become very annoyed. On the other hand, many regard even an excessively noisy environment as a natural one and one of the prices paid for living in a modern society. As an example, the view that an individual holds toward the necessity of the noise (or of its generating activity) may influence his perception of whether it is too loud or annoying.

Despite the somewhat ambiguous results, it is felt that the basic hypothesis and methodology are sound. If further investigations are to be made along the same line the following foundations need to be laid:

Sites should be chosen to insure that traffic noise is the primary source of noise in the area. This could be accomplished

quickly by telephone survey, if possible; no elaborate questionnaire should be used at this stage.

Noise data to be gathered should be gathered at the home (yard or porch) of the respondent over a period of time, e. g. sampling over a 24 hour period or, if possible, even longer.

Traffic data could most likely be obtained from the city engineering department. The average annual daily traffic can thus be obtained and adjusted to give a good indication of the traffic situation in the area without going to the trouble of counting cars oneself.

A short questionnaire (no more than 10 questions) should be administered to obtain attitudes toward traffic noise. The semantic differential response system appeared to work well and offered no problems to the respondent if the questions were understandable and properly worded.

The collection of socioeconomic data could follow much the same pattern as for this study; the major difference recommended would be to collect and maintain cardinal data as such. Other data, such as the occurrence of noise 'incidents' could be obtained as desired.

Fundamentally, the data for this study was gathered on the basis of both temporal and financial practicality. In retrospect, it is recognized that there were often technically better ways to collect the data but, as in many research endeavors, compromises

were made to insure that these temporal and financial constraints were met and to facilitate the accumulation and analysis of the data.

Implications

The preliminary implications of the results are that planners and engineers must go beyond the 'hard' indicators such as measured noise and traffic counts to understand the full impact of noise on individuals or a community. It will become necessary to incorporate other characteristics of the personal and physical environment into any assessment of noise impact. It is hoped this investigation will be of use to further an understanding of these processes and variables and to upgrade the ability of the traffic engineer to limit and control the noise problems in situations of new or increased traffic.

FOOTNOTE

¹Theodore Schultz, Community Noise Ratings, Applied Science Publishers Ltd., London, 1972, p. 3. The quotation, as given, was taken from Schultz who, in turn, had obtained it from W. C. Michaels and B. T. Doser, "Rating Scale Method for Comparative Loudness Measurements," Journal of the Acoustic Society of America, Vol. 27, 1955, pp. 1173-80.

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APPENDIX A: DATA

Data

The collection of the data base for the problem involved the gathering of three basic data types: socioeconomic background data and attitudes toward noise, indications of the traffic noise levels, and traffic and landscape characteristics. The socioeconomic data and noise attitudes were obtained through the administration of a questionnaire conducted on a door to door basis. This questionnaire is shown at the end of the appendix. Approximately sixty different blocks in three sections of Vancouver (the West End, Kitsilano, Fairview/East End) were selected, and an average of six interviews per block was conducted.

The three areas (West End, Kitsilano and Fairview) were selected for two reasons. In a preliminary survey of the greater Vancouver area these three areas were among those indicating a moderately strong annoyance with noise. Also, it was initially felt that the three areas would represent, broadly speaking, different socioeconomic classes of people. This last presumption proved

inaccurate but respondents in the three areas did encompass a wide range of values for the various socioeconomic variables. The approximately twenty block locations within each area were basically chosen to insure that respondents who lived along various types of streets were represented in the sample. In each section residents were interviewed who lived along major arterials, collector roads, and sparsely travelled side streets. Maps showing the block locations of interviews are given in Chapter 3.

Residents were usually quite willing to fill out the questionnaire although isolated incidents of reluctance or refusal were encountered. An additional question asked of respondents and not on the questionnaire was what the noisiest street in their area was. Attempts were also made to determine the relative importance of reducing traffic noise (in comparison with remedying other problems such as air pollution) but the question asked in this regard was poorly chosen and the results obtained are in question.

Noise and traffic data were obtained simultaneously, the streets from which respondents indicated the noise was worst being chosen for the collection of noise and traffic data. Noise readings were made at street level on the side of the street (curb-side) in mid block. Readings were taken here as opposed to at the respondent's home because it was originally intended to relate the noise generated with the composition of traffic along the street. Sound levels were monitored by a wind shielded Elektret condenser

microphone connected to a Bruel and Kjaer A-weighted sound level meter and were recorded on a cassette tape recorder.

In the lab, the tape was played back through a Bruel and Kjaer Model 4420 statistical distribution analyzer and Model 2606

measuring amplifier to obtain the L_{10} , L_{50} and L_{90} sound levels.

The hard copy of the noise levels was obtained using the Bruel and Kjaer Model 2305 Graphic Level Recorder.

Readings were taken for one hour in each location; the times of day during which the noise was measured varied from location to location but did occur between the hours of 10 AM and 4 PM. Thus, no rush hour traffic noise was recorded. A calibration tone of known decibel level (dBA) of approximately 30 seconds duration was placed at the beginning of each one hour's recording prior to the measurement of each location's traffic noise.

During the hour of measurement of the traffic noise the composition of traffic was also recorded, i.e. the number of cars, pickups and vans, trucks, buses, and motorcycles passing the measuring apparatus (both ways) in the given hour. In addition, other traffic characteristics such as speed and flow and 'landscape' features such as the presence of large buildings or trees were noted. The form used to record the traffic and landscape characteristics is shown at the end of this appendix.

Coding

In coding the data for use in the computer by the statistical programs it was necessary to make some compromises which have, no doubt, affected the results obtained. In coding the noise and the number of vehicles, for example, it was quite easy to use the exact number computed or compiled. However, as the questionnaire was designed so that answers could be placed into one of a few categories, it was necessary to code this information such that an ordinal, rather than cardinal, representation of the data was obtained. Two examples of the above will suffice to demonstrate.

1. The responses to certain statements about the resident's attitudes toward traffic noise were to be indicated on a semantic differential Likert scale rating system, i.e. five possible responses were possible: the interviewee could strongly agree, mildly agree, be indifferent to, mildly disagree, or strongly disagree with the statement. In coding these answers it was decided that any answer which indicated the greatest annoyance would be coded 5, an answer which conveyed mild annoyance 4, and so on. Thus, the higher the number, the greater the indication that traffic noise was bothersome and annoying to the person. A value of 3 would indicate the respondent to be somewhat indifferent to his noise

environment or to feel that the noise was of borderline status, noticeable perhaps but not really annoying.

A value of 1 would indicate that the respondent feels he is not at all annoyed by traffic noise.

2. In the coding of the socioeconomic data, certain categories or levels of educational attainment were given rather than have a specific grade level mentioned. It thus became necessary to convert these educational levels to a numeric scale. This was accomplished by assigning to the lowest educational level the value 1 (in this case a public school diploma) and a 6 to the highest level (a post-graduate degree). Intermediate levels of education took on the integer values between 1 and 6. Again, the higher the number, the greater the corresponding level of education.

The use of two types of coding, cardinal (or exact numbers) in the case of vehicle numbers and noise measurements, and ordinal (or rank order) in the case of attitudes and some socioeconomic data presents a problem in that the statistical programs are designed primarily to use cardinal values (i.e. the actual numbers). The use of ordinal rankings in statistical analyses such as factor and discriminant analysis is limited because of the lack of a constant or determinate interval scale in much of the data; e.g. a 4 on the annoyance scale does not indicate twice the annoyance of a 2, and,

in like manner, someone with the education level code of 6 is not three times as intelligent as someone whose coded level is 2.

It was felt necessary to employ these scales in the analysis, however, because the great majority of the data collected was in this form. Here, greater foresight in the construction of the questionnaire would have been extremely prudent and helpful.

In hindsight, it can be seen that several mistakes were made both in the selection and collection of data in addition to the problems involved in the use of the mixed coding schemes described above. Of first importance was the fact that the data, as collected, was not intended to be used for the statistical analyses for which it eventually was used. Noise measurements were taken at the roadside because it was felt, at first, that it would be beneficial to attempt correlations of the traffic noise generated with the traffic composition during that time. It was later decided not to do this. In an effort to understand the relation between measured noise and individual's subjective response, it would have been better to locate the noise measuring apparatus on the porch or lawn of the persons being interviewed for this would have given a much better indication of the noise levels actually experienced by the respondent. The fact that there was often a block or half block separating the respondent from the major noisy street (where the noise measurement was made) would serve to diminish substantially the effects of the noise at the home of the subject. This was partially

accounted for by including this separation in the analysis as one of the variables.

The time aspect of the data collection also could have been improved considerably, particularly with respect to the collection of noise and traffic data. Because of time and security constraints involving use of the noise measuring equipment the noise samples for an area consisted of a one hour sample taken during mid-day, thus, for example, the noise sample for a particular area may consist of the traffic noise from the particular street from 11 AM to 12 noon on a Thursday (all measurements were made on weekdays between 10 AM and 4 PM during the month of August). Noise data collected in this way is vastly inferior to data which is collected properly; e.g. sampling for a few seconds every few minutes over a 24 hour period. Even the above, however, gives a noise profile only at a particular point in time and gives no indication of what the longer term noise environment in the area make be like.

Another adverse aspect of the data was perhaps that of aggregation. A total of 331 interviews was conducted in areas of the city quite different both in terms of the characteristics of the interviewees and in the nature of the traffic in the area. The analysis of the entire block of data as if it were homogeneous may have reduced the possibilities of obtaining more definitive results. Improved reliability might be expected if the data was formed into smaller and possibly more homogeneous data blocks and the

analysis performed on these smaller groups. The one drawback with the above suggestion, however, is that a disaggregation into smaller data blocks implies that the disaggregation be performed on the basis of some common characteristic of the data block and this would, in effect, prejudice or presume an answer to any discriminant analysis on the reorganized data.

In administration of the interview it was initially desired that the interviewee not know the focus of the interview. In most cases, however, the fact that the interview concerned attitudes toward traffic noise became apparent quite quickly. In many cases the respondents even asked if the survey was sponsored by the city or provincial government in an effort to curb what traffic noise already existed. This attitude on the part of quite a few respondents may have led them to offer shaded responses they thought would be helpful either to the interviewer or to their own desires, rather than responses which were objective and more truthful. Unfortunately, it appears that the only way to eliminate a problem such as this is through meticulous design, testing, and redesign of the questionnaire.

Despite the above limitations and shortcomings, it should be emphasized that, in many cases, the decisions taken were made on grounds of practicality even though it could be seen that they would be technically inferior to 'optimal' decisions made under more ideal conditions.

UNIVERSITY OF BRITISH COLUMBIA
DEPARTMENT OF CIVIL ENGINEERING

Interview No.

Date

The Department of Civil Engineering of the University of British Columbia is conducting this survey to determine how you feel about this neighbourhood and improvements you would like to see made. We would appreciate it if you could take a few moments to answer the following questions.

A. Firstly we would like to know something about where you live.

1. House Address? _____

2. Do you own or rent? own ☐ rent ☐

3. How long have you lived at your present address?

less than 1 year ☐ 5 - 10 years ☐

1 - 2 years ☐ 10 - 15 years ☐

3 - 5 years ☐ > 15 years ☐

4. Where did you live before moving to your present address?

Rural ☐

Small town of less than 10,000 ☐

Medium town of 10,000 - 250,000 ☐

Large city of greater than 250,000 ☐

5. Number of vehicles owned by the family?

cars ☐

trucks ☐

motorcycles ☐

- B. Now we would like to know what improvements to the neighbourhood you would like to see carried out.

Governments spend about one hundred dollars per family each year on the improvement of public facilities in the Vancouver metropolitan area. Suppose you had the opportunity of deciding how "your" hundred dollars should be spent. How would you allocate your \$100 among the following possible types of investments in such a way as to improve the area as you think it should be improved? You may spend the whole amount on any one type of improvement, or split it among some or all of the alternatives in any amounts you wish.

1. Reduce air pollution \$ _____
2. Improve police and fire protection \$ _____
3. Reduce traffic noise \$ _____
4. Reduce industrial noise \$ _____
5. Improve parks and recreation facilities \$ _____
6. Improve educational facilities \$ _____
7. Improve public transportation facilities \$ _____
8. Improve welfare services \$ _____
9. Improve public health and hospital facilities \$ _____
10. Improve street and freeway facilities \$ _____
11. Other (specify) \$ _____

TOTAL \$100

- C. We are now going to ask you some questions about the noisiness of your neighbourhood. Please answer each question as accurately as you can.

In thinking about this block where you live, would you please indicate to what extent you are annoyed by each of the following noises.

	1 Not noticeable	2 Noticeable but not annoying	3 Mildly annoying	4 Moderately annoying	5 Very annoying
1. Noise from cars	☐	☐	☐	☐	☐
2. Noise from trucks	☐	☐	☐	☐	☐
3. Noise from motorcycles	☐	☐	☐	☐	☐
4. Noise from aircraft	☐	☐	☐	☐	☐
5. Noise from industry	☐	☐	☐	☐	☐
6. Noise from other houses	☐	☐	☐	☐	☐
7. Noise from children	☐	☐	☐	☐	☐
8. Noise from lawn mowers	☐	☐	☐	☐	☐
9. Other _____ (specify)	☐	☐	☐	☐	☐

Would you please indicate your agreement or disagreement with the following statements.

1. The noise from traffic in this neighbourhood is annoying.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
☐	☐	☐	☐	☐

2. Living here with the traffic noise is a strain on my nerves.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
☐	☐	☐	☐	☐

3. We would seriously consider moving if the traffic noise gets much worse.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
☐	☐	☐	☐	☐

4. Traffic noise bothers us less now than when we first moved here.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
☐	☐	☐	☐	☐

5. There has been a noticeable increase in traffic noise here over the past few years.

Strongly Agree	Mildly Agree	Neither Agree No Disagree	Mildly Disagree	Strongly Disagree
☐	☐	☐	☐	☐

6. We would (do) tolerate some traffic noise because we like living close to work/shopping/schools.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
☐	☐	☐	☐	☐

7. This neighbourhood is no noisier from traffic than the last one I lived in.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
☐	☐	☐	☐	☐

8. As long as the traffic noise is continuous it doesn't bother me; it is the loud bangs, rumblings and screeching which annoy me.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
☐	☐	☐	☐	☐

9. A few loud noises do not bother me, but so many motorcycles and/or trucks go past here that it is annoying.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
-------------------	-----------------	----------------------------------	--------------------	----------------------

☐	☐	☐	☐	☐
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

10. I find it much noisier from traffic downtown than here.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
-------------------	-----------------	----------------------------------	--------------------	----------------------

☐	☐	☐	☐	☐
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11. I notice the noise much less at night than during the day

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
-------------------	-----------------	----------------------------------	--------------------	----------------------

☐	☐	☐	☐	☐
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12. Traffic noise is more annoying here in the summer than in the winter.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
-------------------	-----------------	----------------------------------	--------------------	----------------------

☐	☐	☐	☐	☐
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13. It is only the rush hour traffic which is annoying.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
-------------------	-----------------	----------------------------------	--------------------	----------------------

☐	☐	☐	☐	☐
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

14. Reducing traffic here would get rid of most of the noise.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
-------------------	-----------------	----------------------------------	--------------------	----------------------

☐	☐	☐	☐	☐
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

15. A general restriction on commuter traffic in residential areas (such as was recently done in the West End) should be encouraged to reduce traffic noise.

Strongly Agree	Mildly Agree	Neither Agree Nor Disagree	Mildly Disagree	Strongly Disagree
-------------------	-----------------	----------------------------------	--------------------	----------------------

☐	☐	☐	☐	☐
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

D. Now we would like to get the following factual information.

1. What sex are you? male ☐ female ☐

2. Which age category do you fall into?

under 20	☐	50 - 59	☐
20 - 29	☐	60 - 69	☐
30 - 39	☐	70 or older	☐
40 - 49	☐		

3. Which occupation category most closely fits what you do? (Note: you may fit into more than one category).

Professional	☐	Homemaker	☐
Managerial	☐	Not Employed	☐
Secretarial	☐	Part-time Employee	☐
Sales, Clerical	☐	Student	☐
Craftsman	☐	Shift Work?	☐
Unskilled	☐	day ☐ evening ☐ night ☐	

4. What is the category of school you last attended?

Public School Diploma	☐
High School Diploma	☐
Professional Training	☐
Junior College	☐
University Degree	☐
Post Graduate Degree(s)	☐

5. What is your total household income (including income for all members of the family)?

under 2000	☐	1000 - 11999	☐
2000 - 3999	☐	12000 - 13999	☐
4000 - 5999	☐	14000 - 15999	☐
6000 - 7999	☐	16000 - 20000	☐
8000 - 9999	☐	over 20000	☐

E. Comments?

DAY: _____ TIME: _____

LOCATION: _____

FLOW CHARACTERISTIC: INTERRUPTED? YES ☐ NO ☐

(i.e., the presence of a stop sign, signal etc.)

GRADE GREATER THAN 2%: YES ☐ NO ☐SHIELDING: PARKED CARS YES ☐ NO ☐LARGE TREES YES ☐ NO ☐LARGE BUILDINGS YES ☐ NO ☐OTHER YES ☐ NO ☐

DISTANCE OF POINT OF NOISE MEASUREMENT FROM NEAREST PAVEMENT EDGE (FT): _____

NUMBER OF TRAVELED LANES (BOTH WAYS): _____

TRAFFIC VOLUME: CARS _____ (VPH)

PICKUP & PANEL _____ (VPH)

TRUCKS _____ (VPH)

BUSES _____ (VPH)

MOTORCYCLES _____ (VPH)

TOTAL _____

10 MEASURED SPEEDS (MPH):

OTHER ROAD AND TRAFFIC FEATURES THOUGHT TO BE SIGNIFICANT:

(signals, signs, pavement condition, congestion, pedestrian crossings)

ILLUSTRATE ON MAP PHYSICAL SITUATION (esp. trees, walls, embankments) WHICH MAY EFFECT NOISE.

COMMENTS: _____

APPENDIX B: NOISE

MEASUREMENT AND INDICES

Outline

Sounds are physical disturbances (vibrations or pressure changes) in an elastic medium which propagate through longitudinal wave motion to the ear of the listener. Noise is usually defined as undesirable or unwanted sounds.¹ The ambient noise is the all-encompassing noise associated with a given environment; particular noises are those which are noticeable as distinctly apart from the ambient noise. The noise level is the measured sound pressure level, in decibels (dB), of any unwanted sound, where the sound pressure level (SPL), in decibels, is defined as 20 times the logarithm (base 10) of the ratio of the pressure of this sound to the reference pressure, usually .0002 microbar.

$$\text{SPL (dB)} = 20 \log_{10} \left(\frac{\text{pressure}}{.0002} \right)$$

The decibel is a unit of level measurement when the base of the logarithm is 10 and the measured quantities concerned are proportional to power. Sound is a form of energy or power, and a measure of this energy is the square of the sound pressure. The reference quantity, zero dB, is about the level of the weakest sound that can be heard by a person with good hearing in an extremely quiet location.² The smallest audible sound has a sound pressure of .00002 microbars (1 bar = 1 atmospheric pressure; 1 microbar = 1 dyne/cm²). A decibel is a relative quantity. The measure of power is $10 \log_{10} \left(\frac{P}{.0002} \right)^2$. The sound pressure level in decibels is therefore

$$20 \log_{10} \left(\frac{P}{.0002} \right)$$

In dealing with the measurement of noise, it is the sound pressure level in decibels which is used and not the actual value of the pressure in microbars. This is done to ease the handling of the wide range of sound pressures encountered. A doubling of sound pressure corresponds to an increase in the sound pressure level of 6 dB.

In combining two or more separate sound pressure levels the decibel values cannot be added directly. Rather the resultant sound pressure level is determined from the resultant of the two sound pressures.

$$P_R = \sqrt{P_1^2 + P_2^2}$$

Example:

Add two sound pressure levels of 70 dB and 74 dB

$$70 = 20 \log_{10} \left(\frac{P_1}{.0002} \right) \qquad 74 = 20 \log_{10} \left(\frac{P_2}{.0002} \right)$$

$$3.7 = \log_{10} \left(\frac{P_1}{.0002} \right) \qquad 3.7 = \log_{10} \left(\frac{P_2}{.0002} \right)$$

$$\frac{P_1}{.0002} = 3.16 \times 10^3 \qquad \frac{P_2}{.0002} = 5.01 \times 10^3$$

$$P_1 = .628$$

$$P_2 = 1.002$$

$$P_R = \sqrt{(.628)^2 + (1.002)^2} = 1.18$$

$$20 \log_{10} \left(\frac{P_r}{.0002} \right) = 20 \log_{10} 5.9 \times 10^3 = 75.4$$

Thus 70 dB + 74 dB = 75.4 dB.

The use of tables allows one to read off the amount to be added to the higher initial sound pressure level without going through the above calculations.

For a point source (e.g. an individual truck) in a free field (no obstructions or boundary effects) sound pressure varies

inversely with distance. Thus for each doubling of distance, sound pressure is halved with a resultant decrease in the sound pressure level of 6 dB. Halving the distance between receiver and source will result in an increase of 6 dB in the sound pressure level.

For a line source (stream of traffic) in a free field, sound pressure varies inversely with the square root of the distance. Each doubling of the distance will result in a decrease of 3 dB in the sound pressure level. Again, halving the distance increases the sound pressure level by 3 dB. Examples of this attenuation of sound over distance can be seen in figures 5 through 7.

Sound pressure levels are usually measured on meters with a flat or uniform frequency response. The apparent loudness attributed to a sound, however, is a function of both the sound pressure level and the frequency. To take this into effect when measuring sound pressure levels in an attempt to duplicate human response, it is necessary to add electrical weighting networks or filters to reduce the response of the meter to certain frequencies. The basis for these weighting networks are the equal loudness contours of Robinson and Dadson on the earlier curves of Fletcher and Munson. The sound level of a noise then becomes the weighted sound pressure level obtained by using a meter whose weighting characteristics are specified.³ The frequency response of the most common weighting networks are shown in Figure 8.

Distance as a factor in noise intensity: Survey of specific noise sources.

Figure 5.

Source: C.R. Bragdon, Noise Pollution, Univ. of Pennsylvania Press, 1971, p. 115.

Typical continuous noise produced by surface ground transportation modes.

Figure 6. Falloff of Continuous Transportation Noise over Distance.

Source: U.S. DOT "Recommendations for Northeast Corridor Transportation, Final Report" NTIS, Sept. 1971

Noise reduction provided by various highway configurations.

Figure 7.

Figure 8. Frequency Response Characteristics of Weighting Networks.

Measurement of Noise

The basic instrument of a sound measuring system is the sound level meter, an accurate portable meter which reads the sound pressure level in terms of the standard reference pressure. It will usually be composed of an omnidirectional microphone, an adjustable amplifier, a calibrated attenuator, an indicating meter, and electrical weighting networks. The microphone transforms the changing sound pressure waves into electrical voltage fluctuations which are amplified sufficiently to actuate a meter or recorder. The meter usually reads over only a small range, this range being selected and adjusted by the attenuator to suit the sound being measured. The weighting networks are electrical circuits which provide for various sensitivities to sounds of different frequencies.⁴

Calibrations, which produce sound of a known pressure level and tone, are used to ensure the sound level meter is functioning properly. A frequency analyzer is often used to determine the frequency spectrum of the noise. It consists of a set of individually activated band pass filters, attenuator and amplifier to drive a meter. Magnetic tape recorders are used for recording and storing noise encountered in the field for later analysis in the lab.

The statistical distribution analyzer is used to band analyze and statistically distribute the recorded sounds into channels of a certain bandwidth over a range of sound pressure levels, e.g. that percentage of the sound pressure levels between 70 and 75 dB will

be placed in the 70 - 75 dB channel, that percentage between 75 and 80 dB will be placed in the 75 - 80 dB channel, etc. The analyzer can be calibrated and adjusted to handle a variety of ranges and bandwidths.

Rating Scales

A rating scale describes only the noise exposure itself, either in a simple way such as the reading of the maximum A-weighted sound level during a transient noisy event, or in some more complicated manner that may account for the time variation of noise analyzed into frequency bands. A rating procedure attempts to account for the context in which the noise stimulus is experienced and usually entails the introduction of corrections for the characteristics of the noise (pure tone, duration) and for the particular situation (time of day it occurred).⁵

The rating systems discussed below are but a few of many which have been proposed over the past few years. Each system offers something a little different from the others and each has its proponents.

1. The A-weighted sound level is a relatively old system which attempts to make the sound level meter respond to sounds in a manner more like the human ear. Low frequencies (below 500 Hz) are quite severely discriminated against in the A-weighted system. This is accomplished through the use of electrical weighting

networks in the sound level meter which alters its normally flat response. Over the years no scale or procedure has shown to be consistently better than the A-weighted sound level in correlation with subjective response.⁶

2. Loudness level. S. S. Stevens and E. Zwicker have developed methods for calculating the loudness of a complex noise. Both methods take into account the masking or inhibiting of one component of a complex noise by other components; Zwicker's method also takes into account that this masking is asymmetric (frequencies above the intense band are masked more so than those below the band). Frequency analysis is performed and a loudness index for each band is determined as a function of band sound pressure level and frequency; this index represents the band's contribution to the total loudness. These indices are then summed, each with various weighting factors to reflect the fact that the band with the loudest index will mask the contributions of other bands. This sum becomes a composite loudness index, S , and is converted to a loudness level by the formula $P = 40 + 10 \log_{10} S$.

3. The Perceived Noise Level (PNL) of Kryter is a spinoff of the loudness level and is calculated in much the same way. The few differences occur mainly in the way that individual band loudness indices are computed. Instead of a loudness index, S , Kryter arrives at an index of 'perceived noisiness' (unit is the noy) which is then used in the same equation as above to produce the perceived

noise level (units are PN dB). The PNL is used frequently in analyzing aircraft noise.

4. The Noise and Number Index (NNI) was developed during the course of a social survey outside London (Heathrow) Airport to determine the aspects of aircraft noise which were most annoying. The Wilson Report defined NNI as "a composite measuretaking into account the average peak noise level as well as the number of aircraft heard in a specified period."⁷

$$\text{NNI} = (\text{average peak noise level}) + 15 \log_{10} N - 80.$$

The average peak noise level was defined as

$$10 \log_{10} \left(\frac{1}{N} \right) \sum_i^N 10^{L_i/10}$$

where L was the peak noise level in PNdB (the units of Perceived Noise Level) occurring during the passage of each aircraft and N was the number of aircraft heard in a specified period.

5. The Traffic Noise Index (TNI) is a weighted combination of the average 'background' level and the average 'peak' level found using the base measure of A-weighted sound level.

$$\text{TNI} = 4(L_{10} - L_{90}) + L_{90} - 30.$$

The sound levels L_{10} and L_{90} were those sound levels exceeded 10% and 90% of the time respectively. The first term expresses the range of the noise environment while the second represents the background noise level.

6. The Noise Pollution Level (NPL) was developed by Robinson and is based on two terms, one accounting for the annoyance due to fluctuations of noise level and the other representing that annoyance due to the continuous noise level.

$$L_{NP} = L_{eg} + k\sigma$$

where

L_{eg} = the 'energy' mean of the noise level over a specified period

σ = the standard deviation of the instantaneous noise level over the same period

k = a constant determined by obtaining the best correlation of L_{NP} with subjective response (Robinson found k to be 2.6).

The term, L_{eg} , is determined largely by the average intensity of the noise and is derived from a statistical analysis of the noise history.

$$L_{eg} = 10 \log_{10} \left[\frac{\int_0^T 10^{L(t)/10} dt}{T} \right]$$

where

$L(t)$ = the noise level in dBA as a function of time

T = the time period involved.

As can be seen, the various rating schemes, based on physical measurements of noise, differ greatly in the amount of calculation required. The choice of any rating for a particular purpose should thus consider the tradeoffs involved in computing the index and the precision and accuracy in prediction of response to noise. Because of its relative simplicity, ease of application, and long history of relative accuracy, the A-weighted sound level has often been chosen as the standard sound level measuring system. It was for all of the above reasons that it was used in this study.

FOOTNOTES

¹ M. D. Harmelink, "Noise and Vibration Control for Transportation Systems", Dept. of Highways, Ontario, Report No. RR168, 1970, p. 1.

² Ibid., p. 2.

³ Ibid., p. 4.

⁴ Ibid., p. 5.

⁵ Theodore Schultz, Community Noise Ratings, Applied Science Publishers Ltd., London, 1972, p. 10.

⁶ Ibid., p. 16.

⁷ Sir Alan Wilson, Noise: Final Report of the Committee on the Problem of Noise, Her Majesty's Stationery Office, London, July, 1963.