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ABSTRACT

This building research survey is an analysis of the social nuisance caused by urban motor ways and their noise. The Traffic Noise Index is used to indicate traffic noises and their effects on architectural designs and planning, while suggesting the need for more and better window insulation and acoustical barriers. Overall concern is for--(1) finding unacceptable noise levels, (2) discovering how traffic noise is propagated, and (3) determining effective traffic noise control for buildings. Graphs and charts are used to distinguish the relationship between noise levels and distances. (TG)

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The traffic noise index: a method of controlling noise nuisance

F J Langdon and W E Scholes

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THE TRAFFIC NOISE INDEX: A METHOD OF CONTROLLING NOISE NUISANCE

F.J. Langdon, BA, D Phil, and W.E. Scholes, BSc

A version of this paper is published in the Architects' Journal, 1968, Vol. 147, April 17th.

Recent work by the Building Research Station, now in course of publication, has resulted in a method for assessing social nuisance caused by road traffic noise. The method employs a unit termed the Traffic Noise Index which is derived from the weighted combination of two characteristics of the noise. These are the levels exceeded for 10% and 90% of the time, both averaged over a 24-hour period. Thus a single value of TNI takes into account a number of factors governing social nuisance, such as the noise produced by the general traffic stream, that coming from individual vehicles and the distance of the reception point from the road.

In the present paper a control criterion, based on the Traffic Noise Index, is put forward and some of the considerations involved in fixing an acceptable level are discussed. The use of the Index and some of its implications in planning are considered, such as the siting of buildings, the use of increased window insulation, the effects of acoustic barriers and the rate of traffic flow.

Further research is needed to enable the Traffic Noise Index to be exploited fully in practice. This work would yield more accurate predictions of traffic noise, of the effects of barriers and of improvements to window insulation, in a form compatible with use of the Traffic Noise Index.

CURRENT PAPER 38/68

BUILDING RESEARCH STATION
Ministry of Public Building and Works

THE TRAFFIC NOISE INDEX: A METHOD OF CONTROLLING NOISE NUISANCE

by F.J. Langdon, B.A., D.Phil., and W.E. Scholes, B.Sc.

INTRODUCTION

In recent years considerable attention has been given to the problem of noise nuisance caused by road traffic. The Wilson Committee attempted to balance the general desire for a reduction of noise against the practical needs of road transport, and in their report (1) suggested criteria to control the level of traffic noise inside buildings. These recommendations were of a tentative character and were not based on field surveys or similar studies.

The first requirement for effective control of traffic noise nuisance is a criterion based on systematic studies designed to establish the levels of noise at which people are likely to find living conditions unacceptable. In the second place, to apply such a criterion in practice requires a general understanding of how traffic noise is propagated, and of how it is affected by control devices, such as window insulation and acoustic barriers. The Building Research Station is now engaged on a programme of research to provide information on both of these topics, and has recently published the results of a study which attempts to measure social nuisance and relate it to the level of traffic noise (2).

This article is concerned to develop these conclusions, to discuss criteria capable of limiting nuisance, and to consider some of the design consequences of such controls. It will be understood that as the physical studies of traffic noise propagation have not yet been completed, a number of assumptions have had to be made about the effects of distance, and in consequence some of the conclusions are subject to qualification.

THE BRS SURVEY

It is known that large fluctuations in traffic flow and the effects of congestion on conventional urban roads tend to complicate the measurement of traffic noise, and that urban motorways offer the best conditions for study (3). As there are insufficient numbers of sites in this country located on urban motorways, it was decided to base the enquiry on ordinary main roads in urban areas. It is worth pointing out that the loss of accuracy resulting from more disordered traffic flow may be counterbalanced by the gain in general applicability of the conclusions.

Fourteen sites in the Greater London area were chosen to represent a wide range of main road traffic volumes and noise levels. So far as was possible, only roads which were free from congestion, straight, level and without intersections, were selected. The roads were flanked for a sufficient length with rather uniform semi-detached two storey housing, sited parallel to the roadway at distances ranging from 7 to 46 metres from the kerbsides.

It will be useful to begin by outlining how the physical values were arrived at. The noise levels were measured in dB(A). That is, the microphone signals were electrically weighted to give a frequency response similar to that of the human ear at low levels of intensity. It has been found that in the case of traffic noise, the use of the 'A'weighting at all intensity levels results in high correlations with loudness calculated from weighted summations of the noise spectrum (4).

The level of noise fluctuates with traffic flow, both over the 24 hours and during shorter periods. Even during a short period of a minute or two, it is not possible to describe the noise level by a single number but only by representative values derived from statistical analysis. Figure 1 shows a typical trace of traffic noise over a period of 100 sec. A statistical analysis may be made to yield the levels exceeded in dB(A) for any designated proportion of the time, such as 10, 50 or 90%, as shown in the figure. The extreme peaks in the trace indicate the passage of particular noisy vehicles during the period measured. They are therefore unique, and taken alone, not a useful quantity. The 10% level may be taken as representative of the average maxima, the 50% level indicates the mean value, while the 90% level represents the average background. The successive values for these three levels plotted over 24 hours, as illustrated in Fig. 2, show the diurnal variations of traffic noise at a typical site.

The propagation of traffic noise is a complex phenomenon which will be discussed later. For the present it is sufficient to say that errors can arise by making measurements close to the roadway, and extrapolating the results to some reception point. In the BRS survey such errors were avoided by locating the microphone one metre from the building façade at first floor level. At each site, samples of week-day traffic noise were recorded over a 24-hour period by means of an automatic mechanism installed in one of the houses and linked to the external microphone.

A problem encountered by all studies of noise nuisance, and reported by a number of investigators (5, 6, 7, 8) is the occurrence of wide variations in subjective response. Individual differences in noise tolerance, together with variations in family living patterns, make it difficult to achieve high correlations between social and physical data. It is particularly necessary to do so where the aim is not merely to show that noise levels are related to social nuisance in some way, but to produce criteria of practical value for prediction. Since it was essential that the sample should be adequate for this type of analysis, 1400 residents were interviewed by means of an extensively tested questionnaire. This was designed to measure both general dissatisfaction with traffic noise, and specific nuisances and difficulties occasioned by it. Other questions dealt with topics such as traffic nuisances other than noise, the way in which the dwelling was used, length of residence, and so on.

These results are given at length in the full report of the survey (2). Here the findings are discussed in more general terms. The most important result of the study was to show that no single measure of traffic noise is very closely related to social nuisance. Thus the best correlation obtained, which was between the 10% noise level and general dissatisfaction, was only 0.6, which merely demonstrates a trend and is quite inadequate for predicting dissatisfaction at any particular noise level. Neither the 90% level nor the mean value yielded significant correlations. An alternative method of measuring traffic noise has been developed by continental workers (9), termed the $\bar{Q}$ or 'equivalent' noise level. However, correlations obtained using this method, while higher than those produced using the 10% level, were still inadequate for practical purposes.

THE TRAFFIC NOISE INDEX

It seemed possible that a higher correlation might be obtained from some combination of the average 10% and 90% levels, since this would take into account the background levels against which the maximum levels were heard. A multiple correlation of various combinations of the 10% and 90% levels with the dissatisfaction scale yielded the highly significant relationship illustrated in Fig. 3. The basic combination of levels which yields this correlation is the 10% level, minus 0.75 of the 90% level. To make such a combination easier to use in practical noise control, it has been modified to the form:

$$4 \times \text{(10\% level - 90\% level)} + \text{90\% level} - 30$$

and this expression has been termed the Traffic Noise Index (abbreviated TNI).

At first sight the TNI as expressed above may appear more complex than the basic combination of levels. However, it has been found that in the form given it is easier both to apply, and to understand the noise characteristics involved. Thus the TNI includes the range of the noise climate, over the 24 hours, together with a smaller contribution from the 90% level representing the average background and which is an absolute value. The basic combination is multiplied by four in order to eliminate the need for fractional quantities, and 30 units of TNI are subtracted merely to yield a convenient numerical scale.

The Traffic Noise Index was derived from data representative of traffic noise levels at the façades of buildings varying in distance from the source, is weighted to take account of variations in traffic flow, and correlates highly with general dissatisfaction.

Predictions made with its aid are therefore independent of short term variations, such as the level of noise at a particular time of day or night. Moreover, TNI values may be very simply adjusted to allow for the effects of attenuation with distance.

CONTROL CRITERIA

As traffic noise measured by TNI correlates very highly (0.88) with the experience of those exposed to it, the relationship can be plotted as a graph. Figure 3 enables the level of dissatisfaction to be predicted for any level of noise indicated on the TNI scale. Although the relationship is very close it is not perfect so that there must remain an area of uncertainty about the exact position of the line plotted on the graph and this is allowed for by indicating limits of confidence shown by the dashed lines.

The solid line shows the best possible prediction from the data taken as a whole. The purpose of a control criterion however, is to enable this prediction to be applied to a particular case. If the solid line itself were used for this purpose there would be an equal likelihood of conditions being worse than predicted as of their being better. This is avoided by basing the criterion on the lower dashed line, which automatically ensures that there is only one chance in forty that dissatisfaction would be greater than predicted. In deciding at what level of noise a control criterion should be set it is therefore advisable always to use the lower 95% confidence limit as the guiding line.

Putting forward a noise control criterion means deciding the permissible level of dissatisfaction, and it is essential to realise that doing so represents a conscious value judgement. It would be disingenuous to present results in such a manner as to convey the impression that the standard put forward was in some unexplained way a direct consequence of the scientific data, though such a procedure is not uncommon in the literature of environmental standards.

There are two main considerations which would appear to govern the choice of a criterion for controlling traffic noise. First, that the social nuisance it causes ought not to exceed a level acceptable to a certain proportion of the population. Second, that the measures which may have to be taken to achieve this should be neither unreasonable nor unduly expensive. Such a criterion is therefore a compromise between what is desired and what can be afforded, and this is a question which has to be settled by public and administrative bodies. However, to show how the Traffic Noise Index may be applied, and to illustrate some of its consequences, the results of the survey may be interpreted so as to yield a tentative criterion.

With the foregoing considerations in mind, the noise level of 74 TNI has been indicated in Fig. 3 as representing a reasonable standard of amenity in present day urban conditions. It may be predicted that at this level there is only one chance in forty that the average person living in the vicinity of main road traffic is likely to be dissatisfied. On the second consideration, the suggested criterion is satisfied at two of the sites, whereas any more stringent requirement would fail them all, while practical remedial measures are capable of improving conditions at the noisiest site to meet the criterion.

The suggested criterion is based on the relationship between noise level and general dissatisfaction, which may be regarded as the sum total of a large number of particular discomforts and annoyances. These include such things as difficulty in getting to sleep and the likelihood of being awakened from it, being compelled to keep windows closed, or not being able to entertain visitors or listen to the radio in comfort. All these particular complaints are very closely linked with general dissatisfaction and this is illustrated graphically in Fig. 4. Two sets of conditions have been plotted, one of living conditions during waking hours, the other during the hours of rest. Each of the specific annoyances has been plotted against the level of general dissatisfaction. It will be seen that as noise conditions deteriorate almost all residents have to close their windows at some time because of noise. Similarly, an increasing proportion claim to be wakened from sleep. Other activities are affected, though as may be seen, to a lesser degree. The important point which these additional observations illustrate is that at the level of general dissatisfaction suggested as the basis for the control criterion, less than half of the residents claim to be suffering from any of the particular annoyances reported. Although these specific complaints are closely related to general dissatisfaction, not all of them are as closely related to noise level. This is because some of them are affected only at particular times of day, while the great differences between ways of using the home and in family composition tend to obscure any general trend. This is best represented by the scale of general dissatisfaction, and for this reason it is advisable to use this scale as the basis for any proposed control criterion, rather than the degree of interference with a particular activity.

THE PRACTICAL APPLICATION OF THE TRAFFIC NOISE INDEX

A full exposition of how to apply a noise control criterion of this kind would require precise knowledge of the way traffic noise is propagated, the effects of building façades, noise barriers, and so on. At present, much of this is known only in very general terms, and further study of these topics is still in progress. Nevertheless, by basing certain fairly simple considerations on the limited data at present available, it is possible to prescribe a number of useful procedures.

1. Effect of distance

The 10% level attenuates with distance at a greater rate than the 90% level, since the noise which it represents emanates from particular moving sources close to the reception point, decaying with distance according to the inverse square law. On the other hand, the 90% level is assumed to represent the noise coming from numerous sources distributed along the length of the road and attenuates inversely with distance. Although this is a somewhat over-simplified account of a complex phenomenon, it is possible to state as a simple working rule, that over moderate distances the 10% level falls by 6 dBA, and the 90% level by 3 dBA each time the distance from the source is doubled. This is illustrated by Fig. 5 which gives the results of measurements made at the side of a motorway up to a distance of 150 metres. These findings are in agreement with results obtained by Lamure and Auzou (3).

On the basis of these rates of decay the Traffic Noise Index may be applied to the planning and allocation of land, and also to indicate the need for remedial measures in existing environments. For this purpose a chart has been constructed which predicts values of TNI at various distances from the source, and this is shown in Fig. 6.

To use this chart it is necessary to know the noise levels at a point near the source. It will be seen from Fig. 5 that at extremely short distances the 10% and 90% levels do not decay at the rates stated above. The traffic noise should therefore be measured from a point not less than about 7 metres, and preferably further, from the edge of the roadway in order to ensure that reliable values are obtained.

TNI values are best computed from a representative sample of measurements yielding the 10% and 90% levels over 24 hours. Alternatively, it may be possible to utilise the method recently described by Johnson and Saunders (9) for the prediction of 50% levels, and from these to estimate the 10% and 90% levels.

The values obtained in the BRS survey were slightly increased by the circumstance of the microphone being located one metre from the building face. Values obtained in the free field therefore need to be corrected to allow for the presence of a building. It is estimated that for this purpose an addition of 3 TNI units to free field measurements would suffice. The prediction will then apply to the actual distance at which it is desired to site a building, despite the fact that the source measurements are being made in the free field.

The distance may be read directly from the chart by finding the intercept of the TNI value and the distance from source of the measuring point. From this point a line constructed parallel with the nearest decay contour will intersect the control criterion level at TNI 74. A perpendicular dropped from this point gives the minimum distance from the roadway at which a building may be sited while ensuring acceptable conditions for the occupants.

An imaginary example may be helpful. Assuming the noise were measured 10 metres from the roadway, and the value of TNI obtained to be 94, 3 units are added to allow for the effect of the building façade. Lines from the two axes at 10 metres and 97 TNI are produced to meet, and from this point the contour is followed to reach TNI value 74. A perpendicular from this point gives the minimum distance as 32 metres.

It is perhaps worth drawing attention to an apparent peculiarity of the TNI scale. Comparing two sites where the 10% noise levels are similar, the site with the lower 90% level will be found to yield a higher value of TNI. This seeming paradox is resolved as soon as it is realised that with a lower background noise level more nuisance is occasioned by traffic in the immediate vicinity. The Traffic Noise Index takes account of these circumstances and this is one reason why it relates closely to the experience of residents exposed to traffic noise.

2. Effects of extra insulation

While it is useful to be able to calculate such distances for planning purposes, it does not follow that it is always possible or most desirable to safeguard standards of amenity by sacrificing land. In a particular case it may be worthwhile considering the alternative of extra sound insulation. From recent work by Scholes and Parkin (10), it would be reasonable to conclude that approximately 15 dB of extra insulation may be obtained from acoustic double glazing fitted to conventional two-storey housing, where the source is close to the ground.

Reference to the definition of TNI above will show that a reduction of 15 units of TNI may be achieved by reducing both 10% and 90% levels by 15 dB. From the chart it will also be seen that a difference of 15 units of TNI is equivalent to a halving of the ,tance from the source, so that conversion from single to double glazing allows the halving of this distance while still preserving the same environmental standards within the dwelling.

It is therefore possible to consider trading distance for sound insulation by comparing the value of land not otherwise available with the cost of double-glazed windows, together with the necessary noise attenuating ventilators. Moreover, it is probable that attention to the internal layout of the building would e· ·ble the number of rooms requiring such treatment to be minimised by locating the aximum number of rooms requiring quiet on the side away from the noise source.

The reduction in noise level resulting from double-glazing has been given in units of TNI, making possible a cost comparison with distance as a means of noise control. While the Traffic Noise Index is a measure of external noise level, it is equally applicable to internal conditions modified by acoustic treatment, since the effect of such treatment is to reduce the internal level to what it would have been with a lower external level.

The report of the Wilson Committee proposed environmental standards for traffic noise control based on the 10% noise level, giving suggested criteria in the form of internal values. The internal noise level produced by road traffic will be influenced by whether windows are open or closed. In the publication referred to, Scholes and Parkin state that typical insulation values against broad band noise for ordinary windows are 14 or 25 dBA, according to whether they are open or closed. As it is difficult to know exactly how occupants actually use their windows, an internally measured unit of traffic noise, or a control criterion defined in such terms, would appear a variable quantity of dubious significance. This was in fact a major consideration prompting the choice of an external value in the BRS survey, and also one reason why comparisons with Wilson Committee Standards are difficult to make.

None of the housing covered by the BRS study was specially treated, and the degree of dissatisfaction expressed by the occupants is that which arises in the context of their customary practice of opening windows as circumstances indicate. The problem of relating external to internal noise levels may therefore be ignored, whether in the case of planning new development or improving conditions in existing property, for the point at which such action needs to be taken is determined solely by the external noise level.

With normal glazing and natural ventilation, the internal noise climate will vary with the opening and closing of windows. The installation of sealed double-glazing removes this source of variation.

It might be argued that, to apply acoustic treatment where the suggested noise criterion is marginally exceeded would result in internal standards superior to those in untreated dwellings where the external conditions satisfied the criterion level. However, this apparent anomaly is an eventuality to which all general criteria are necessarily subject, since it is hardly ever possible to provide just enough and no more improvement for each individual case.

In practice it is possible to consider graded levels of treatment. For example, simple fixed glazing with a powered fan having a small cross-sectional area will provide better insulation than an open window. In all cases, the principle remains the same; namely, the action taken should be that required to bring the internal noise level to what it would have been in a dwelling with single glazing had the suggested criterion not been exceeded externally.

3. Effects of barriers

An entirely different approach to the problem is the employment of acoustic barriers. At present it is difficult to make precise statements about this topic, for the effects of barriers, being determined by large numbers of factors, are not easy to predict in other than very general terms. Part of the study of traffic noise propagation being carried on at BRS is devoted to quantifying these factors so that the performance of barriers may be evaluated. Such factors include the source to barrier distance, the effect of source width, the receiver to barrier distance, the relative heights of source, barrier and reception point, the nature of the terrain and the design of the barrier.

From work already carried out, and from results reported elsewhere (11, 12), it has been suggested that a barrier 4 to 5 metres high, located close to the traffic stream, can reduce the noise level within the sound shadow thus created by 10 dBA or more. However, since this article is concerned with the application and consequences of the Traffic Noise Index rather than with comprehensive discussion of traffic noise control, at present somewhat premature, it is sufficient to draw attention to one of the consequences of this index in relation to acoustic barriers.

It is known that the effectiveness of a barrier is greatest when both source and receiver distances are small, and that it declines as either of these is increased. Consider the case in which noise emanating from a single moving vehicle reaches a fixed point at the side of a road along which a barrier has been constructed. During the approach of the vehicle, the distances between the source and the barrier, and the barrier and the receiver are greater than when the vehicle is at the point closest to the receiver. As the vehicle continues on its course, these distances will again increase. It may therefore be expected that a barrier will give a greater noise reduction for nearby traffic than for traffic which is approaching or receding.

It has already been pointed out that the 10% levels are chiefly the result of local concentrations of vehicles close to the reception point, while the 90% levels are caused by traffic distributed along the length of the road. In consequence, barriers may be expected to reduce the 10% level more than the 90% level, in their shadow region. If it were assumed that a barrier reduced the 10% level by, for example, 10 dBA and the 90% level by 5 dBA, the definition of the Traffic Noise Index indicates that the reduction would be 25 TNI units. While it is not yet possible to give actual values for the relative disparity in attenuation of the average 10% and 90% levels over 24 hours, it would seem that a barrier is likely to reduce social nuisance more effectively than window insulation giving an equal amount of attenuation as measured by the 10% noise level. For the effect of the Traffic Noise Index, which is more closely related to social nuisance, is to weight the calculation in favour of the barrier. In addition to this apparent, though not yet proven advantage, barriers have also the effect of improving the external as well as the internal environment.

4. TNI and traffic volume

Whatever means of noise control are adopted in any particular case, it is necessary to begin with some known value of TNI with which the required value may be compared. The way in which these values may be obtained has already been described, but there remains the case where this is not possible. An example would be where no road at present exists, or a route development is planned and it is necessary to consider the use of neighbouring land or judge the need for noise control measures.

It would be very convenient to be able to predict an expected TNI value on the basis of road capacity or anticipated traffic volume, even if only very approximately at this stage of planning. A number of investigators have produced curves relating traffic volume to noise level. Stephenson and Vulkan (13) have published data for urban roads using the 50% noise level, while Meister (14) and Lamure and Auzou (3) have produced curves based on motorways for levels ranging from 1% to 99%. While the sum total of this work is to demonstrate that for traffic with a normal proportion of heavy vehicles the relationship is close enough for predictive purposes, none of it is relevant to the present discussion, since it is all based on relatively short periods of vehicle-counting and noise-recording at particular times of day. As against this, the Traffic Noise Index is a measure of the noise climate over the 24 hours, and derives its predictive power from relating this to the human response to the general traffic noise situation. To predict social nuisance by means of measured or anticipated traffic volume through the agency of the Traffic Noise Index therefore requires a representative count of vehicle flow, related to noise measurements over the 24 hours.

The only data of this kind which exists at present is that gathered in the course of the BRS survey, and as it is drawn from a small number of sites the correlations derived from it will not be very high. Nevertheless, from the sites used in the main survey a correlation of 0.76 is obtained between traffic volume and TNI, which is statistically significant, and adequate for a rough prediction to be made. The results of this procedure are given in Fig. 7 which shows expected levels of noise for traffic flows over 24 hours, grouped into five bands ranging from 1000-4000 to 32 000-45 000 vehicles per day.

The range of prediction within each band of traffic volumes is that of the 95% limit of confidence; that is to say, there is only one chance in twenty that for each band, the noise levels would fall outside the limits of the range. While the estimates which can be derived from this data are somewhat crude they are not altogether useless. Nevertheless, they are given here as an indication that such estimates are possible rather than for practical use. If the Traffic Noise Index is to be applied as a planning tool in this way, the continued collection of vehicle flow and noise level data is necessary. Given sufficient information of this kind there is every reason to believe that a high degree of predictive accuracy is attainable.

In conclusion it needs to be once more emphasized that what has been discussed is only the partial outcome of a research effort on a much broader front. From what has been said, and particularly from what has been left unsaid, it may be deduced that much remains to be done in order to provide the planner with effective tools of noise control. Despite this, it may be claimed that the Traffic Noise Index represents an advance towards the solution of a widespread and difficult problem.

ACKNOWLEDGEMENT

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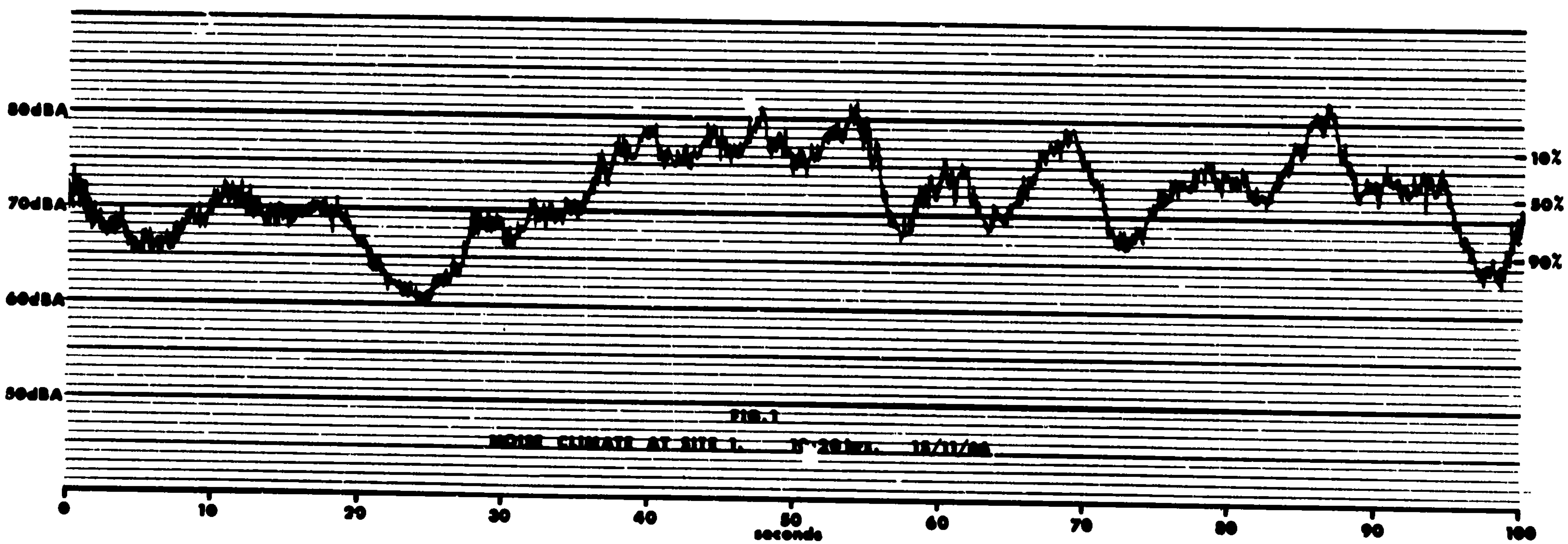

FIG.1

NOISE CLIMATE AT SITE 1. [illegible] hrs. [illegible]

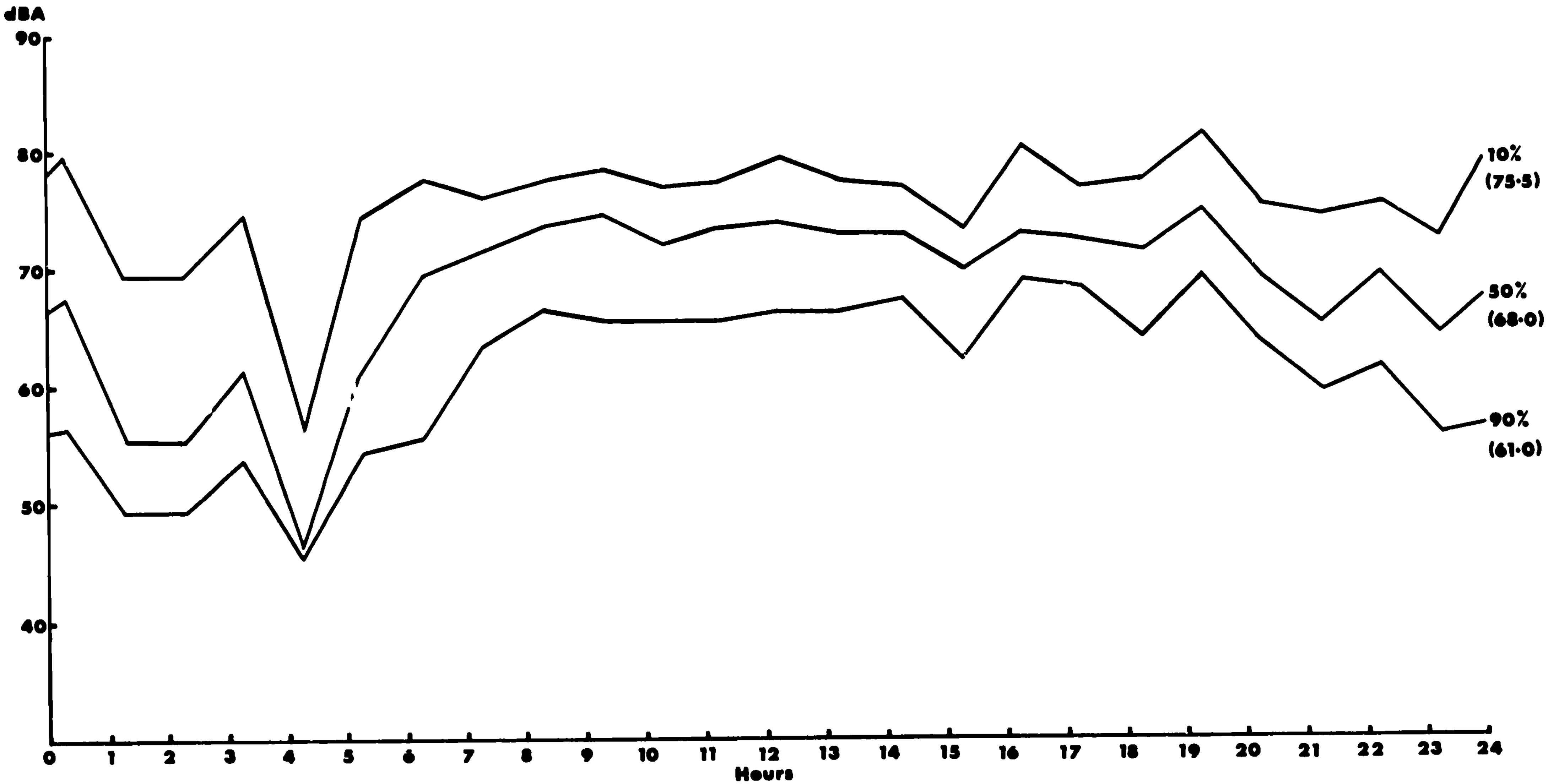

Fig. 2. Analysis of noise climate at site 1.

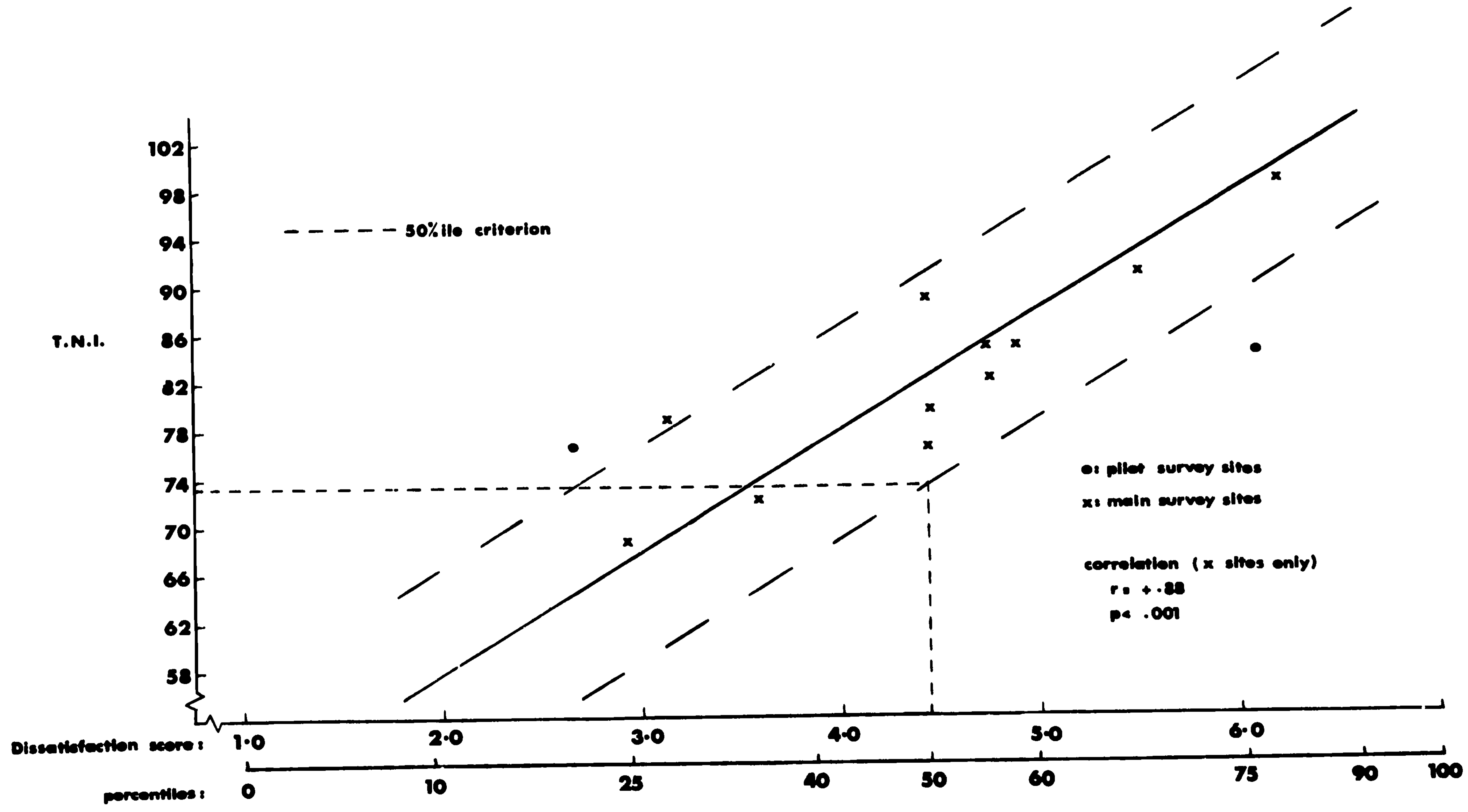

Fig. 3. Relationship between TNI and dissatisfaction with traffic noise.

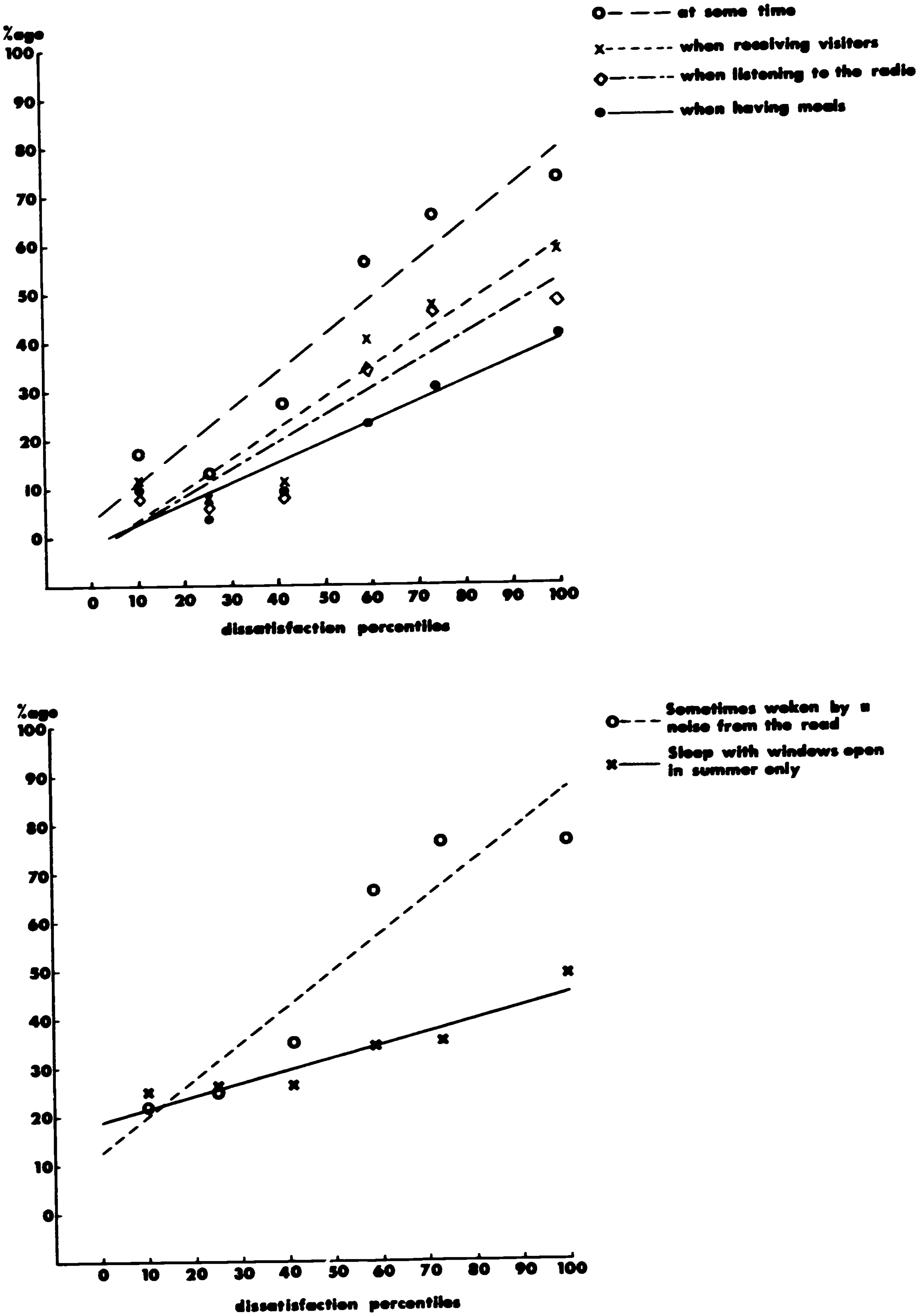

Fig. 4. Measures of disturbance by noise - percentages of informants (top) having to close windows at various times, and (bottom) woken by noise from the road and sleeping with windows open.

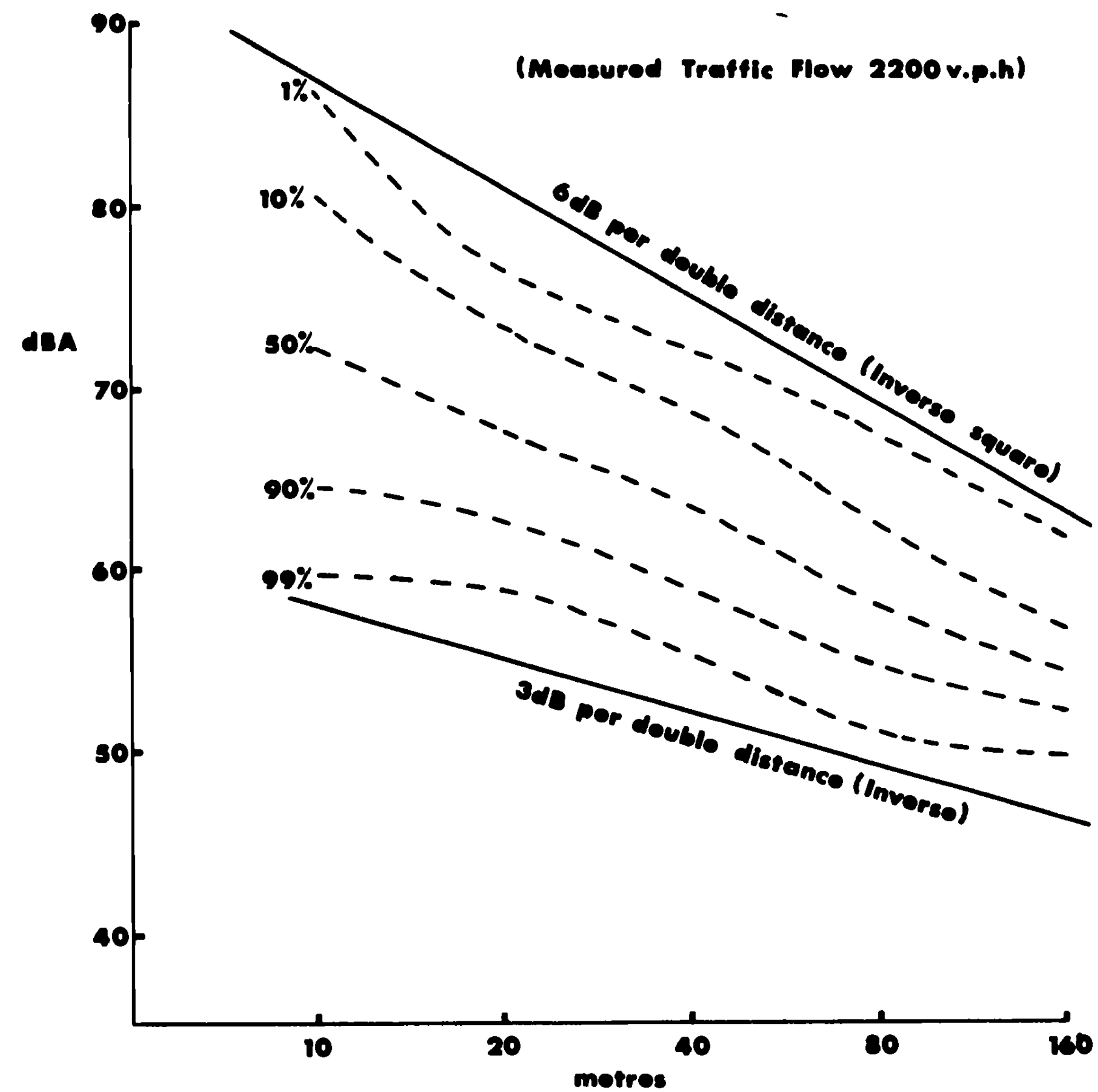

Fig. 5. Attenuation of noise with distance.

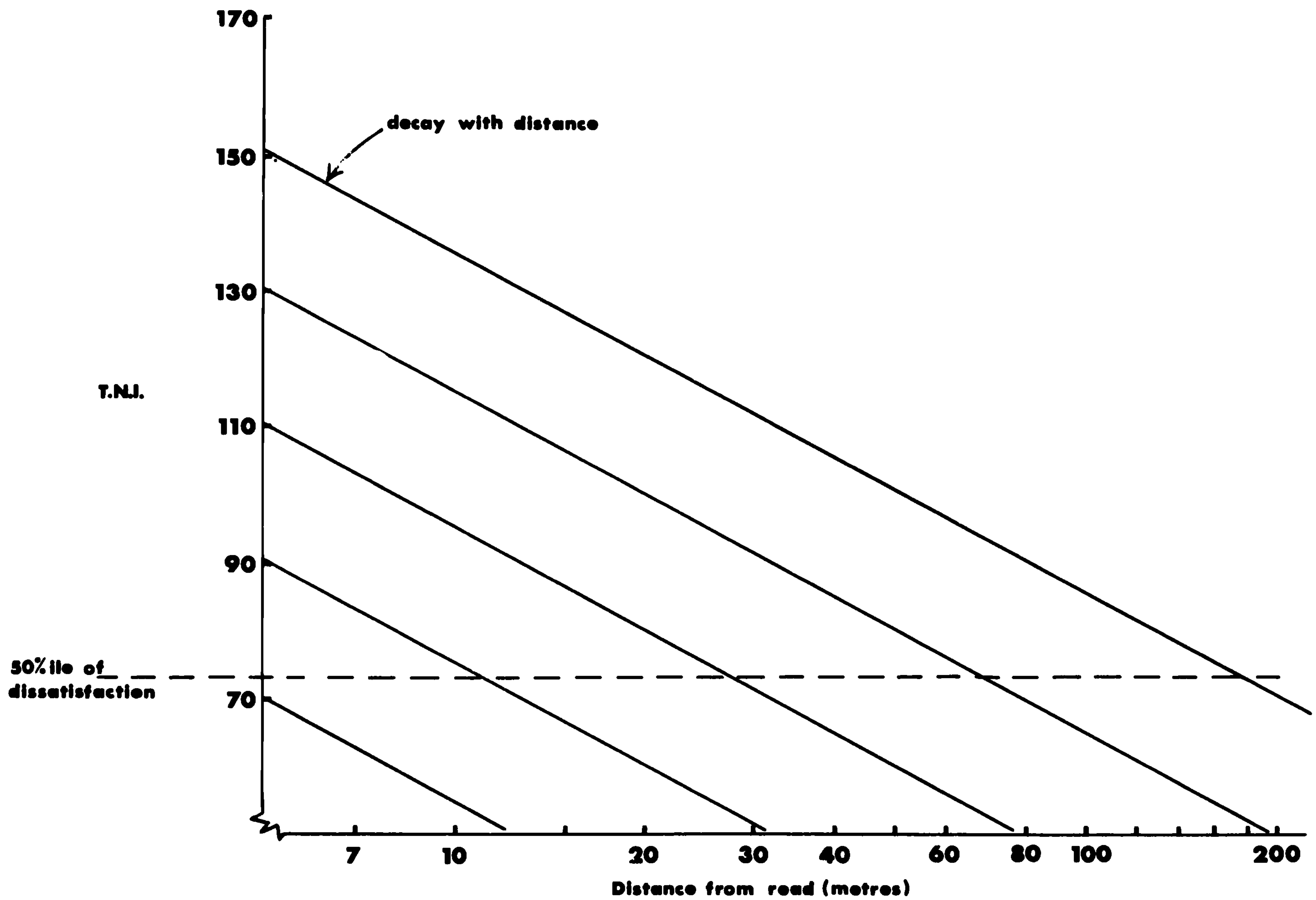

Fig. 6. Minimum acceptable distance from road at any noise level.

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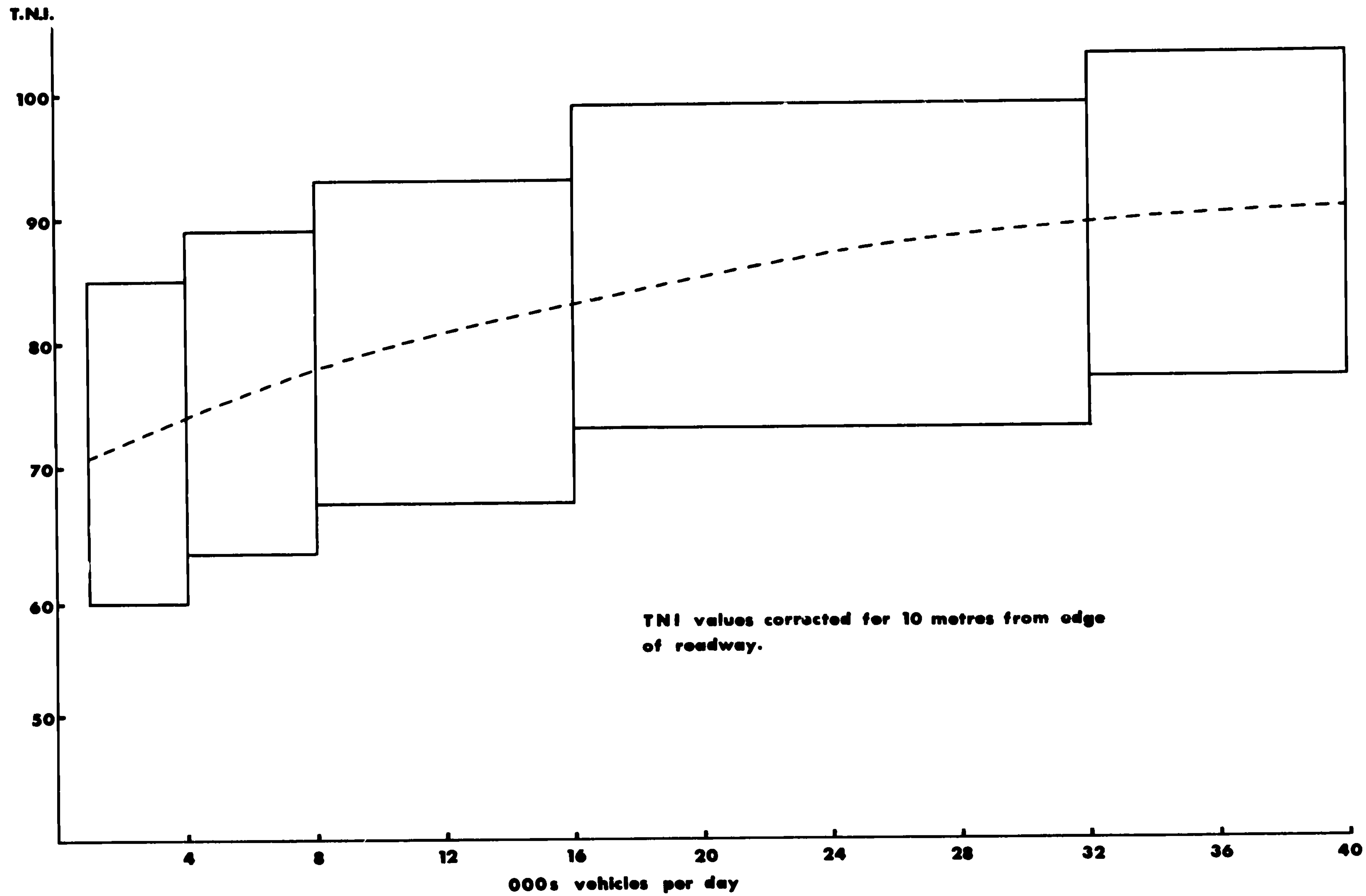

Fig. 7. Noise level in relation to traffic volume.

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