ARCHIVES OF ACOUSTICS
2, 2, 83-94 (1977)

A METHOD FOR DETERMINING THE EQUIVALENT LEVEL L_{eq}

RUFIN MAKAREWICZ

Chair of Acoustics, A. Mickiewicz University (Poznań)

The constantly growing traffic noise caused, among others, by the rapid development of motorization, is a considerable menace to the human environment. From the view point of acoustics the rating scale generally used to evaluate the environment is the equivalent level L_{eq}. In this paper the relationships between such parameters as the traffic flow, the speed and sound power of individual vehicles, and parameters describing the paths of the moving noise sources are derived.

1. Introduction

The equivalent sound level L_{eq} is one of the many rating schemes of traffic noise now used. The investigations carried out in Sweden [27], France [2], the Federal Republic of Germany [20], Australia [11] and in Poland [23] have shown that L_{eq} is a valid rating scales for the evaluation of noise. It is also widely used in the U.S.A. [3]. It serves, among others, for the determination of the "day-night" equivalent level [5, 23]. The results of the investigations performed in Great Britain [4, 24] indicate that the Traffic Noise Index – TNI [7] and the Perceived Noise Level – PNL [21] are both superior to L_{eq} as noise evaluation indices, since they are a better "measure" of the fluctuation of noise level. These fluctuations have a decisive effect on the noise exposure. Because of measurement difficulties the TNI and PNL are not so widely used as the equivalent – L_{eq}, which can be measured directly using meters such as those produced by Brüel-Kjaer and RFT.

The definition of L_{eq} is

$$L_{eq} = 10\log\frac{1}{T}\int\limits_{-T/2}^{T/2} 10^{0.1\,L(t)}\,dt, \tag{1}$$

where $L(t)$ denotes the sound intensity level measured in dB(A) and T the averaging time.

According to the definition of sound intensity level, to each value of the sound intensity $L(t)$ measured in dB(A) can be assigned the corresponding sound intensity

$$I(t) = I_0 \cdot 10^{0.1} L(t),$$

where I_0 denotes the reference intensity.

Substituting this relation into the definition of the equivalent level (1) we obtain

$$L_{eq} = 10 \log \frac{\langle I \rangle}{I_0}, \tag{2}$$

where

$$\langle I \rangle = \frac{1}{T} \int_{-T/2}^{T/2} I(t)\, dt$$

is the average sound intensity.

The purpose of this paper is to find the relationship between the equivalent level L_{eq} and such parameters as the traffic flow, the speed, those describing the route of moving noise sources, and sound power of the individual source types.

2. Method for the calculation of L_{eq} in urban areas

Among others, KUTTRUFT, LYON, LINDQUIST, MALCHAIRE, SHAW, OLSON and THIESSE have been engaged in the problem of calculating some of the quantities characterizing urban noise. In this paper it is assumed that the parameter characterizing the urban noise, the rating scale of this noise, is the equivalent level L_{eq}. The proposed method for predicting the magnitude of L_{eq}

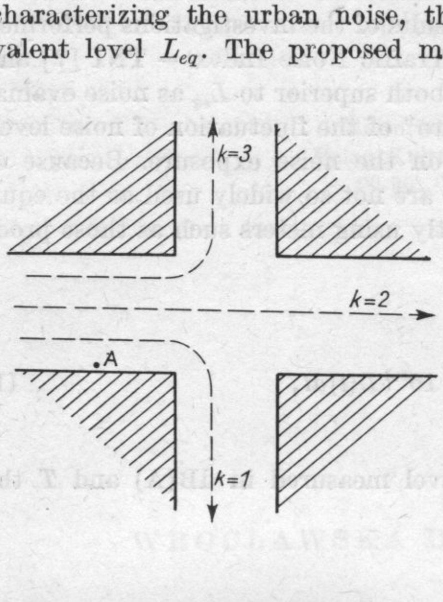

Fig. 1. Vehicle routes near the crossroad

differs from previous methods in that it only requires the measurement of $L_i(t)$, the intensity level of the sound emitted by a single passing vehicle.

Let us assume that we want to calculate the equivalent level L_{eq} at a point A located as shown in Fig. 1 which represents a partial view of central building development.

For further calculations let us form several classes of vehicles that differ by their sound intensity $I(t)$. We take into consideration:

(a) The power of the noise emitted while travelling at a constant speed determined by standard recommendations.

The vehicles considered: lorries, passenger cars, tramway, motorcycles etc. will have different values of this parameter which in the following text will be marked by the letter j.

(b) Travelling route.

In Fig. 1 several possible routes are marked, which will be given the symbol k.

(c) Speed.

We shall assume that there exist "discrete realizations" of the travel $V_l(t)$, e.g. travel at a constant speed, travel at a speed $V_1(t)$, where the function $V_1(t)$ is strictly defined, etc. This will be denoted by the subscript l.

In this manner the class jkl contains the vehicles of type j, which are moving at speed l ($V_l(t)$), along route k. Each of the possible combinations j, k, l will be denoted by the letter i. In this manner the class i ($i = 1, 2, \ldots, n$) comprises the vehicles that are characterized at a point A by the same sound intensity as a function of time. The moment at which vehicle m belonging to class i passes the point of observation is a stochastic quantity. Thus the intensity of sound coming from this source is a function of the form

$$I_{m,i} = I_{m,i}(t - \gamma_{m,i}),$$

where $\gamma_{m,i}$ is the moment at which the source noise is passing the point of observation. The maximum value of sound intensity is then recorded (Fig. 2). We assume that γ is a stochastic quantity with a probability density function $p(\gamma)$.

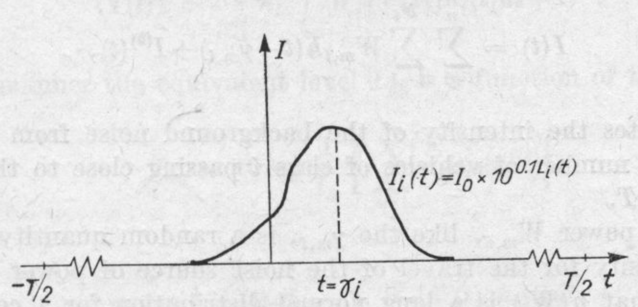

Fig. 2. Changes of the intensity of noise caused by i-class vehicle — $I_i(t)$

The vehicle, travelling at a speed $V(t)$ in open space, is a source of sound intensity

$$I_{m,i} = \frac{W_{m,i}[V(t-\gamma_{m,i})]}{[r(t-\gamma_{m,i})]^{\varrho}}, \tag{3}$$

where r denote the distance of the vehicle from the point in relation to which the computations are made. Movement of the source implies that this is a quantity which changes with time, while the sound power depends on the speed V.

In order to explain more closely the physical meaning of the exponent ϱ let us notice that, under the assumption of a loss-free medium, a sound intensity at the distance r from a spherical sound source is (in an open space) given by the formula

$$I = \frac{W}{r^2}.$$

Because of the absorption of the energy in air, and also the absorption observed at the reflection from the earth's surface, the level decrease of sound intensity, when doubling the distance, is higher than 6 dB ($\varrho = 2$). This means that the intensity changes with distance can be described by formula (3) assuming $\varrho > 2$. LJUNGGREN has shown that in flat terrain $\varrho = 3$ (for terrains covered with thick wood $\varrho = 4$).

In a semi-open space, such as a street, the intensity of the sound I depends not only on the distance $r(t)$ between the moving sound source and the observation point, but also on the mutual location of reflecting surfaces, on the distance of the source and the observation point from these surface, etc.

We assume that all these parameters are included in the function $h(t)$ which replaces $1/r^{\varrho}$ in formula (3):

$$I_{m,i} = W_{m,i}[V(t-\gamma_{m,i})]h(t-\gamma_{m,i}). \tag{3a}$$

The resulting intensity of sound arriving at the point A (Fig. 1) is the sum of these forms,

$$I(t) = \sum_{i=1}^{n}\sum_{m=1}^{N_i} W_{m,i}h(t-\gamma_{m,i}) + I^{(0)}(t), \tag{4}$$

where $I^{(0)}$ denotes the intensity of the background noise from other streets, while N_i is the number of vehicles of class i passing close to the point A in a time interval T.

The sound power $W_{m,i}$, like the $\gamma_{m,i}$, is a random quantity. Writing the probability density for the travel of the noise source of power W_i as $p(W_i)$, OLSON states that $p(W_i)$ is a long normal distribution for a certain type of vehicle travelling at a constant speed.

Since $I(t)$, according to (4), is dependent upon the random variables γ_i and W_i, the mean intensity

$$\langle I(t)\rangle = \int_{-\infty}^{\infty}\int_{-T/2}^{T/2} I(t, W_i, \gamma_i)p(W_i)p(\gamma_i)\,dW_i\,d\gamma_i + \bar{I}^{(0)},$$

where $\bar{I}^{(0)}$ denotes the average intensity of the background noise.

Consequently, from (4), we have

$$\langle I(t)\rangle = \sum_{i=1}^{n}\sum_{m=1}^{N_i}\int_{-T/2}^{T/2}\Big[\int_{-\infty}^{\infty} W_i(V)p[W_i(V)]\,dW_i\Big]h_i(t-\gamma_i)p(\gamma_i)\,d\gamma_i + \bar{I}^{(0)}$$

and

$$\langle I(t)\rangle = \sum_{i=1}^{n}\sum_{m=1}^{N_i}\int_{-T/2}^{T/2}\overline{W}_i[V(t-\gamma_i)]h_i(t-\gamma_i)p(\gamma_i)\,d\gamma_i + \bar{I}^{(0)},$$

where $\overline{W}_i$ denotes the mean sound power of a vehicle belonging to the class which is moving at a speed V.

If we assume that the passing of any vehicle is random in a time T, then $p(\gamma_i) = 1/T$, and we obtain

$$\langle I(t)\rangle = \sum_{i=1}^{n} n_i \int_{-T/2}^{T/2}\overline{W}_i[V(t-\gamma_i)]h_i(t-\gamma_i)\,d\gamma_i + \bar{I}^{(0)}, \tag{5}$$

where $n_i = N_i/T$ denotes the number of vehicles, belonging to class i, passing near the point A in unit time.

It may be noticed further that $I_i = \overline{W}_i h_i(t-\gamma_i)$, the intensity changes of a sound caused by the passage of a single vehicle, is a function which decreases very rapidly to zero (Fig. 2). Thus the following equalities occur:

$$\int_{-T/2}^{T/2}\overline{W}_i h_i\,d\gamma_i = \int_{-\infty}^{\infty}\overline{W}_i[V(t-\gamma_i)]h_i(t-\gamma_i)\,d\gamma_i = \int_{-\infty}^{\infty}\overline{W}_i[V(t)]h_i(t)\,dt.$$

Inserting this into (5) we have

$$\langle I(t)\rangle = \sum_{i=1}^{n} n_i \int_{-\infty}^{\infty}\overline{W}_i[V(t)]h_i(t)\,dt + \bar{I}^{(0)}. \tag{6}$$

In this manner the equivalent level L_{eq} is a function of the form

$$L_{eq} = 10\log\frac{1}{I_0}\Big[\sum_{i=1}^{n} n_i a_i + \bar{I}^{(0)}\Big], \tag{7}$$

where

$$a_i = \int_{-\infty}^{\infty} I_i(t)\,dt = \int_{-\infty}^{\infty}\overline{W}_i[V(t)]h_i(t)\,dt, \tag{8}$$

in which $I_i(t)$ denotes the intensity change of a sound (with time) during the passage of a single vehicle belonging to class i (Fig. 2), $\bar{I}^{(0)}$ is the average intensity of the background, while n_i is the number of vehicles of class i passing near the point A in unit time (e.g. in hours). In other words, this is the traffic flow of vehicles of class i.

The average intensity of the background can be measured or calculated with the aid of the so-called *homogeneous model* for an ideal city [26, 28].

In many cases in the proximity of motorways or in high traffic flow, the magnitude $\bar{I}^{(0)}$ can be neglected. Formula (7) then permits prediction of the value of L_{eq} at any point of observation, since we know:

(a) the signal $L_i(t)$ at this point, caused by the movement of a single source of class i (Fig. 2) and

(b) the number of sources n_i of class i passing the observation point in unit time.

The already existing urban situations causes that the measurement of $L_i(t)$ can only be done at night when the sum amount of traffic permits the recording of a signal coming (without doubt) from a single source of a determined class. Model investigations are thus much more convenient.

If the point A (Fig. 1) is located in a one-way street and there are three possible travel routes along which lorries or passenger cars can move at equal speeds, then we can record six various signals coming from six different sources, as shown in Fig. 2. According to the previous definition of the source class, we have in this case $k = 1, 2, 3$ – three different travelling times, $j = 1, 2$ – two types of vehicles, $l = 1$ – the travelling speed – is the same for all vehicles, and it can be seen that the number of sources $n = 6$.

An advantage of the method proposed, which is expressed by relation (7), is the possibility of determining the equivalent level L_{eq} (for an acoustic field generated by any number of moving sources) on the basis of the sound intensity level $L_i(t)$ (Fig. 2) of a single source and traffic flows – n_i.

3. Method for the calculating L_{eq} close to the motorway

The problem of propagation of the noise, generated by vehicles moving along a motorway, is much simpler than that connected with the noise propagation in urban situation, for the simple reason that the only reflecting plane is the earth's surface. This permits of a theoretical determination of the sound intensity $I_i(t)$, and thus the magnitude a_i in formula (7). In this case it is necessary to determine experimentally the average sound powers of vehicles of various types $\overline{W}_j$, and also the magnitude of ϱ (formula (3)), which describes the sound attenuation in open spaces. For many types of vehicles the magnitude $\overline{W}_j$ and values of the exponent ϱ can be found in the literature.

The problem of calculation of L_{eq} and of the mean sound intensity $\langle I \rangle$ in the proximity of motorways has engaged many authors, including, ANDERSON, GORDON, JOHNSON and SAUNDERS, KURZE, LJUNGGREN, MARCUS, RATHE, SCHREIBER. The results of this paper are in some cases more general than the results of these authors.

Let the point A, at which L_{eq} is calculated, be located as shown in Fig. 3. The presence of woods or of compact building developments, lining an area, determines the fact that during the passage of a vehicle belonging to class i, the noise reaches the point A only in a time ϑ_i. Formally, it means that $\overline{W}_i = 0$ outside this time interval. If the point A is in entirely free space, then one should accept $\vartheta_i = \infty$.

The motorway is a road on which the traffic moves at constant speeds, except for such cases as, for instance, a change of traffic lane. This permits of the rewriting of expression (8) in the form

$$a_i = \overline{W}_i[V] \int_{-1/2\vartheta_i}^{1/2\vartheta_i} h_i(t)\,dt,$$

since the sound power $W_i[V]$, being a function of speed, is thus independent of time.

If we also assume that we have n_1 traffic lanes and n_2 types of vehicles: lorries, passenger cars etc., then the number of vehicle classes is given by $n = n_1 \times n_2$, since a vehicle of any type can move along any traffic lane, maintaining only the speed and travelling direction. Taking this all into consideration we obtain from (6)

$$\langle I(t) \rangle = \sum_{i=1}^{n_1 n_2} n_i \overline{W}_i[V] \int_{-1/2\vartheta_i}^{1/2\vartheta_i} h_i(\tau)\,d\tau + \bar{I}^{(0)}.$$

If we also denote by n_{jk} the traffic flow of vehicles of type j on traffic lane k, and by $W_j(V_k)$ the sound power of the vehicle of type j moving at a speed V_k (thus moving along the traffic lane k), then

$$\langle I(t) \rangle = \sum_{k=1}^{n_1} \int_{-1/2\vartheta_k}^{1/2\vartheta_k} h_k(\tau)\,d\tau \sum_{j=1}^{n_2} n_{jk} \overline{W}_j(V_k) + \bar{I}^{(0)}. \tag{9}$$

The integral $\int_{-1/2\vartheta_k}^{1/2\vartheta_k} h_k(\tau)\,d\tau$ will be calculated for two cases:

(a) the smallest distance of the point A from the axis of the motorway is considerably higher than the width of the motorway: $D \ll d$ (Fig. 3). It is then possible to assume that the travel routes of all vehicles are the same ($k = 1$) and are described by the curve $y(x)$;

(b) the smallest distance of the point A from the motorway is comparable with its width ($d \approx D$), for example when the point A is located on the shoulder of the motorway. In this case it can be assumed that the length of the motorway on which the vehicles, that contribute essentially to the resultant noise intensity, are moving is a straight line.

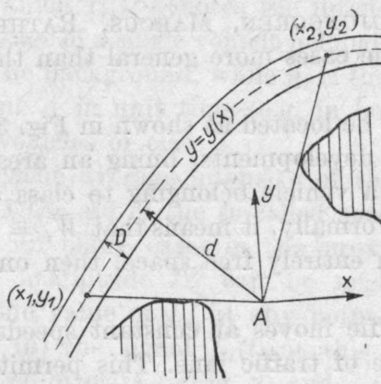

Fig. 3. The highway course $- y(x)$ for the outlying point A.

In this case, in contradistinction to case (a), it is necessary to distinguish the traffic lanes.

By comparing relations (3) and (3a) we get

$$h_k(t) = \frac{1}{[r(t)]^{\varrho}}, \quad \varrho > 2.$$

If the vehicle is moving at a speed V_k, then by virtue of formula

$$ds = \sqrt{1+[y'(x)]^2}\, dx = V_k\, dt$$

and on the basis of Fig. 3, we obtain for case (a)

$$\int\limits_{-1/2\vartheta_k}^{1/2\vartheta_k} h_k(t)\, dt = \frac{1}{V_k}\int \frac{ds}{[r(x,y)]^{\varrho}} = \frac{1}{V_k}\int\limits_{x_1}^{x_2} \frac{\sqrt{1+[y'(x)]^2}}{[x^2+y^2(x)]^{1/2\varrho}}\, dx. \tag{10}$$

By substituting in (9), we obtain the formula for average sound intensity at point A located far from the motorway,

$$\langle I(t)\rangle = \int\limits_{x_1}^{x_2} \frac{\sqrt{1+[y'(x)]^2}}{[x^2+y^2(x)]^{1/2\varrho}}\, dx \sum_{k=1}^{n_1}\sum_{j=1}^{n_2} n_{jk}\frac{\overline{W}_j(V_k)}{V_k} + \bar{I}^{(0)}, \tag{11}$$

and

$$L_{eq} = 10\log\frac{1}{I_0}\langle I(t)\rangle,$$

where $y(x)$ denotes a curve describing the course of the motorway, x_1, x_2 are the abscissae of points (Fig. 3) that limit the length of the motorway from which the noise reaches the point A, n_{jk} is the traffic flow of vehicles of type j moving along traffic lane k, $\overline{W}_j(V_k)$ — the sound power of a type j vehicle moving at a speed V_k, $\bar{I}^{(0)}$ — the average background intensity, n_1 — the number of traffic lanes, and n_2 — the number of vehicle types.

For case (b) it can be seen from Fig. 4 that equation (10) takes the following form:

$$\int_{-1/2\vartheta_k}^{1/2\vartheta_k} h_k(t)\,dt = \frac{1}{V_k}\int \frac{ds}{[r(x,\,y)]^{\varrho}} = \frac{1}{V_k}\int_{x_1}^{x_2} \frac{dx}{[x^2+d_k^2]^{1/2\varrho}}.$$

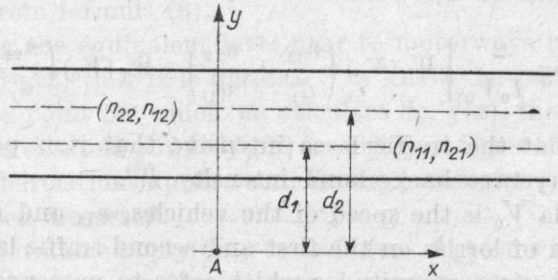

Fig. 4. Two-sided way with the given traffic intensity — n_{jk}

Since we assumed that the point A is located very near to the motorway we can accept that $x_{1/2}\to\pm\infty$. For $\varrho > 2$ (this condition is always satisfied) we obtain

$$\int_{-1/2\vartheta_k}^{1/2\vartheta_k} h_k(t)\,dt \int_{-\infty}^{\infty} \frac{dx}{[x^2+d_k^2]^{1/2\varrho}} = \sqrt{\pi}\,\frac{\Gamma(\frac{1}{2}\varrho-\frac{1}{2})}{\Gamma(\frac{1}{2}\varrho)}\,\frac{1}{d_k^{\varrho-1}},$$

where $\Gamma(x)$ denotes the Euler function.

Substituting the expression obtained into formula (9), we obtain for the average sound intensity at a point A near to the motorway the expressions

$$\langle I(t)\rangle = \sqrt{\pi}\,\frac{\Gamma(\frac{1}{2}\varrho-\frac{1}{2})}{\Gamma(\frac{1}{2}\varrho)} \sum_{k=1}^{n_1} \frac{1}{d_k^{\varrho-1}} \sum_{j=1}^{n_2} n_{jk}\frac{\overline{W}_j(V_k)}{V_k} + \bar{I}^{(0)} \qquad (12)$$

and

$$L_{eq} = 10\log\frac{1}{I_0}\langle I\rangle,$$

where d_k denotes the distance of the traffic lane k from the point A, and n_{jk} the traffic flow of vehicles of type j moving along traffic lane k.

The other quantities are the same as in formula (11) describing $\langle I(t)\rangle$ at a point located far from the motorway. The magnitude ϱ, which determines the magnitude of sound attenuation (3), occurs in formulae (11) and (12).

As an example, let us consider a two-lane motorway ($n_1 = 2$) along which two types of vehicles — lorries and passenger cars ($n_2 = 2$) — are moving at a constant speed V_0 in both directions. We wish to determine the equivalent level near to the motorway in case (b) (Fig. 4).

If atmospheric and terrain conditions are such that we can take $\varrho = 3$, then

$$\frac{\Gamma(\frac{1}{2}\varrho-\frac{1}{2})}{\Gamma(\frac{1}{2}\varrho)} = \frac{2}{\sqrt{\pi}}.$$

Substituting into formula (12), we obtain the following expression for the equivalent level near to this road:

$$L_{eq} = 10\log\frac{2}{I_0 V_0}\left[\overline{W}_1(V_0)\left(\frac{n_{11}}{d_1^2}+\frac{n_{12}}{d_2^2}\right)+\overline{W}_2(V_0)\left(\frac{n_{21}}{d_1^2}+\frac{n_{22}}{d_2^2}\right)\right].$$

We assume that the traffic is so intensive that it is possible to neglect the value of the average background intensity $\bar{I}^{(0)}$.

In this formula V_0 is the speed of the vehicles, n_{11} and n_{12} denote the intensity of a stream of lorries on the first and second traffic lanes, respectively, n_{21} and n_{22} are the same magnitudes which refer to passenger cars, d_1 and d_2 are the distances of the traffic lanes from point A, $\overline{W}_1$ and $\overline{W}_2$ are the sound powers of a typical lorry and passenger car, respectively, and I_0 is a reference intensity.

4. Conclusions

The method presented permits of the calculation of the equivalent level L_{eq} of noise generated by means transportation systems in urban situations (formula (7) and Fig. 1), and in open space: near to (formula (12) and Fig. 4) and far from the motorway (formula (11) and Fig. 3).

The method of calculating L_{eq} for the first case is given by formula (7) which requires the knowledge of the traffic flow of vehicles of each class n_i (the notion of the class has been previously given), the intensity level of sound generated by passing typical vehicles of each class $L_i(t)$, and of the average background intensity $\bar{I}^{(0)}$, which can be neglected in the case of intensive traffic.

The measurement of $L_i(t)$ can be done only at night when traffic is small and it is possible to record the noise generated by a single vehicle. In order to describe the proposed method more precisely let us return to the example previously discussed (Fig. 1).

Neglecting the acoustic background and having available six records of the intensity level of sound $L_i(t)$ dB(A) related to the passage of single vehicles of particular classes (remembering that lorries and passenger cars may move on any lane (Fig. 1)), and taking relation (8) we obtain constants $a_1, \ldots, a_6$. Formula (7) then takes the form

$$L_{eq} = 10\log\frac{1}{I_0}(n_1 a_1 + n_2 a_2 + \ldots + n_6 a_6).$$

By this relation we can predict the equivalent level L_{eq} at a point A (Fig. 1) for any values $n_1, n_2, \ldots, n_6$ describing the traffic flow, e.g. for various times of day, various cases of traffic restriction, etc. To this extent formula (7) is of universal application.

In any case, we have to obtain only a few records of the intensity level of sound $L_i(t)$ dB(A) for particular classes of vehicles in order to determine the values of a_i from formula (8).

In calculating the equivalent level near to motorways it can be seen from formulae (11) and (12) that it is necessary to know the parameters describing the location of the point for which we calculate d_k, $y(x)$, the traffic parameters n_{jk}, and the values of sound power $W_j(V)$ for different types of vehicles depending on their speed. The relationship also contain the parameter ϱ, whose significance has previously been discussed.

The derived formulae apply only to flat areas. It seems advisable to extend theoretical works to give consideration to a great many parameters of the environment which are essential from the viewpoint of acoustics, such as e.g. the configuration of the terrain.

Acknowledgment. The author is very grateful to prof. dr H. RYFFERT for discussion and keen remarks.

References

[1] G. ANDERSON, *The transportation system center (TSC) traffic noise prediction mod as an experimental tool*, Proc. 8th ICA, London 1974.

[2] D. AUBREE, *Étude de la gene duo au trafic automobil urbain*, C. S. T. B., Paris 1971.

[3] D. BISHOP, M. SIMPSON, *Correlation between different community noise measures*, Noise Control Engineering, **1**, 2, 74-78 (1973).

[4] D. FISK, *The problem of traffic noise*, Royal Society of Health Journal, **93**, 6 (1973).

[5] H. GIERKE, *Draft report on impact characterization of noise including implications of identifying and achieving levels cumulative noise exposure*, EPA Aircraft/Airport noise report study, 1973.

[6] C. GORDON, *Highway noise – a design guide for highway engineers*, NCHRP Report 117, 1971.

[7] I. GRIFFITHS, F. LANGDON, *Subjective response to road traffic noise*, J. Sound Vibr., **8**, 1 (1968).

[8] D. JOHNSON, E. SAUNDERS, *The evaluation of noise from freely flowing road traffic*, J. Sound Vibr., **7**, 287-309 (1971).

[9] U. KURZE, *Statistics of road traffic noise*, J. Sound Vibr., **18**, 171-195 (1971).

[10] H. KUTTRUFF, *Ausbreitung von Pegelschwankungen bei Verkehrslärm*, Proc. 8th ICA, London 1974.

[11] A. LAWRANCE, *Stop-start traffic noise*, Proc. 8th ICA, London 1974.

[12] T. LINDQUIST, *Street traffic noise and sound absorbing facade*, Proc. 8th ICA, London 1974.

[13] S. LJUNGGREN, *A design guide for road traffic noise*, National Swedish Building Research, D 10, 1973.

[14] K. Lee, H. Davies, R. Lyon, *Prediction of propagation in a network of sound channels with application to noise transmission in city streets*, Acoustic and Vibration Laboratory, MTI, 1974.

[15] R. Lyon, *Sound propagation in city streets*, Acoustic and Vibration Laboratory, MTI, 1974.

[16] J. Malchaire, *Urban noise model*, JASA, **56**, 6, 1811-1814 (1974).

[17] A. Marcus, *Theoretical prediction of highway noise fluctuation*, JASA, **56**, 1, 132-136 (1974).

[18] N. Olson, *Survey of motor vehicle noise*, JASA, **52**, 1291-1306 (1972).

[19] E. Rathe, *Über den Lärm des Strassenverkehrs*, Acustica, **17**, 268-277 (1966).

[20] E. Rathe, J. Munheim, *Evaluation methods for total noise exposure*, J. Sound Vibr., **7** (1968).

[21] D. Robinson, *The concept of noise pollution level*, NPL Aer. Report AC 38, Nat. Phys. Lab., London 1969.

[22] J. Sadowski, *Acoustics in town planning, architecture and building*, Arkady, Warszawa 1971 [in Polish].

[23] J. Sadowski, B. Szudrowicz, *Final report on the subject PA-05-202-2, FA-50. The influence of materials and constructions on the acoustical climate of flats and its influence on the health of inhabitants*, Inst. Tech. Bud., Warszawa 1975 [in Polish].

[24] W. Scholes, J. Sargent, *Designing against noise from road traffic*, Appl. Acoustics, **4**, 3 (1971).

[25] L. Schreiber, *Zur Berechnung des energiequivalenten Dauerschallpegels der Verkehrsgeräusche von einer Strasse*, Acustica, **21**, 121-123 (1969).

[26] E. Shaw, N. Olson, *Theory of steady-state urban noise for ideal homogeneous city*, JASA, **51**, 1781-1793 (1972).

[27] Anon, *States Institut for Byggnasforsking*, Trafikbuller 1, Bosladsomraden, Rapport 36-38, Stockholm 1969.

[28] G. Thiessen, *In community noise levels in transportation*, Ed. Chalupnik J. D., University of Washington Press, 1970.

[29] G. Weiss, *On the noise generated by a stream of vehicles*, Transport Research, **4**, 229-233 (1970).

Received on 28th November 1975;
in revised form on 22nd September 1976