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An Urban Noise Survey in Sapporo, Japan

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Abstract

The city noise status was studied in Sapporo, the capital of Hokkaido, Japan, which had a population of 1.2 million as of May 1975 and an area of 1,118 km^2, at 184 measuring points determined geometrically by the sector-belt division method.

(1) High noise levels were observed inside Kanjoh-dori Avenue, which was constructed as a beltline to relieve traffic congestion, and high noise levels were also clustered around the main roads spreading outwards radially.

(2) The city noise levels decreased in proportion to the distance from the center of the city.

(3) The city noise levels studied according to zoned areas were especially high in the commercial and industrial areas.

(4) Since the noise levels of the civic center area measured by the sector-belt division method were numerically almost equal to those by the grid-square division method, the sampling of noise by the sector-belt division seems to be useful, especially when a city has developed radially from a certain civic center area.

(5) There were significantly high correlations between the city noise levels (L_x and Leq) and the traffic flows (W.N.V.); hence, it is suggested that the noise levels in Sapporo are greatly influenced by the traffic flows. Since there is the possibility of overestimating the noise levels when using the Leq values in the suburban areas, it seems reasonable that the use of the L_{50} values in combination with the Leq values is necessary to evaluate the noise levels in those areas.

Key Words: Urban noise, L_x, Leq.

1. Introduction

Sapporo is the capital of Hokkaido, Japan, and it had a population of approximately 1.2 million (as of May 1. 1975), with an area of 1,118 km^2. Since this city is a center of not only political and commercial activities but also of the transportation of people and commodities in Hokkaido, the nuisance of city noise is a considerable social problem, just as in well as other big cities (Sapporo city, 1975–1978). Although several noise surveys of Sapporo have been reported (Sapporo city 1975–1978, Sasaki et al., 1981), most of them were performed only along the main roads or by using grid square division of the city. Since this city has a rather large area and it has spread radially since the beginning of its development (Ohta et al., 1966 a, Ohta et al., 1966 b, Ohta et al., 1975, Ohta et al., 1976), the noise surveys along the main roads only were not able to give a clear picture of the noise conditions in the entire city, and studies using the grid square division require too much equipment and would take too much time to measure noise levels in the whole city. In order to perform such a survey more efficiently and economically, there is another way to divide the city; namely the sector-belt division. In another research project on air pollution caused by heavy metals, studied by their concentrations in the snow falls in Sapporo, we have effectively demonstrated the actual status of air pollution by sampling according to such a sector-belt division (Saito et al., 1981).

Noise levels have been expressed by using several predictors such as L_5, L_{10}, L_{50}, L_{90}, L_{95} and Leq, which have been adopted in most countries for the evaluation of city noise levels (Acoustic Society of Japan, 1981). In Japan the noise predictor was altered from L_{50} to the combination of L_{50} and Leq in 1983 (Igarashi).

The purpose of this report is to describe the pattern of city noise levels by using this sector-belt division of almost all the area of the city of Sapporo to study the relationships between city noise and traffic flow, and to discuss the noise predictors, mainly L_{50} and Leq.

2. Experimental design

(1) *Noise-measuring points*

Measuring points of city noise in the present investigation were determined as the intersections where 24 equally spaced radial lines and 8 concentric circular division lines were drawn from a center point. Sapporo station of the Japanese National Railways was determined as the center point. The radii of these 8 circles were determined by 1 km steps from 1 to 8 km. The measurements of noise levels and traffic flows were made along the radial lines from the center point to the outer circles at distances of 1, 2, 3, 4, 5, 6, 7 and 8 km and at 20 minute interval. One hundred and ninety three points were geometrically determined and, in practice, noise levels were measured at 184 points. Most of the densely inhabited districts of Sapporo, having a population density of more than 40 persons per hectare were covered by the circle with a radius of 8 km. In order to observe the temporal coincidence of samplings of parameters as strictly as possible, the measurements for all directions were determined at equal distances from Sapporo station.

The noise levels of the civic center area were also measured by the grid square division method (Makizuka et al., 1983).

(2) *Survey of noise and traffic flow*

Noise levels were measured according to the standard of JIS Z 8731-1966, and the percentile sound levels of L_5, L_{10}, L_{50}, L_{90}, L_{95} and energy equivalent sound levels (Leq) were calculated for 5 minute periods. At the same time, the traffic flow was also counted in order to investigate the relationship between noise levels and traffic flow rates. In practice, the traffic flows were expressed using the unit Weighted Number of Vehicles per 5 minutes (abbr W. N. V.) which was calculated according to the following equation ;

$$\text{W. N. V.} = 3.2 \times A_1 + A_2 + 16 \times A_3$$

where A_1, A_2 and A_3 were the numbers of vehicles passing in 5 minutes.

A_1 : light vehicles··············minicars and trucks (<500 cc) and motorcycles.

A_2 : intermediate vehicles·····passenger cars and station wagon types.

A_3 : heavy vehicles··············trucks and buses.

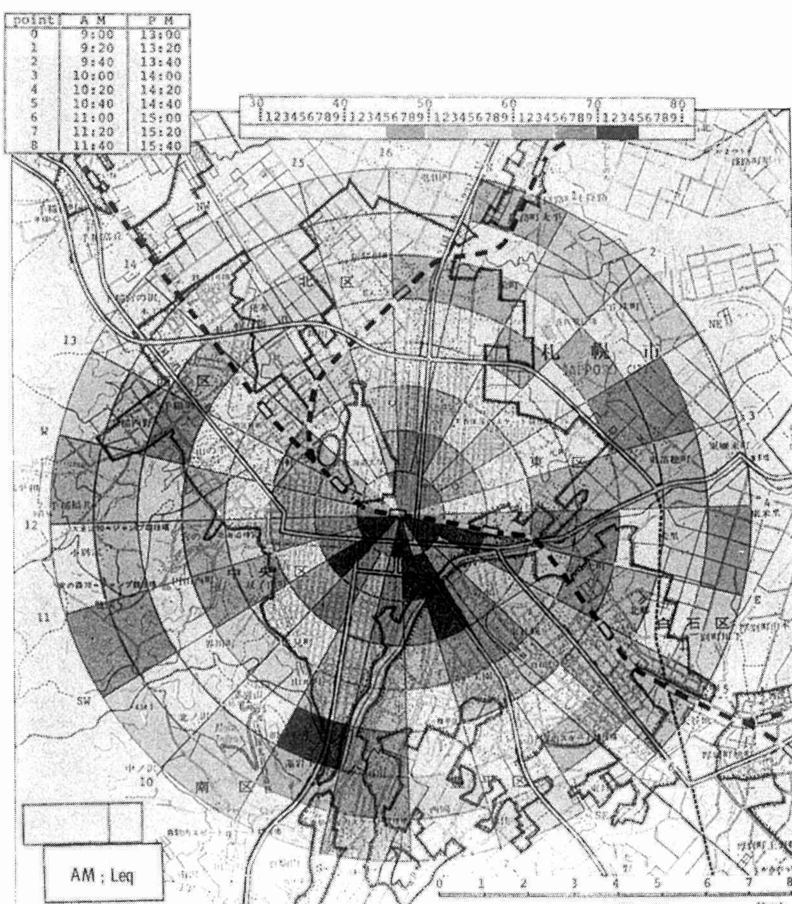

Figure 1. Noise Levels in Sapporo in Leq.

This survey was performed from Oct. 1977 to Oct. 1979. Noise and traffic flow were measured repeatedly every Thursday in October beginning at 9 A.M. and 1 P.M. because traffic flows and noise levels were considered to be almost constant through those periods on that day.

Considering the time required for measurements, 9 measuring points at interval of 1 km were selected for each direction.

Each research group, which consisted of three or four members, started at 9 A.M. and 1 P.M. from the center and moved 1 km toward the urban fringe at 20 minute interval.

(3) *Instruments for the survey*

Instruments used for this noise survey were : three sound level meters (RION NA-09, Kokubunji, Japan) with digital units (RION DA-01), and a sound level meter (JEIC 1015, Tokyo, Japan) with a digital unit (JEIC 4303).

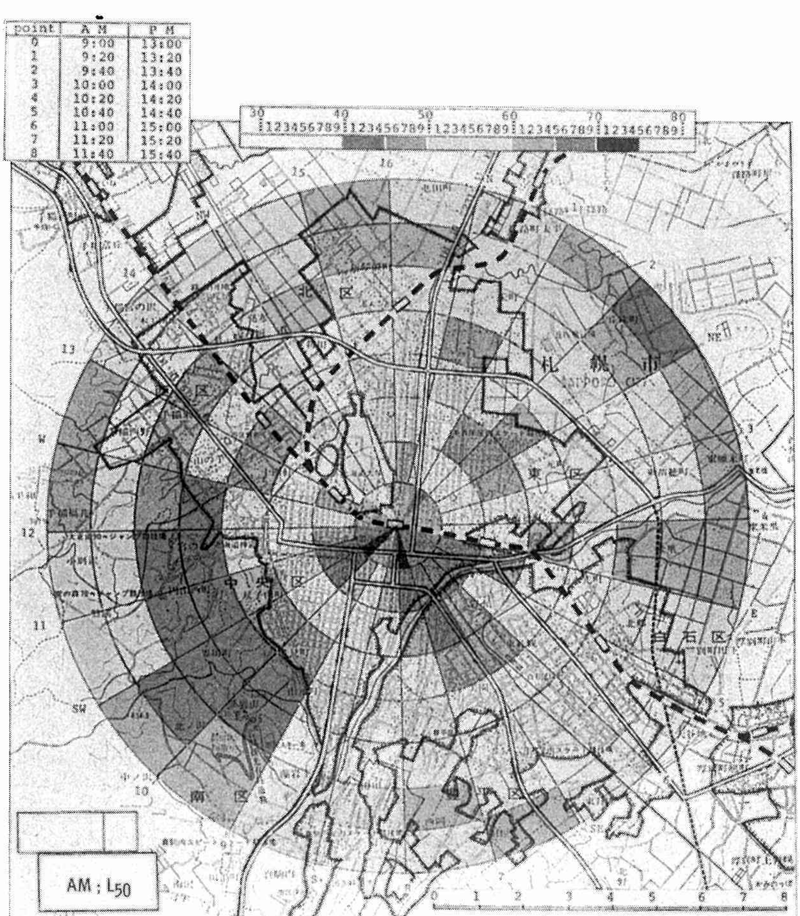

Figure 2. Noise Levels in Sapporo in L_{50}.

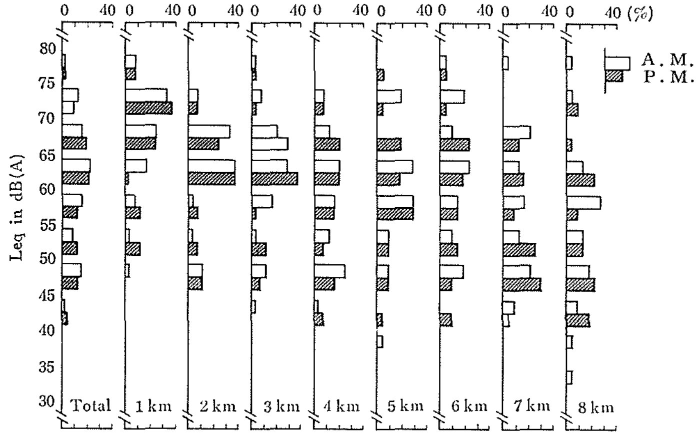

Figure 3(a). Histograms of City Noise Levels in Sapporo in Leq.

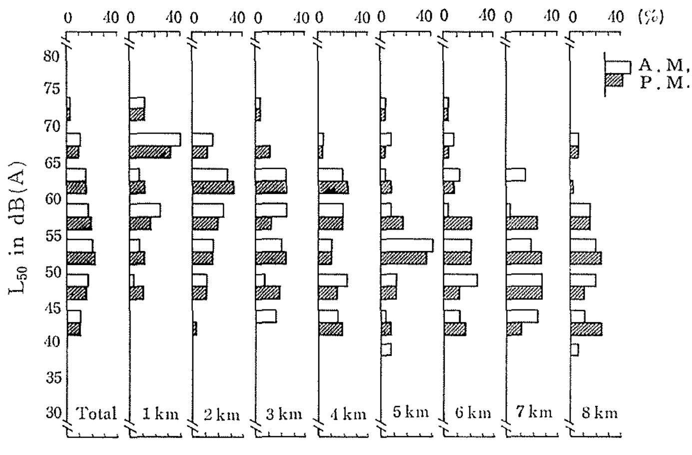

Figure 3(b). Histograms of City Noise Levels in Sapporo in L_{50}.

Table 1. Noise Levels According to the Zoned Areas

Zoned areas	Mean Noise Levels in L_{50}	Mean Noise Levels in Leq
Residential area (n = 44)	49.5±7.2	56.4±8.8
Residential and commercial area (n = 158)	54.0±7.6	59.6±8.8
Commercial area (n = 106)	60.1±7.5	64.7±7.2
Industrial area (n = 4)	59.0±6.3	62.1±5.7
Unzoned area (n = 54)	48.5±6.6	53.4±9.1

n: Number of measurements.

Table 2. Weighted Number of Vehicles Calculated with W.N.V. $= 3.2 \cdot A_1 + A_2 + 16 \cdot A_3$

A_1: Number of Light Vehicles/5 min. A_2: Number of Middle Vehicles/5 min.

A_3: Number of Heavy Vehicles/5 min.

Each number of vehicles was measured for 5 minutes which was the same duration as the measurement of city noise levels in Sapporo. Weighted number of vehicles at 0 km (at Sapporo station) was 476.0 in A.M. and 303.0 in P.M., and were the mean of 6 measurements

Direction	1 km		2 km		3 km		4 km		5 km		6 km		7 km		8 km	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
N	7.4	0	107.6	94.0	7.4	13.6	3.2	0	41.6	19.0	9.6	0	84.6	81.2	239.6	350.8
1	412.3	240.0	22.3	59.3	19.9	11.3	20.9	22.3	5.0	40.8	25.9	26.4	13.7	53.3	19.0	41.5
2	78.8	94.8	0	0	3.2	3.2	7.4	0	9.4	9.4	—	—	—	—	0	0
NE	32.0	49.6	17.0	15.6	6.4	4.2	0	0	0	3.2	8.4	3.2	3.2	0	4.2	3.2
3	12.5	54.8	0	1.0	5.0	13.8	0	0	21.4	36.6	307.2	152.2	3.8	0	—	—
4	109.4	51.6	1.0	0	84.4	55.8	407.4	333.6	480.8	406.0	226.0	114.8	196.8	196.8	—	—
E	33.8	33.8	174.6	191.6	9.2	6.2	170.6	76.6	8.4	3.0	—	—	—	—	—	—
5	281.8	349.8	38.0	40.4	0	1.0	9.0	8.4	48.4	53.6	268.4	136.2	9.4	11.6	—	—
6	531.4	631.6	748.6	502.4	33.8	39.2	193.4	104.6	5.2	5.0	8.4	8.2	6.4	3.2	119.4	215.4
SE	217.2	175.0	91.2	62.6	407.0	516.2	47.4	39.6	13.2	20.6	16.0	26.4	20.0	21.8	0	1.0
7	198.8	218.6	209.6	224.2	168.4	232.4	36.2	67.4	3.0	18.2	0	0	0	0	—	—
8	369.8	427.0	13.4	14.4	179.0	195.4	0	4.2	355.0	193.2	9.6	3.0	37.8	45.4	532.4	458.8
S	116.2	168.8	32.6	15.4	146.4	138.6	111.4	205.4	182.6	177.4	161.2	101.6	15.6	14.4	1.0	0
9	10.2	14.2	30.4	11.4	82.2	85.6	4.2	1.0	—	—	—	—	—	—	6.4	6.2
10	169.8	214.2	110.2	124.2	42.2	26.0	1.0	1.0	—	—	—	—	7.4	4.2	1.0	4.2
SW	734.2	688.8	180.8	139.4	1.0	4.2	46.4	21.8	—	—	—	—	—	—	—	—
11	858.4	377.6	8.2	11.2	0	1.0	—	—	1.0	1.0	42.2	25.4	41.8	75.8	—	—
12	390.6	441.4	221.8	206.2	228.2	251.0	0	0	3.2	1.0	—	—	0	0	4.0	17.0
W	8.4	1.0	29.6	35.0	8.4	2.0	0	4.2	3.0	1.0	300.4	292.0	0	3.2	—	—
13	255.2	296.6	122.2	70.6	40.4	36.0	18.8	15.4	593.4	716.6	36.4	26.0	—	—	—	—
14	0	6.4	93.8	154.0	0	3.2	0	0	23.0	19.0	42.4	11.6	0	0	—	—
NW	54.6	57.0	1.0	3.2	42.6	46.8	8.4	3.2	0	1.0	0	6.4	60.6	21.2	3.2	6.4
15	60.4	25.8	—	—	—	—	25.4	29.2	17.0	10.4	0	1.0	40.2	8.4	259.0	277.4
16	266.4	321.4	6.2	21.2	0	6.4	42.6	29.8	0	0	59.4	45.2	4.2	1.0	51.6	142.2

—: Unmeasurable point.

3. Results

The noise value of each site was obtained by the mean of 2 or 4 determinations. The distribution of city noise levels in Sapporo is shown in Figure 1 (in Leq dB(A)) and Figure 2 (in L_{50} dB(A)). Figures 1 and 2 clearly show the distribution pattern of city noise levels in Sapporo. High noise levels were concentrated inside Kanjoh-dori Avenue, which was constructed as a beltline avenue to relieve traffic congestion, especially around Sapporo station and along the main roads Route 5 and Route 36. Noise levels decreased in proportion to the distance from the station to the suburban areas. The noise levels in the morning and in the afternoon were approximately equal. The values in Leq were higher than those in L_{50}, as is generally accepted. In the south-western suburban area around Mt. Moiwa, the Leq values were markedly higher than L_{50} values (Figure 1).

Figure 3 shows the city noise levels in histograms. This figure shows more clearly the decrease of noise levels in proportion to the distance from Sapporo station to suburban areas. The most frequent noise levels at the 1 km points were between 65 and 75 dB(A) in Leq and between 65 and 70 dB(A) in L_{50}. And at the 2 km points, they were between 60 and 70 dB(A) in Leq and 60 and 65 dB(A)

Table 3. Equations of Regression Lines of Noise Levels for Traffic Flow Rates and Correlation Coefficients in the Morning and in the Afternoon

measuring time	content	equation	correlation coefficient
A. M. (n=122)	L_{95}	$Y=40.71+6.76 \log X$	r=.701 (p<.001)
	L_{90}	$Y=41.13+7.71 \log X$	r=.736 (p<.001)
	L_{50}	$Y=43.44+8.98 \log X$	r=.818 (p<.001)
	L_{10}	$Y=51.88+8.83 \log X$	r=.828 (p<.001)
	L_{5}	$Y=55.26+8.48 \log X$	r=.800 (p<.001)
	Leq	$Y=52.01+7.63 \log X$	r=.796 (p<.001)
P. M. (n=129)	L_{95}	$Y=42.12+5.91 \log X$	r=.684 (p<.001)
	L_{90}	$Y=42.41+6.33 \log X$	r=.715 (p<.001)
	L_{50}	$Y=44.44+8.42 \log X$	r=.820 (p<.001)
	L_{10}	$Y=51.18+9.13 \log X$	r=.855 (p<.001)
	L_{5}	$Y=53.88+9.06 \log X$	r=.845 (p<.001)
	Leq	$Y=50.30+8.34 \log X$	r=.832 (p<.001)
Total (n=251)	L_{95}	$Y=41.50+6.29 \log X$	r=.692 (p<.001)
	L_{90}	$Y=41.85+6.71 \log X$	r=.725 (p<.001)
	L_{50}	$Y=44.00+8.67 \log X$	r=.819 (p<.001)
	L_{10}	$Y=51.48+9.00 \log X$	r=.843 (p<.001)
	L_{5}	$Y=54.47+8.82 \log X$	r=.826 (p<.001)
	Leq	$Y=51.03+8.04 \log X$	r=.817 (p<.001)

"X" indicates the weighted number of vehicles.

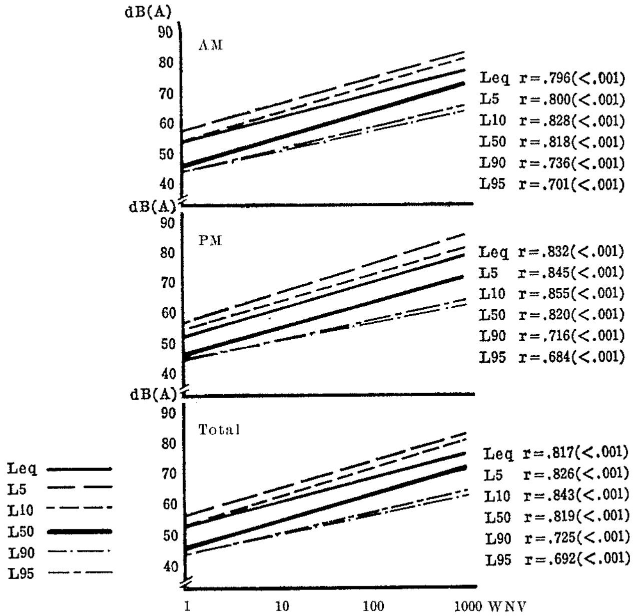

Figure 4. Correlations between Noise Levels (L_x and Leq) and Weighted Number of Vehicles.

in L_{50}.

Table 1 shows the noise levels according to zoned areas. The high noise-level areas were commercial areas (mean level was 64.7 dB (A) in Leq, and 60.1 dB(A) in L_{50}, n=106) and industrial areas (mean level was 62.1 dB (A) in Leq, and 59.0 dB(A) in L_{50}, n=4). In the combined residential and commercial areas, mean noise levels were 59.6 dB (A) in Leq and 54.0 dB (A) in L_{50} (n=158).

Traffic flows in W. N. V. are shown in Table 2 and the interrelationships between noise levels and traffic flows (W. N. V.) are shown in Table 3 and Figure 4. These correlation coefficients were significantly high (0.684–0.855) ($p<0.001$). There were no apparent differences in regression lines between the morning and the afternoon (Table 3). The regression coefficients of lower percentile sound levels (L_5 and L_{10}) were greater than those of higher percentile sound levels (L_{90} and L_{95}). In the regression line, the regression coefficient of L_{50} was quite similar to that of the lower L_x but the Y-intercept was approximately equal to that of the higher L_x. Both the regression coefficient and the Y-intercept of Leq were almost equal to those of the lower L_x.

4. Discussion

(1) *Determination of the center points*

Sapporo is a planned city which has developed from the present civic center area to the outer portions. From the socio-economical point of view, the city activity of the area enclosed by Kanjoh-dori Avenue, which was constructed as a beltline avenue with a radius of 2 or 3 km from the civic center, has almost arrived at the maturity stage. From this area, the city has been developing toward the urban fringe along 6 main roads (Ohta et al., 1966 a ; Ohta et al., 1966 b ; Ohta et al., 1975 ; Ohta et al., 1976).

In the present investigation, we located the center point at on Sapporo station for the following four reasons. The first is that the center point should exist permanently. The second is that the center point must be located on the northern side of the civic center, because the northern area of the Hakodate trunk line of the Japanese National Railways has much space to develop compared with the southern and southwestern areas of this trunk line where, geographically, Mt. Moiwa and Hiragishi hill are located and there is little space to expand. The third is that it must be easy for the researchers to move to perform the present investigation. The fourth is that this method should be applicable to other cities which have been developing in concentric zones from the station area.

As shown in the figures, the distribution patterns of the city noise levels were clearly and inclusivily demonstrated (Figure 1 and Figure 2). In the case of cities with a concentric zone type structure like this city, noise measurement by the sector-belt division method seems to be more effective and economic than that by the grid square division method, though urban noise has been generally studied using the grid square division method.

(2) *L_{50} and Leq*

As is generally known, in the analysis of intermittent noise by the digital sampling method, the values of L_{50} and Leq are influenced by the sampling interval (Igarashi et al., 1983 ; Ohta and Yamaguchi, 1975 ; Ikegaya, 1975). In the suburban areas where the traffic flows were less than in the urban areas, the Leq values were influenced by the high levels of intermittent noise and this may have resulted in an overestimation of the noise levels there. In the civic center area where the traffic flows were massive, noise levels could be accurately evaluated by the Leq values (Figures 1 and 2).

On the basis of the present observations, these results support that the combination of L_{50} and Leq sould be used as noise predictors.

(3) *Characteristics of regression lines*

The authors have already reported noise levels in small towns (Makizuka et al., 1981). In the regression lines of the noise levels of the traffic flows, there were apparent differences in the regression coefficients between the large city and the small towns. In the small towns, the differences between the values of L_{90} and L_{95} and the values of L_5 and L_{10} were augmented according to the increase in traffic flow rate (W. N. V.). On the other hand, in the large city, these differences were almost constant when traffic flow rate increased. Consequently, the correlation coefficients between the noise levels and the traffic flows were generally small compared to those in the small towns.

(4) *Background noise*

Usually, the background noise level has been approximated by L_{90} and L_{95}

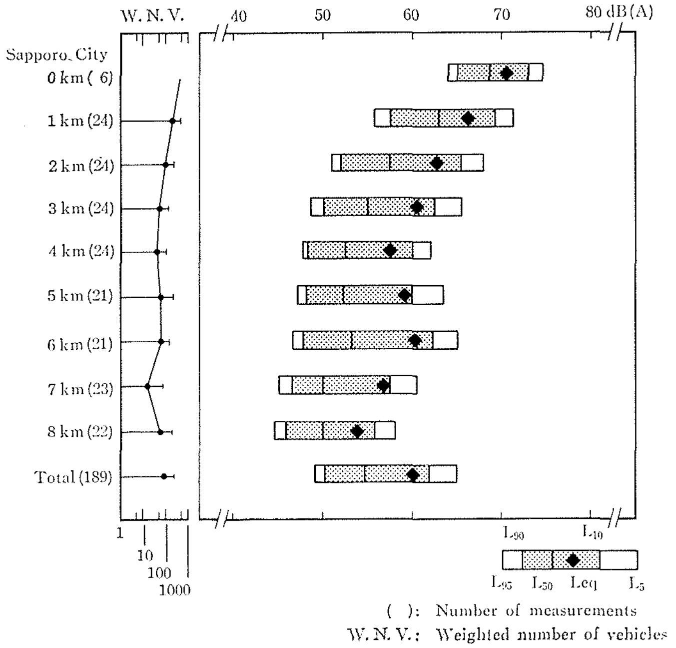

Figure 5. Noise Levels in L_x and Leq measured at 183 Locations on 8 Concentric Circles with Radii of 1 to 8 km and at the Center Point.

(Acoustic society of Japan, 1981). It is well understood that the background noise levels are high in the civic center area where traffic flows massive (>100 W. N. V.) and the density of buildings is high. Although the traffic flows (W. N. V.) in the suburban areas were similar to those in the civic center area, the levels of L_{90} and L_{95} were lower compared with those in the civic center area. These results may suggest that the background noise level was influenced by the traffic flows around the measuring point and the density of buildings. Sapporo has been geographically developing as a concentric zone type city and city activity gradually decreases toward the urban fringe. Each level of L_{90} and L_{95} steadily decreased according to the distance from the station (Figure 5).

Although the regression line of Leq in the civic center area was quite similar to those in the urban fringe and in the suburban areas, the Y-intercept of the regression line of L_{50} was high in the civic center area. This suggested that it was influenced by the increase of background noise.

(5) *L_x and traffic flows*

Traffic flows decreased to the 4 km point from Sapporo station, but thereafter there was no obvious relation (Figure 5). L_5, L_{10}, L_{50} and Leq values were influenced by the traffic flows. On the other hand, L_{90} and L_{95} values were independent and steadily decreased according to the distance, as mentioned above.

In the noise level regression lines for the traffic flows, there were apparent differences between the predictors of L_{90} and L_{95} and those of L_5, L_{10} and Leq.

The former predictors, which, as described previously, indicate the background noise around measuring areas, indicated high levels in the civic center area and low levels in the urban fringe. The three regression lines of the latter predictors nearly corresponded with each other and it is believed that those predictors were mainly influenced by the traffic flows (Namba et al., 1976). These predictors (L_x) seem to be useful for the evaluation of the characteristics of urban noise.

Part of this study was presented at the 39th annual meeting of the Japanese society of public health (Makizuka et al., 1980).

5. Acknowledgments

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