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Application of a Genetic Algorithm as the Selection Technique for Optimal Measures against Road Traffic Noise in City Areas

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Abstract [740] Since the control of noise pollution is implemented as a public work in Japan, it is important to enforce the control measures with the greatest effect and at a minimum investment. The areas affected by noise pollution are numerous, and the countermeasures to be taken against noise are various. It is most important, therefore, to decide which measures should be applied and to which locations in order to decrease the level of noise as much as possible at a constant cost. However, the number of combinations of measures and locations is so huge that it is difficult to find optimal solutions manually. With such a background, the purpose of this study is to present a new selection technique, for the optimal measures against noise pollution in city areas, through a computer simulation. In this paper, the application of a genetic algorithm is proposed which can search for practical optimal solutions, on the basis of the theory of natural selection, without performing all searches. Numerical simulations are performed to verify the validity of the proposed method. This method is worthwhile in its practical use for performing countermeasures against road traffic noise over a widespread area and incorporates a balance between the environment and costs.

1 INTRODUCTION

In Japan, many city areas are formed close to arterial roads. Thus, road traffic noise in residential areas is a very serious type of noise pollution. This research places particular focus on the countermeasures of road structure and traffic flow. For the control of road traffic noise pollution, the measures are enforced at units of a divided roadside, which is regarded as having uniform conditions for noise. However, many more units would be needed in order to enforce the control measures against noise pollution over an entire city area. Moreover, there are various other countermeasures to noise such as making improvements to the road surface and the insertion of noise barriers, *etc.* Therefore, the number of "measure patterns," namely, the combinations of measures and locations, is huge. It would be too difficult a task to try to find the most efficient pattern out of the thousands of possible combinations. On the other hand, it is very important to find and then enforce the control measures that would have the greatest effect and be realized for a minimum investment, because the control of noise pollution is implemented as a public works project. The actual countermeasures chosen for the control of road traffic noise pollution, however, ultimately depend on the experience and/or the intuition of the persons involved with enforcing these countermeasures.

2 TECHNIQUE FOR SELECTING MEASURES AND LOCATIONS

2.1 Kinds of Countermeasures against Noise

In this report, a total of six kinds of countermeasures were assumed. The first four countermeasures were assumed for road structure, namely, (1) Improvements to the road surface, (2) Insertion of low-height noise barriers [1], (3) Insertion of noise barriers [2], and (4) Installation of green belts. The fifth and sixth countermeasures were assumed for traffic flow, namely, (5) Traffic control of heavy vehicles, and (6) Speed regulations. In addition, asphalt pavements and drainage pavements were considered to be two types of road surface improvements, and a unified type and a new type of noise barriers were considered as two kinds of noise barriers. Figure 1 shows a model of the kinds of countermeasures discussed in this report.

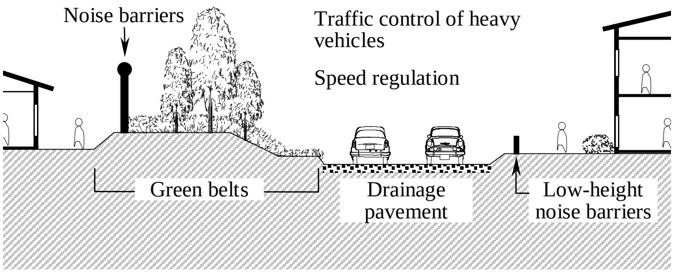

Figure 1: *Example model of the kinds of countermeasures*

2.2 Enforcement Units for the Control Measures against Noise

In this report, two enforcement units for countermeasures against noise were assumed for each type of countermeasure, as follows. One was a “section” which was considered to have a uniform amount of influence from road traffic noise. The other was a “block” which was regarded as having almost the same amount of noise attenuation on condition of buildings around that.

The two units to receive improvements to the road surface and the insertion of low-height noise barriers were set to be enforced by blocks, because they were enforceable in comparatively small areas. The insertion of noise barriers, the installation of green belts, the traffic control of heavy vehicles, and speed regulations were fixed so that the unit was a section, because this group of measures was to be enforced in larger areas.

2.3 Requirements of the Countermeasures against Noise

According to the road conditions, the implementation of the measures currently assumed may be difficult. Thus, enforcement requirements were determined for each measure. And, a measure was not chosen for a unit unless all requirements were satisfied. For example, if noise barriers are inserted in positions where the distance from buildings is not sufficient, there is a possibility for misapplication such as obstructions in sunshine. If green belts do not have a certain amount of depth, the effect of noise attenuation cannot be achieved. Thus, whether or not it is possible to install noise barriers or green belts can be judged by the actual width of the sidewalk. The enforcement requirements were over 6 m for noise barriers and over 10 m for green belts.

The effect of restrictions against heavy vehicles is not sufficient if no heavy vehicles are running. Thus, the enforcement requirements for the amount of attenuation were to be above 2 dB when heavy vehicles were restricted. Therefore, the actual rate of heavy vehicles mixed among others was above 17 %.

2.4 Estimation of the Effect of the Countermeasures

This paper has focused on the selection technique of the optimal countermeasure patterns. The estimation of the effect of the countermeasures was greatly simplified and assumed a fixed amount of noise attenuation for every type of measure. The amounts of each measure assumed in this report are collectively shown as Table 1.

However, the effect of the restrictions against heavy vehicles was considered to be the amount of attenuation in the power level [3] when all heavy vehicles were exchanged for light ones. And, the same amount of attenuation was assumed for all buildings under evaluation. The amount of attenuation in the power level was estimated as follows:

$$\Delta L_{\mathrm{WA}} = 10 \cdot \log_{10} \left(\frac{10^{0.65} \cdot N_{\mathrm{H}} + N_{\mathrm{L}}}{N} \right) \tag{1}$$

where

ΔL_{WA} : Amount of attenuation in the power level [dB]
N : Number of all automatic vehicles [vehic./h]
N_{H} : Number of heavy vehicles [vehic./h]
N_{L} : Number of light vehicles [vehic./h].

It was assumed that all vehicles were running at the same speed and that speed regulations successfully reduced the speed 20 % from the actual average speed. The effect was thought of as the amount of attenuation in the power level, like the restrictions against heavy vehicles. The effect was established as 3 dB or 1 dB when the actual average speed was 50 − 140 km/h or 13 − 50 km/h, respectively.

Table 1: *Kinds of countermeasures against road traffic noise*

Measures	Noise attenuation	Unit of enforcement	Rate of difficulty for enforcement	Enforcement requirements
Improvement of road surface				
Asphalt pavement	1dB	Block	–	–
Drainage pavement	3dB			
Insertion of low-height noise barriers	5dB	Block	–	–
Insertion of noise barriers				
Unified type of Japan	10dB	Section	–	Width of sidewalk: 6m and over
New type	15dB			
Installation of green belts				
10m and over	5dB	Section	–	Width of sidewalk: 10m and over
20m and over	10dB			
Traffic control of heavy vehicles	*Eq.* (1)	Section	ON	Mixing rate of heavy vehicles: 17% and more
Speed regulation				
13~50km/h	1dB	Section	ON	–
50~140km/h	3dB			

2.5 Evaluation of the Effect of the Countermeasures

The effect of the countermeasures against noise is subtracted from the actual noise level during the daytime for each building, and this value is compared with the value for the Environmental Quality Standards for Noise (in daytime) [4]. The measure pattern with the greatest achievement was selected as an optimal solution.

2.6 Costs of the Countermeasures

The most expedient method for calculating the cost of each countermeasure was used. The method makes a relative comparison among the measure patterns. Based on the cost to improve the road surface, therefore, the cost to insert low-height noise barriers was two times, the cost to insert noise barriers was four times, and the cost for green belts was three times.

3 APPLICATION OF A GENETIC ALGORITHM AS THE SELECTION TECHNIQUE

3.1 Genetic Expression and the Operation of Solutions

The candidate for a solution in a genetic algorithm [5], GA, is called an "individual." One or more "chromosomes" characterize an individual. Furthermore, a chromosome consists of an aggregate of "genes."

In this paper, the application of a GA is proposed which can search for practical optimal solutions. It is based on the theory of natural selection and does not require performing all searches. In order to use the GA as the selection technique for countermeasures against road traffic noise, it is necessary to genetically express the measure pattern that is the best candidate for the solution. In this report, an individual as a solution consists of six chromosomes according to each kind of measure shown in Table 1. The GA expression of an individual is shown in Figure 2. Each chromosome has many genes. The number of genes is equal to the number of evaluation sections or blocks that represent the enforcement units of each measure. The gene shows "the state of the measure," the chromosome shows "the enforcement sites of the measure," and the individual expresses "the measure pattern" with the number of chromosomes being equal to "the kinds of measures." In addition, the extended values from the present situations are held as genes, in a computer program, so that the amount of attenuation increases from the present situation.

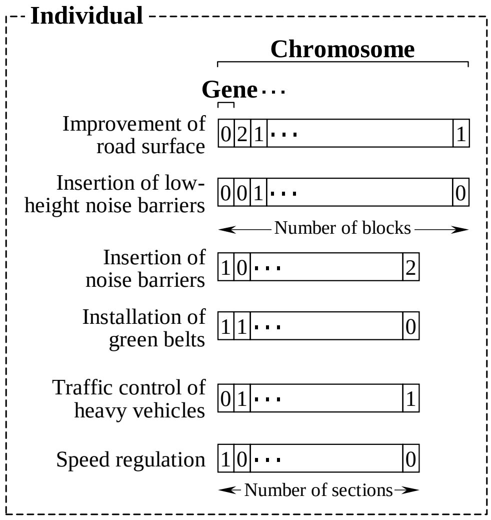

Figure 2: *GA expression model for an individual*

After genetically expressing the candidate for a solution as an individual, genetic operations are performed on the basis of the theory of natural selection. Various genetic operations like the "selection" of parents and the "crossover" of them are performed on the candidate to create solutions called the "population." A new "generation" was formed due to an improvement in fitness, which is an evaluation value for each individual over the subject. At the time, arbitrary individuals were mutated for the population not lapsing into a collection of partial solutions. And, individuals who do not satisfy the enforcement conditions might not be generated. By repeating a number of such processes, the optimal solution, or an approximate one, can finally be obtained.

3.2 Function for Evaluating

For countermeasures against road traffic noise, it is important that the effect of noise attenuation be large and that the effect of the attenuation over the expense be high. The average rate of the number of buildings successfully affected by the measures to the total number of buildings for each block was defined as the "average rate of achievement." The rate of the cost required for the selected measures to the cost required for all the measures was defined as the "rate of cost." They take values from 0.0 to 1.0. The measure pattern that had the highest average rate of achievement and the lowest rate of cost was regarded as having the highest noise attenuation over the expense.

On the other hand, the approach that restricts heavy vehicles and regulates speed and types of traffic flow measures, may bring social or other types of loss. It is difficult to estimate the influence on physical distributions, *etc.* Thus, they are not thought to be easy countermeasures against noise. In this report, the rate of these two kinds of measures to the total number of measures was defined as the "difficulty of enforcement." It takes a value from 0.0 to 1.0. The measure pattern that had the lowest value was considered to be the most profitable one in terms of enforcement.

An evaluating function that shows the degree of adaptation for each individual consists of the three above-mentioned elements. It is thought that the importance of these elements differs and that the optimal measure pattern differs with the present states of noise and budgets, *etc.* Thus, each element was weighted by a coefficient, and the function was able to reflect an administrative intention. As mentioned above, "evaluation function" F indicates "fitness" and is defined in Equation (2). F takes values from 0.0 to 1.0.

$$F = \frac{1 + w_{\mathrm{a}} \cdot R_{\mathrm{a}} - w_{\mathrm{c}} \cdot R_{\mathrm{c}} - w_{\mathrm{d}} \cdot R_{\mathrm{d}}}{2} \tag{2}$$

where

$$w_{\mathrm{a}} + w_{\mathrm{c}} + w_{\mathrm{d}} = 1$$

R_{a} : Average rate of achievement [–]
R_{c} : Rate of cost [–]
R_{d} : Rate of the difficulty of enforcement [–]
w_{a} : Weight coefficient for the average rate of achievement [–]
w_{c} : Weight coefficient for the rate of cost [–]
w_{d} : Weight coefficient for the rate of the difficulty of enforcement [–].

4 SIMULATION

4.1 Verification of the Selection Technique

Numerical simulations are performed to verify the validity of the selection technique for the optimal measure patterns against the road traffic noise stated in Chapter 3. A search for a simulation of the measure patterns was performed for a city area composed of 3 sections and 4 blocks with example data in which all combinations can be calculated. The data used for the

Table 2: *Conditions along the road before the simulation*

L_{Aeq} in daytime [dB] (Achievement of Environmental Quality Standards)	62.3 (OK)	64.0 (NG)	61.0 (NG)	71.2 (NG)	78.9 (NG)	64.3 (NG)
Number of sections				3		
Number of blocks	2		1		1	
Number of buildings	1	1	1		3	
Width of sidewalk [m]	12.0	2.1	10.0		9.0	
Mixing rate of heavy vehicles [%]	10		10		17	
Speed [km/h]	60.0		60.0		90.1	
Environmental Quality Standards in daytime [dB]	70	55	55	55	55	55
Present situation						
Improvement of road surface	2	1	1		1	
Insertion of low-height noise barriers	0	0	1		0	
Insertion of noise barriers	0		0		0	
Installation of green belts	0		0		0	
Traffic control of heavy vehicles	0		0		0	
Speed regulation	0		0		0	

simulation is shown in Table 2. For the simulation, each weight coefficient for the evaluating function was set at $w_{\mathrm{a}} = 0.5$, $w_{\mathrm{c}} = 0.2$, and $w_{\mathrm{d}} = 0.3$.

The value of F transited upward, as shown as Figure 3. The tendency shows that individuals are pushed up toward the optimal solution. The individuals generated beyond the 500th reached the optimal solution. The results of the solution are shown in Table 3. The value of F was calculated for all 18,432 combinations in order to examine the accuracy of this solution. Consequently, there was only one measure pattern with the highest evaluation, and the pattern was in agreement with the solution obtained by the GA. With this technique, it was possible to obtain the optimal solution by performing the evaluation just a few times compared with all the searches.

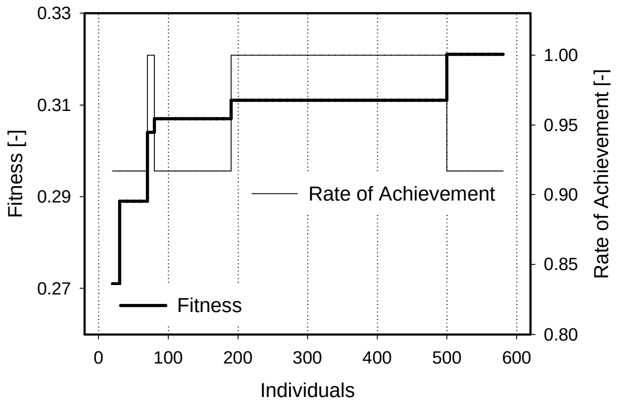

Figure 3: *Example of the convergence of value F in the simulation for verification*

Furthermore, the transition of the average rate of achievement of the Environmental Quality Standards is also shown in Figure 3. Although the value showed 1.0 several times along the way, it was 0.92 in the end. This is because the value of F is an index which considers not only the effect of noise reduction, but also the cost, *etc.*

As mentioned above, it was proved that the selection technique using the GA proposed in this paper was effective.

Table 3: *Conditions along the road after the simulation*

<table>
<tr><td>Environmental Quality Standards in daytime [dB]</td><td>70</td><td>55</td><td>55</td><td>55</td><td>55</td><td>55</td></tr>
<tr><td>Result of simulation</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Improvement of road surface</td><td>2</td><td>2</td><td>2</td><td></td><td>2</td><td></td></tr>
<tr><td>Insertion of low-height noise barriers</td><td>0</td><td>1</td><td>1</td><td></td><td>1</td><td></td></tr>
<tr><td>Insertion of noise barriers</td><td colspan="2">0</td><td>0</td><td></td><td>1</td><td></td></tr>
<tr><td>Installation of green belts</td><td colspan="2">0</td><td>1</td><td></td><td>0</td><td></td></tr>
<tr><td>Traffic control of heavy vehicles</td><td colspan="2">0</td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td>Speed regulation</td><td colspan="2">1</td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td>L_{Aeq} in daytime [dB] (Achievement of Environmental Quality Standards)</td><td>59.3 (OK)</td><td>53.0 (OK)</td><td>53.0 (OK)</td><td>53.2 (OK)</td><td>60.9 (NG)</td><td>46.3 (OK)</td></tr>
<tr><td>Rate of achievement</td><td colspan="6">0.92</td></tr>
<tr><td>Rate of cost</td><td colspan="6">0.50</td></tr>
<tr><td>Rate of difficulty for enforcement</td><td colspan="6">0.13</td></tr>
<tr><td>F</td><td colspan="6">0.32</td></tr>
</table>

4.2 Expansion to a Widespread Area

As an example, the technique using the GA is applied to the city of Fukuoka, Japan. However, only one complete set of required data is extracted, and there are 342 sections, 3,794 blocks, and 30,050 buildings in the whole city [6]. There are $2.18 \times 10^{3,424} (= 3^{3,794} \times 2^{3,794} \times 3^{342} \times 2^{342} \times 2^{342} \times 2^{342})$ patterns of countermeasures when an assumption is made that all measures can be implemented throughout the city. It would be impossible, therefore, to conduct all the searches.

Each weight coefficient of the evaluation function was set at $w_a = 0.5$, $w_c = 0.2$, and $w_d = 0.3$. This search took the achievement of improvements in the environmental quality very seriously. The transit of value F is shown as Figure 4. The value of F transited upward like the case of the application in a small-scale area. The generated individuals beyond the 84,000th reached the optimal solution or an approximate one.

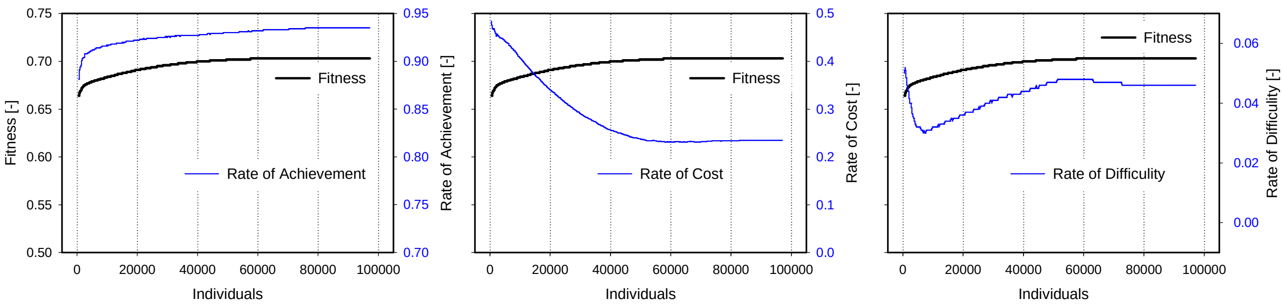

Figure 4: *Examples of the convergence of value F and factors ($w_a = 0.5$, $w_c = 0.2$, and $w_d = 0.3$)*

The value of the average rate of achievement of the Environmental Quality Standards was 0.94, and the contents of the solution were as follows. Improvements to the road surface were obtained for 940 blocks, the insertion of low-height noise barriers were conducted for 808 blocks, the traffic control of heavy vehicles covered 6 sections, and speed regulations were set in 78 sections. Almost no noise barriers or green belts were installed. This is because it was not possible to secure a sufficient width of the sidewalk.

A simulation that attaches great importance to the rates of cost and the difficulty of enforcement was also performed. Each weight coefficient of the evaluating function was set at $w_a = 0.2$, $w_c = 0.3$, and $w_d = 0.5$. The transit of value F and the rates of the averaged achievement, cost, and the difficulty of enforcement are shown as Figure 5. The value of F increased as the rates of cost and the difficulty of enforcement decreased. Moreover the average rate of achievement transited downward, because this search take the achievement of improvements in the environmental quality lightly.

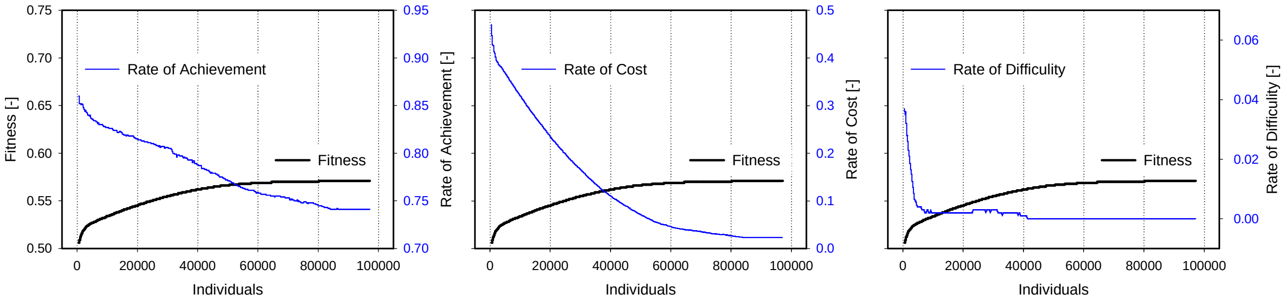

Figure 5: *Examples of the convergence of value F and factors ($w_{\mathrm{a}} = 0.2$, $w_{\mathrm{c}} = 0.3$, and $w_{\mathrm{d}} = 0.5$)*

The results of the measure patterns were as follows. Improvements to the road surface were obtained for 250 blocks, while the other measures did not accomplish anything. The average rate of achievement of the Environmental Quality Standards was 0.74, which was lower than the value yielded under the previous simulation. The measure pattern consisted of only a drainage pavement which was low in cost. It appears that the evaluating function was effective.

5 CONCLUSION

In this research, a new technique was proposed for selecting rational countermeasures against the problem of road traffic noise pollution over a widespread area through the use of computers. This technique enables us to choose rational control measures against noise at the proper sections and blocks along various roads. Consequently, the method is worthwhile in its practical use for performing countermeasures against road traffic noise pollution over a widespread area and incorporates a balance between the environment and costs.

ACKNOWLEDGEMENTS

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