Selection Technique of Optimal Measure Against the Road Traffic Noise in City Areas

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Abstract

There are many residential areas affected by road traffic and the measures against noise are strongly needed there. There are also several measures against noise. It is the most important to decide which measures are applied to where, in order to decrease the noise level as much as possible at constant cost. However, the number of combination of the measures and places is so huge that it is difficult to find the optimal solution of such a problem. The purpose of this paper is to present a new selection technique of the optimal solution. An application of the Genetic Algorithm, GA, which can search for the practical optimal solution from a huge combination without performing all searches, is proposed. The data of roads and buildings accumulated in GIS is utilized. As a result of GA simulation, it is ensured that this technique is practical for selecting the measures and places in actual city areas.

1. Introduction

Road traffic noise is the most serious problem at the residential areas facing to arterial roads, and quick enforcement of the measures against noise is need. As the noise pollution-control is implemented as public works, it is very important to take measures with maximum efficiency in minimum investment. Namely, it is necessary to select the best method and place for enforcing the measures under a given cost. However, the number of the "measure pattern" which is combination of the measures method and the target road is so huge that it is difficult to find the most efficient pattern out of all combinations.

With these points as background, the purpose of this paper is to present a new selection technique of the optimal solution of the measures against road traffic noise at residential areas facing roads. An application of the Genetic Algorithm, GA [1], which can search for the practical optimal solution from a huge combination without performing all searches, is proposed. The data of traffic and buildings near the target road, traffic volume, speed of vehicle, mixing rate of heavy vehicles, etc., are necessary for deciding which measures are more optimal. In this paper, the data in GIS [2] are utilized.

2. Selection technique of the measures against noise

2.1. The measures against noise

In this paper, six kinds of measures are assumed as follows: (1) improvement of road surface, (2) insertion of low-height noise barriers [3], (3) insertion of noise barriers [4], (4) installation of green belts, (5) traffic control of heavy vehicles and (6) speed regulation. Nos. (1) to (4) are concerned with the road structure and Nos. (5) and (6) are with the traffic flow. Fig. 1 shows the image chart of the measures.

2.2. Enforcement unit of the measures

Two enforcement units of the measures are assumed in this paper. One is "section", where the influence of road traffic noise is almost the same. The other is "block", where the amount of attenuation by buildings is regarded as being constant.

"Section" is adopted as the unit of the improvement of road surface and the insertion of low-height noise barriers, which are suitable for wide area. And "block" is adopted as the unit of the insertion of noise barriers, the installation of green belts, the traffic control of heavy vehicles and the speed regulation, which are suitable for relatively narrow area.

2.3. Requirements of the measures

The enforcement of the measures currently assumed might be difficult because of the situation around the road. Considering it, some requirements for enforcement

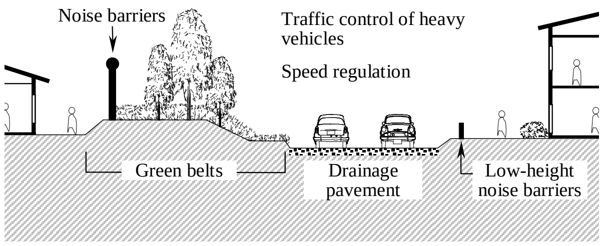

Figure 1: *Image of measures against road traffic noise.*

are set in each measure. In the simulation, any measure whose requirement is not wholly satisfied is not enforced. Noise barriers must be inserted at the place efficiently apart from buildings, because they might cause obstruction of sunshine if they are inserted near the buildings. Green belts must have a certain amount of depth, because they cannot bring noise attenuation effectively if the depth is not enough. Therefore, installation possibilities of noise barriers and green belts are judged by the width of actual sidewalk. Namely, the requirements for noise barriers and green belts are 6m and over and 10m and over, respectively.

As the traffic control of heavy vehicles is effective for noise attenuation only when the traffic volume of heavy vehicles is large, the traffic control of heavy vehicles is enforced only when the mixing rate of heavy vehicles is more than 17%, at which more than 2dB of attenuation is expected at least.

2.4. Estimation of the measure effect

The effect of each measure is assumed to be only one value of noise attenuation because of simplicity. They are collectively shown in Table 1. Only the effect of the traffic control of heavy vehicles is estimated by the following equation, where the noise attenuation by the traffic control of heavy vehicles is considered to be equal to the amount of attenuation of power level [5] when all heavy vehicles are interchanged by small ones.

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

where ΔL_{WA} is the amount of attenuation of power level in dB, N is the number of vehicles in cars per hour, N_{H} is the number of heavy vehicles in cars per hour, N_{L} is the number of small vehicles in cars per hour.

It is assumed that all vehicles are running at the same speed, and 20% of the velocity of vehicles is reduced by the speed regulation, and its effect is equal to the amount of attenuation of power level in the same way of the traffic control of heavy vehicles. Thus, the effect is assumed to be 3dB and 1dB when the speed is between 50 and 140 km/h and between 13 and 50 km/h, respectively.

Table 1: *Properties of each measure against 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 measure effect

The effect of the measures is subtracted from the actual noise level in daytime on each building, and the reduced value is compared with the Environmental Quality Standards for Noise [6], which is an individual value for each building. Thus, the measure pattern with the greatest achievement is selected as an optimal solution.

2.6. Cost for the measures

The expedient method, in which only relative comparison is possible, is used here for the calculation of the cost for measures. Namely, the cost for the improvement of road surface is assumed as a base unit, and the cost for the installation of low-height noise barriers, green belts and noise barriers are assumed to be twice, three times and four times, respectively.

3. Application of the GA to the selection technique

3.1. Genetic expression and operation of solutions

The candidate of a solution in the GA is called “individual”. Each “individual” is characterized by one or more “chromosomes”, and each “chromosomes” consists of an aggregate of “gene”.

In order to apply the GA to the selection technique of the measures against road traffic noise, it is necessary to express genetically the measure pattern that is the candidate of a solution. In this paper, an individual as a solution consists of six chromosomes corresponding to each measure as shown in Table 1. Namely, an individual can be expressed as shown in Fig. 2. Each chromosome has some gene, the number of which is equal to the number of “section” or “block” that is the enforcement unit of each measure. The gene shows “the state of the measures”, and the chromosome shows “the enforcement places of the measures”. Thus, the individual expresses “the measure pattern” with the number of chromosomes equal to “the kinds of measures”. In addition, in the GA simulation, the extension value is held so that the amount of attenuation always increases from the present situation.

After the candidate of a solution is genetically expressed as an individual, genetic operations are performed based on the theory of natural selection. Various genetic operations such as “selection” or “crossover” of parents are performed to the candidates of the solutions called “population”. New “generation” is formed in due to the improvement on the “fitness”, which is an evaluation index of each individual. When making new generations, some arbitrary individuals are mutated for the population in order to prevent new generations from lapsing into a collection of partial solutions. By repeating such a process many times, the optimal solution or the approximate one can be obtained finally.

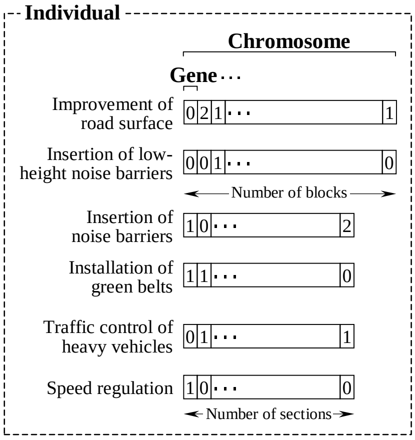

Figure 2: *GA expression of "individual".*

3.2. Function for evaluating

It is important for measures against road traffic noise that both the effect of noise attenuation and the cost-effectiveness are high. In this paper, the effectiveness is evaluated by the achievement of the Environmental Quality Standards for Noise. The rate of the number of achieved buildings to the number of all buildings at each block is defined by "average rate of achievement", which is from 0.0 to 1.0. And the rate of cost required for the selected measures to the cost required for all measures is defined by "rate of cost", which is from 0.0 to 1.0. The higher "average rate of achievement" is and the lower "rate of cost" is, the better the measure pattern is evaluated as. The traffic control of heavy vehicles and the speed regulation might bring social loss, which is difficult to be estimated, and the enforcement of them in actual is expected to be hard. Considering it, the rate of these two measures to the total number of all measures is introduced as another element defined by "difficulty for enforcement", which is from 0.0 to 1.0. It is evaluated as more profitable that the measures are lower "difficulty for enforcement".

Then, an evaluating function showing the degree of adaptation of each individual is constructed by the above three elements. It is thought that the importance of each element differs corresponding to the present state of noise and the budgets etc. and consequently the optimal measure pattern differs. Therefore, each element should be weighted by a coefficient as an administrative intention can be employed into the selection.

Thus, the "evaluation function", F, is defined by equation (2). F takes the values from -1.0 to 1.0.

$$F = w_{\mathrm{a}} R_{\mathrm{a}} - w_{\mathrm{c}} R_{\mathrm{c}} - w_{\mathrm{c}} R_{\mathrm{c}} \qquad (2)$$

Where, R_{a} is the average rate of achievement, R_{c} is the rate of cost, R_{d} is the rate of difficulty for enforcement, w_{a} is weight coefficient for the average rate of achievement, w_{c} is weight coefficient for the rate of cost, w_{d} is weight coefficient for the rate of difficulty for enforcement.

4. Simulation

4.1. Verification of the selection technique

The validity of the optimal selection technique of the measure pattern against road traffic noise proposed in the chapter **3** is examined. The city area composed of three sections and three blocks, in which all combinations can be wholly checked, is adopted as a test data for the GA simulation. It is shown in Table 2. In the simulation, weighting coefficients, w_{a}, w_{c}, w_{d}, in the evaluating function are set 0.5, 0.2 and 0.3, respectively.

The growth of F according to the progress of alternation of generations is shown in Fig. 3. It is found that individuals are gradually pushed up towards the optimal solution. After the individuals are generated about 500 times, they reach the optimal solution. The result of the obtained solution is shown in Table 3. In order to examine the rightness of this solution, F is calculated for all combinations, which is 18,432. As a result, only one measure pattern with the highest fitness is obtained, and it is in agreement with the solution by the GA. In this way, the optimal solution is obtained with few times of calculations compared with whole searches. The transition of the average rate of achievement of the Environmental Quality Standards is also illustrated in Fig. 3. It is found that the value reaches 1.0 several times on the way to convergence while the value is 0.92 finally. This is because not only the noise reduction effect but also the cost etc. are considered in the evaluation function, F. This indicates that the evaluation function defined in this study operates correctly.

Thus, it is proved that the selection technique using the GA proposed in this paper is effective.

4.2. Application to a wide area

In order to examine whether or not the proposed technique can be applied to the selection of the measure pattern in actual city area, the GA simulation is tried with the data of the city of Fukuoka, which composed of 342 sections, 3,794 blocks and 30,050 buildings. The number of measure pattern is $2.18 \times 10^{3,424} (= 3^{3,794} \times$

Table 2: *Properties of the roads before 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	

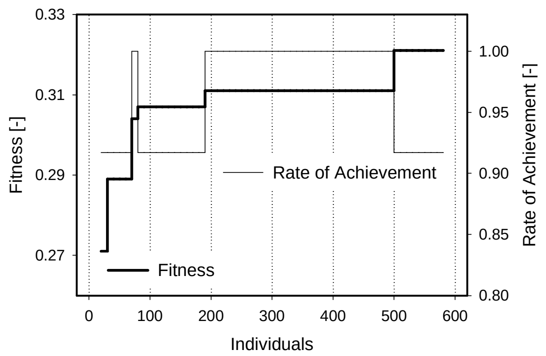

Figure 3: *Convergence of F.*

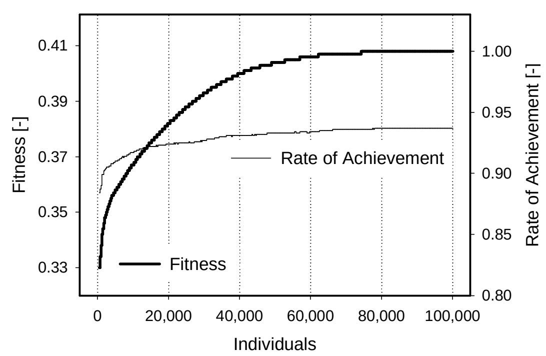

Figure 4: *Convergence of F.*

Table 3: *Properties of the roads after simulation.*

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

$2^{3,794} \times 2^{342\times 4}$) when all measures are implemented. Although the number of the combinations is too huge to search wholly, the GA simulation is expected to be able to find the optimal or approximate solution. In the simulation, weighting coefficients, w_{a}, w_{c}, w_{d}, in the evaluating function are set 0.5, 0.2 and 0.3, respectively, where the improvement in the achievement of the Environmental Quality Standards is considered as the most important.

The transit of F is shown in Fig. 4. It is found that individuals are gradually pushed up towards the optimal solution in the same way of small areas. After the individuals are generated about 88,000 times, they reach a certain solution, which may be optimal or approximate solution. The average rate of achievement of the Environmental Quality Standards is 0.94, and the contents of the solution are as follows: the improvement of road surfaces are 963 blocks, the insertion of low-height noise barriers are 801 blocks, the insertion of unified type noise barriers is 1 section, the installation of green belts is 0 section, the traffic control of heavy vehicles are 9 sections, and the speed regulation are 75 sections. The reason why noise barriers and green belts are hardly installed is that the sufficient width of sidewalk is not secured.

Another simulation in which both the "rate of cost" and "difficulty for enforcement" are emphasized is performed while weighting coefficients, w_{a}, w_{c}, w_{d}, in the evaluating function are set 0.2, 0.3 and 0.5, respectively. The measure pattern where the improvement of road surfaces is 248 blocks and the other measures are nothing is selected. The average rate of achievement of the Environmental Quality Standards is 0.74, which is lower than that in the former simulation. The fact that only "improvement of road surface" whose cost is low is set in the solution indicates the evaluating function operates effectively.

5. Conclusions

To reduce the noise in the city over a wide area with maximum efficiency in minimum investment, we must decide which kinds of measures are enforced to which roads in the city. To solve such a problem, a new technique applying the GA is proposed. The technique enables us to select easily the optimal measures against noise. It is possible to regard cost or noise attenuation as important in selecting process by setting proper values to the coefficients in the evaluation function. The results by computer simulation show that this method is worthwhile in practical use for performing the measures against road traffic noise over a wide area with the well-balanced environment and costs.

6. Acknowledgments

This research is supported by the 21st Century COE Program under the Ministry of Education, Culture, Sports, Science and Technology of Japan.

7. References

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