Procedures for Prioritizing Noise Barrier Locations on Freeways

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The ranking of potential noise barrier locations is not a straightforward process and requires consideration of several criteria. The development of multicriteria ranking procedures for prioritizing the locations with noise problems is discussed. Three ranking methods were developed to determine the priority of each of the candidate projects. They are sequential ranking scheme (SRS), analytic hierarchy process (AHP), and weighted index methods. These methods are presented, and their application to a set of data from the Chicago area is discussed. Each of these methods can be used independently by the users. It is proposed that a combination of the SRS and AHP methods be used to improve computational efficiency when a large number of locations are to be ranked. The ranking variables used in developing these procedures are existing noise level, number of people affected, land use type of the adjacent area, and effectiveness and feasibility of building a noise barrier at that location. The ranking variables and their relative importance are the user-specified inputs to these procedures.

The selection of locations where noise barriers should be put up is not straightforward because several criteria need to be considered. The Illinois Department of Transportation (IDOT) needed prioritization procedures to rank potential freeway Type II noise barrier locations in District 1 of IDOT (the Chicago area). This paper briefly discusses the development of multicriteria procedures for prioritizing the locations with noise problems in the Chicago area. Three ranking methods were developed: sequential ranking scheme (SRS), analytic hierarchy process (AHP), and weighted index (WI) methods. Application of these models to a set of data from the Chicago area is discussed. For further information about the procedures refer to Benekohal et al. (1).

DEVELOPMENT OF NEW PRIORITY RANKING METHODS

Determining Ranking Variables

Cohn (2) provided a brief description of the priority rating methods and variables used by 11 state highway agencies. After reviewing these ranking procedures and consultation with IDOT, it was decided that four variables would be used in developing the ranking methods. These variables are existing noise level, number of people, land use type, and effectiveness/feasibility factor. These variables are listed in decreasing order of importance. For a given condition the appropriate variables and their relative importance factors should be decided by the user.

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Data Collection for Study Sites

There are approximately 223 centerline mi of Interstate freeway in District 1 of IDOT. The freeways were divided into 1-mi segments. Each side of the roadway was regarded as a separate segment. Therefore 446 segments were identified in the entire area.

For developing the ranking procedures 40 sites were selected from the population of 446 segments. A stratified random sampling with balanced outcome (SRSBO) method was developed and used (1). These 40 sites are expected to represent the population of expressways around the Chicago area with respect to land use type, freeway type, and freeway locations.

The land use type for each segment was determined by using the land use maps of the U.S. Geological Survey (USGS) (3–6). The predominant roadside development for a segment was used to group them into residential (R), commercial (C), industrial (I), public (P), or vacant (V). The land use types determined from the USGS map were further verified by using recent aerial photographs and video images of selected sites taken by the research team (1).

A computerized noise prediction program, STAMINA 2.0 (7), was used to compute noise levels. Because barriers are not considered for vacant sites, noise levels were not computed for them. Predicted existing noise levels for study sites are given in Table 1.

Data on the number of people were obtained mainly from 1990 Census data and the ITE Trip Generation report (5th edition). The census data were used to determine the number of people in residential areas. For areas of land use types other than residential, the number of people affected was computed (1) by using the ITE Trip Generation report. These numbers are shown in Table 1.

The effectiveness and feasibility of putting up a noise barrier was considered for each site. A value of between 1 and 9 was assigned to each site. The rationale for assigning such values is to determine whether a noise barrier can be physically constructed at that site and whether it can reduce the noise level. A guideline for assigning the feasibility/effectiveness factor (E/F in Table 1) is given below:

9—Ground level, enough space to put barrier, no gap on barrier because of a crossing road, no parallel roads behind.

8—Same as number 9, but with a low-volume parallel frontage road.

7—Ground level, enough space to put barrier, three or fewer crossing roads.

6—Same as number 7, but more than three crossing roads.

5—Elevated or depressed freeway with earth embankments, enough space to put barrier, three or fewer crossing roads.

4—Same as number 5, but more than three crossing roads.

TABLE 1 Summary of Site Data

Site	Noise Level	Land Use	Fwy Type	No. of People	E/F	Site	Noise Level	Land Use	Fwy Type	No. of People	E/F
A1	72.4	I	G	176	8	C43	--	V	G	23	8
A2	72.3	C	G	212	7	C45	--	V	G	13	8
A11	72.4	R	D	141	5	E3	65.0	R	D	300	5
B10	71.4	C	E	157	3	E12	69.6	R	G	53	7
B14	71.7	C	D	383	2	E22	--	V	G	5	9
B16	71.0	R	E	189	2	E24	--	V	G	44	9
B17	66.0	C	E	206	2	E33	--	V	G	2	9
B19	72.0	R	D	211	4	F16	70.5	V	G	43	7
B20	71.8	R	D	190	5	F28	--	V	G	17	9
B21W	74.4	R	D	429	5	G0	69.6	C	D	267	3
B21E	74.7	C	D	100	5	G6	66.7	R	D	147	2
B23	69.5	C	D	286	5	G7N	67.8	R	D	211	3
B25	73.4	I	D	112	5	G7S	69.9	R	D	58	2
B26	71.3	C	D	211	5	G10N	70.5	R	D	139	5
B37	74.8	R	G	131	7	G10S	70.5	R	D	187	5
C2	69.3	R	E	344	3	G16	72.2	R	E	46	4
C7	66.8	I	E	31	5	H1	69.4	R	G	107	7
C20	72.2	R	G	70	7	H5W	70.5	R	G	40	8
C22	70.9	R	G	50	8	H5E	72.1	R	G	135	8
C26	70.5	R	G	161	8	H10	--	V	G	9	8

Notes: Land Use: R = Residential, C = Commercial, I = Industrial, V = vacant;
Fwy Type = Freeway type: G = Ground Level, D = Depressed, E = Elevated;
E/F = Effectiveness/Feasibility.

3—Elevated freeway on structure or depressed freeway with retaining walls, enough space to put barrier.

2—Same as number 3, but narrow space to put barrier.

1—Worse than the above.

Sequential Ranking Scheme

Harness and Sinha (*8*) proposed a priority ranking approach in which projects were divided into progressively smaller subsets by using various criteria. McGeehan and Samuel (*9*) modified the procedure for prioritizing the road improvement. The method was further modified and improved and was used for priority setting in the project described here. The modified method is the SRS method.

The basic idea of the SRS method is to group candidate projects into different levels by progressively using each of the ranking variables, one at a time. Projects are first grouped into levels by using the most important variable. Then each project is evaluated by using the second most important variable. At this step a project may move to an adjacent higher or lower level or stay at the same

level. This process is continued until the last variable is used for grouping (*1*).

The projects were grouped into the following four levels: top, high, medium, and low. The thresholds are decided beforehand on the basis of the evaluation of the range of each variable (*1*). Seven of 40 sites have vacant land use type, and building of noise barriers on those sites is not considered. The thresholds for number of people were 286 (85th percentile) for moving up and 157 (50th percentile) for moving down a rank. Sites that are of the residential type are moved up one rank, whereas sites that are of the industrial or vacant type are moved down one rank. For downgrading the rank of a project, an effectiveness and feasibility factor of 5 or less was considered.

Two additional rules are applied for changing the rank of a project. The rules are as follows. (a) If a project moved up or down in the previous step, it cannot move up again in the current step; however, it may still move down. (b) A project is not allowed to move up at the last step. The rationale for the first rule is to prevent a project from moving down in one step and moving up again in the next step. It also would prevent a project from moving up too rapidly on the basis of less important variables. The second

rule is used to prevent moving a project to a higher level on the basis of the least important variable. These rules may be modified by the users to fit their needs. The results of ranking are shown in Figure 1.

The main strength of SRS is that it is easy to learn and use, and the user can easily see where a project is located after applying each ranking variable. The main weakness of SRS is that it requires threshold values for each ranking criterion. Furthermore projects must be placed in a limited number of groups, and within a given group all projects are ranked the same.

Analytic Hierarchy Process

AHP is fully discussed in works by Saaty (*10*) and Saaty and Kearns (*11*). It is used to develop a methodology for modeling unstructured problems in the economic, social, and management sciences. The AHP is a systematic procedure for representing the elements of any problem hierarchically. The main idea is to break a large complex system that is to be dealt with into various independent or dependent subsystems. The decision makers are guided through a series of pairwise comparison judgments to express the relative strength and intensity of impacts of the elements in the hierarchy. The relative comparisons are processed through numerical expressions.

Using AHP for priority ranking the overall evaluation is performed by constructing a connection diagram among the upper and lower levels. Proposed projects are first evaluated among each at the lower levels. The overall priority is achieved on the basis of the priority that each project gained at the lower level and the connection between levels.

The method is applied to the 33 projects with four ranking variables: noise level, number of people, land use type, and effectiveness/feasibility. The AHP method is carried out in three steps. Step 1 is to determine the relative importance among ranking variables. This is done by pairwise comparison of the variables and assignment of numerical importance factors. The assignment is known as *Level 1*. For example, noise level was considered to be 1.5 times as important as number of people, 3 times as important as land use type, and 4 times as important as effectiveness/feasibility. The relative importance matrix is completed by assigning factors for each pair of variables. For the four ranking variables used in this example, six relative importance factors are to be assigned.

It should be noted that the ranking variables to be included and their relative importance factors are decided by the users of this approach. The variables and the relative factors used in this paper are for illustration purposes. The user may decide to include a different set of variables or may assign different relative importance factors. The importance factors assigned to the variables must be consistent. Small changes in the importance factors would not significantly affect the outcome of the AHP method; however, if the factors are significantly changed the ranking may be affected.

The second step in the process is to determine the relative importance between each pair of projects by considering each of the ranking variables, one at a time. This is done by assigning relative importance factors between each pair of projects by considering only one variable. The matrix here will be known as a *Level 2* matrix. The final step, Step 3, in the AHP procedure is to do matrix multiplication of the Level 1 and Level 2 rankings. Step 3 uses the results from Steps 1 and 2 and computes the ranking for
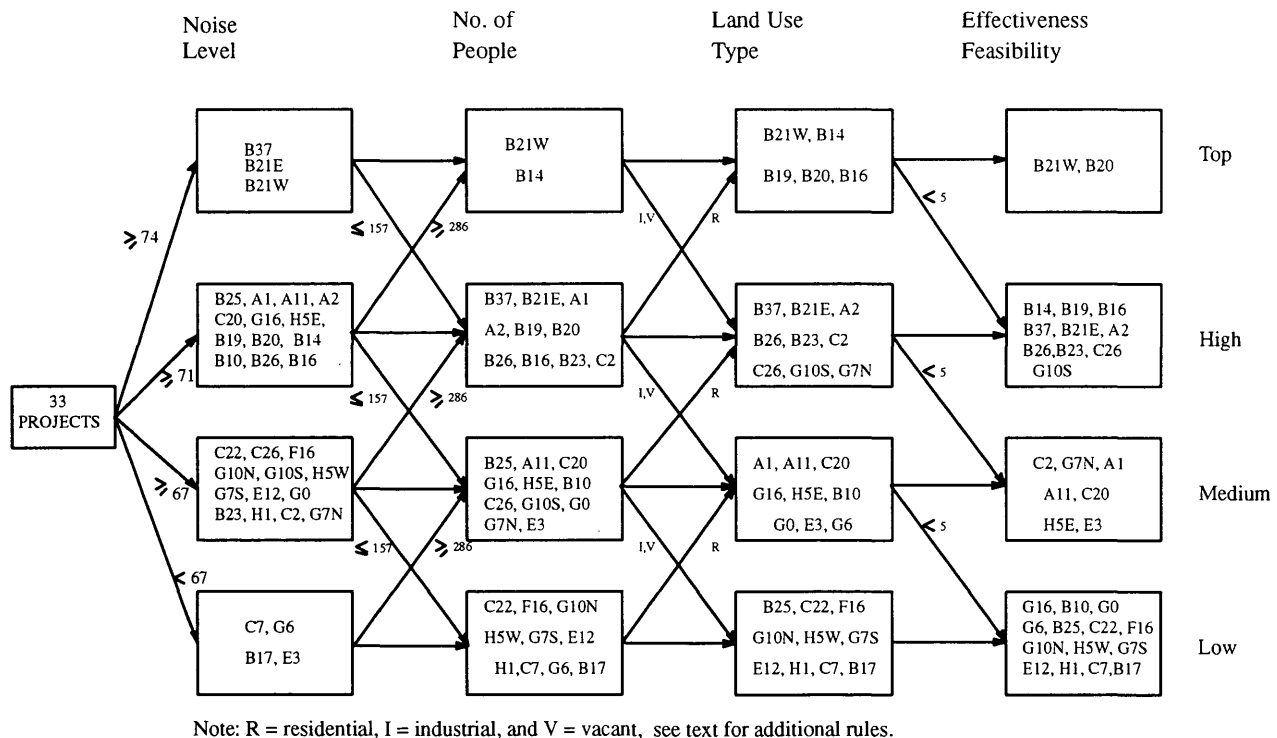

Note: R = residential, I = industrial, and V = vacant, see text for additional rules.

FIGURE 1 Sequential ranking scheme applied to 33 projects.

the projects. The result of the ranking of the 33 projects, in descending order, is shown in Table 2.

It may appear that the relative ranking factors used in AHP are arbitrary numbers assigned by the user. In fact they are not so arbitrary, but reflect the assessment of the user when comparing the variables or projects. Minor changes in the relative importance factors may not affect the ranking outcome, but drastic changes may change the order. To show the effects of changing the factors, the Level 1 factors were changed for the 33 projects. This time it was assumed that the noise level and the number of people are equally important and that either one is twice as important as land use type or freeway type. The ranking outcomes obtained with these modified factors were compared with the ones obtained with the original factors. The top 13 projects were the same in both cases. Similar comparisons were made, and it was observed that most of the projects that were ranked in the top half by using the original factors remained in the top half when reasonable changes in the importance factors were made.

The main strength of the AHP method is that it can rank projects on the basis of several criteria. Its main weakness is that it needs a lot of input when the number of projects is large. This weakness can be overcome by computerizing the input process.

Weighted Index

Candidate projects are evaluated and ranked on the basis of a WI, which is a linear combination of four variables. The basic idea is to standardize each of the variables and assign a weight for each of the standardized variables. Then the standardized value is multiplied by the weight and they are summed to find the WI. The formula is

$$WI = Fn * Sn + Fp * Sp + Fl * Sl + Ff * Sf$$

where Sn, Sp, Sl, and Sf are standardized values (ranging from 0 to 5) and Fn, Fp, Fl, and Ff are weighting factors of variables of noise level, number of people, land use type, and effectiveness/feasibility, respectively.

The WI method is illustrated by using the data for the 33 projects. Weighting factors were assigned as follows: $Fn = 4$, $Fp = 3$, $Fl = 2$, and $Ff = 1$. Weighted values for each site are given in Table 2.

The main advantage of the WI method is that it is simple and straightforward. Contributions of each variable to the total index value are quantitative. Once the weighting factors and the standardizing formulas are determined, each project would have a WI value. The main disadvantage of the method is that the WI value may be dominated by a single variable.

Comparison of Results from Three Methods

Table 2 shows the results of ranking. It should be noted that the results from SRS are in four groups because SRS does not determine the relative standings within a group. The results indicate that the three methods yield very similar rankings, although there is not a perfect match among the outcomes. A general agreement is achieved for most of the projects, especially for the top 10 and the bottom 10 projects.

The three methods in general need different human and computer resources. When threshold values are fixed, SRS and WI are less labor-intensive than AHP. The input data for AHP would increase exponentially when the number of projects increases.

It is easier to add or delete one or more projects to the SRS and WI methods. The addition or deletion of a project does not significantly affect the relative rankings of projects. In AHP, however, when projects are added or deleted one needs to modify the matrices to reflect the changes, and this may affect the previous ranking for other projects.

The three methods are flexible to fit the needs of the users. The users can change the variables on the basis of their own judgment or preference and set the thresholds at levels with which they are most comfortable. For example users may change the thresholds in SRS, extend or shorten the number of levels, modify the values in WI standardization, or assign different relative importance factors in AHP.

Proposed Priority Procedure

Each of the three methods can individually be used to obtain reasonable results. The WI method is easy to use, but the standardization and weighting factors must be carefully studied so that the outcome is not heavily influenced by a single factor. For this reason the WI method in its current stage is less preferred than SRS. It is proposed that the combination of the SRS and AHP methods be used when a large number of projects are to be ranked because AHP would require a lot of input.

TABLE 2 Comparison of Ranking Results

Rank	SRS	AHP		WI	
		Site	Priority value	Site	Index value
1	TOP: B21W, B20	B21W	0.057	B21W	48.60
2		B37	0.044	B37	38.81
3	HIGH:	B14	0.041	B14	37.74
4		B21E	0.040	A2	34.81
5	B14, B19, B16,	A2	0.037	B19	34.65
6	B37, B21E, A2,	C2	0.035	B21E	34.40
7	B26, B23, C26,	B19	0.035	B20	33.92
8	G10S	B20	0.034	H5E	33.90
9		H5E	0.033	C2	33.77
10		A1	0.033	A11	33.25
11		A11	0.033	B26	31.71
12		B26	0.032	C26	31.61
13	MEDIUM:	B23	0.032	G10S	31.13
14		B25	0.032	C20	31.07
15	C2, G7N, A1,	G0	0.030	B23	30.92
16	A11, C20, H5E,	C26	0.030	B16	30.73
17	E3	G10S	0.030	A1	30.11
18		B16	0.030	G0	29.39
19		C20	0.030	G10N	29.26
20		E3	0.029	B10	28.81
21	LOW:	B10	0.029	G16	28.64
22		G10N	0.028	B25	28.18
23	G16, B10, G0,	G16	0.027	C22	28.11
24	G6, B25, C22,	G7N	0.026	H5W	26.90
25	F16, G10N,	C22	0.025	H1	26.74
26	H5W, G7S, E12,	H1	0.025	F16	26.52
27	H1, C7, B17	H5W	0.024	G7N	25.49
28		F16	0.024	E12	25.05
29		E12	0.022	E3	24.19
30		B17	0.022	G7S	23.36
31		G7S	0.020	G6	20.23
32		G6	0.020	B17	19.09
33		C7	0.012	C7	11.42

A two-step ranking procedure is proposed here.

Step 1. Use SRS to classify the candidate projects into four groups.

Step 2. Combine two upper groups and two lower groups separately (or two upper groups only) from Step 1. Then use the AHP method to rank each combined group.

By going through Step 1 the low-priority projects will be filtered out and the ranking will be focused on high-priority projects.

CONCLUSIONS AND RECOMMENDATIONS

Three multicriteria ranking procedures (SRS, AHP, and WI) were developed and used for priority ranking noise barrier projects. These procedures are flexible, and the users can specify the variables to be included and their relative importance factors. It is recommended that a combination of the SRS and AHP methods be used when ranking a large number of projects. For a small number of projects the AHP method may be used alone to obtain the ranking. The SRS may be used to classify the project into different priority levels when ranking of projects within that level is not required.

The variables used for ranking, threshold values in SRS, standardization formula and weighting factors in WI, and relative importance factors in AHP are reasonable parameters used in developing the ranking procedures. The users may decide to change the variables or the parameters, or both, depending on their needs and conditions. Changing the variables or the parameters would not alter the ways that the procedures work; however, the outcomes of the ranking may be different, depending on the changes. The variables and parameters used should be determined by the users. These procedures are developed to provide such a flexibility for the users.

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