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Analyzing Construction Noise by a Level/Duration Weighted Population Technique

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ABSTRACT

A technique is described for comparing the potential noise impacts of construction hauling for a number of project alternatives. The technique is used on a modification of the level weighted population method to account for the duration of the hauling activity on the various haul route links; the resultant descriptor is termed Level/Duration Weighted Population (LDWP). A complex microcomputer spreadsheet was developed to facilitate data entry and calculation of LDWP for a base case and each study scenario, as well as a relative change in impact (RCI) over the base case for the scenarios.

River flood control construction projects funded by the U.S. Army Corps of Engineers require environmental assessments. Project alternatives typically include the construction of tall levees or flood walls or the cutting of channels to divert the river flow from floodplain. Such projects can take as long as 6 to 7 years to construct; hence, a serious potential impact of the project can be construction noise--in particular, the extensive material-hauling operations.

To assess and compare the construction haul-noise impacts of a set of different alternatives for a flood control project in Harlan, Kentucky, a technique was developed that considered existing community noise levels, future haul-noise levels, duration of haul activities, and population densities. In this paper that technique is described; it was implemented with a sophisticated microcomputer spreadsheet program.

PROBLEM DEFINITION

Harlan, Kentucky, and its neighboring communities of Loyall, Rio Vista, and Baxter are located along the Cumberland River and two of its forks in Southeast Kentucky (1). The study area, shown in Figure 1, is characterized by steep-sided valleys with most of the commercial and residential development concentrated in narrow floodplains. Major floods occur mostly in the winter or spring; the flood of record, in April 1977, crested at over 30 ft above gauge zero. To minimize potential future damage, the Corps is evaluating a series of alternatives for flood control (1). These alternatives include the following:

1. A-77: Building levees and flood walls in the Harlan and Loyall areas for the 1977 flood levels.
2. A-SPF: Same as A-77, but for the Standard Projected Flood level.
3. B-SPF-Filled: Cutting new channels through the 200- to 300-ft high hills behind Harlan and Loyall, building diversion dikes along the river at the ends of these channels, and filling in the existing riverbeds between the diversion dikes.
4. B-SPF-Unfilled: Same as B-SPF-Filled, but leaving the riverbeds unfilled in the diversion areas.

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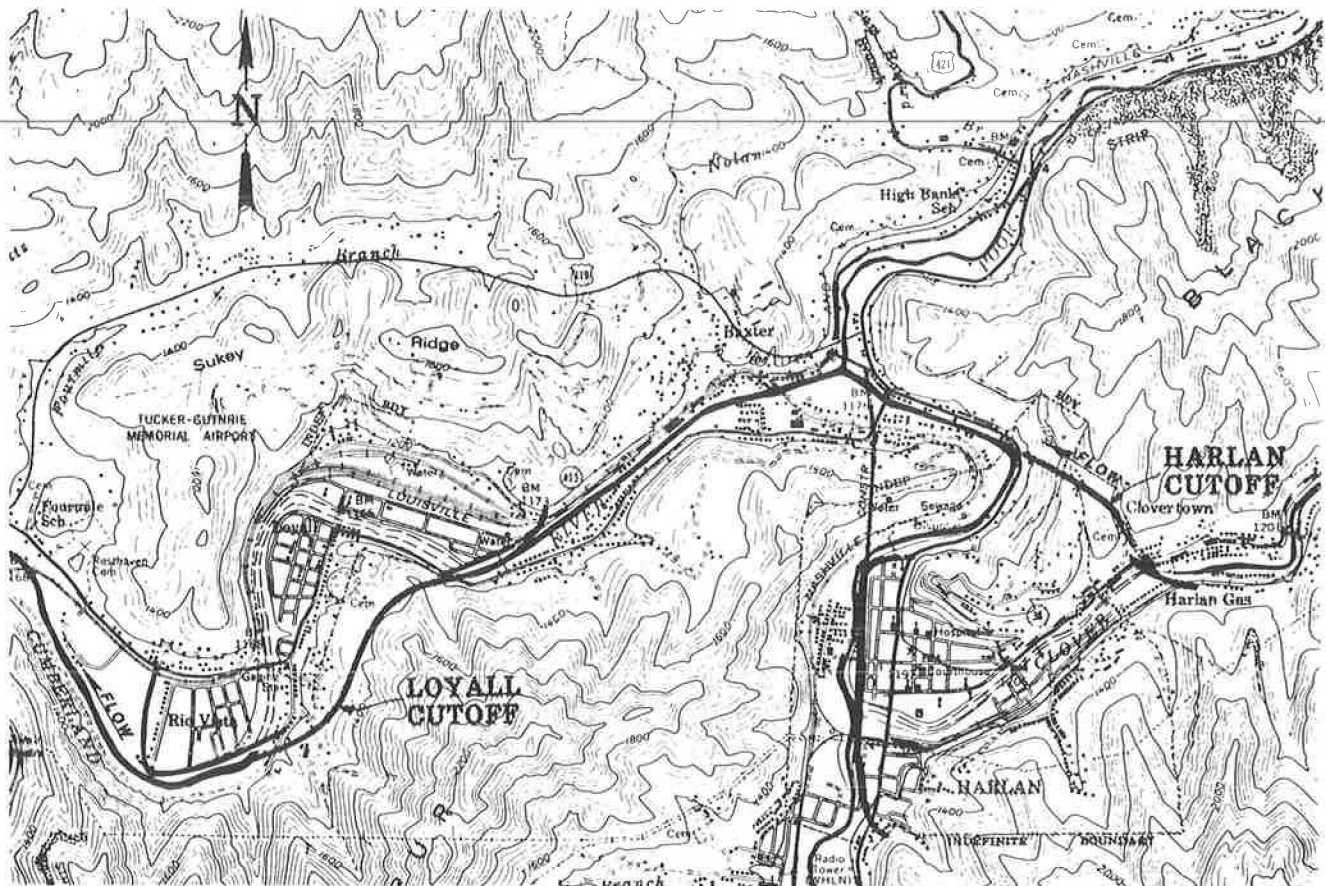


FIGURE 1 Project area, Harlan County, Kentucky.

5. C-SPF-Filled: A combination of A-SPF in the Harlan area (new channel) and B-SPF-Filled in the Loyall area (flood walls and levees).

6. C-SPF-Unfilled: The same as C-SPF-Filled, but leaving the riverbed in Harlan unfilled.

Early in its alternatives analysis process, the Corps identified several potential short- and long-term noise impacts that warranted additional investigation. The major long-term impact dealt with traffic noise, namely,

1. A potential increase in levels in Harlan because of reflections off flood walls and

2. A potential decrease in levels in Loyall because of relocation of State Route 840 along a bench cut in the Loyall channel.

Secondary long-term impacts dealt with railroad noise, namely,

1. A potential increase in levels because of reflections off the flood walls in north Loyall and south Harlan and

2. A potential decrease in levels because of shielding by the flood walls in western Loyall.

The major potential short-term noise impact, as defined by the Corps, dealt with construction. Although there would be many sources of noise during construction, the scope of services for the project noted that the only source to be analyzed quantitatively was the truck hauling. One should note that in this case the qualifier "short-term" implies a 4- to 7-year duration, depending on the chosen al-

ternative. The impact analysis technique described in this paper will be limited to the haul-noise impact assessment strategies.

CRITERIA AND MODELS

A major consideration in the analysis was that much of the hauling would be on the existing road network. As a result, the existing noise environment for the potentially affected residences was established largely by highway traffic. The assessment technique thus needed to accommodate impact criteria and prediction methods for construction haul trucks as well as for conventional highway traffic.

Time-Averaging Concept

Accepted criteria for transportation and construction noise impacts deal with the "time averaging" of the acoustic energy reaching a sensitive receptor. The averaging is done over different time periods depending on the noise source. The time-averaged level, or A-weighted equivalent sound level, is commonly abbreviated L_{eq} , with units of decibels (dBA). The A-weighting refers to an attenuation or amplification of the sound pressure levels of the different frequencies composing environmental noise to simulate human hearing response.

Traffic Noise Criteria

For traffic noise, FHWA requires state highway agencies to use the hourly time-averaged level [$L_{eq}(1h)$]

or $L_{eq}(h)$ or the hourly 10th-percentile exceedance level [$L_{10}(h)$] (2). Traffic noise predictions are done for the "worst" noise hour, which typically occurs during the daytime, inclusive of the morning and evening rush periods.

The FHWA noise standards (2) indicate that noise mitigation must be considered when (a) the future "design-year" project levels "substantially exceed" existing levels and (b) the future levels "approach or exceed" stated noise abatement criteria. For residential land use, the criterion is an $L_{eq}(lh)$ of 67 dBA. Note that these criteria define when mitigation must be considered, not when an impact occurs. Although not stated in the noise standards, subsequent FHWA policy guidance suggests that impacts occur when the $L_{eq}(lh)$ exceeds 55 dBA (3). The standards also do not define the phrase "substantially exceed," although many agencies have settled on an increase of 10 to 15 dBA as an indication of impacts worthy of mitigation study.

Construction Noise Criteria

For construction noise, the U.S. Army Construction Engineering Research Laboratory (CERL) supports use of a measure called the representative level (\overline{L}_A) (4). \overline{L}_A is defined by a Society of Automotive Engineers (SAE) measurement procedure, which was developed before the common availability of integrating sound-level meters (5), as follows:

$$\overline{L}_A = \frac{1}{n} \sum_{i=1}^n (L_A)_i \quad (1)$$

where $(L_A)_i$ are those sound-level samples that fall within a range from the maximum sampled level to 6 dB less than the maximum sampled level [e.g., if the maximum sampled level was 70 dB, all sound-level samples from 64 to 70 dB would be $(L_A)_i$ values] and n is the number of $(L_A)_i$ values used for computing the arithmetic average.

\overline{L}_A is related to the time-averaged level (L_{eq}) by the fraction of samples within 6 dB of the highest:

$$L_{eq} = \overline{L}_A - \Delta \quad (2)$$

where

$\Delta = 0$ dB	for	$0.8 < (n/60) \leq 1.0,$
$= 1$ dB	for	$0.7 < (n/60) \leq 0.8,$
$= 2$ dB	for	$0.6 < (n/60) \leq 0.7,$
$= 3$ dB	for	$0.5 < (n/60) \leq 0.6,$
$= 4$ dB	for	$0.4 < (n/60) \leq 0.5,$
$= 5$ dB	for	$0.3 < (n/60) \leq 0.4,$
$= 7$ dB	for	$0.2 < (n/60) \leq 0.3,$ and
$= 10$ dB	for	$0 < (n/60) \leq 0.2.$

The CERL specifications do not specify a particular period over which levels should be averaged, although use of the SAE procedure will typically require at least 30 min of data collection. CERL simply specifies daytime and nighttime periods.

In addition, the CERL impact criteria specifications address noise generated within the construction boundary; they do not address trucks hauling beyond the site (4). Nor does the FHWA have construction noise impact criteria; as guidance, it suggests that users could develop their own criteria by considering absolute levels as well as relative differences in levels (6).

The FHWA noise standards address construction noise but do not require prediction of construction noise levels for federal-aid highway projects (2).

However, FHWA models are available that predict 1-hr or 8-hr time-averaged levels [$L_{eq}(lh)$ or $L_{eq}(8h)$] (7,8). One component noise source in the FHWA construction noise model is the haul truck. The model requires specification of an hourly flow rate (trucks per hour), thus assuming a constant flow throughout the day. As a result, the predicted hourly L_{eq} will be equal to the 8-hr average. Because haul-truck noise generation is so similar to normal highway truck noise generation and because the haul trucks will often travel the same paths as does the normal traffic, the most appropriate measure for studying haul-truck noise for this project was the hourly L_{eq} or $L_{eq}(lh)$.

Relative Change in Impact

Because this study needed to gauge the impact of the introduction of the construction haul traffic to a static situation, it was appropriate to use some method of comparing "build" and "no-build" levels. Such a method was described by Kugler et al. in 1976 (6). The method is based on the concept of the level-weighted population (LWP), also referred to as "fractional impact." The method uses the "day-night" time-averaged level, or L_{dn} , which is a 24-hr average of acoustic energy where 10 dB is added to all values between 10:00 p.m. and 7:00 a.m. as a penalty for nighttime sensitivity.

A scale is established where an L_{dn} of 55 dB is assumed to "highly annoy" zero percent of the population, whereas an L_{dn} of 75 dB is assumed to highly annoy 100 percent of the population. The number of people exposed to different L_{dn} values for each case is then weighted according to the L_{dn} values. An "equivalent highly annoyed" population (or level-weighted population) is then computed for the base case and the alternative being studied. Mathematically,

$$LWP = \sum_{i=1}^n 0.05P_i [(L_{dn})_i - 55] \quad (3)$$

where P_i is the number of people exposed to day-night level $(L_{dn})_i$ and n is the number of L_{dn} values or ranges used in the calculations typically; the calculation is performed by grouping subjects in 5-dB L_{dn} bands.

A relative change in impact (RCI) is then computed by subtracting the LWP for the base case (LWP_{base}) from the LWP for the alternative (LWP_{alt}), dividing by the base-case LWP, and multiplying by 100:

$$RCI = \left[\frac{LWP_{alt} - LWP_{base}}{LWP_{base}} \right] \times 100 \quad (4)$$

The LWP values for each case are also good indicators of the absolute impact as compared with an L_{dn} of 55 dB. The RCI method has been used for nontraffic noise sources as well, as illustrated in the U.S. Environmental Protection Agency background document on rail carrier noise standards (9).

For the flood control study, it appeared that a slightly modified version of the RCI method was the most appropriate to compare the various construction haul scenarios for each project alternative. Instead of using a 24-hr L_{dn} , which is appropriate rail-road noise, the hourly L_{eq} was used. Kugler et al., as well as the EPA, suggested that an L_{dn} of 55 dB was an indicator of zero percent highly annoyed. As noted earlier, FHWA considers a traffic noise $L_{eq}(lh)$ of 55 dB to also represent no impact. Given the similarity of haul-truck noise to traffic noise, the construction noise LWP values could also be computed

by using a 55-dB L_{eq} (1h) as the baseline value. The LWP for the various construction haul scenarios could then be compared with a base-case LWP, which would be caused by traffic noise with no project haul trucks. Thus, the relative impacts of each haul scenario could be analyzed by computation of the RCI.

Traffic Noise Model

Once this means of quantifying and comparing impacts had been selected, the next step was to choose models to predict future noise levels for traffic and construction haul trucks.

The accepted model for traffic noise is the FHWA Highway Traffic Noise Prediction Model (10), which consists of the basic acoustics equations for sound emission and propagation and attenuation by barriers. Several methods are available for using the model, including charts, nomographs, and various levels of computer programs. The nomograph method was the most appropriate for predicting base-case traffic noise levels given the general nature of the site modeling.

Several methods are available to predict haul-truck noise, including the FHWA HICNOM computer program (8) and the FHWA Highway Traffic Noise Prediction Model (10). The methods are similar in concept for the truck noise source, differing in the values for the basic emission-level equation. On the basis of observations by the study team during field sound-level measurements, the trucks currently in use in the project area for hauling coal have emission levels similar to the typical heavy truck modeled in the FHWA traffic noise model. These coal haul trucks, including muffler systems, are relatively new and generally well maintained. It was anticipated that many of these same, or similar, trucks would be employed for hauling during the flood control project construction. Therefore, it was appropriate to model them by using the heavy-truck vehicle type in the FHWA traffic noise model and use that model to predict hourly haul-truck L_{eq} -values.

STUDY METHOD

The study method consisted of a series of steps. First, the LWP technique needed to be modified to incorporate the duration of construction hauling in a particular area. This modification was a key factor in the analysis technique. Next, a haul network and haul scenarios were developed for each project alternative. Then, base-case impacts were determined as a basis for comparison with hauling impacts. Finally, the hauling impacts were determined and used to compute changes in impact relative to the base case. These steps are discussed in detail in the following paragraphs.

Consideration of Haul Duration

As noted earlier, the RCI technique is based on the fractional impact or LWP concept, which, in its simplest form, states that the impact on a few people exposed to high noise levels is equivalent to the impact on a larger number of people exposed to lower noise levels. In this technique, a person exposed to a level of 55 dB or less is assumed to receive zero impact, whereas a person exposed to a level of 75 dB is assumed to receive 100 percent impact. A linear change in impact is then applied for those exposed to levels between 55 and 75 dB; for example, a person would be considered 25 percent impacted at a

level of 60 dB, 50 percent impacted at a level of 65 dB, and 75 percent impacted at a level of 70 dB.

The technique then involves the weighting of the population according to the noise-level exposures to determine an equivalent population that is 100 percent impacted. This normalization procedure thus gives a meaningful method to compare the relative differences between scenarios and hence alternatives.

Construction noise analysis has an additional factor that needed to be considered. Traffic noise, which forms the base case or "do-nothing" alternative, is typically considered a permanent type of noise. However, construction is a temporary noise of finite duration. The analysis technique thus needed to account for the duration of the haul activities. For example, it is obvious that a person exposed to noise from 100 haul trucks per hour for 2 years would be more seriously impacted than a person exposed to the same number of trucks for a 1-year period. The question is how to quantitatively compare the impact of the two situations.

Guidance may be found in the CERL report on construction noise specifications (4), in which a logarithmic relationship is used when durations are considered in its "maximum permissible" noise-level specification, normalized to a 32-day period. Specifically, each halving of the duration of the activity would raise the permissible noise level by 3 dB. Mathematically,

$$A_{\text{duration}} = 10 \log (\text{duration}/32) \quad (5)$$

Choice of the 32-day period by CERL was arbitrary, probably a compromise on a 1-month's duration and a factor of 2 for ease of calculation. Thus, just as the dwelling units are normalized to an equivalent population that was 100 percent impacted, the haul operations of varying durations may be normalized to some base-case value. In this manner, one may redefine the LWP as a level/duration weighted population, or LDWP.

During project discussions, it was determined that the longest construction period for any of the alternatives would be approximately 7 years. It was decided therefore to normalize the levels to this period. Based on an assumption of 45 work weeks per year, a 7-year period equaled 315 weeks. Thus, the construction haul noise levels were adjusted for the LDWP calculation by

$$A_{\text{duration}} = 10 \log (\text{duration}/315) \quad (6)$$

Representative Distance Bands

In performing the fractional impact analysis, one could predict a precise noise level at every house along a project haul-road link. However, given the nature of the analysis, such precision would be unwarranted and probably deceiving. A much more efficient method, with little loss in overall accuracy, would be to group the dwelling units on the basis of their distances from the haul link.

To accomplish this grouping, representative distance bands needed to be defined. Typical distances for traffic noise predictions are 25, 50, 100, 200, and 400 ft. Based on sound-level propagation calculations, five distance bands were defined: 10 to 35 ft, 35 to 70 ft, 70 to 165 ft, 165 to 280 ft, and 280 to 560 ft. The band outer limits are such that for soft-site propagation (grassy ground cover) the level at a house located anywhere within a given band would be within 2.2 dB of the level at the corresponding representative distance.

Noise levels could then be computed at the five representative distances, and those levels applied

to all the houses within the corresponding distance bands. Thus, knowing the noise levels, adjusted for duration of activity, and the number of people exposed to those duration-corrected levels, one could compute an LDWP for a hauling scenario for a project alternative.

Development of a Hauling Network and Hauling Scenarios

Field reviews and project team meetings led to the definition of a series of links along existing roads or along construction roads that defined a potential network over which the haul trucks could travel. Figure 2 shows the link map on which a link is defined as a section of road connecting two numbered roads.

Then, for each project alternative (A-77, A-SPF, B-SPF-Filled, B-SPF-Unfilled, C-SPF-Filled, and C-SPF-Unfilled), quantities were established of the amounts of material to be removed from a channel cut or to be used to build a diversion structure or fill a riverbed. Next, on the basis of construction sequencing analyses, several scenarios were developed to accomplish the various haul activities, including hauling material from the Harlan or Loyall cuts to several potential disposal sites, hauling from several potential borrow areas to build the levees and diversion structures, and hauling material to fill the old riverbeds. Haul routes over particular links in the network were established for each scenario, and hourly haul-truck rates and weekly durations for the hauling activity were computed for each pertinent link.

Base-Case LDWP

The next step in the analysis involved determining a base-case impact on the dwelling units in the vicinity of the haul-road links due to traffic noise during the construction period.

The base-case traffic noise levels were computed for each distance for each link by using 1989 traffic data adjusted from 1982 data provided by the Kentucky DOT. Standard FHWA model equations for hourly L_{eq} prediction on soft sites were used for automobiles, medium trucks, and heavy trucks, as follows:

$$[L_{eq}(h)]_j = [(\overline{L}_O)_E]_i + 10 \log(N_i D_0 / S) + 15 \log(D_0 / D_j) - 33.4 \tag{7}$$

where

- $[(\overline{L}_O)_E]_i = 38.1 \log(S) - 2.4$ for $i =$ automobiles,
- $= 33.9 \log(S) + 16.4$ for $i =$ medium trucks,
- $= 24.6 \log(S) + 38.5$ for $i =$ heavy trucks,
- $S =$ vehicle speed (mph),
- $N_i =$ hourly flow rate of the i th vehicle type,
- $D_0 =$ reference distance of 50 ft,
- $D_j =$ perpendicular distance from the road to the receiver (ft), and
- 33.4 = constant adjusting for unit conversion and infinitely long soft-site propagation.

Levels were calculated for values of D_j of 25, 50,

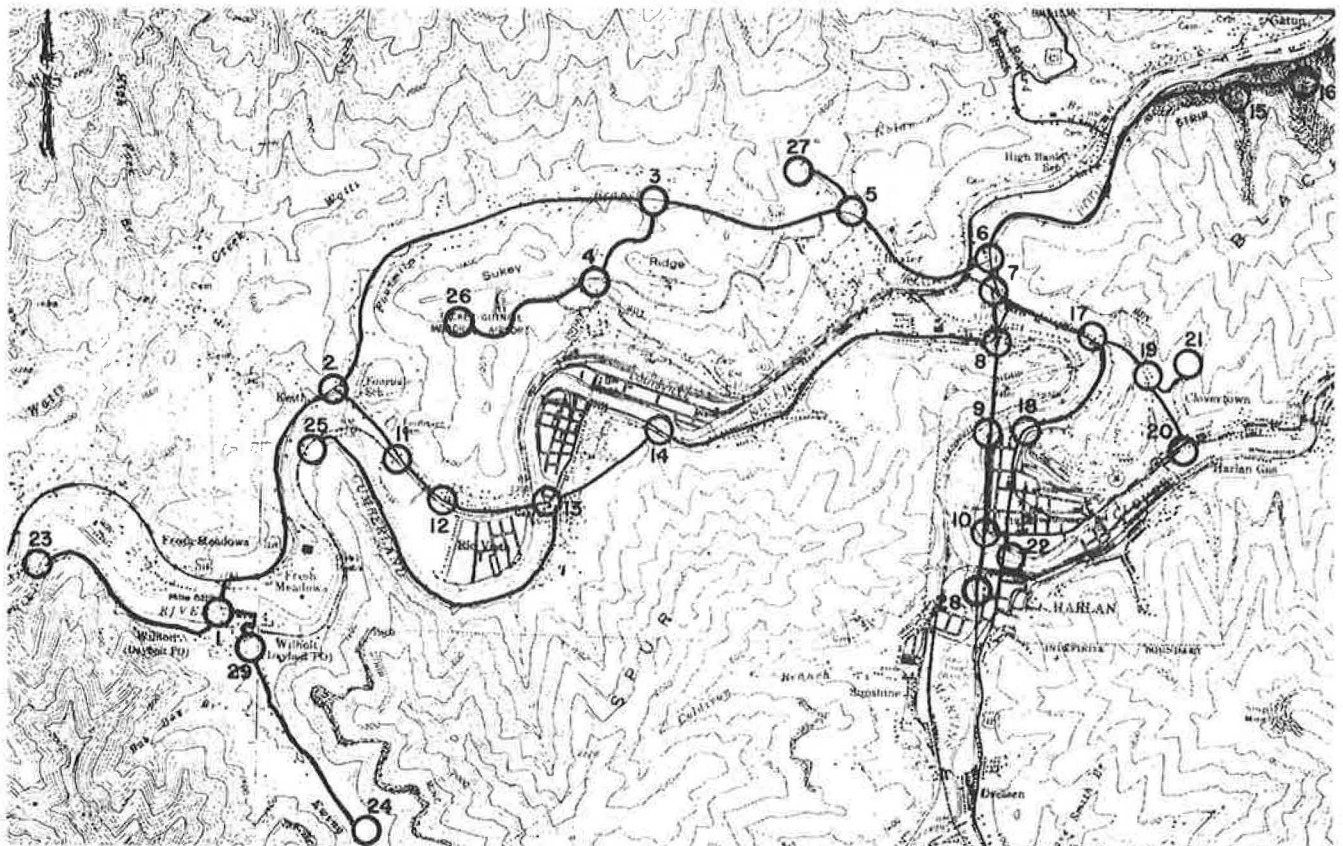


FIGURE 2 Construction haul route link network.

100, 200, and 400 ft. Then, the $[L_{eq}(h)_i]$ values were combined for the total hourly average sound level on the link at each distance $[L_{eq}(h)_T]_j$:

$$[L_{eq}(h)_T]_j = 10 \log \left\{ \sum_i 10^{[L_{eq}(h)_i]_j/10} \right\} \quad (8)$$

For several of the potential haul links, no future highway traffic data were available, or no road actually existed. In these situations, the base-case noise levels were determined from field measurements of existing noise levels.

A base-case LDWP was then computed for each of the five distance bands for each link, $(LDWP_{BASE})_j$, based on the predicted traffic noise levels and number of dwelling units within each band:

$$\begin{aligned} (LDWP_{BASE})_j &= 0 \\ &= 0.05P_j \{ [L_{eq}(h)_T]_j - 55 \} \\ &\quad \text{if } [L_{eq}(h)_T]_j \leq 55 \text{ dB} \\ &\quad \text{if } [L_{eq}(h)_T]_j > 55 \text{ dB} \end{aligned} \quad (9)$$

where P_j is the number of dwelling units in the j th band for this link.

The base-case LDWP values for each distance band for a link were then arithmetically summed to get a base-case LDWP for the link. The LDWP values for each link were then summed to get a total base-case LDWP ($LDWP_{BASE}$). This total was then used as a basis for comparison for all of the haul scenarios for each project alternative.

Construction Haul Scenario LDWP

The next step was to determine the construction LDWP ($LDWP_{CONSTR}$) for the given haul scenario under study for a given project alternative. This calculation first involved computation of an average sound level at each representative distance for the construction haul traffic, $[L_{eq}(h)_{haul}]_j$, on each link for that scenario, using the heavy-truck emission level in Equation 7. Then, the overall hourly average sound level at each representative distance, $[L_{eq}(h)_{const}]_j$, was determined by a logarithmic combination of the base-case average sound level, $[L_{eq}(h)_T]_j$, and the duration-adjusted haul traffic average sound level, $[L_{eq}(h)_{haul}]_j$, in a similar manner to that shown in Equation 8. Finally, the LDWP for each distance for that link was determined in a similar manner to that in Equation 9 by using these overall noise levels.

These distance-related LDWP values were then summed to get a total LDWP for the link. If a link had no construction traffic for a particular scenario, the construction scenario LDWP for that link would be equal to the base-case traffic LDWP. The total LDWP for the haul scenario ($LDWP_{CONSTR}$) was then determined by arithmetically summing the LDWP value for each link in the project network.

RCI

The RCI for each scenario was then determined by

$$RCI = [(LDWP_{CONSTR} - LDWP_{BASE})/LDWP_{BASE}] \times 100 \quad (10)$$

Once RCI values were determined for each scenario for a given project alternative, a worst-case scenario could be defined for that alternative, and a worst-case RCI computed. Thus, the potential construction haul-noise impacts of each alternative could be compared as part of the overall study of the flood control project alternatives.

USE OF A MICROCOMPUTER SPREADSHEET

To perform the analysis, a VisiCalc spreadsheet template was developed (VisiCalc is a registered trademark of VisiCorp). The spreadsheet concept was used in part because of its convenience for data entry and formatted output. The analysis called for a good deal of data entry. For example, the analysis network had over 30 construction and traffic links; for each scenario to be analyzed, the pertinent links had construction truck volumes and durations. Each link had base-case noise levels and numbers of dwelling units for each of the five representative distance bands. This extensive arrayed data entry was greatly simplified by the screen-editing feature of a spreadsheet. In addition, as over 40 individual scenarios needed to be analyzed for the project alternatives, a spreadsheet offered an efficient means for producing concise, readable output. VisiCalc was chosen because of its availability to the authors and their familiarity with it.

Six similar templates were established, one for each project alternative. Each template had data common to all of the alternatives as well as data unique to each. The basic template consisted of four sections, which are described in more detail in the succeeding paragraphs:

1. A data base of the construction haul-truck volumes, travel speed, and durations of hauling along each link for all of the scenarios for a given alternative; this section was unique for each alternative.
2. A data base of a number of dwelling units and base-case traffic noise levels for each distance band for each link; this section was the same for each alternative.
3. A look-up table, common to all alternatives, of haul-truck reference emission levels as a function of travel speed.
4. A calculation area for the construction haul sound levels, the LDWP for each link, and the overall LDWP and RCI for the scenario; this area was utilized for each scenario for each alternative.

Figure 3 shows a portion of Section 1 of the spreadsheet for the B-SPF-Filled alternative. Note that link names (LINK) consist of the node numbers at both ends of a link and that the links were segregated by geographic location (AREA). The speeds along each link (SPEED) were assumed to be the same for all scenarios and alternatives, although these data would be easily changed variables. The rest of the columns of this section of the template are for entry of haul traffic hourly flow rates (VOL) and activity durations in weeks (DUR) for each scenario or case to be studied for each alternative. The VOL and DUR values were developed externally for the appropriate links on the basis of data on the amount of material to be moved, location of borrow or disposal sites, and construction sequencing. These values were then simply entered into the corresponding cells of the spreadsheet template for that alternative.

Figure 4 gives a portion of Section 2 of the spreadsheet. The data in this section remained the same for all of the alternatives. On the left, again, links are identified by node numbers. In the center, the number of dwelling units is listed by distance band; these data were collected from maps and field reviews. To the right are the base-case daytime hourly traffic noise levels for the analysis year 1989 as a function of distance from the link. These data were either externally computed by using the FHWA model nomograph or assumed based on the existing noise level field survey. (The data could

U.S. CORPS OF ENGINEERS HARLAN FLOOD CONTROL NOISE STUDY CONSTRUCTION HAUL NOISE ANALYSIS												
ALTERNATIVE:		BSPF FC		CASE 1: HARLAN CUT, NO BACK HAUL CASE 2: FHC-L/119, FLC-L/B-RIO, ROCK TO A/P CASE 3: FHC-L/119, FLC-L/B-RIO, ROCK TO A/P-L CASE 4: CASE 1 PLUS 3								
AREA	LINK	SPEED	CASE: 1 VOL	1 DUR	2 VOL	2 DUR	3 VOL	3 DUR	4 VOL	4 DUR	5 VOL	5 DUR
DAYH	1-23	30										
	1-29	20					64	79	64	79		
	29-24	40					64	79	64	79		
	1-2	50					64	79	64	79		
RIO	2-11	40			64	192	64	182	64	182		
	11-12	40			68	192	68	182	68	182		
	12-13	30			64	192	64	182	64	182		
	13-25	20										

FIGURE 3 Section of spreadsheet template: haul speeds, volumes, and durations for each case for an alternative.

AREA LINK	NO. OF DWELLING UNITS BY DISTANCE BAND FROM ROAD					BASE CASE TRAFFIC NOISE LEVELS, 1989 (LEQH, DBA)					
	25	50	100	200	400	25	50	100	200	400	
DAYH	1-23	2	6	1	0	4	50	50	50	50	50
	1-29	7	2	2	4	3	60	57	52	48	43
	29-24	0	7	8	2	2	60	57	52	48	43
	1-2	1	3	0	2	0	77	74	70	65	61
RIO	2-11	0	2	4	1	2	69	66	62	57	53
	11-12	1	4	12	3	5	69	66	62	57	53
	12-13	1	7	25	24	52	67	64	60	55	51
	13-25	2	20	15	4	34	53	53	53	53	53

FIGURE 4 Section of spreadsheet template: dwelling units and base-case traffic noise levels.

have been computed by using the spreadsheet concept, but project scheduling restricted development time.) Along links where traffic was the clearly responsible major noise source, the levels show a 3-dB reduction from 25 to 50 ft, representing hard-site propagation, whereas a 4.5-dB reduction per doubling of distance beyond 50 ft was exhibited, representing soft-site propagation. All of the data in this section of the template would be referenced by the formulas in Section 4 of the template.

Shown in Figure 5 is Section 3 of the spreadsheet, a simple look-up table of heavy-truck reference energy and mean emission level as a function of speed. Note that at speeds below 30 mph, a level of 83 dB was assumed to represent slightly increased levels due to acceleration and deceleration noise. During the calculations in Section 4 of the template, the appropriate speed-dependent emission level would be read from this table. The look-up function was used rather than the emission-level equation for reasons related to calculation speed and ease of programming.

Figure 6 shows a portion of the heart of the spreadsheet--the calculations. Shown in the upper left section is the number of the case (or scenario) being studied for a particular alternative. In this example, it is case 3 of the B-SPF-Filled alternative. The case number is a key that is used in this

REF. LEVELS	
SPD	LEV
20	83
25	83
30	80
35	82
40	83
45	84
50	85
55	86

FIGURE 5 Section 3 of spreadsheet template: truck reference emission levels.

section of the spreadsheet to read the appropriate data from the other three sections. Once Sections 2 and 3 had been prepared for all of the alternatives and Section 1 prepared for all of the cases for a given alternative, all that had to be done to perform the calculations for a given case was to enter

BSPF FC CASE: 3				ALPHA = .5						REFERENCE DURATION = 315 CRITERION LEVEL = 55						
AREA LINK	SPEED	VOL	DUR	REF LEV	LEVEL AT DISTANCE:					LEVEL/DURATION WEIGHTED POPULATION						
					25	50	100	200	400	25	50	100	200	400	SUM	
DAYH	1-23	30	0	0	80	0	0	0	0	0	0	0	0	0	0	0
	1-29	20	64	79	83	76	73	68	64	59	5	1	1	1	0	8
	29-24	40	64	79	83	73	70	65	61	56	0	3	2	0	0	5
	1-2	50	64	79	85	74	71	67	62	58	1	3	0	1	0	5
RIO	2-11	40	64	192	83	73	70	65	61	56	0	1	2	0	0	3
	11-12	40	68	192	83	73	70	66	61	56	1	3	6	1	0	11
	12-13	30	64	192	80	71	68	63	59	54	1	5	11	5	0	22
	13-25	20	0	0	83	0	0	0	0	0	0	0	0	0	0	0
HAR	10-22	20	0	0	83	0	0	0	0	0	0	0	0	0	0	0
	20-22F	20	0	0	83	0	0	0	0	0	0	0	0	0	0	0
	10-28	20	0	0	83	0	0	0	0	0	0	0	0	0	0	0
	22-28	20	0	0	83	0	0	0	0	0	1	1	1	0	0	3
SUM = 269																
LDWP FOR CASE # 3 = 269																
LDWP FOR BASE CASE = 238																
RELATIVE CHANGE IN IMPACT = 12.90																

FIGURE 6 Section 4 of spreadsheet template: calculation of construction haul levels, LDWP, and RCI.

the corresponding case number in Section 4. When the calculations were completed, this section of the spreadsheet could be quickly printed and the next case number entered to have the next set of calculations performed.

Shown on the left of Figure 6 are the link names, again in terms of node numbers. The next three columns represent the haul speed, volume, and duration for the case being studied. These data are read directly from Section 1 of the spreadsheet according to the case number entered, as described earlier. The next column, REF LEV, is the truck emission level, read from Section 3 of the spreadsheet, based on the speed value, which had been read from Section 1. These data look-up features eliminated one source of update anomalies that can plague data bases. If one wanted, for example, to change the travel speed along a certain link, the change would only have to be made once, in Section 1, and the change would automatically be incorporated into Section 4.

The next five columns (LEVEL AT DISTANCE) represent the construction haul traffic hourly L_{eq} for this link as a function of distance, based on Equation 7 for heavy-truck emission levels. The calculation was set up for soft-site propagation beyond 50 ft, although this could easily be changed by modifying the ALPHA = .5 cell of the spreadsheet, shown above the column heading. A typical formula in one of these haul L_{eq} calculation cells is as follows:

$$\begin{aligned} & @IF (F140=0, 0, +H140+(10*@LOG10(F140*50/E140)) \\ & + (10*(1+K136)*@LOG10(50/J138)) \\ & - 33.4). \end{aligned}$$

This formula says that if the haul volume, VOL (located for this link in the cell at column F, row 140), is zero, assign a value of zero for the level, or else compute the level by adding the reference level, REF LEV (in cell H140), to the flow adjustment-- $10 \log(VOL*50/SPEED)$ --and to the distance ad-

justment-- $10(1+ALPHA) \log(50/DISTANCE)$ --and subtracting a constant value, 33.4.

Shown on the right-hand side of Figure 6 are the LDWP calculation results for each distance, and to the extreme right, the LDWP sum for all distances for each link. The calculation that occurs in each of the individual distance cells is complex. A typical cell formula is

$$\begin{aligned} & @IF (G74 = 0, 0, \\ & @IF (G140=0, 0.05*G74*@MAX(0, L74-A6), \\ & 0.05*G74*@MAX(0, (A3*@LN(X74+@EXP(J140 \\ & + (A3*@LN(G140/A5)))*A4))-A6))). \end{aligned}$$

This formula states that if the number of dwelling units for this link (in cell G74) is zero, set LDWP to zero, or else do the following:

1. If the construction duration, DUR (G140), is zero, compute the LDWP as 0.05 times the dwelling units (G74) times the maximum of zero or the difference between the traffic L_{eq} (L74) and the criterion level (A6);
2. Or else compute the LDWP as follows:
 - a. Adjust the construction level (J140) by the logarithmic ratio of the duration (G140) to the reference duration (A5);
 - b. Logarithmically combine this adjusted level and the base-case traffic noise level to get the overall level;
 - c. Subtract the criterion level (A6) from the overall level; and
 - d. Compute the LDWP by multiplying this difference by the number of dwelling units (G74) times 0.05.

This calculation is performed for each distance for each link. These distance-based LDWP values are then summed for each link in the rightmost column of the spreadsheet and then summed over all of the links to get the total LDWP for this case for this alterna-

tive (shown as 269 in the bottom right of Figure 6). Finally, the RCI for this case is computed, as shown in the lower left of the figure. In this example, this particular hauling scenario (Case 3) for alternative B-SPF-Filled will cause a 12.9 percent increase in the LDWP over the base case of 1989 traffic.

Again, once Sections 1-3 were prepared, all that had to be done to compute the RCI for a given case for a given alternative was to change the case number at the top of Section 4. In this manner, the many cases could be quickly analyzed and the results compiled and evaluated.

SUMMARY AND CONCLUSIONS

To assist the Corps of Engineers in assessing the construction haul-noise impact of a series of flood control project alternatives, a technique was developed based on a modification to the LWP technique to account for construction haul activity duration. The resulting parameter was the LDWP.

By computing an LDWP for a base case of no construction hauling, where the major noise source was generally traffic, and computing an LDWP for the duration-adjusted construction haul-noise levels combined with the regular traffic noise levels, the relative change in impact (RCI) could be determined for different haul scenarios for each proposed alternative. The analysis technique produced aggregate impact values for comparing alternatives as well as disaggregate details on the link-by-link impacts that could be used subsequently in mitigation strategy development.

The technique was implemented with a complex microcomputer spreadsheet template that permitted easy data entry, rapid calculation of impacts, and immediate formatted presentation of results. The spreadsheet included several sections of data for each project alternative that were accessed by the calculations section by using look-up type functions. Development of the spreadsheet template was somewhat time-consuming and not very amenable to easy modification of the template structure. However, use of the template, once developed, was simple and fast, and permitted many different scenarios to be easily analyzed.

The analysis procedure, then, involved setting up the first section of each template for each alternative and running the calculations in the last section of the template for each case for each alternative. The resultant spreadsheets were printed after each recalculation. The RCI values were then tabulated for all of the cases for each alternative, permitting an evaluation of the relative impacts as input into the environmental assessment.

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