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CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 13/3
CONSTRUCTION-SITE NOISE CONTROL COST-BENEFIT ESTIMATION TECHNIC--ETC(U)
JAN 78 F M KESSLER, P D SCHOMER, R C CHANAUD

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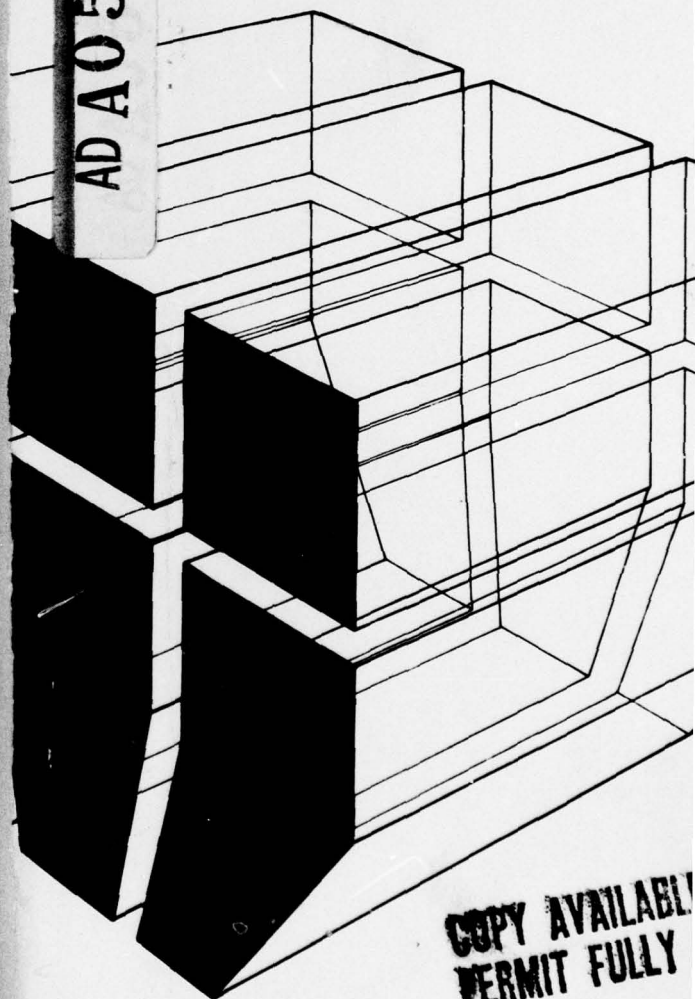
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FOREWORD

The U.S. Army Construction Engineering Research Laboratory (CERL) conducted this study for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project A476720A968, "Pollution Control Technology"; Task 03, "Environmental Quality Technology for Operation and Construction of Military Facilities"; Work Unit 002, "Construction Site Noise: Specification and Control." The QCR number is 1.03.006. The OCE Technical Monitor was Mr. D. Spivey, DAEN-MCC-C.

The report is the result of a joint effort by Dr. Fred Kessler of Dames and Moore (main contractor); Dr. Robert Chanaud of Engineering Dynamics, Inc.; Mr. Eugene Rosendahl of General Electric TEMPO; and Dr. Paul Schomer of CERL's Acoustics Team, Environmental Division (EN).

Dr. R. K. Jain is Chief of EN, and Dr. Paul Schomer is Leader of the Acoustics Team. COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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CONSTRUCTION-SITE NOISE CONTROL COST-BENEFIT ESTIMATION TECHNICAL BACKGROUND

1 INTRODUCTION

Background

Noise is a pollutant generated by construction activity. This pollution may interfere with activities such as watching television, listening to radios or recorded music, or carrying on conversations. Noise can affect the ability to concentrate or to perform mental or intricate manual tasks. Although often of short duration, construction noise, because of its level and character, is more than simply a minor annoyance or irritation. Many Federal agencies such as the U. S. Environmental Protection Agency (EPA), the Federal Highway Administration (FHWA), and the General Services Administration (GSA), in addition to the Department of the Army and others, have recognized the need to reduce construction noise.

A recent CERL publication on construction noise proposed specifications for limiting noise emitted from construction activities.¹ These proposed specifications are applicable to all military construction. To comply with these specifications, it might be necessary to use unconventional construction methods, quieter construction equipment, or other noise-control measures. The implementation of necessary noise-control measures may require that the contractor incur additional material, labor, and equipment costs.

Purpose

The purpose of this report is to examine the cost-benefit(s) of construction site noise control and to provide the rationale and data in support of a companion interim report.² Users of the companion report may refer to this report for detailed data used in the development of the estimating procedures.

¹P. Schomer and B. Homans, *Construction Noise: Specification, Control and Mitigation*, Technical Report E-53/ADA010629 (U.S. Army Construction Engineering Research Laboratory [CERL], April 1975).

²F. M. Kessler, et al., *Construction-Site Noise Control-Cost-Benefit Estimating Procedures*, Interim Report N-36 (CERL, January 1978).

Approach

Two construction-site noise models have been developed for this study. The first method considers the construction activity noise as emanating from a relatively small area and radiating considerable distances. An alternative model was developed which computes the average noise level contours around the construction activity. The second model, developed by Dr. Chanaud and his associates, was used to check the first and simpler model. The results indicate that the simpler model is satisfactory for the noise-estimating procedures needed by contractors and cost-estimating procedures needed both by contractors and cost estimators. Both models are discussed in Chapter 2. Details of the second model including computer programs are provided in Appendices A through D.

The basis for the noise-reduction benefit analyses are field noise measurements made by CERL at Fort Hood and Fort Carson. The Fort Hood noise data have been presented in CERL Interim Report N-3.³ The Fort Carson results are discussed in Chapter 3.

Noise-control methods and their associated costs are discussed in Chapter 4, with an emphasis on equipment modifications. Some discussion of the use of barriers and equipment substitution is also included. Detailed discussions of process noise control have been reported in CERL Interim Report N-3.

Chapter 5 contains data which support the development of Table 6 of the companion manual. Detailed equipment and operating costs are provided for the scenarios used in the estimating manual. The chapter concludes with a discussion of the actual phases and cumulative costs observed at Fort Hood. A computation of feasible equipment noise control, if applied there, discloses that increased construction costs would amount to less than 1 percent for a 10-decibel reduction in construction-site noise.

Conclusions are provided in Chapter 6. A reference list is also included and contains all the documents used in developing this report plus some additional reports which may be of interest.

³P. D. Schomer, et al., *Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing*, Interim Report N-3/ADA028922 (CERL, July 1976).

Appendix E contains equipment models, their noise levels, and other miscellaneous information. Appendix F presents an alternative cost estimating procedure; it is very detailed and is based on construction trade documents.

Mode of Technology Transfer

This report provides background information to a companion report, *Construction-Site Noise Control Cost-Benefit Estimating Procedures*, Interim Report N-36 (CERL, December 1977). Information in the companion report can be disseminated by OCE as a Technical Bulletin.

2 CONSTRUCTION-SITE NOISE MODELS

Basic Model

The model used in this study is similar to one developed for the U.S. Environmental Protection Agency (EPA). Use of the model yields an estimation of the average sound level, L_{eq} , emitted from a construction site. The model is simple to use and reasonably accurate. With the model, one may evaluate the noise emitted from construction sites as a result of construction equipment operating at present noise levels or future quieted levels.

Required Equipment Data

To apply the model, the following data must be known:

1. **Equipment Schedule**—A list of the types and numbers of equipment used during each construction scenario
2. **Equipment Noise Levels**—Noise levels for each equipment type used are needed. The maximum A-weighted sound level produced by the equipment and the distance at which the measurements were made
3. **Usage Factors***—The fraction of time the equipment is operated in its noisiest mode.

*For example, the usage factor relates to the time a backhoe is digging with its engine at full load and producing near-maximum noise levels. It does not relate only to the time of instantaneous high noise produced by extraneous noise sources such as blade-to-rock impact (Figure 1).

In the course of a typical work cycle, construction equipment spends part of its cycle idling or preparing to perform a task. During some part of its work cycle, the level of the noise the machine emits is higher than at any other time. Since L_{eq} is an average value representing the total sound energy emitted during the period of interest, the maximum sound level and the duration of maximum noise as a fraction of the total period must be known to determine the equivalent (energy average) sound level emitted by the machine during a total work period: for example, a typical work day. The fraction of this period that the equipment operates in its noisiest mode is designated as the Usage Factor (UF). The usage factor is considered to be the product of two component elements, an operating factor (F_1) and a utilization factor (F_2); $UF = F_1 \times F_2$. The operating factor is that portion of the typical work cycle during which the equipment emits its maximum noise. This factor is illustrated in Figure 1 where $F_1 = T_1/T_2$. Three possible time-varying modes of equipment noise emission are possible.

Mode 1: The equipment works cyclically; for example, a backhoe or front-end loader may generate maximum sound while trenching but significantly less sound while using its loader.

Mode 2: The equipment moves throughout the site.

Mode 3: An operation is performed sporadically, possibly only once during the observation period.

The utilization factor is that portion of the work period (e.g., 8-hr work day) that the equipment is on the site and is being used. Thus, the utilization factor considers the number of work cycles for the equipment

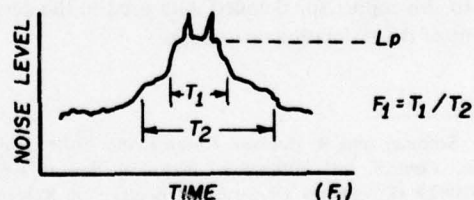


Figure 1. Operating factor (F_1) of determination of T_1 .

during typical operations over the work period. Figure 2 illustrates possible time histories applicable to each mode. The utilization factor is then multiplied by the operating factor to yield the usage factor.

Stationary equipment may not be operating, may be idling while other preparatory activities are in process, or may be operating at full load (and maximum noise level). These operations may be repeated often during a typical construction day.

Mobile equipment may be operating at maximum noise levels for a short duration; an example is a front-end loader while loading. The equipment (the loader) may travel a considerable distance to place this load. At a receiver, sound levels drop significantly as the loader leaves the scene even though the source noise level has not diminished.

Operating factors and utilization factors are best determined from measurements at a construction site where operations similar to those at the site under study are occurring. Data on usage factors for various construction sites are sparse.

Description of Model

Construction-site noise levels are estimated for each construction phase of activity. The construction-site noise is calculated by adding applicable construction equipment average noise levels and extrapolating these levels to the locations of interest.

If the major dimensions of the construction area are small compared to the distance from the site to the noise-sensitive land-use area considered (in a 1:5 ratio), the noise produced by the equipment can be assumed to be emanating from a point at the center of the site. The noise from all the equipment is normalized to a common distance and then summed as:

$$L_{eq} = 10 \log \sum_i^n UF_i \times N_i \times 10^{L_{Pi}/10}$$

where

L_{eq} = average noise level of all equipment

UF_i = usage factor of equipment type i

N_i = number of units of equipment type i

L_{Pi} = maximum sound level of equipment type i .

The resulting sound level is then extrapolated to the site boundary or various noise-sensitive land-use areas assuming hemispherical spreading.

For large sites which cannot be treated as point sources, the average noise level for each equipment unit must be individually extrapolated to the land-use area considered, and the resulting average sound levels (L_{eq}) are then added to obtain the total value.

These procedures are even further complicated if the equipment moves appreciable distances on the site, as is the case for dump trucks or earth-moving equipment which transfer material from one location to another. If the equipment path length is comparable to the distance from the noise source to the observer, then the construction operation cannot be considered stationary. Equipment movement can be classified into several categories.

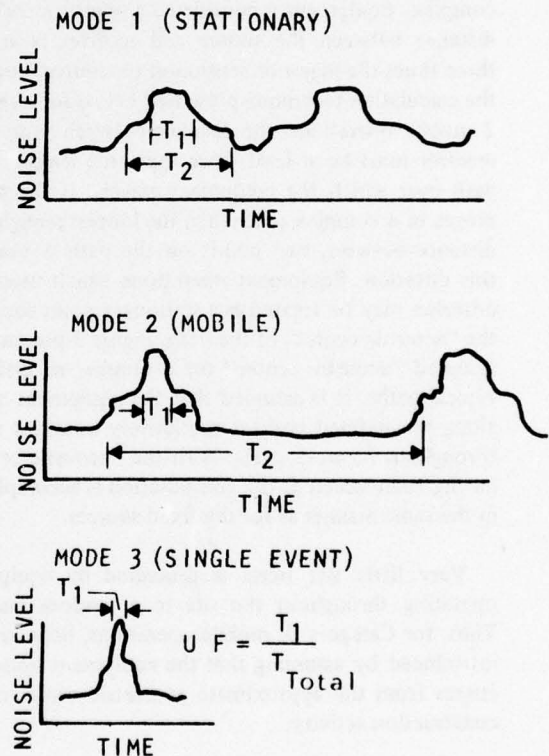


Figure 2. Usage factor—examples of the evaluation of F_1 and UF .

Category 1: Equipment moves from one point on a site to another. The transit time is short and the equipment spends most of its time stationary.

Category 2: Equipment moves in a simple, predictable pattern from one point on the site to another. The equipment spends the majority of its time moving.

Category 3: Equipment moves in a random or complex path, spending part of the time in motion and part of the time stationary.

The first category is dealt with by assuming that the equipment spends all of its time at different site locations. Transit time is ignored. The equipment is considered individually for each location at which it operates. The equipment usage factor is adjusted to reflect the operations at the separate locations. A separate usage factor is used for subsequent calculations for each location.

Calculations for Category 2 are somewhat more complex. Equipment is considered a point source if the distance between the source and receiver is at least three times the major dimension of the source. To apply the calculation technique presented below for Category 2 mobile operations, the distance between source and receiver must be at least three times the length of the path over which the equipment travels. If the source moves in a complex path, then the longest straight-line distance between two points on the path is used for this criterion. Equipment operations which meet this criterion may be treated as a stationary point source at the "acoustic center" of the path. Figure 3 presents the assumed "acoustic center" for a number of different typical paths. It is assumed that the equipment moves along the defined path at a relatively constant speed throughout its work cycle. With the "acoustic center" having been selected, the computation is accomplished in the same manner as for the fixed sources.

Very little site noise is generated by equipment operating throughout the site in a random manner. Thus, for Category 3, mobile operations, little error is introduced by assuming that the equipment noise emanates from the approximate geometric center of the construction activity.

Computer Models

Alternative construction-site noise models were developed. These models calculate noise contours of equal equivalent energy levels (L_{eq}) equal to 55 and 65 dB. There are five models, each based on progressively sim-

pler equations and more assumptions. Model 1 is a base model where L_{eq} is expressed as a function of any number of vehicles and vehicular paths. Model 2 is a simplification of Model 1 in which the motion of each vehicle is represented by its mean position. Model 3 assumes that each vehicle is a point source radiating noise at the acoustical center of the site. Model 4 further simplifies construction noise by representing the time-varying characteristics of noise emitted from each vehicle by the maximum sound level and vehicle usage factor. This model is similar to the basic construction-site model discussed in Chapter 2. Model 5 is a modification of Model 1 which includes the effects of attenuation by barriers. These models and their governing equations are discussed in Appendix A. To simplify the computational procedure required of each model, computer programs were developed and are listed in Appendix B. The accuracy of replacing vehicle motions by single point sources is discussed in Appendix C. Equations used in the computation of barrier effects and their applicability are discussed in Appendix D.

3 CONSTRUCTION-SITE NOISE MEASUREMENTS

Much of the procedure presented in the companion manual is based on data acquired at construction sites located on two Army military bases: Fort Hood, TX, and Fort Carson, CO. Data relating to the construction of 1000 family housing units at Fort Hood can be found in CERL Interim Report N-3.⁴ Data on the construction of barracks at Fort Carson are presented below.

Measurement Locations

Noise levels were measured at eight locations near different construction activities. The locations and the construction activities are presented in Table 1. A map of these locations is shown in Figure 4. A list of the construction equipment at each location and their noise data are presented in Table 2. Sound-level measurements at Fort Carson were chosen to minimize the number of measurements acquired while maximizing the information obtained. Each measurement location was at the boundary of a work area (or at a similar location) at which a particular construction phase was in progress.

⁴P. D. Schomer, et al., *Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing*, Interim Report N-3/ADA028992 (CERL, 1976).

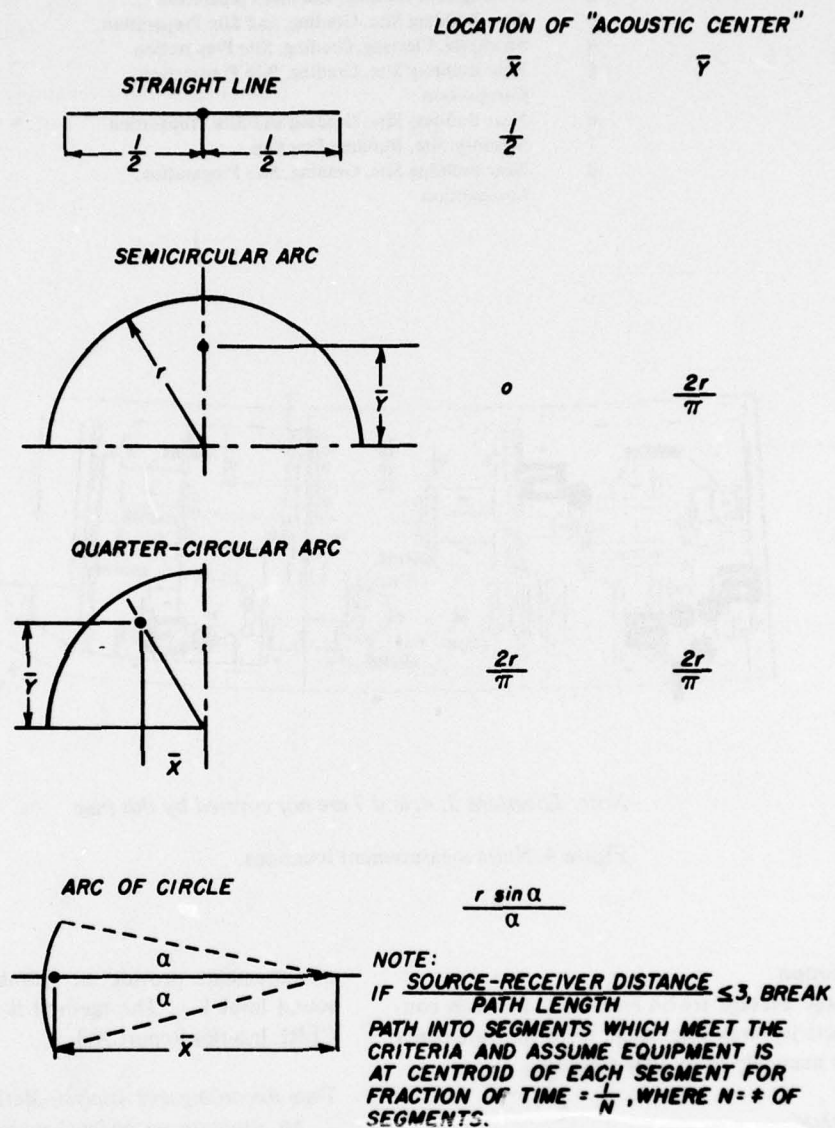
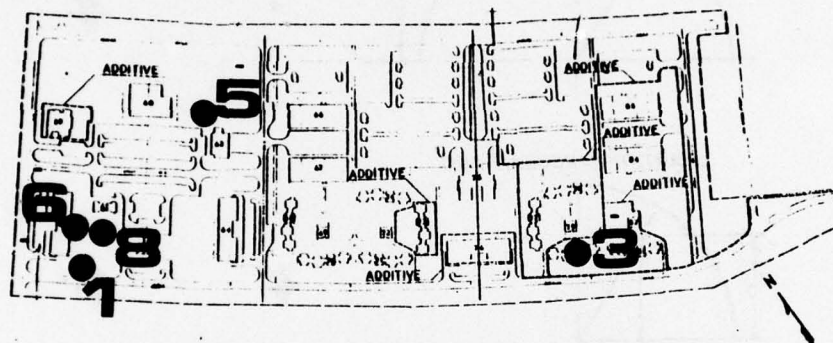


Figure 3. Location of acoustic center.

Table 1
Description of Measurement Locations
at Fort Carson Construction Site

Location	Activity
1	Sewer Construction, Backfill, and Compaction
2	Parking Lot, Grading, and Site Preparation
3	Near Building Site, Grading, and Site Preparation
4	Stockpile, Clearing, Grading, Site Preparation
5	Near Building Site, Grading, Site Preparation, Compaction
6	Near Building Site, Grading and Site Preparation
7	Masonry Site, Building Erection
8	Near Building Site, Grading, Site Preparation, Compaction



Note: Locations 2, 4, and 7 are not covered by this map.

Figure 4. Noise measurement locations.

Data Acquisition

The energy average sound level, L_{eq} , for each construction activity was calculated from measurements made either manually or by tape recording.

Manual Method

The procedures for measurement of construction-site boundary sound levels were those recommended by the Society of Automotive Engineers (SAE).⁵ The

measurements provide an estimate of the equivalent sound level L_{eq} . The method is described in detail in CERL Interim Report N-3.

Tape Recording and Analysis Method

An alternate sound-level measurement and analysis procedure consists of recording the sound on magnetic tape. Such measurements were conducted simultaneously with the manual acquisition of data. This method is also described in CERL Interim Report N-3.

Results

A summary of the measured equivalent sound level at each work area is presented in Table 3. Comparison

⁵SAE Recommended Practice: Measurement Procedure for Determining a Representative Sound Level at a Construction Site Boundary Location, Draft 6 (Society of Automotive Engineers, 1975).

Table 2
Estimated Energy Equivalent Sound Level at Various Locations—Fort Carson

Location No.	Type of Equipment	Equipment Model Name and/or No.	Maximum Sound Level dBA @ 50 ft (15 m)	Operating Factor	Equivalent Sound Level Leq (dB) @ 50 ft (15 m)
1	Backhoe	Drott 50	84	.29	78.6
	Front-End Loader	CAT 988	88	.10	78.0
	Tamper	Koehring D1000	96	.55	93.0
2	Scraper (2)	CAT 633C	86	.35	84.0
	Grader		88	.32	83.0
	Water Truck		89	.19	82.0
3	Bulldozer	CAT D8H	83	.15	75.0
	Grader	CAT 120	84	.34	79.0
	Grader	CAT 12F	93	.29	88.0
	Scraper	JD 860A	76	.14	67.0
	Backhoe	Koehring 466	80	.21	73.0
4	Scraper (3)	JD 860A	89	.33	89.0
	Scraper (2)	CAT 633C	86	.35	81.0
	Water Truck		89	.19	82.0
	Pick-Up Truck	Ford	—	—	—
5	Scraper	JD 860A	88	.43	84.0
	Grader	CAT 12F	83	.19	76.0
	Dozer	CAT D8H (with sheepsfoot)	96	.12	87.0
	Water Truck		—	—	—
6	Grader	CAT 12F	83	.74	82.0
	Scraper (2)	CAT 633C	86	.19	82.0
	Dozer	CAT D8H (with sheepsfoot)	96	.70	94.0
	Water Truck		89	.04	75.0
7	Forklift	White	—	—	—
	Forklift	Warner and Swasey 1200	—	—	—
	Saw	Clipper Bricksaw-matic	—	—	—
	Saw	Cardinal Concrete Saw	82	.20	75.0
	Portable Air Compressor	Leroi Dresser 160	—	—	—
	Front-End Loader	Vermeer Dutchman	80	.28	74.0
8	Scraper (3)	JD 860A	88	.43	89.0
	Scraper (2)	CAT 6336	86	.19	82.0
	Grader	CAT 120	84	.90	84.0
	Grader	CAT 12F	83	.74	82.0
	Dozer	CAT D8H	96	.70	94.0
	Compactor	CAT 815	—	—	—
	Water Truck		89	.04	75.0

Table 3
Summary of Equivalent Sound Levels Calculated from
Measured Sound Data at Representative Site Boundary
Locations, Fort Carson, CO

Location	Calculated L_{eq} (dB)		
	SAE Procedure	Computer Controlled Analysis Procedure	Construction Noise Model
1	73.0	72.3	72.0
2	62.3	64.0	67.0
3	72.7	74.5	73.0
4	59.9	61.6	66.0
5	71.4	70.4	70.0
6	71.2	73.1	75.0
7	68.4	64.9	67.0
8	74.3	74.2	79.0

of results from the SAE and tape-recording measurement procedures reveals that most of the L_{eq} values obtained by both methods agree to within ± 2 dB. At location 7, the agreement is within 4 dB. The discrepancies between the equivalent sound levels from the two methods are greatest when the construction activity produces noise which is impulsive in nature, such as hammering and sawing. The agreement between the L_{eq} calculated by the two procedures is best when the construction activities produce relatively constant sound levels, such as grading or earth removal.

The measured results compared with values calculated using the construction-site noise model. (The model is described in Chapter 2.) The results are presented in Table 3. The comparison indicates that L_{eq} values calculated from the construction-site model are within ± 5 dB of the values obtained by tape recording.

Equipment Cost

The cost of specific construction equipment used at the eight Fort Carson sites is listed in Table 4. These costs were used as baseline information in the development of the cost-benefit estimating manual. They were estimated from information contained in the U.S. Army Corps of Engineers North Pacific Division's Equipment Ownership and Operating Expense Schedule.

4 NOISE-CONTROL METHODS AND ASSOCIATED COSTS

For construction activities near residential areas and other noise-sensitive land uses, construction noise should be kept to levels as low as possible. Construction noise

can be reduced by either using quieter construction equipment or employing other noise-control methods. The most commonly used noise-control methods are:

1. Equipment Modification
2. Noise-Control Barrier Installation
3. Equipment Substitution
4. Scheduling.

Use of one of the above methods to limit construction-site noise is an additional cost to the construction project. The added cost for each noise-control method is almost proportional to the amount of noise reduction needed. The cost associated with each noise-control method is discussed in the following sections.

Equipment Noise Control

Survey of Manufacturers

Equipment manufacturers were contacted by letter (by Dames and Moore) and asked to provide noise-control and related cost data. Twenty-eight manufacturers were contacted for the 64 different pieces of equipment present at the Fort Hood and Fort Carson construction sites. Information on similar and easily interchangeable equipment was also requested. Requests for additional information were also sent to manufacturers contacted previously during the preparation of CERL Interim Report N-3. A list of the manufacturers is given in Table 5. A copy of the letter sent appears in Figure 5. An equipment noise-control cost data sheet was prepared to assist manufacturers in providing the requested information. A copy of the data sheet is presented in Figure 6.

Table 4
Measurement Locations, Phases of Construction, and Equipment Present
at Fort Carson Housing Construction Site

Location No.	Description	Phase of Construction	Type of Equipment	Equipment Model Name and/or No.	Estimated Equipment Cost/Unit (\$)
1	Sewer Construction by Building 58	Backfilling, Compaction	Backhoe	Drott 50	35,000
			Front-End Loader	CAT 988	175,000
			Hand Tamper	Koehring	1,200
2	Parking Area	Grading, Site Preparation	Scraper (2)	Cat 633C	235,000
			Grader		50,000
			Water Truck		129,400
3	Fill Site by Building 81	Grading, Site Preparation	Bulldozer	CAT D8H	130,000
			Grader	CAT 120	50,000
			Grader	CAT 12F	61,000
			Scraper	JD 860A	94,500
			Backhoe	Koehring 466	80,000
4	Stockpile	Clearing, Grading, Site Preparation	Scraper (3)	JD 860A	94,500
			Scraper (2)	CAT 633C	235,000
			Water Truck		129,400
			Pick-up Truck	Ford	5,000
5	Fill Site by Building 60	Grading, Site Preparation	Scraper	JD 860A	94,500
			Grader	CAT 12F	61,000
			Bulldozer (with sheepsfoot roller)	CAT D8H	130,000
			Water Truck		129,400
6	Fill Site by Building 58	Grading, Site Preparation, Compaction	Grader	CAT 12F	61,000
			Scraper (2)	CAT 633C	235,000
			Bulldozer (with sheepsfoot roller)	CAT D8H	130,000
			Water Truck		129,400
7	Masonry Site	Erection	Forklift	Warner and Swasey 1200	25,000
			Forklift	White	25,000
			Saw	Clipper Bricksaw-matic	
			Saw	Cardinal Concrete Saw M352E	
			Portable Air Compressor	Leroi Dresser 160	8,000
8	Fill Site by Building 58	Grading, Site Preparation, Compaction	Front-End Loader	Vermeer Dutchman	30,000
			Scraper (3)	JD 860A	94,000
			Scraper (2)	CAT 633C	235,000
			Grader	CAT 120	50,000
			Grader	CAT 12F	61,000
			Bulldozer	D8H	130,000
			Compactor	CAT 815	70,000
			Water Truck		129,400

Table 5
List of Manufacturers Contacted

Mr. W. E. Bueche
Allis-Chalmers
P.O. Box 512
Milwaukee, Wisconsin 53201

Mr. Ray C. Broce, President
Broce Manufacturing Company
S. Highway
Box 580
Dodge City, Kansas 67801

Mr. D. D. Lipson, Sales Manager
Cardinal Engineering Corp.
100 Barren Hill Road
Conshohocken, Pennsylvania 19428

Mr. David Abbott, Vice President
and General Manager
J.I. Case Company
700 State Street
Racine, Wisconsin 53404

Mr. D. P. Burks, General Manager
Drott Manufacturing Company
Division of J.I. Case Company
Box 1087
Warsaw, Wisconsin 54401

Mr. David E. Starcher
Vibramax Corporation
Division of J.I. Case Company
5324 Distributor Drive
Richmond, Virginia 23225

Mr. Walter Tempas
Sales Engineering AB2C
Caterpillar Tractor Company
Peoria, Illinois 61629

Mr. J. E. Hall
Challenge-Cook Brothers, Inc.
15421 E. Gale Avenue
Industry, California 91745

Mr. James C. Huntington, Jr.
Clarke Equipment Company
P.O. Box 31
Buchanan, Michigan 49107

Mr. Robert J. Gerstenberger,
Vice President
Deere & Company
John Deere Road
Moline, Illinois 61265

Mr. L. E. Elliott, Products Manager
LeRoi Division, Dresser Industries
320 Russell Road
Sidney, Ohio 45365

Mr. V. T. Ward, General Manager
Dumont Machinery, Ltd.
163 Carlingview Drive
Rexdale, Ontario, Canada

Mr. L. H. Hobson, Customer Service Manager
Essick Manufacturing Company
1950 Santa Fe Avenue
Los Angeles, California 90021

Mr. Ralph E. Keidel
Euclid, Inc.
22221 St. Clair Avenue
Cleveland, Ohio 44117

Mr. Frank J. Strand, Assistant to the
President and Technical Director
FMC Corporation, Crane and Excavation
Division
1201 Sixth Street, S.W.
Cedar Rapids, Iowa 52406

Mr. Robert D. Strawser, President
Hyster Company
Construction Equipment Division
Box 289
Kewanee, Illinois 61443

Mr. Joseph A. Windel, Vice President
Ingersoll-Rand
200 Chestnut Ridge Road
Woodcliff Lake, New Jersey 07075

Mr. John W. Barnett, Vice President
Ingram Manufacturing Company
P.O. Box 2020
San Antonio, Texas 78297

Mr. J. L. Adams, Vice President
International Harvester Company
Pay Line Division, Construction Equipment
Sales
600 Woodfield Avenue
Schaumburg, Illinois 60172

Mr. Orville R. Mertz, President
Koehring Company
780 North Water Street
Milwaukee, Wisconsin 53201

Mr. Ken Handa
Komatsu-American Corp.
555 California Street
San Francisco, California 94104

Mr. G. E. Willis
The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117

Table 5 (Cont'd)
List of Manufacturers Contacted

Mr. K. M. Ligare, Sales Manager Miller Electric Manufacturing Co. 718 S. Bounds Street Appelton, Wisconsin 54911	Mr. J. B. O'Keefe Thomas Equipment, Ltd. Box 130 Centerville, NB, Canada
Mr. Frederick W. Dalton, President Poclain 3401 Tidewater Trail Fredericksburg, Virginia 22401	Mr. Klaus Wacker, Executive Vice President Wacker Corporation 3808 West Elm Street Milwaukee, Wisconsin 53209
Mr. Alan J. Stone, President Stone Construction Equipment, Inc. 32 E. Main Street Honeoye, New York 14471	Mr. R. N. Franz, Vice President Worthington Compressors, Inc. Construction Equipment Division 57 Appleton Street Holyoke, Massachusetts 01040

These contacts were followed up by telephone calls to confirm data received and to request additional information. Approximately 75 percent of the manufacturers contacted responded to the requests. A summary of the responses, presented in Table 6, indicates that costs of noise control are not readily available from manufacturers. Most manufacturers produce noise-control features as standard equipment. The cost of these features on new machinery cannot be easily isolated from the cost of other improvements. In addition, only a limited number of equipment items are available with optional noise control features for which noise-control costs are directly related to the purchase price.

Published Data

Most of the construction equipment at Fort Hood and Fort Carson can be grouped into four categories: (1) trucks, (2) wheel and crawler tractors, (3) pneumatic impact tools, and (4) air compressors.

In its program to regulate construction noise, the EPA conducted extensive studies on the technology and economics of quieting construction equipment in these categories. As a result of these studies, data on noise control methods and their costs for these types of construction equipment were published. These data were based on literature searches, manufacturers surveys, inquiries, and other communications with the industry.

Trucks. This category of construction equipment includes diesel- and gasoline-powered heavy and medium trucks, concrete mixers, water trucks, and dump trucks.

Studies conducted by International Harvester⁶ have indicated that the primary noise sources of trucks are the cooling fan and the exhaust system. For a truck passby noise level of 88 dBA at 50 ft (15 m), the noise contribution from each noise-generating component is as follows:

Noise Sources	Noise Level (dBA)
Cooling fan	86
Exhaust system	83
Engine	78
Air intake	73
Others	71

The estimated costs of quieting trucks to meet levels of 81 dBA, 78 dBA, 76 dBA, and 73 dBA are presented in Table 7. The percent increase in truck prices required if gasoline and diesel trucks were to meet these levels is presented in Table 8.

Wheel and Crawler Tractors. The basic construction equipment in this machine category are dozers and loaders. These tractors, when equipped with different attachments such as dozer blades, loader buckets, leg clamps, backhoes, rippers, block tines, side booms, and forklifts, may be converted into dozers, loaders, graders, backhoes, scrapers, shovels, or other equipment.

⁶E. E. Landis, *International Harvester's Approach to Diesel Truck Noise Reduction*, paper presented at the National Conference on Noise Control Engineering, October 15 to 17, 1973.

July 14, 1976

Mr. W. E. Bueche
Allis-Chalmers
P.O. Box 512
Milwaukee, Wisconsin 53201

Dear Mr. Bueche:

Thank you for your response to our inquiry of February 12, 1975. Dames & Moore has again been retained by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) to further study the cost-benefit of construction equipment noise control as it relates to construction site noise. We have developed a model of construction site noise which utilizes construction equipment sound levels and usage factors. Our desire, at the end of the study, is to obtain information on the cost of reducing site sound levels by

- a) reducing equipment sound levels,
- b) changes in the construction process.

We are directing our efforts to family housing construction being undertaken at Fort Hood, Texas and Fort Carson, Colorado. Field measurements are being made there and compared with engineering analysis.

The following list of Allis-Chalmers equipment are operated at Fort Hood and Fort Carson construction sites:

Scraper 260B
Grader M65
Backhoe 918
Bulldozer 7G

We would appreciate any information you could forward us on present sound levels, feasible future quieted sound levels, and the estimated added cost to the purchaser or leaser of this quieted equipment and other easily interchangeable equipment.

We have prepared an equipment information sheet to assist you in responding with the needed data. We would very much appreciate your completing the information sheet for equipment indicated above and other similar equipment. We would also appreciate your sending us any related sales brochures. If you have any questions, please do not hesitate to contact us at 201-272-8300.

Your earliest assistance in this matter would be greatly appreciated.

Very truly yours,

DAMES & MOORE

Brown K. Yue
Project Manager

BKY/kb
Att.
cc: Dr. P. Schomer-CERL

Figure 5. Sample of letter sent to manufacturer.

EQUIPMENT INFORMATION SHEET

1. Equipment name: _____
2. Model No: _____
3. Principal use: _____

4. Suggested retail price: _____

5. Equipment Sound Level
Describe test procedure and mode of operation: _____

Sound level is _____ dBA @ _____ feet.

6. List noise control devices included as standard equipment
e.g. muffler, etc.

- a. _____
- b. _____
- c. _____
- d. _____
- e. _____

7. List optional noise control equipment available (e.g. engine shroud, etc.) and additional price.

<u>Optional Equipment</u>	<u>Price</u>
a. _____	_____
b. _____	_____
c. _____	_____
d. _____	_____
e. _____	_____

8. Indicate sound levels of the product with optional noise control equipment (if available).

<u>Equipment</u>	<u>Sound level (dBA)</u>
a. _____	_____ feet
b. _____	_____ feet
c. _____	_____ feet
d. _____	_____ feet
e. _____	_____ feet

Describe test procedure for above measurements. _____

Preparer _____

Telephone No. _____

Figure 6. Data response sheet provided to manufacturers surveyed.

Table 6
Summary of Responses From Manufacturers Survey

Manufacturer	Type of Response*	Equipment Name	Model No.	Price (\$)	Sound Level (dBA)	Standard Noise Control Devices	Optional Noise Control Equipment	
							Type	Noise Level with Optional Equipment
Allis-Chalmers Broce Cardinal Essick	1	Backhoe	918	28,500	81 @ 50 ft (15 m)	Muffler		
	2	Broce Broom	D18	8,450				
	2	Concrete Saw	M352E					
	3	Tamper Roller	VR30W	3,795				
Euclid	1	Dump Truck	R22	79,800	84 @ 50 ft (15 m)	Muffler Muffler	Thermatic Fan Insulated Engine Enclosure Special Exhaust System	900 2,100 500 <80 @ 50 ft (15 m)
Hyster	3	Vibratory Soils Compactor	C610A	27,370	92 @ 23 ft (7 m)	Muffler Air Cleaner Engine Enclosure Muffler		
International Harvester	1	Backhoe	3600A	29,780	79 @ 50 ft (15 m)	Muffler		
International Harvester	1	Cement Mixer	Paystar 5000		86 @ 50 ft (15 m)	Muffler	Larger Muffler, Engine & Chassis Shields	450 83 @ 50 ft (15 m)
Miller Electric	1	Arc Welder	Big 40	2,592		Air Cleaner	Above plus - Encapsulated Engine Muffler	2,150 80 @ 50 ft (15 m)
Poclain	2	Backhoe	100	73,310	85 @ 50 ft (15 m)	Muffler Housing around Engine Engine Sound Insulated	Low Level Noise Muffler Kit	14.30 57.60 80 @ 50 ft (15 m) 73 @ 50 ft (15 m)
Stone	2	Compactor	1845	829				
Ingersoll-Rand	1	Portable Air Compressor	DRRF160	11,180	99 @ 3 ft (.9 m)	Muffler	Silencing Kit	560 92 @ 3 ft (.9 m) 83 @ 23 ft (7 m)
					87 @ 23 ft (7 m)	Side Doors	Residential Muffler	Included
							Pan & Muffler on blowdown valve	Included
Worthington	1	Air Compressor	160 Diesel	10,395	102 @ 4 ft (1 m)	Shrouding Muffler Acoustical Lining Acoustical Wrap	Kit	578 93 @ 3 ft (.9 m)

*1 - Returned Questionnaire
2 - Equipment Specification
3 - Both

Table 6 (Cont'd)
Summary of Responses From Manufacturers Survey

Manufacturer	Type of Response*	Equipment Name	Model No.	Price (\$)	Sound Level (dBA)	Standard Noise Control Devices	Optional Noise Control Equipment		
							Type	Price (\$)	Noise Level with Optional Equipment
Worthington	1	Air Compressor	160 Gas	8,155	100 @ 4 ft (1 m)	Shrouding Muffler	Kit	578	93 @ 3 ft (.9 m)
Fiat-Allis	3	Scraper	260B	118,000	80 @ 50 ft (15 m)	Acoustical Lining	Kit	1,161	85 @ 3 ft (.9 m)
Fiat-Allis	3	Grader	M65	23,000	80 @ 23 ft (7 m)	Muffler	Cab Sound Kit	1,155	88 @ 50 ft (15 m)
Fiat-Allis	3	Loader	76			Muffler			
Fiat-Allis	3	Backhoe	981						
Challenge-Cook	3	Truck Mixer	M6002	14,075					
Ingram	3	Flat Roller	12-ton 3-wheel	23,500					
					77 @ 50 ft (15 m) ^{a†}	Muffler			
					74 @ 50 ft (15 m) ^b	Air Cleaner			
						Engine Enclosure			
Ingram	3	Roller	9-2800P	13,500	83 @ 50 ft (15 m) ^c	Muffler			
					79 @ 50 ft (15 m) ^d	Air Cleaner			
						Engine Enclosure			
Le Roi Dresser	3	Air Compressor	160RG1E	7,200	101.2 @ 1 m	Muffler	Residential Muffler	189	95.6 @ 3 ft (.9 m)
Koehring	3	Hand Tamper	T100D	1,198	88 @ 50 ft (15 m)	Housing			
Koehring	3	Backhoe	466D		86 @ 50 ft (15 m)	Fan Shroud	Muffler Kit	50	83 @ 50 ft (15 m)
						Exhaust Deflector			
						Exhaust System			
						Air Intake			
Koehring	3	Backhoe	666D		83 @ 50 ft (15 m)	Engine Assembly			
						Insulation			
						Exhaust System			
						Air Intake			
						Engine Assembly			
						Insulation			
Koehring	3	Trencher	77						
John Deere	2	Loader	JD755						
John Deere	2	Bulldozer	JD750						
John Deere	2	Backhoe Loader	JD310-A						
John Deere	2	Backhoe Loader	JD410						
John Deere	2	Backhoe Loader	JD510						
John Deere	2	Backhoe Loader	JD500-C						
John Deere	2	Utility Tractor	JD301-A						

*1 - Returned Questionnaire
2 - Equipment Specification
3 - Both

†a - 8 mph
b - 3 mph
c - 15 mph
d - 5 mph

Table 6 (Cont'd)
Summary of Responses From Manufacturers Survey

Manufacturer	Type of Response*	Equipment Name	Model No.	Price (\$)	Sound Level (dBA)	Standard Noise Control Devices	Optional Noise Control Equipment		
							Type	Price (\$)	Noise Level with Optional Equipment
John Deere	2	Utility Tractor	JD300B						
John Deere	2	Utility Tractor	JD302						
John Deere	2	Utility Tractor	JD302-A						
John Deere	2	Utility Tractor	JD401B						
John Deere	2	Utility Tractor	JD401C						
John Deere	2	Forklift	JD380						
John Deere	2	Forklift	JD480B						
John Deere	2	Loader	JD544B						
John Deere	2	Loader	JD644B						
John Deere	2	Excavator	JD690B						
John Deere	2	Scraper	JD762						
John Deere	2	Scraper	JD860A						
John Deere	2	Motor Grader	JD570A						
John Deere	2	Motor Grader	JD670						
John Deere	2	Motor Grader	JD770						
John Deere	2	Crawler	JD350C						
John Deere	2	Crawler	JD450C						
John Deere	2	Bulldozer	JD550						
John Deere	2	Loader	JD555						
John Deere	2	Loader	JD14						
John Deere	2	Loader	JD24						
John Deere	2	Compactor	JD646B						
John Deere	2	Bulldozer	JD350C						
Caterpillar	3	Grader	12G	61,000	85.5 @ 50 ft (15 m)	Quieted Power Train			
Caterpillar	3	Grader	14G	83,000	81.5 @ 50 ft (15 m)	Low Speed Engine Fan Muffler			
Caterpillar	3	Dozer	977L			Rubber Mounted Hydraulic Pump			
Caterpillar	3	Dozer	D-6C	82,000	83.5 @ 50 ft (15 m)	Hood, Side Door			
Caterpillar	3	Dozer	D-8K	66,000	84 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Front End Loader	930	130,000	88.5 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Front End Loader	950	45,000	86.5 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Front End Loader	966C	61,000	86 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Front End Loader	988B	78,000	86 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Backhoe	235	175,000	85 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Scraper	6330	135,000	80 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Compactor	815	235,000	86.5 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Grader	120G	70,000	87 @ 50 ft (15 m)	Muffler			
Caterpillar	3	Grader		50,000	83.5 @ 50 ft (15 m)	Muffler			

*1 - Returned Questionnaire
2 - Equipment Specification
3 - Both

Table 7
Estimated Increase in Prices for Quieted Medium and Heavy Truck

ENGINE MODEL	TRUCK TYPE	Percentage of Total Truck Population	Engine 77 dBA Fan 73 dBA Exhaust 73 dBA Air Intake 72 dBA All Others 70 dBA TOTAL 80.6 dBA						Engine 73 dBA Fan 70 dBA Exhaust 69 dBA OR 69 dBA Air Intake 69 dBA All Others 70 dBA TOTAL 77.5 dBA						Engine 74 dBA Fan 70 dBA Exhaust 69 dBA Air Intake 65 dBA All Others 70 dBA TOTAL 77.5 dBA		
			Fan	Exhaust	Engine	Cab	Air Intake	TOTAL	Fan	Exhaust	Engine	Cab	Air Intake	TOTAL	Fan	Exhaust	TOTAL
Gasoline Medium duty (1)	Medium	55.1%	a1	b1	—	—	—	\$35	a2	b2	—	d1	—	\$180	a3	b2	
75-77 dBA (2)	Heavy	10.2%	\$10	\$25	—	—	—	\$135	\$25	\$50	—	\$100	\$5	\$280	\$50	\$50	
			a1	b1	—	—	—		a2	b2	—	d1	e1		a3	b2	
			\$110	\$25	—	—	—		\$125	\$50	—	\$100	\$5	\$280	\$200	\$50	
Diesel-2 stroke, naturally aspirated Heavy duty Manufacturer A	Heavy	12.0%	a1	b1	—	d1	—	\$290	a2	b2	—	d2	e1	\$685	a3	b2	
78-79 dBA			\$110	\$80	—	\$100	—		\$125	\$155	—	\$400	\$5	\$685	\$200	\$155	
Diesel-4 stroke, naturally aspirated Medium duty Manufacturer B	Medium	0.79%	a1	b1	—	d2	—	\$565	a2	b2	—	d3	e2	\$1010	a3	b2	
83-85 dBA	Heavy	5.21%	\$10	\$55	—	\$500	—	\$665	\$25	\$105	—	\$850	\$30	\$1110	\$50	\$105	
			a1	b1	—	d2	—		a2	b2	—	d3	e2		a3	b2	
			\$110	\$55	—	\$500	—		\$125	\$105	—	\$850	\$30	\$1110	\$125	\$105	
Diesel-4 stroke, turbocharged Heavy duty Manufacturer B	Heavy	6.0%	a1	b1	—	d2	—	\$565	a2	b2	—	d2	e2	\$760	a3	b2	
81-83 dBA			\$110	\$55	—	\$400	—		\$125	\$105	—	\$500	\$30	\$760	\$125	\$105	
Diesel-4 stroke, turbocharged Heavy duty Manufacturer C	Heavy	4.8%	a1	b1	—	d1	—	\$240	a2	b2	—	d1	e2	\$410	a3	b2	
76-78 dBA			\$110	\$30	—	\$100	—		\$125	\$55	—	\$200	\$30	\$410	\$200	\$55	
Diesel-4 stroke, naturally aspirated Medium duty Manufacturer D	Medium	0.29%	a1	b1	—	d1	—	\$165	a2	b2	—	d2	e1	\$635	a3	b2	
80 dBA	Heavy	1.91%	\$10	\$55	—	\$100	—	\$265	\$25	\$105	—	\$500	\$5	\$735	\$50	\$105	
			a1	b1	—	d1	—		a2	b2	—	d2	e1		a3	b2	
			\$110	\$55	—	\$100	—		\$125	\$105	—	\$500	\$5	\$735	\$200	\$105	
Diesel-4 stroke, turbocharged Heavy duty Manufacturer D	Heavy	1.5%	a1	b1	—	d1	—	\$265	a2	b2	—	d1	e2	\$460	a3	b2	
76-78 dBA			\$110	\$55	—	\$100	—		\$125	\$105	—	\$200	\$30	\$460	\$200	\$105	
Diesel-2 stroke, 12 cylinder Heavy duty Manufacturer A	Heavy	0.9%	a1	b1	—	d1	—	\$390	a2	b2	—	d2	e1	\$785	a3	b2	
79-81 dBA			\$110	\$80	—	\$200	—		\$125	\$155	—	\$500	\$5	\$785	\$200	\$155	
Diesel-4 stroke, naturally aspirated Medium duty Manufacturer E	Medium	0.10%	a1	b1	—	d1	—	\$140	a2	b2	c1	d1	e1	\$460	a3	b2	
78-79 dBA	Heavy	0.67%	\$10	\$30	—	\$100	—	\$240	\$25	\$55	\$175	\$200	\$5	\$560	\$50	\$55	
			a1	b1	—	d1	—		a2	b2	c1	d1	e1		a3	b2	
			\$110	\$30	—	\$100	—		\$125	\$55	\$175	\$200	\$5	\$560	\$200	\$55	
Diesel-4 stroke, naturally aspirated Heavy duty Manufacturer C	Heavy	0.47%	a1	b1	—	d1	—	\$240	a2	b2	c1	d1	e1	\$560	a3	b2	
78-79 dBA			\$110	\$30	—	\$100	—		\$125	\$55	\$175	\$200	\$5	\$560	\$200	\$55	
Diesel-4 stroke, naturally aspirated Heavy duty Manufacturer F	Heavy	0.225%	a1	b1	—	d1	—	\$265	a2	b2	c1	d1	e1	\$635	a3	b2	
78-79 dBA			\$110	\$55	—	\$100	—		\$125	\$105	\$200	\$200	\$5	\$635	\$200	\$105	
Diesel-4 stroke, naturally aspirated Medium Duty Manufacturer G	Medium	0.02%	a1	b1	—	d1	—	\$165	a2	b2	c1	d1	e1	\$485	a3	b2	
78-79 dBA	Heavy	0.15%	\$10	\$55	—	\$100	—	\$265	\$25	\$105	\$150	\$200	\$5	\$585	\$50	\$105	
			a1	b1	—	d1	—		a2	b2	c1	d1	e1		a3	b2	
			\$110	\$55	—	\$100	—		\$125	\$105	\$150	\$200	\$5	\$585	\$200	\$105	
Diesel-4 stroke, turbocharged Heavy duty Manufacturer H	Heavy	0.015%	a1	b1	—	—	—	\$140	a2	b2	—	d1	e1	\$285	a3	b2	
75 dBA			\$110	\$30	—	—	—		\$125	\$55	—	\$100	\$5	\$285	\$200	\$55	

- (1) Medium Duty and Heavy Duty refer to the severity of service for the engine, not to the weight class of the truck.
- (2) Engine levels are for engines inside the truck as measured according to SAE J366b test procedure.

AVERAGES

Medium Gasoline = \$35
Heavy Gasoline = 135
Medium Diesel = 426
Heavy Diesel = 387

AVERAGES

Medium Gasoline = 180
Heavy Gasoline = 280
Medium Diesel = 865
Heavy Diesel = 715

*Background Document for Medium and Heavy Truck Noise Emission Regulations, EPA-550/9-76-008 (U.S. Environmental Protection Agency [EPA], March 1976).

Table 7

Increase in Prices for Quieted Medium and Heavy Trucks*

Engine 73 dBA 74 dBA Fan 70 dBA 70 dBA Exhaust 69 dBA OR 69 dBA Air Intake 69 dBA 65 dBA All Others 70 dBA 70 dBA TOTAL 77.5 dBA 77.5 dBA						Engine 71 dBA 72 dBA Fan 64 dBA 64 dBA Exhaust 69 dBA 69 dBA Air Intake 65 dBA 65 dBA All Others 70 dBA 65 dBA TOTAL 75.6 dBA 75.1 dBA						Engine 68 dBA Fan 64 dBA Exhaust 65 dBA Air Intake 65 dBA All Others 65 dBA TOTAL 72.6 dBA					
Exhaust	Engine	Cab	Air Intake	TOTAL	Fan	Exhaust	Engine	Cab	Air Intake	TOTAL	Fan	Exhaust	Engine	Cab	Air Intake	TOTAL	
b2 \$50	—	d1 \$100	e1 \$5	\$180	a3 \$50	b2 \$50	c1 \$100	d1 \$100	e2 \$30	\$330	a3 \$50	b3 \$260	—	d2 \$325	e2 \$30	\$665	
b2 \$50	—	d1 \$100	e1 \$5	\$280	a3 \$200	b2 \$50	c1 \$100	d1 \$100	e2 \$30	\$480	a3 \$2000	b3 \$260	—	d2 \$325	e2 \$30	\$815	
b2 \$155	—	d2 \$400	e1 \$5	\$685	a3 \$200	b2 \$155	—	d2 \$500	e2 \$30	\$885	a3 \$125	b3 \$365	—	d3 \$850	e2 \$30	\$1370	
b2 \$105	—	d3 \$850	e2 \$30	\$1010	a3 \$50	b2 \$105	—	d4 \$1075	e2 \$30	\$1260	a3 \$50	b3 \$315	c1 \$275	d4 \$1075	e2 \$30	\$1745	
b2 \$105	—	d3 \$850	e2 \$30	\$1110	a3 \$125	b2 \$105	—	d4 \$1075	e2 \$30	\$1335	a3 \$125	b3 \$315	c1 \$275	d4 \$1075	e2 \$30	\$1820	
b2 \$105	—	d2 \$500	e2 \$30	\$760	a3 \$125	b2 105	—	d3 \$850	e2 \$30	\$1110	a3 \$125	b3 \$315	—	d4 \$1075	e2 \$30	\$1545	
b2 \$55	—	d1 \$200	e2 \$30	\$410	a3 \$200	b2 \$55	—	d2 \$500	e2 \$30	\$785	e3 \$125	b3 \$265	—	d3 \$850	e2 \$30	\$1270	
b2 \$105	—	d2 \$500	e1 \$5	\$635	a3 \$50	b2 \$105	—	d2 \$500	e2 \$30	\$685	a3 \$50	b3 \$315	—	d4 \$1075	e2 \$30	\$1470	
b2 \$105	—	d2 \$500	e1 \$5	\$735	a3 \$200	b2 \$105	—	d2 \$500	e2 \$30	\$835	a3 \$125	b3 \$315	—	d4 \$1075	e2 \$30	\$1545	
b2 \$105	—	d1 \$200	e2 \$30	\$460	a3 \$200	b2 \$105	—	d2 \$500	e2 \$30	\$835	a3 \$125	b3 \$315	—	d3 \$850	e2 \$30	\$1320	
b2 \$155	—	d2 \$500	e1 \$5	\$785	a3 \$200	b2 \$155	c1 \$200	d2 \$500	e2 \$30	\$1085	a3 \$125	b3 \$365	—	d4 \$1075	e2 \$30	\$1545	
b2 \$55	c1 \$175	d1 \$200	e1 \$5	\$460	a3 \$50	b2 \$55	—	d2 \$500	e2 \$30	\$635	a3 \$50	b3 \$265	—	d3 \$850	e2 \$30	\$1195	
b2 \$55	c1 \$175	d1 \$200	e1 \$5	\$560	a3 \$200	b2 \$55	—	d2 \$500	e2 \$30	\$785	a3 \$125	b3 \$265	—	d3 \$850	e2 \$30	\$1270	
b2 \$55	c1 \$175	d1 \$200	e1 \$5	\$560	a3 \$200	b2 \$55	—	d2 \$500	e2 \$30	\$785	a3 \$125	b3 \$265	—	d3 \$850	e2 \$30	\$1270	
b2 \$105	c1 \$200	d1 \$200	e1 \$5	\$635	a3 \$200	b2 \$105	—	d2 \$500	e2 \$30	\$835	a3 \$125	b3 \$315	—	d3 \$850	e2 \$30	\$1320	
b2 \$105	c1 \$150	d1 \$200	e1 \$5	\$485	a3 \$50	b2 \$105	—	d2 \$500	e2 \$30	\$685	a3 \$50	b3 \$315	—	d3 \$850	e2 \$30	\$1245	
b2 \$105	c1 \$150	d1 \$200	e1 \$5	\$585	a3 \$200	b2 \$105	—	d2 \$500	e2 \$30	\$835	a3 \$125	b3 \$315	—	d3 \$850	e2 \$30	\$1320	
b2 \$55	—	d1 \$100	e1 \$5	\$285	a3 \$200	b2 \$55	—	d1 \$200	e2 \$30	\$485	a3 \$200	b3 \$265	—	d2 \$500	e2 \$30	\$995	
AVERAGES Medium Gasoline = 180 Heavy Gasoline = 280 Medium Diesel = 865 Heavy Diesel = 715					AVERAGES Medium Gasoline = 330 Heavy Gasoline = 480 Medium Diesel = 1059 Heavy Diesel = 976					AVERAGES Medium Gasoline = 665 Heavy Gasoline = 815 Medium Diesel = 1624 Heavy Diesel = 1454							

Table 7 (Cont'd)
Key to Noise Treatments and Costs for Table 7*

SYSTEM	Code for Noise Treatment	Description of Noise Control Treatment	Increase in Truck Purchase Price
Fan	a1	Improved fan and fan shroud design. Thermostatically controlled fan clutch on heavy trucks to allow removal of radiator shutters.	\$ 10 - Design substitutes for similar equipment. \$110 - Design substitutes (\$10) plus net increase for replacing radiator shutters with fan clutch (\$100).
	a2	Advanced system with improved fan design, fan shroud and radiator design. Includes fan clutch on heavy trucks.	\$ 25 - Net price increase for replacing radiator, fan and fan shroud with ones of improved design. \$125 - Improved radiator, fan and fan shroud (\$25) and fan clutch (\$100).
	a3	Best system possible using available technology; includes larger radiator which requires redesigned cab on heavy trucks.	\$ 50 - Radiator, fan and fan shroud of improved design (\$25) and larger fan and radiator (\$25). \$125 - Radiator, larger fan and fan shroud of improved design (\$25), and fan clutch (\$100). Costs for larger radiator and redesigned cab are included in cab treatment d3 or d4. \$200 - Radiator, fan and fan shroud of improved design (\$25), larger fan and radiator (\$25), redesigned cab (\$50) and fan clutch (\$100).
Exhaust	b1	Best of presently available mufflers and seals for exhaust leaks.	\$25-75 - Net price increase for replacing existing mufflers. Depends on unmuffled noise level; on 4-stroke engines \$25-50 and on 2-stroke engines \$75.
	b2	Advanced mufflers better than presently available on 4-stroke engines; manifold muffler and best of available mufflers on 2-stroke engines. Seals for exhaust leaks.	\$50-150 - On 4-stroke engines; net increase for advanced mufflers, twice increased for best available mufflers (\$25-75), depends on unmuffled noise level.
	b3	Best system possible using available technology; includes advanced mufflers, exhaust seals, double-wall piping and muffler wrapping.	\$260-360 - Advanced mufflers (\$50-150) depending on unmuffled noise level, manifold muffler (\$150), muffler jackets (\$30) and insulated double-wall exhaust piping (\$30). For diesel trucks, add \$5 for exhaust gas seals.
Engine	c1	Engine quieting kits - close fitting covers and isolated or damped exterior parts - supplied by engine manufacturer.	\$150-275 - For Diesel engines, estimates based on engine manufacturers' prices for available kits. \$100 - For Gasoline engines.
Cab	d1	Underhood treatment, such as acoustic absorbing material, side shields and recirculating panels.	\$100-200 - For Diesel trucks; based on truck manufacturers' estimates. Depends on needed noise reduction; 2-3 dBA (\$100) and 4 dBA (\$200). \$50-100 - For Gasoline trucks.
	d2	Underhood treatment and underpan.	\$400-500 - For Diesel trucks; underhood treatment (\$100-200) plus underpan (\$300). \$275-325 - For Gasoline trucks.
	d3	Partial (open front and back) engine enclosure and special engine mounts.	\$850 - Partial engine enclosure (\$775) and special engine mounts (\$75). Includes costs for larger radiator and redesigned cab.
	d4	Full engine enclosure and special engine mounts.	\$1075 - Average of truck manufacturers' estimates for full engine enclosure (\$775-1300) and special engine mounts (\$75). Includes costs for larger radiator and redesigned cab.
Air Intake	e1	Improve air intake design.	\$ 5 - Design substitute for similar equipment.
	e2	Air intake silencer and improved air.	\$ 30 - Air intake silencer (\$25) and design substitute for similar equipment (\$5).

*Background Document for Medium and Heavy Truck Noise Emission Regulations, EPA-550/19-76-008 (EPA, March 1976).

1

2

Equipment Purchase Price	Design Source Level of Noise Reduction
Equipment. No net increase for replacing clutch (\$100).	73 dBA
Adding radiator, fan and fan clutch design. Fan shroud (\$25) and fan clutch (\$100).	70 dBA
Use of improved design (\$25) and fan shroud of improved design (\$25), and larger radiator and redesigned cab at d3 or d4.	64 dBA
Use of improved design (\$25), larger redesigned cab (\$50) and fan clutch (\$100).	
Using existing mufflers. Depends on 2-stroke engines \$25-50 and on 2-stroke	73 dBA
Increase for advanced mufflers, twice mufflers (\$25-75), depends on	69 dBA
10) depending on unmuffled noise (150), muffler jackets (\$30) and exhaust piping (\$30). Exhaust gas seals.	65 dBA
Based on engine manufacturers'	2-3 dBA Noise Reduction
Truck manufacturers' estimates. Reduction; 2-3 dBA (\$100) and 4 dBA	2-4 dBA
Sound treatment (\$100-200) plus underpan	5-9 dBA Noise Reduction
775) and special engine mounts (\$75). Radiator and redesigned cab.	10-11 dBA Noise Reduction
Manufacturers' estimates for full engine special engine mounts (\$75). Radiator and redesigned cab.	12-15 dBA Noise Reduction
Equipment.	69 dBA
Design substitute for similar	65 dBA

Table 8
Percent Increase in Truck Prices*

Type of Truck	Average Truck Price	Percent Increase in Price Associated with Given Truck Level			
		81 dBA	78 dBA	76 dBA	73 dBA
Medium gasoline	\$ 5,836	0.6	3.1	5.6	11.4
Heavy gasoline	11,613	1.2	2.4	4.1	
Medium diesel	7,360	5.8	11.8	14.4	
Heavy diesel	25,608	1.5	2.8	3.8	
Average for all trucks	—	1.0	3.0	4.9	9.2

*Background Document for Medium and Heavy Truck Noise Emission Regulations,
EPA-550/9-76-008 (EPA, March 1976).

In general, wheel and crawler tractors are powered by diesel engines. Many of the engine-related noise sources for such equipment are very similar to those of a diesel-engine truck. Primary differences are associated with the location of the noise sources and the shielding provided by the vehicle body. Also characteristic of the noise emission is noise from tracks and operational attachments. The major noise sources are identified as:

Cooling fan

Engine casing

Exhaust system

Air intake

Transmission

Hydraulics

Track (for crawler-type machines).

The contributions of these noise sources to the total vehicle noise level as a function of engine horsepower are shown in detail in a forthcoming EPA publication.⁷

The techniques used to achieve an overall reduction in equipment noise include:

Partially enclose engine

Improve exhaust muffler

Add air intake silencer

Install muffler on hydraulic lines

Install flexible hose on hydraulic lines

Enclose hydraulic pumps, lines, and valves

Isolate engine from frame

Isolate panel covers from frame

Damp panel covers

Enclose transmission

Replace noisy hydraulic pumps

Improve cooling air fan

The estimated material costs and labor associated with these noise abatement techniques for different equipment horsepower classes are presented in Table 9. Details are available in the forthcoming EPA publication.⁸

Pneumatic Impact Tools. Such equipment includes paving breakers, rock drills, tampers, and sheet pile drivers. Data relating to equipment sound level, purchase price, and cost of noise control from a manufacturers survey are available in EPA documents to be published soon.

Air Compressors. The U.S. has measured and studied air-compressor noise extensively in its development of air-compressor noise regulations. Measurements made on standard and silenced air compressors are presented in Tables 10 and 11, respectively. A summary is presented in Figure 7. The estimated increases in list prices for air compressors to meet levels of 76 dBA, 75 dBA, 74 dBA, and 73 dBA are presented in Table 12.

⁷Background Document for Wheel and Crawler Tractor Noise Emission Regulation, U.S. Environmental Protection Agency (in preparation).

⁸Background Document for Wheel and Crawler Tractor Noise Emission Regulation, U.S. Environmental Protection Agency (in preparation).

Table 9
Estimated Initial Capital Cost of Retrofit Noise Control on Diesel-Powered Mining Equipment*

Method for Noise Reduction	Less than 100 hp		100-200 hp		Greater than 200 hp		Comments
	Material Costs	Labor Hours	Material Costs	Labor Hours	Material Costs	Labor Hours	
Partial Engine Enclosure	\$150	40	\$180	60	\$220	80	Manufacturer's estimate and similar construction for trucks
Install muffler(s) with sealed connectors on exhaust	\$ 75	8	\$100	12	\$150	16	Advertised prices
Install silencer(s) on air intake	\$ 35	2	\$ 55	4	\$ 65	5	Advertised prices
Install muffler(s) on hydraulic lines	\$ 15	3	\$ 35	6	\$ 45	12	Advertised prices
Install flexible hose on hydraulic lines	\$ 10	2	\$ 20	4	\$ 30	6	Advertised prices
Enclose hydraulic pumps, lines, and valves	\$ 15	4	\$ 45	12	\$ 65	16	From similar construction for tractors
Isolate engine from frame	\$ 50	6	\$ 60	12	\$ 80	16	Manufacturer's estimate
Isolate panel covers from frame	\$ 20	8	\$ 30	12	\$ 40	16	Product literature
Damp panel covers	\$ 75	8	\$100	12	\$125	16	At \$2.00/sq ft (\$22.00/m ²)
Enclose transmission	\$100	35	\$115	50	\$135	60	From similar construction for tractors
Replace noisy hydraulic	\$ 45	3	\$150	8	\$200	12	Advertised replacement price over original price
Improve cooling air fan performance	\$ 30	24	\$ 40	32	\$ 45	40	From similar construction for trucks

*W. N. Patterson, et al., *Noise Control of Underground Mining Equipment*, Publication PB 243-896 (National Technical Information Service [NTIS], January 1975).

Table 10
Noise Levels of Standard Compressors
Using the CAGI/PNEUROP Measurement Method*

Manufacturer	Model	S/N	Cfm [†]	Average Noise Level (dBA)	
				4ft (1m)	23ft (7m) [‡]
Atlas Copco	VT85Dd	ARP203149	85	94.8	81.4
Atlas Copco	ST-48	51-232751	160	96.6	83.3
Atlas Copco	ST-95	51-274977	330	91.9	80.2
Jaeger	E	RC32032	85	92.5	81.5
Jaeger	A	RS32189	175	98.9	88.2
Ingersoll-Rand	DXL750	77380	750	98.6	87.7
Ingersoll-Rand	DXL900	75847	900	97.9	89.9
Ingersoll-Rand	DXLCU1050	75613	1050	100.8	90.2
Ingersoll-Rand	DXL1200	74430	1200	103.0	92.6

*Background Document for Portable Air Compressors, EPA-550/9-76-004 (EPA, December 1975).

[†] 1 cfm = 35.31 m³/min

[‡] Includes overhead measurement point

Table 11
Noise Levels of Silenced Compressors
Using the CAGI/PNEUROP Measurement Method*

Manufacturer	Models	S/N	Cfm [†]	Average Noise Level (dBA)	
				4ft (1m)	23ft (7m) ⁺
Atlas Copco	VS85	ARP203903	85	89.0	75.5
Atlas Copco	STS35Dd	ARP550924	125	85.5	73.5
Atlas Copco	VSS125Dd	51-345060	125	81.0	70.1
Atlas Copco	VSS170Dd	51-235072	170	83.9	70.2
Worthington	160G/2QT	821478	160	84.5	74.2
Gardner-Denver	SPHGC	629717	185	87.0	77.1
Gardner-Denver	SPQDA/2	608227	750	86.1	78.2
Worthington	750QTEX	848-019	750	84.0	74.7
Ingersoll-Rand	DXL900S	73693	900	82.4	76.0
Ingersoll-Rand	DXL900S	74050	900	82.0	75.1
Ingersoll-Rand	DXL900S	74051	900	83.1	75.3
Ingersoll-Rand	DXL900S	740471	900	82.4	75.0
Gardner-Denver	SPWDA/2	635851	1200	84.1	73.7

*Background Document for Portable Air Compressors,
EPA-550/9-76-004 (EPA, December 1975).

[†] 1 cfm = 35.31 m³/min

⁺ Includes overhead measurement point

Table 12
Estimated Portable Air Compressor List Price Increases
by Major Engine/Capacity Class and All Models*

SPL Target (at 7 m)	Percent Increase in Price			
	Gasoline	Diesel Below 251 cfm [†]	Diesel Above 250 cfm [†]	All Models
76 dBA*	8.5%	7.0%	11.4%	10.0%
75 dBA ⁺	10.3	8.2	12.1	11.1
74 dBA*	12.1	9.6	13.0	12.3
73 dBA ⁺	14.2	10.9	13.9	13.6

*2 dBA tolerance

⁺ 3 dBA tolerance

[†] 1 cfm = 35.31 m³/min

*Background Document for Portable Air Compressors,
EPA-550/9-76-004 (EPA, December 1975).

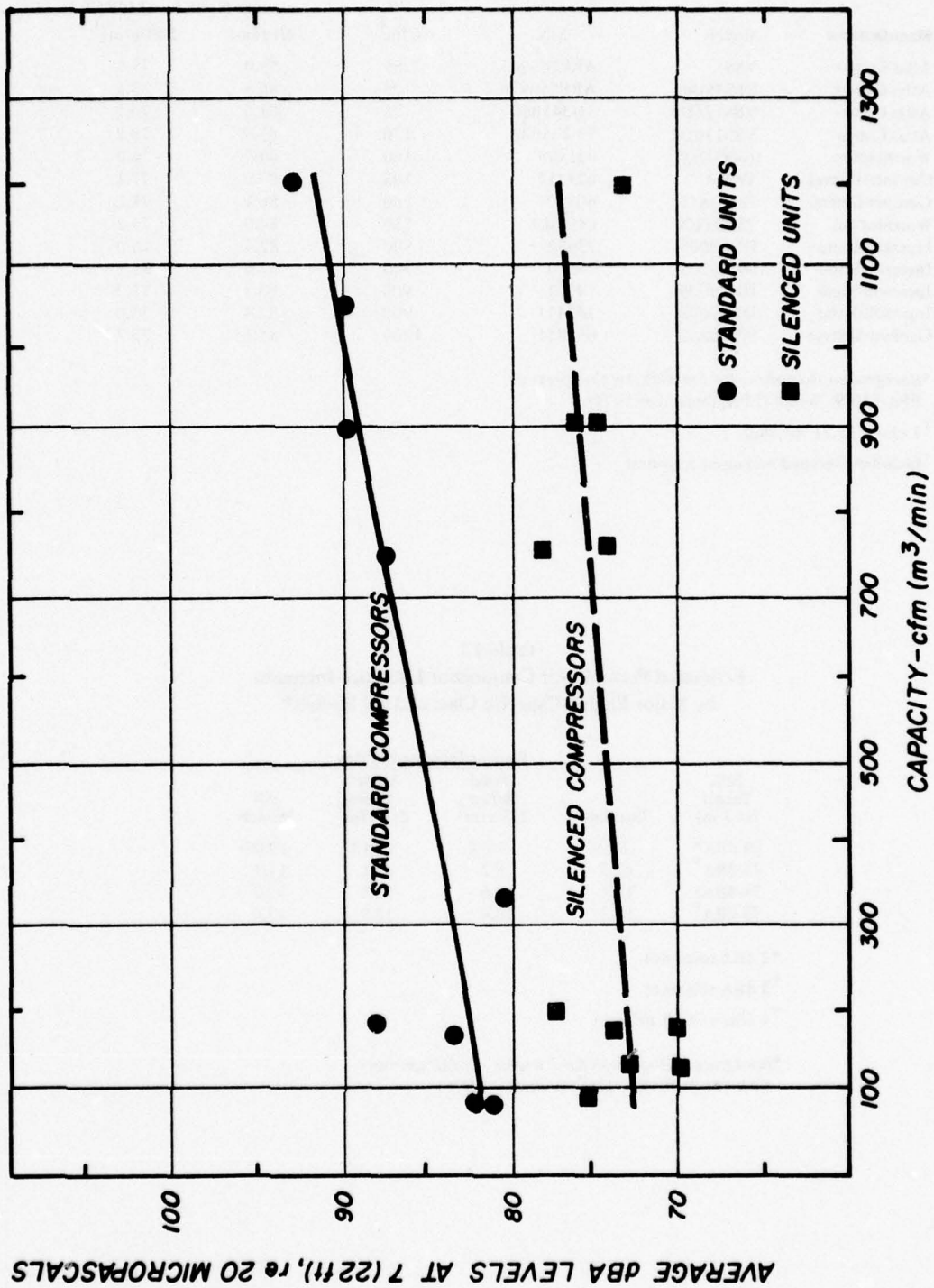


Figure 7. Noise of standard and silenced compressors as a function of capacity. (Source: Background Document for Portable Air Compressors, EPA-550/9-76-004 [EPA], December 1975.)

Barriers

An effective site noise-control technique is the use of barriers. Barriers shield an observer from a noise source in much the same manner as they shield an observer from a light source. The placement of a barrier between a source and an observer increases the minimum distance the sound has to travel to reach the observer (around the barrier). It is assumed that the contribution over the top of the barrier (and not through or around it) controls the noise levels reaching the observer. Noise attenuation from barriers is discussed in detail in CTERL Interim Report N-3.

Plywood Barriers

Solid fences of plywood are commonly constructed around the perimeter of a construction site to prevent unwanted entry, to shield neighbors from flying debris, and to reduce noise. To be effective as a noise barrier, the fence should be made of plywood at least 3/8 in. (10 mm) thick and properly constructed to avoid leaks or cracks. Plywood is usually found on a construction site, so its cost as an additional material is nominal. Other sturdy material such as wood planking or sheet metal reinforced by wood lathing can be used in its place when these materials are more readily available.

A barrier of plywood construction costs approximately \$650 per 100 m² (1000 sq ft).

Stockpile

Material stockpiles on a construction site can be used as shielding either by proper placement of materials around noise or by placing machinery behind material storage area. Any material can be used and can, if needed, be covered or draped with sound-absorbing material (matting) to reduce reflectivity and increase sound absorption. Lumber can be placed to provide shielding, if necessary, or can be used to plug gaps in other types of shielding. This method is simple, mobile, and effective. The cost is nominal, since the material will be eventually used on-site in the construction process.

Earth Berms

At most home construction sites, earth is moved, the site is physically changed, and the earth is redistributed. The removed fill can be used on-site to form an earth fence or berm which can reduce noise emissions from the site. Earth from road excavation, foundation excavation, or high-spot excavation can be placed on the perimeter of the site or between noise-sensitive areas and the construction activity. The earth should be piled as high or higher than a fence or other site enclosure:

3.0 to 4.5 m (10 to 16 ft), if possible. The earth berm can be used as the foundation for a plywood barrier, thus increasing its effective height and reducing the amount of plywood needed. Planning beforehand is essential.

Equipment Substitution

The selection of processes or equipment to perform various tasks, based upon their noise emissions, is one method of achieving noise reduction. A single, large piece of equipment used in place of several small units may do the job and result in reduction of the average site noise level. One type of equipment can be selected in preference to others to perform a task because of its lower noise emissions and/or higher efficiency. For example, a scraper can be used instead of a loader for earth removal, since scrapers have large capacities and are usually quieter than loaders. Wheeled vehicles can be used in place of track vehicles because of their lower noise.

The cost associated with this noise control option is variable. A method of selecting substitution scenarios is outlined below. A procedure for estimating the cost associated with a given equipment mix is presented in Appendix F.

Table 13
Average Minimum Sound Level Difference
Required Between the Permissible Total
Site Sound Level and Each Vehicle's Sound Level

Total Number of Vehicles	Sound Level Difference
1	0
2	3.0
3	4.8
4	6.0
5	7.0
6	7.8
7	8.5
8	9.0
9	9.5
10	10.0
11	10.4
12	10.8
13	11.1
14	11.5
15	11.8
16	12.0
17	12.3
18	12.6
19	12.8
20	13.0

The total site sound level at 15 m (50 ft) which will comply with the regulation at the nearest land use is calculated. Table 13 is used to determine the average minimum sound level difference between the total site sound level and each vehicle's sound level. The permissible sound level for each vehicle is then calculated as

$$L_v = L_s - \Delta$$

where L_v = permissible sound level of vehicle at 15 m (50 ft)

L_s = permissible site sound level at 15 m (50 ft)

Δ = average minimum sound level difference.

The difference between L_v and the actual sound level produced by the equipment unit is the noise reduction for each equipment unit necessary to bring the site into compliance. Those equipment units requiring noise reduction (as calculated above) should be replaced by equipment having lower noise levels. Since some equipment may produce lower maximum noise levels but have higher usage factors, it is important to compare average noise levels (L_{eq}).

Scheduling

An effective noise control method is the proper scheduling of noisy activities. *Scheduling as a noise control measure will not decrease the total noise energy emitted during the duration of construction activity*; however, it may reduce annoyance to people at nearby noise-sensitive land-use areas. The most commonly applied scheduling methods involve allocating construction activities over the following periods:

1. Time of day
2. Day of week
3. Season of year

Other scheduling methods include controlling the duration of construction activities and conducting noisy operations simultaneously. These methods are discussed in detail in CERL Report N-3.

The cost associated with scheduling methods cannot be designated on a general basis. It is very site specific and even project specific. Construction schedules generating the least annoyance are usually not the quickest way to complete an operation. In situations where an operation has to be completed in a timely manner, this

method cannot be applied or the incurred cost will be exorbitant. However, in other situations—for example, road construction in a business district—construction activity scheduled during nighttime or a weekend period will not only reduce annoyance but will increase efficiency as well.

5 COST-BENEFIT ANALYSIS

Construction Scenarios

This cost-benefit analysis is based on construction activities at Fort Carson and Fort Hood. Measurements at these two sites indicate that the grading, backfilling, trenching, and foundation phases of construction emit the most noise. Several construction scenarios relating to these activities have been selected for this study. Construction scenarios and the equipment used for each scenario are listed in Table 14. This table also includes the estimated cost for unquieted equipment. Equipment noise levels and site noise level (L_{eq}) for each scenario are presented in Table 15. The noise data and cost data in Tables 14 and 15, respectively, are used as baseline information for this cost-benefit analysis.

Costs relating to quieting construction site noise levels by 3 dB, 6 dB, and 10 dB are summarized in Table 16. These costs are estimated from the cost information on equipment noise control presented in Chapter 4. The cost of noise control is presented as a percentage increase in equipment cost as well as a percentage increase in construction cost. The relationships between equipment cost and construction cost are based on average cost data published in *Building Construction Cost Data*.⁹

Cost-Benefit Analysis Example

This example is based on actual construction of military barracks at Fort Carson, Colorado, and costs related to those construction activities. The cost of construction with noise abatement is estimated by determining the present cost of construction without noise abatement and then estimating the added cost for noise control.

⁹*Building Construction Cost Data*, 33rd Annual Edition (Robert Snow Means Company, Inc., 1974).

Table 14
Construction Scenarios

Construction Scenario	Equipment	Quantity	Model	Estimated Purchase Price/Unit (\$)	Total Purchase Price (\$)
Road Grading	Grader	1	CAT 120	50,000	50,000
	Water Truck	1		129,400	129,400
	Scraper	2	CAT 633C	235,000	470,000
					<u>649,400</u>
Site Grading	Scraper	1	JD860A	94,500	94,500
	Grader	1	CAT 120	50,000	50,000
	Tractor	1	CAT D8H	130,000	130,000
					<u>274,500</u>
Street Grading and Compacting	Grader	1	CAT 120	50,000	50,000
	Flat Roller	1	Ingram	30,000	30,000
					<u>80,000</u>
Rough Backfill	Scraper	1	CAT 633C	235,000	235,000
	Scraper	3	JD860A	94,500	283,500
	Water Truck	1		129,400	129,400
					<u>647,900</u>
Site Backfill	Loader	1	CAT D8H	130,000	130,000
	Scraper	2	CAT 633C	235,000	470,000
	Grader	1	CAT 12F	61,000	61,000
	Water Truck	1		129,400	129,400
					<u>790,400</u>
Ditching	Backhoe	2	Koehring 466	80,000	160,000
Filling the Trench	Loader	1	CAT 988	175,000	175,000
	Backhoe	1	Drott 50	35,000	35,000
					<u>210,000</u>
Sheet Piles	Sheet Pile Driver	2		1,200	2,400
	Truck	1		20,000	20,000
	Mobile Crane	1		100,000	100,000
	Air Compressor	1		7,000	7,000
					<u>129,400</u>
Concrete Preparation	Batch Plant	1		-	-
	Loader	1		130,000	130,000
	Concrete Truck	2		37,000	74,000
Concrete Footings	Concrete Truck	1		37,000	37,000
	Concrete Vibrator	1		1,200	1,200
	Air Compressor	1		7,000	7,000
					<u>45,200</u>

Construction Without Noise Control

Construction cost data in the form of a computer analysis of time and cost schedules are available from Corps of Engineers site engineers. A chart showing construction activity by tasks from August 1975 to April 1976 is presented in Figure 8. This chart indicates that most of the earth work took place during the latter part of 1975, when the CERL acoustics team conducted field noise measurements. Construction costs in terms of cost per day and the cumulative costs for the

same period are presented in Figures 9 and 10, respectively.

Construction With Noise Control

Construction activity during November 1975 to February 1976 (12th to 25th week) was selected to illustrate the cost of site noise control. During this period, numerous activities occurred on the site including installation of sewers, demolition, filling and grading, and fabrication and delivery of electrical equip-

Table 15
Construction Scenario Noise Data

Construction Scenario	Equipment	Quantity	L _p at 15m (50ft)*	Operating Factor*	Total L _{eq} at 15m (50 ft)	Site L _{eq} at 15m (50ft)
Road Grading	Grader	1	88	.32	83.1	
	Water Truck	1	89	.19	81.8	
	Scraper	2	86	.35	84.5	88.0
Site Grading	Scraper	1	88	.43	84.3	
	Grader	1	83	.19	75.8	
	Tractor	1	96	.12	86.8	90.0
Street Grading and Compacting	Grader	1	88	.32	83.1	
	Flat Roller	1	84	.6	81.8	85.5
Rough Backfill	Scraper	1	86	.35	81.4	
	Scraper	3	89	.33	84.2	
	Water Truck	1	89	.19	81.8	87.4
Site Backfill	Loader	1	96	.12	86.8	
	Scraper	2	86	.19	81.9	
	Grader	1	83	.74	81.7	
	Water Truck	1	89	.19	81.8	89.7
Ditching	Backhoe	2	80	.21	76.2	76.2
Filling the Trench	Loader	1	88	.10	78.0	
	Backhoe	1	84	.29	78.6	81.3
Sheet Piles	Sheet Pile Driver	2	88	.2	84.0	
	Truck	1	83	.03	67.8	
	Mobile Crane	1	88	.03	72.8	
	Air Compressor	1	82	1.0	82.0	86.4
Concrete Preparation	Batch Plant	1	95	1.0	95.0	
	Loader	1	89	.4	85.0	
	Concrete Truck	2	81	1.0	84.0	95.7
Concrete Footings	Concrete Truck	1	81	1.0	81.0	
	Concrete Vibrator	1	88	.5	85.0	
	Air Compressor	1	82	1.0	82.0	87.8

*Based on actual measurements

ment and material. The cost data relating to these construction activities are presented in Table 17. The total construction cost incurred during that period is estimated to be \$551,000, which includes approximately \$159,000 for labor costs, \$198,000 for equipment, \$105,000 for material, and the contractor's overhead costs and profit. This cost does not include the fabrication and delivery of electrical equipment and material, which took place primarily off site.

The application of site noise abatement will increase construction cost (Table 18). It is estimated that for

site noise levels to be reduced by 3 dB, 6 dB, and 10 dB, total construction cost for the period would increase by approximately \$1,000, \$1,700, and \$4,700, respectively. These costs represent increases in construction cost of approximately .18 percent, .31 percent, and .85 percent, respectively.

The above analysis assumes that site noise levels are reduced by using quieted equipment. It is anticipated that the use of plywood barriers to achieve similar site noise reduction would be more costly because of the dispersed nature of the construction activities.

Table 16
Costs Associated With Noise Reduction
of Construction Scenarios

Construction Scenario:				Road Grading		
Total Equipment Cost (\$)				649,400		
Equipment Cost/Construction Cost* (%)				.75		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				2,455	4,705	12,660
Percentage of Equipment Cost (%)				.38	.73	1.95
Percentage of Construction Cost* (%)				.29	.54	1.46
Construction Scenario:				Site Grading		
Total Equipment Cost (\$)				274,500		
Equipment Cost/Construction Cost* (%)				.60		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				1,810	3,445	9,300
Percentage of Equipment Cost (%)				.66	1.26	3.39
Percentage of Construction Cost* (%)				.39	.75	2.03
Construction Scenario:				Street Grading and Compacting		
Total Equipment Cost (\$)				80,000		
Equipment Cost/Construction Cost* (%)				0.5		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				910	1,570	4,430
Percentage of Equipment Cost (%)				1.13	1.96	5.53
Percentage of Construction Cost* (%)				.55	.98	2.76
Construction Scenario:				Rough Backfill		
Total Equipment Cost (\$)				647,900		
Equipment Cost/Construction Cost* (%)				0.7		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				3,225	6,300	16,800
Percentage of Equipment Cost (%)				.50	.97	2.60
Percentage of Construction Cost* (%)				.35	.68	1.82
Construction Scenario:				Site Backfill		
Total Equipment Cost (\$)				790,400		
Equipment Cost/Construction Cost* (%)				.65		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				3,100	5,965	16,020
Percentage of Equipment Cost (%)				.39	.75	2.03
Percentage of Construction Cost* (%)				.25	.49	1.32
Construction Scenario:				Ditching		
Total Equipment Cost (\$)				160,000		
Equipment Cost/Construction Cost* (%)				.65		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				1,040	1,850	5,160
Percentage of Equipment Cost (%)				.65	1.16	3.23
Percentage of Construction Cost* (%)				.42	.75	2.10
Construction Scenario:				Filling the Trench		
Total Equipment Cost (\$)				210,000		
Equipment Cost/Construction Cost* (%)				.6		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				1,165	2,185	5,940
Percentage of Equipment Cost (%)				.55	1.04	2.83
Percentage of Construction Cost* (%)				.33	.62	1.70
Construction Scenario:				Sheet Piles		
Total Equipment Cost (\$)				129,400		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				200	1,000	1,760
Percentage of Equipment Cost* (%)				.15	.77	1.36
Construction Scenario:				Concrete Footings		
Total Equipment Cost (\$)				45,200		
Noise Reduction				3 dB	6 dB	10 dB
Cost to Quiet (\$)				745	2,160	4,500
Percentage of Equipment Cost* (%)				1.65	4.78	9.96

*Excluding Material Cost, such as pipe, concrete, wood, gravel, etc.

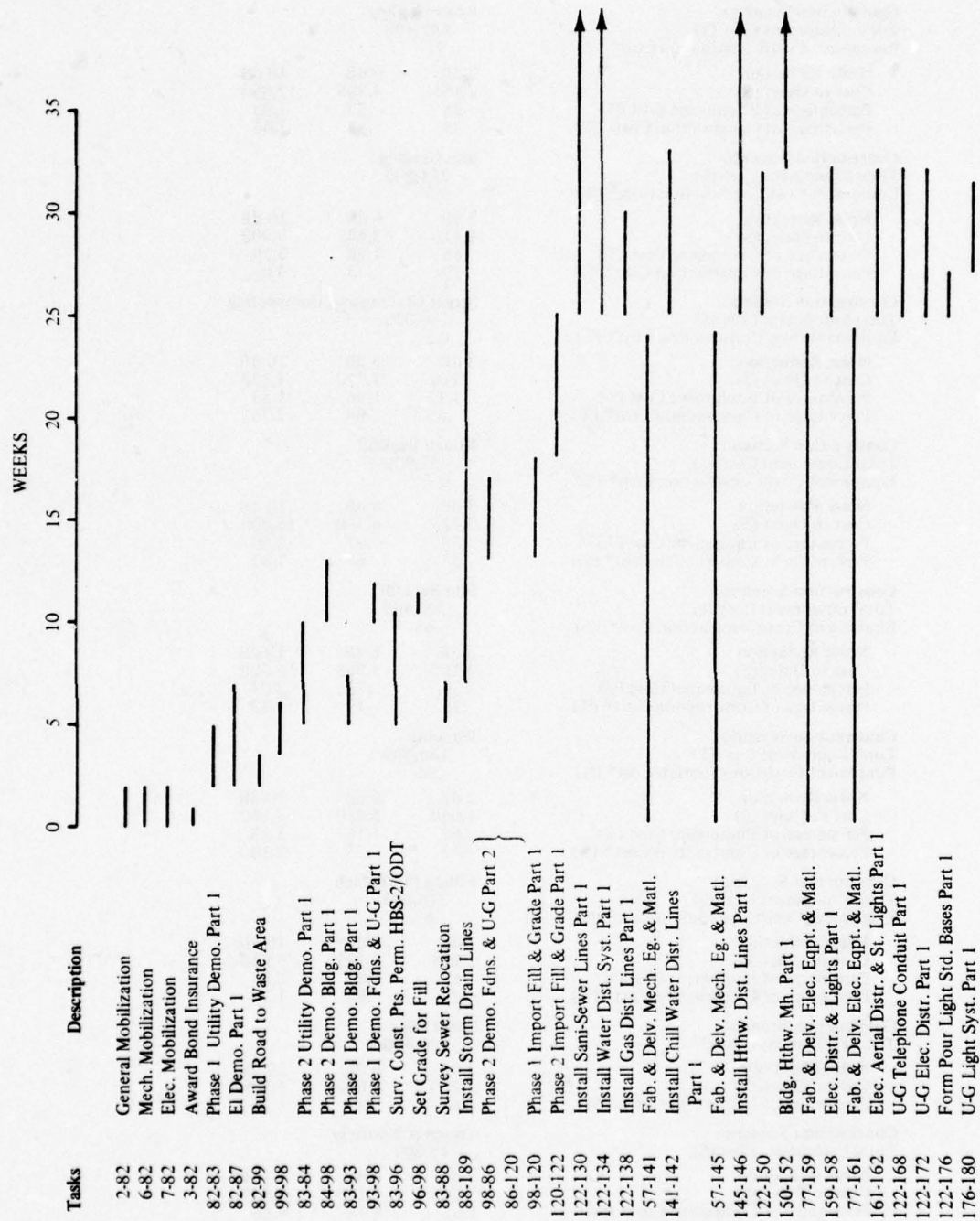


Figure 8. Construction activity from August to April 1976, Fort Carson, CO.

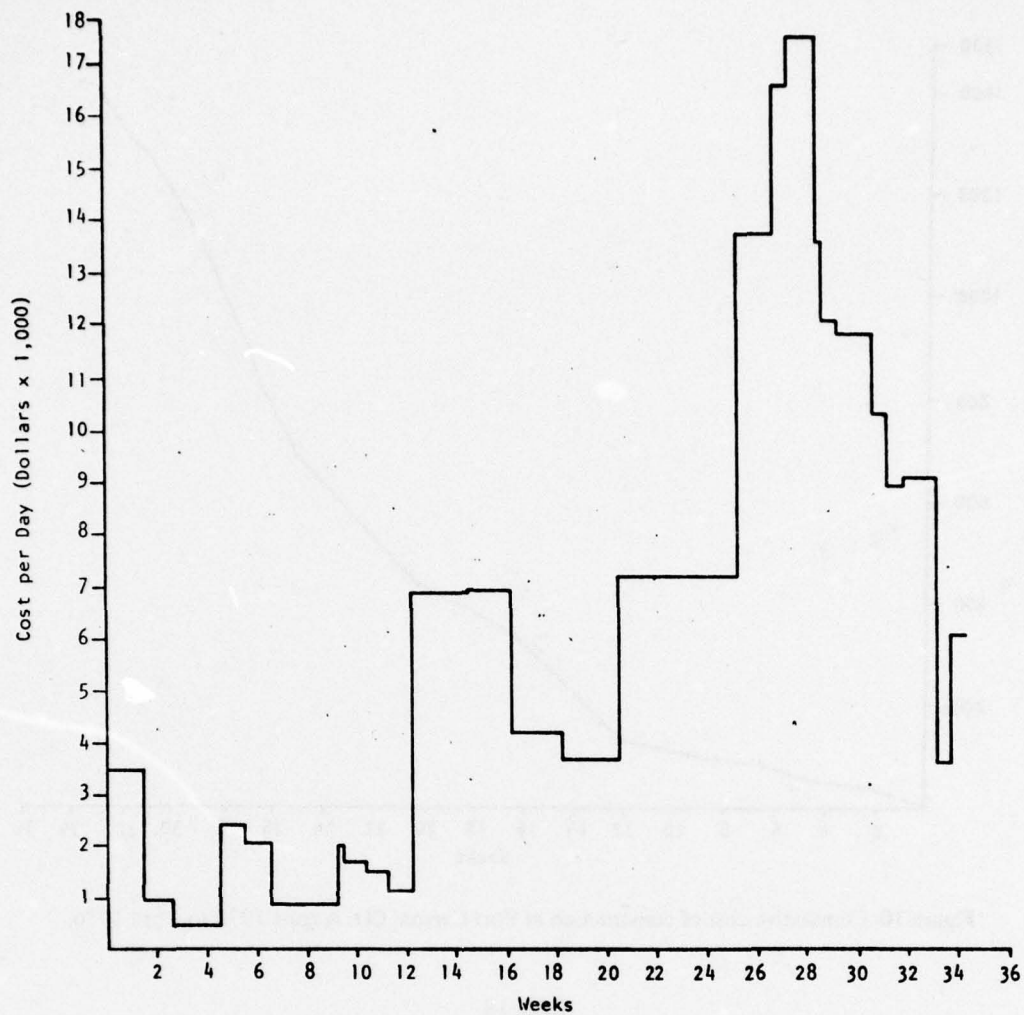


Figure 9. Construction cost per day at Fort Carson, CO.

Table 17
Construction Cost Data, November 1975 to February 1976,
Fort Carson, CO

Task	Description	Task Duration (Days)	Cost Per Day (\$)	Cost Breakdown*		
				Labor (%)	Equipment (%)	Material (%)
94-189	Install Drainage	33	3,893	3	10	76
92-94	Install Sewer	42	286	34	4	44
90-92	Install Sewer	16	229	34	4	44
98-86 86-120	Demolition Demolition }	28	2,750	53	25	0
98-120	Phase 1 Import Fill & Grade	42	3,929	33	50	0
120-122	Phase 1 Import Fill & Grade	49	3,367	33	50	0

*Percentages do not sum to unity due to contractor's overhead and profit.

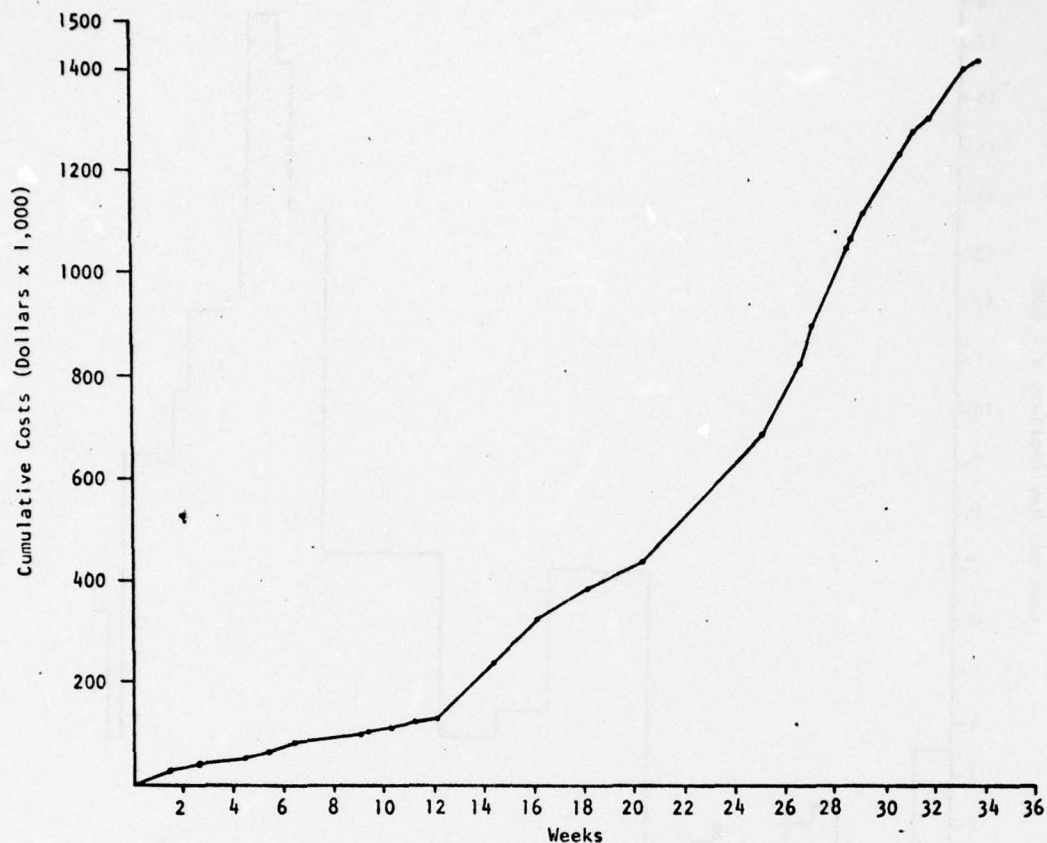


Figure 10. Cumulative cost of construction at Fort Carson, CO, August 1975 to April 1976.

Table 18
Increase in Equipment Cost for Noise Control

Task*	Equipment Cost (\$)	Percentage Increases in Equipment Cost from Site Noise Reduction		
		3 dB (%)	6 dB (%)	10 dB (%)
94-189	12,847	.55	1.04	2.83
92-94	480	.55	1.04	2.83
90-92	147	.55	1.04	2.83
98-86 ⁺	19,250	1.0	1.80	5.0
86-120 ⁺				
98-120	82,509	.39	.75	2.03
120-122	82,492	.39	.75	2.03
Total Equipment Cost (\$)	197,725	198,635	199,449	202,418
Increase in Equipment Cost (\$)		~1,000	~1,700	~4,700

*See Table 17 for explanation of Task numbers

⁺ Estimated

6 CONCLUSIONS

Modest reductions (5 dB) in construction-site noise are both technically feasible and economically reasonable for the types of construction studied at Fort Carson and Fort Hood. In general, these reductions will result in an increase of less than 1/2 percent in overall construction costs.

A variety of noise-reduction techniques are available, with one particular method normally preferred in a given situation.

This report furnishes supporting rationale and data for the companion manual, *Construction-Site Noise Control-Cost-Benefit Estimating Procedures*, Interim Report N-36 (CERL, January 1978), which offers a means to estimate costs and select the preferred reduction technique.

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APPENDIX A:

COMPUTER MODELS

Nomenclature

L_{eq}	energy average equivalent sound level
t_n	time count
m	equipment count
X_o, Y_o	coordinates at observer position
$X_m(t_n), Y_m(t_n)$	position of m^{th} equipment at time t_n
M	total number of equipment units
N	total units of time
X_a, Y_a	acoustic center of vehicle movements
L_{max}	maximum sound level
UF	fraction of time equipment operates at maximum sound level

Model 1: Base Model

The base model accepts both location and pseudo sound power data for several equal interval points in time for any given number of vehicles. Pseudo sound power is the sound power of a monopole giving the sound levels observed. The L_{eq} values are calculated by the following, discrete summation equation:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{N} \sum_{t_n=1}^N \sum_{m=1}^M \frac{10^{L'_m(t_n)/10}}{(X_o - X_m(t_n))^2 + (Y_o - Y_m(t_n))^2} \right] \quad [\text{Eq A1}]$$

where (X_o, Y_o) is the observer position, $(X_m(t_n), Y_m(t_n))$ is the position of vehicle m at time t_n , and $L'_m(t_n)$ is the pseudo sound power of vehicle m at time t_n .

The computer examines the L_{eq} for several points along several rays extending from the origin (0,0) until it locates the points on each ray which equal 55 and 65

dB. It then plots the $L_{eq} = 55$ and 65 dB contours, and the vehicles' movements.

Figure A1 is a printout based on the contours of three vehicles' movements. The vehicle movements and levels utilized for this computer run were based on data collected at Fort Hood, TX.

Model 2: Motion of Each Vehicle is Represented by its Mean Position

The base equation of Model 1 is simplified by representing the motion of each vehicle by a single point (X_m, Y_m) , using the following equation:

$$L_{eq} = 10 \log_{10} \left[\sum_{m=1}^M \frac{\frac{1}{N} \sum_{t_n=1}^N 10^{L'_m(t_n)/10}}{(X_o - X_m)^2 + (Y_o - Y_m)^2} \right] \quad [\text{Eq A2}]$$

The effect of this assumption on the results of modeling the three vehicles depicted by Figure A1 is illustrated in Figure A2.

Model 3: Single-Point-Source Model

This model involves the assumption that the movements of all the vehicles can be replaced by a single point (X_a, Y_a) located at the acoustic center of the site. The model is based on this equation:

$$L_{eq} = 10 \log_{10} \left[\frac{\frac{1}{N} \sum_{m=1}^M \sum_{t_n=1}^N 10^{L'_m(t_n)/10}}{(X_o - X_a)^2 + (Y_o - Y_a)^2} \right] \quad [\text{Eq A3}]$$

Figure A3 depicts the effect that this assumption has on the same three-vehicle site modeled by the two previous procedures.

Model 4: Single-Point-Source and Acoustical Utilization-Factor Model

Model 3 is further simplified such that for each vehicle the changes in sound level as a function of time are replaced by each vehicle's maximum sound level (L_{max_m}) times the fraction of time the vehicle emits this maximum level (UF_m). The equation embodying this further simplification is:

$$L_{eq} = 10 \log_{10} \left[\frac{\sum_{m=1}^M UF_m 10^{L_{max_m}/10}}{(X_o - X_a)^2 + (Y_o - Y_a)^2} \right] \quad [\text{Eq A4}]$$

Figure A4 illustrates the effect of this simplification on the three-vehicle site. Note that this figure is half scale as compared to Figures A1 to A3.

$$L_{eq} = 10 \log_{10} \left[\frac{1}{N} \sum_{n=1}^N \sum_{m=1}^M \right]$$

Model 5: Base Model Plus Barrier Attenuation

Model 1, the base equation, is expanded to include the ability to calculate the impact of a single, thin barrier on the $L_{eq} = 55$ and 65 dB contours. The amount of attenuation is calculated for each vehicle position over time with respect to each observer point under consideration. The equation for Model 5 is:

$$\frac{.0514}{\delta m(t_n)} 10^{L'_m(t_n)/10} \left[\frac{1}{(X_o - X_m(t_n))^2 + (Y_o - Y_m(t_n))^2} \right]$$

[Eq A5]

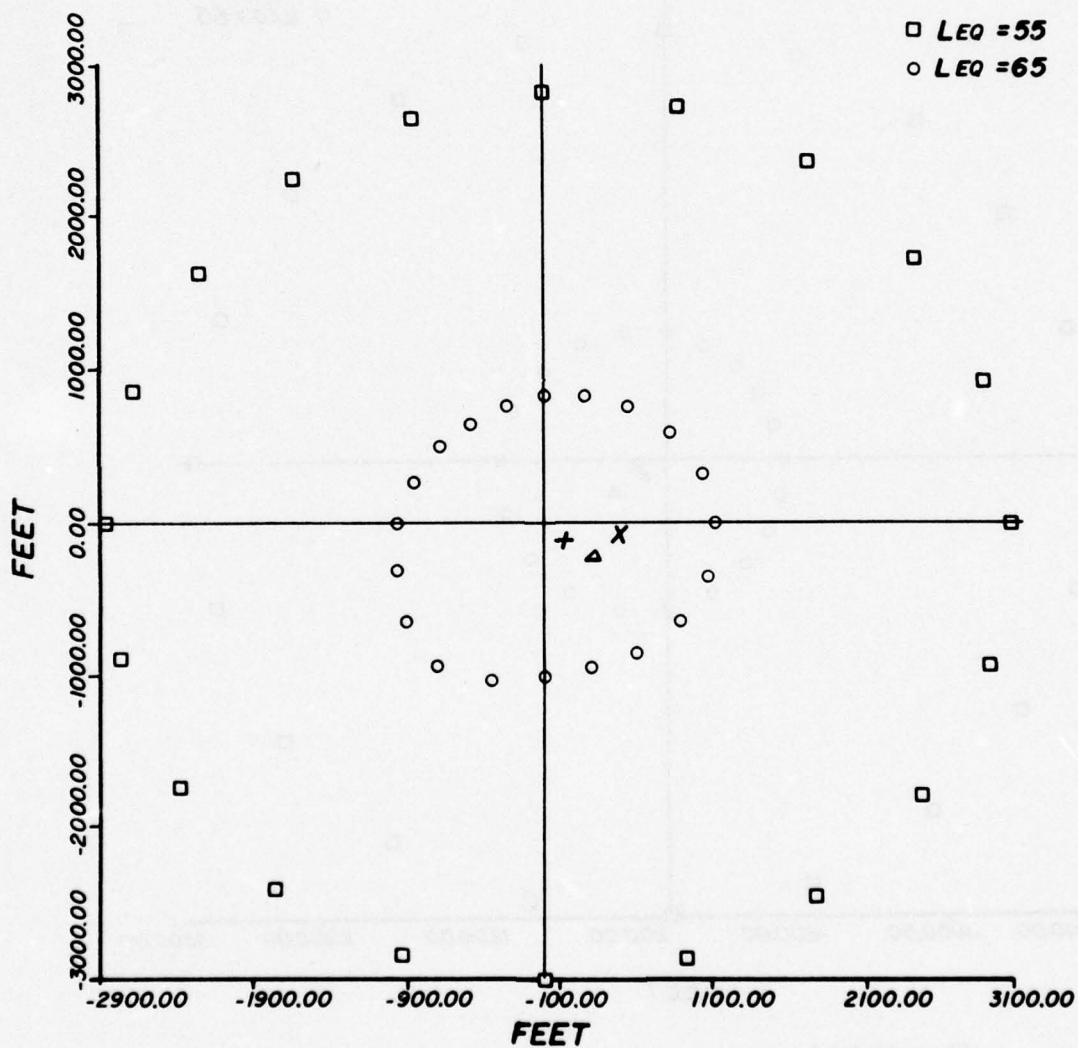


Figure A1. Printout from computer model 1: base equation.

where

$$\delta m(t_n) = a + b - c$$

$$a = \sqrt{(h_b - h_m)^2 + d^2}$$

$$b = \sqrt{(h_m - h_o)^2 + e^2}$$

$$c = \sqrt{(h_m - h_o)^2 + (d + e)^2}$$

$$d = \sqrt{(Y_i - Y_m(t_n))^2 + (X_i - X_m(t_n))^2}$$

$$e = \sqrt{(Y_i - Y_o)^2 + (X_i - X_o)^2}$$

(Refer to Figure A5 for the definition of these variables.)

Derivation of the barrier effect is discussed in Appendix D.

Particularly relevant to the equation form of Model 5 is Eq D10 of Appendix D, where if variable L_A is replaced by the expression for L_{eq} of Model 1 and if the term $10 \log_{10} \frac{0.0514}{\sigma}$ is altered to represent the variables of vehicle and time:

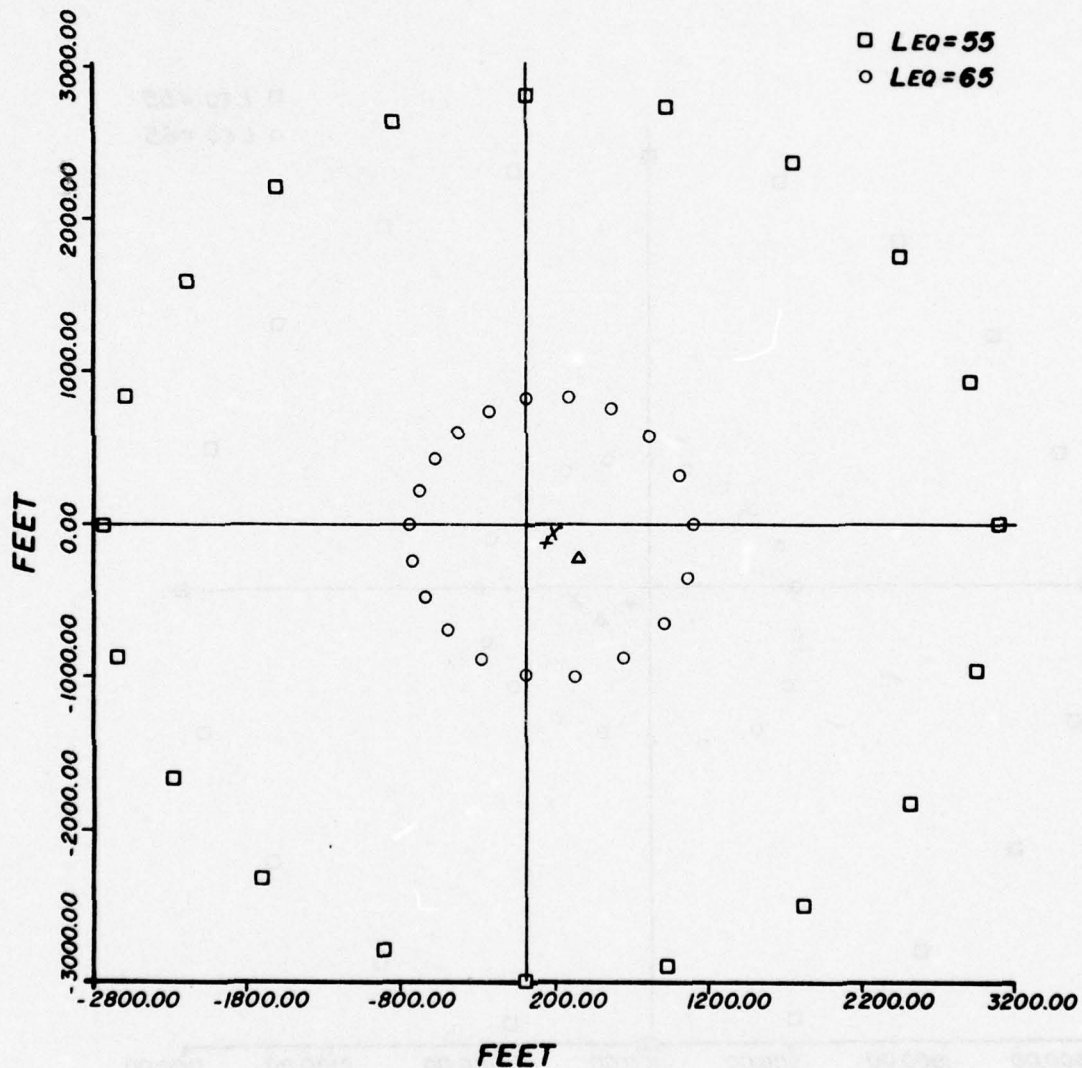


Figure A2. Printout from computer model 2: motion of each vehicle is represented by its mean position.

$$10 \log_{10} \sum_{n=1}^N \sum_{m=1}^M \frac{0.0514}{\sigma_m(t_n)}$$

then the equation for Model 5 can be derived.

Figure A6 shows the effect of a 16-ft (5-m) high and 600-ft (183-m) long barrier on the three-vehicle site.

The programs and definition of their variables are provided for Models 1 through 5 in Appendix B. These programs are written in Fortran IV.

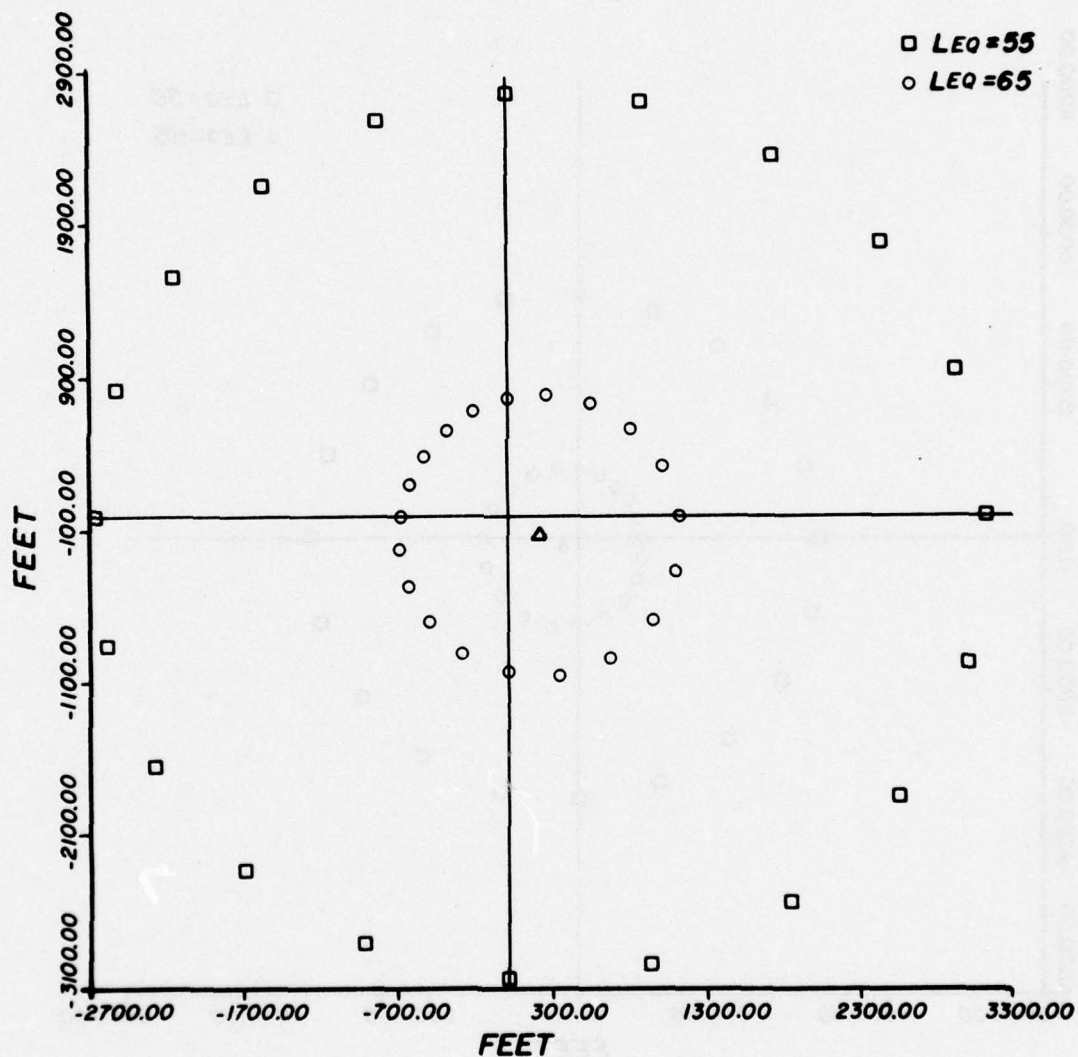


Figure A3. Printout from computer model 3: single-point-source model.

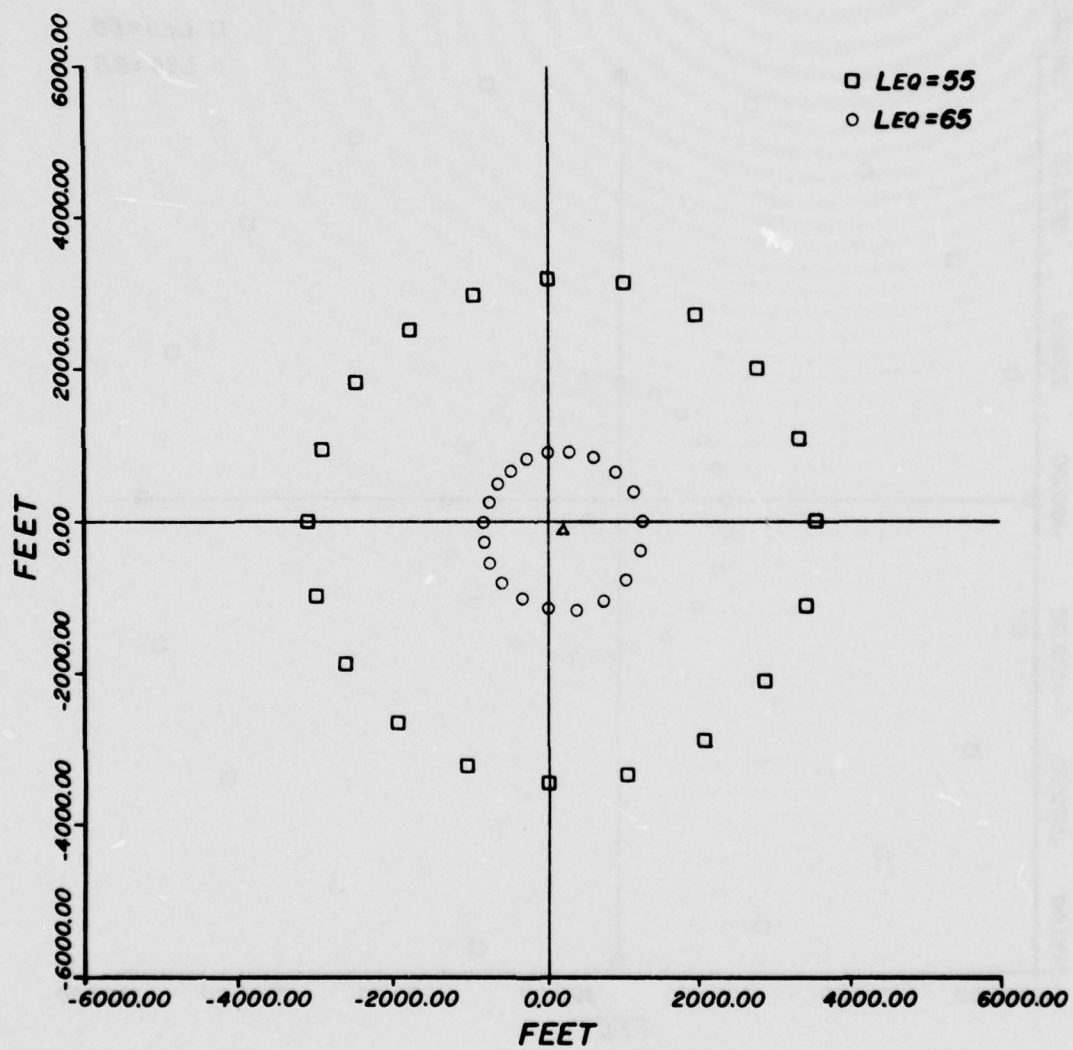
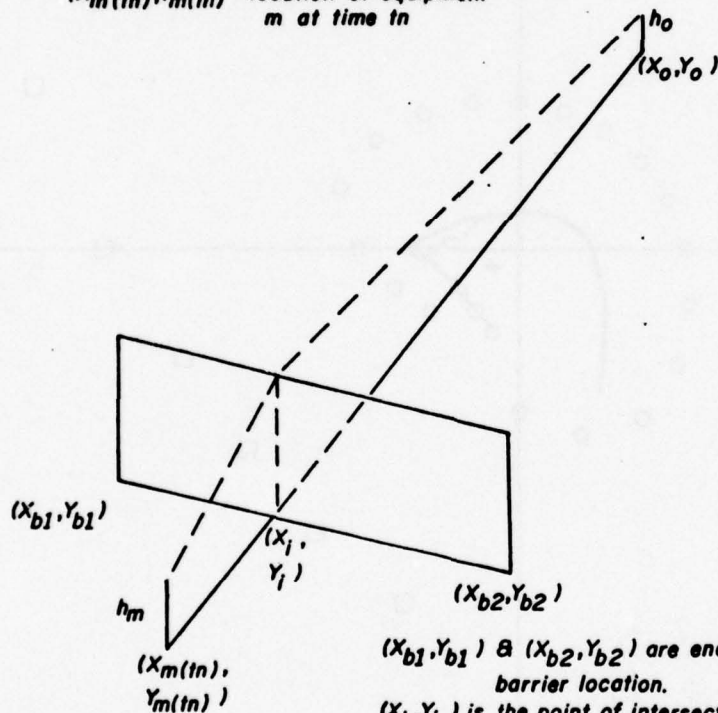
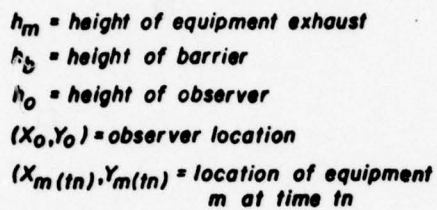


Figure A4. Printout from computer model 4: single-point-source and utilization-factor model.



(X_{b1}, Y_{b1}) & (X_{b2}, Y_{b2}) are end points defining the barrier location.
 (X_j, Y_j) is the point of intersection between a line defined by the points (X_0, Y_0) and $(X_m(tn), Y_m(tn))$ and a line defined by the points (X_{b1}, Y_{b1}) & (X_{b2}, Y_{b2}) .

Figure A5. Barrier equation variables.

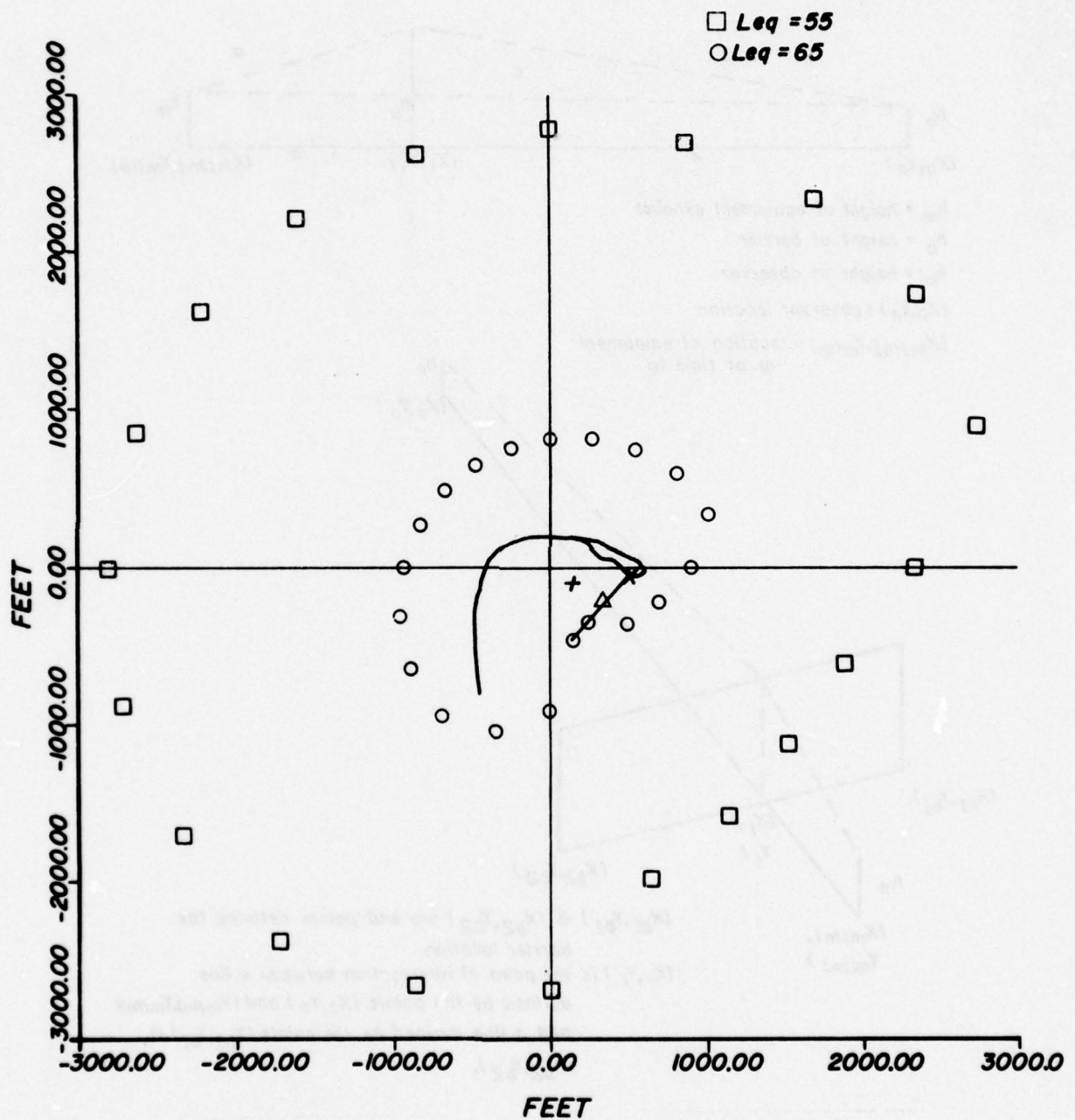


Figure A6. Computer printout of model 5: base equation plus barrier attenuation.

APPENDIX B:

COMPUTER PROGRAMS FOR MODELS 1 THROUGH 5

Computer Program for Model 1: Base Equation

PAGE 1

```
// JOB      0180 0181 0182 0183 0184
0000      0190      0180      0000
0001      0191      0181      0001
0002      0182      0182      0002
0003      0193      0183      0003
0004      0194      0184      0004
```

V2 M11 ACTUAL 32K CONFIG 32K

// FORTRAN

```
*NO IOCS
*IOCS(1132 PRINTER, CARC, DISK, TYPEWRITER)
*ONE WORD INTEGERS
*LIST ALL
```

C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```
C*****
C
C PROGRAM TO PRODUCE A PLOT OF NOISE LEVEL CONTOURS. THIS PROGRAM
C WAS PREPARED FOR ENGINEERING DYNAMICS INC. USING EQUATIONS
C PROVIDED BY THEM.
C
C*****
```

```
INTEGER TITL1(40),TITL2(40),TITL3(40)
REAL LS(220,12)
DIMENSION XS(220,12),YS(220,12)
DIMENSION X055(42),Y055(42),X065(42),Y065(42)
DIMENSION MAX(10),TIME(2),XLIN(10),YLIN(10)
DIMENSION SOURC(2)
DATA AL/'L',EG/'EG',EQUAL/'='/,FF/'55',SF/'65',SOJRC/'SOUR',
1 'CE' '/'
DATA BLANK/' '/
DATA TUL/'.01/
```

```
C READ TITLE
READ(2,1)TITL1,TITL2,TITL3
READ(2,2)DEGRE,STEP,XCI,YCI

N=1
M=0
IFLAG=0
MMAX=0
WRITE(3,21)
```

```
C READ DATA
100 READ(2,3)TIME,X,Y,ALW,ALW2
IF(ALW)1000,200,200
200 M=M+1
IFLAG=0
XS(M,N)=X
```

PAGE 2

C-EERS...STNO,C..... FORTRAN SOURCE STATEMENTS

```
      YS(M,N)=Y
      LS(M,N)=ALW
      WRITE(3,20)TIME,X,Y,ALW,ALW2
      GO TO 100

C      END OF DATA SET
1000  IF(IFLAG)1100,1100,1200
1100  IFLAG=1
      WRITE(3,21)
      MAX(N)=M
      IF(M-498)1104,1104,1103
1103  WRITE(3,22)M
      CALL EXIT
1104  IF(M-MMAX)1110,1110,1105
1105  MMAX=M
1110  N=0
C      N=N+1
      GO TO 100

C      END OF ALL DATA SETS
1200  NCONT=N-1
      IF(NCONT-5)1210,1210,1205
1205  WRITE(3,23)
      CALL EXIT
1210  MCONT=MMAX

C      BEGIN COMPUTATIONS OF CONTOURS
      ISTEP=360./DEGRE
      IX55=0
      IY55=0
      IX65=0
      IY65=0

      DO 5000 IRAD=1,ISTEP
      XC=XCI
      YC=YCI
      ANG=(IRAD-1)*DEGRE
      ANG = ANG *.017453293
      XINC=COS(ANG)*STEP
      YINC=SIN(ANG)*STEP
      ILEG=1

C      LOOP TO COMPUTE ENERGY AT A GIVEN POINT
1250  SUML=0.0
      DO 1300 N=1,NCONT
      MX=MAX(N)
      AMX=MX
      DO 1300 MM=1,MCONT
      AM=MM
      TEMP1=AM/AMX
      TEMP2=MM/MX
```


C-ERRS...SYNC.C..... FORTRAN SOURCE STATEMENTS

```

      M=(TEMP1-TEMP2)*AMX
      IF(M)1260,1260,1275
1260  M=MX
1275  SJML=SUML+10.**(LS(M,N)/10.)/((XC-XS(M,N))**2+(YC-YS(M,N))**2)
1300  CONTINUE
      SJML=10.0*ALOG(SUML/MCONT)/ALOG(10.)

C      BRANCH TO CORRECT SECTIONS BASED ON OBSERVER POSITION
      GO TO(1400,1700,1800,2000,3000,4100,4100,1575),ILEG

C      ILEG=1 OBSERVER AT ORIGIN
1400  IF(SUML-55.)1550,1500,1600
1500  IX55=IX55+1
      IY55=IY55+1
      XO55(IX55)=XC
      YO55(IY55)=YC
      ILEG=2
      GO TO 4900

1550  ILEG=8
      GO TO 4900

1575  IF(SUML-55.)1580,1500,2020
1580  IF(SUML-SUMA)5000,5000,4900

1600  IF(SUML-65.)1660,1650,1670
1650  IX65=IX65+1
      IY65=IY65+1
      XO65(IX65)=XC
      YO65(IY65)=YC
      ILEG=3
      GO TO 4900

1660  ILEG=4
      GO TO 4900

1670  ILEG=5
      GO TO 4900
C      ILEG=2 OBSERVER AT 55 LEVEL
1700  IF(SUML-55.)5000,1500,1720
1720  ILEG=4
      GO TO 4900

C      ILEG=3 OBSERVER AT 65 LEVEL
1800  IF(SUML-65.)1840,1650,1820
1820  ILEG=5
      GO TO 4900

1840  ILEG=4
      GO TO 4900

```

PAGE 4

C-ERRS...STNG.C..... F O R T R A N S O U R C E S T A T E M E N T S

```
C      ILEG=4 OBSERVER BETWEEN 55 AND 65 LEVEL
2000  IF(SUML-55.)2020,1500,2040
2020  TARGT=55.
      ILEG=6
      GO TO 4000

2040  IF(SUML-65.)4900,1650,2050
2050  TARGT=65.
      ILEG=7
      GO TO 4000

C      ILEG=5 OBSERVER AT LEVEL GREATER THAN 65
3000  IF(SUML-65.)2050,1650,4900

C      ITERATE AROUND TARGET POINT
4000  X3=XC
      Y3=YC
      SJMB=SUML
4010  XC=(XB+XA)/2.
      YC=(YE+YA)/2.
      GO TO 1250

C      ILEG=6 OR 7 ITERATING AROUND TARGET LEVEL
4100  IF(ABS(SUML-TARGT)-TCL)4500,4500,4120
4120  IF(SUML-TARGT)4130,4130,4140
4130  IF(SUMB-TARGT)4000,4137,4137
4137  XA=XC
      YA=YC
      SJMA=SUML
      GO TO 4010

4140  IF(SUMB-TARGT)4137,4137,4000

C      CONTOUR POINT FOUND
4500  ILEG=ILEG-5
      GO TO(1500,1650),ILEG

C      STEP OUT ON RADIUS
4900  XA=XC
      YA=YC
      SJMA=SUML
      XC=XC+XINC
      YC=YC+YINC
      GO TO 1250

5000  CONTINUE

      WRITE(3,6)
      WRITE(3,4)(X055(I),Y055(I),I=1,IX55)
      WRITE(3,7)
      WRITE(3,4)(X065(I),Y065(I),I=1,IX65)
```

C-ERRS...SYN.C..... F O R T R A N S O U R C E S T A T E M E N T S

```

C      PRODUCE PLOT OF RESULTS
      PAUSE
      CALL RECT(-0.5,0.0,11.0,8.5,0.0,3)
      CALL SCALE(X055,6.,IX55,1)
      CALL SCALE(Y055,6.,IY55,1)
      FIRX=X055(IX55+1)
      DTX=X055(IX55+2)
      FIRY=Y055(IY55+1)
      DTY=Y055(IY55+2)
      CALL AXISN(1.0,3.5,BLANK,-1.6,0.0,0,FIRX,DTX,2)
      CALL AXISN(1.0,3.5,BLANK,1.6,0.90,0,FIRY,DTY,2)
      XLIN(1)=FIRX
      XLIN(2)=FIRX+6.0*DTX
      XLIN(3)=FIRX
      XLIN(4)=DTX
      YLIN(1)=0.0
      YLIN(2)=0.0
      YLIN(3)=FIRY
      YLIN(4)=DTY
      CALL PLOT(1.0,3.5,-3)
      CALL LINE(XLIN,YLIN,2,1,0,0)
      XLIN(1)=0.0
      XLIN(2)=0.0
      YLIN(1)=FIRY
      YLIN(2)=FIRY+6.0*DTY
      CALL LINE(XLIN,YLIN,2,1,0,0)
      CALL LINE(X055,Y055,IX55,1,-1,0)
      X065(IY65+1)=FIRX
      X065(IY65+2)=DTX
      Y065(IY65+1)=FIRY
      Y065(IY65+2)=DTY
      CALL LINE(X065,Y065,IY65,1,-1,1)
C      PLOT SOURCE LOCATIONS
      DO 6000 N=1,NCONT
      MCONT=MAX(N)
      XS(MCONT+1,N)=FIRX
      YS(MCONT+1,N)=FIRY
      XS(MCONT+2,N)=DTX
      YS(MCONT+2,N)=DTY
      CALL LINE(XS(1,N),YS(1,N),MCONT,1,0,0)
      XPAGE=(XS(1,N)-FIRX)/DTX
      YPAGE=(YS(1,N)-FIRY)/DTY
      ISYM=N+1
      CALL SYMB(XPAGE,YPAGE,.105,ISYM,0.0,-1)
6000  CONTINUE

C      PLOT TITLE
      CALL PLOT(-1.0,-3.5,-3)
      CALL CNTR(TITL1,21,2)
      CALL CNTR(TITL2,21,2)

```


C-ERRS...STNG.C..... FORTRAN SOURCE STATEMENTS

```

      CALL CNTR(TITL3,21,2)
      CALL SYMB(1.06,2.75,..14,TITL1,0.0,3042)
      CALL SYMB(1.06,2.47,..14,TITL2,0.0,3042)
      CALL SYMB(1.06,2.19,..14,TITL3,0.0,3042)
      CALL SYMB(1.13,1.76,..105,0.0,0,-1)
      CALL SYMB(1.34,1.69,..14,AL,0.0,0,1)
      CALL SYMB(1.48,1.69,..07,EQ,0.0,0,2)
      CALL SYMB(1.76,1.69,..14,EQUAL,0.0,0,1)
      CALL SYMB(2.04,1.69,..14,FF,0.0,0,2)

      CALL SYMB(1.13,1.48,..105,1.0,0,-1)
      CALL SYMB(1.34,1.41,..14,AL,0.0,0,1)
      CALL SYMB(1.48,1.41,..07,EO,0.0,0,2)
      CALL SYMB(1.76,1.41,..14,EQUAL,0.0,0,1)
      CALL SYMB(2.04,1.41,..14,SF,0.0,0,2)

      DO 7000 N=1,NCONT
      AN=N
      ISYM=N+1
      YPAGE=1.69-.1575*(N-1)
      CALL SYMB(5.635,YPAGE,..105,SOURC,0.0,0,6)
      CALL NUMB(6.37,YPAGE,..105,AN,0.0,-1)
      CALL SYMB(6.9475,YPAGE+.0525,..105,ISYM,0.0,-1)
7000  CONTINUE
      CALL PLOT(15,..0.0,999)
      CALL EXIT
1      FORMAT(40A2)
2      FORMAT(8F10.0)
3      FORMAT(2A4,6F12.0)
4      FORMAT(4(F9.2,2X,F9.2,6X))
6      FORMAT(' COORDINATES OF LEG = 55 LEVEL')
7      FORMAT(' COORDINATES OF LEG = 65 LEVEL')
20     FORMAT(1X,2A4,4F10.2)
21     FORMAT(1H1)
22     FORMAT(1X,14('****ERROR')) ' DATA SET TO LARGE'//15, ' POINTS'////////
23     FORMAT(1X,14('****ERROR')) ' TOO MANY DATA SETS'//////////
      END

VARIABLE ALLOCATIONS
XS(R) =149E-0000    YS(R) =293E-14A0    X055(R) =2992-2940    Y055(R) =29L6-2994
TIME(R) =2A92-2A90  XLIN(R) =2A46-2A94    YLIN(R) =2ABA-2AAB    SOURC(R) =2A0E-2ABC
STEP(R) =3F62       XCI(R) =3F64         YCI(R) =3F66         X(R) =3F63
ALW2(R) =3F6E       XC(R) =3F70         YC(R) =3F72         ANG(R) =3F74
SUNL(R) =3F7A       AMX(R) =3F7C         AM(R) =3F7E         TEMP1(R) =3F00
TARGT(R) =3F65      XB(R) =3F86         YB(R) =3F8A         SUMB(R) =3F0C
TOL(R) =3F92        FIRX(R) =3F94        DTX(R) =3F96        FIRY(R) =3F93
XPAGE(R) =3F9E      YPAGE(R) =3FA0        AL(R) =3FA2        EQ(R) =3FA4
SF(R) =3FAA         AN(R) =3FAC         MAX(I) =3F8F-3F86    TITL1(I) =3FE7-3FC0
N(I) =4038          M(I) =4039          IFLAG(I) =403A      MMAX(I) =4033
ISTEP(I) =403E      IX55(I) =403F          IY55(I) =4040      IX65(I) =4041
ILEG(I) =4044       MX(I) =4045          MM(I) =4046         I(I) =4047

```

PAGE 7

STATEMENT ALLOCATIONS

1=409F	2=40A2	3=40A5	4=40AA	6=40B1	7=40C2	20=4
100=4160	200=4180	1000=41E2	1100=4186	1103=41CD	1104=41J4	1105=4
1210=41F5	1250=423D	1260=4277	1275=4276	1300=42A5	1400=42J8	1500=4
1600=4310	1650=4326	1660=434A	1670=4350	1700=4356	1720=435F	1800=4
2020=4383	2040=438D	2050=4396	3000=43A0	4000=43AB	4010=43B7	4100=4
4140=43F3	4500=43FC	4900=4408	5000=4422	6000=45DA	7000=45BA	

FEATURES SUPPORTED

ONE WORD INTEGERS
STANDARD PRECISION
IOCS-
1132 PRINTER
DISK
TYPEWRITER
CARD

CALLED SUBPROGRAMS

FCOS	FSIN	FALOG	FABS	RECT	SCALE	AXISN	PLOT	LIVE	SYMB
FSUBX	FMPY	FDIV	FLD	FLOX	FSTO	FSTOX	FSBR	FOVR	FAXI
SRED	SWRT	SCOMP	SFIO	SICAI	SIOAF	SIOFX	SIOF	SIOI	SURSC

REAL CONSTANTS

.360000E 03=404E	.174532E-01=4050	.000000E 00=4052	.100000E 02=4054
.200000E 01=405A	.500000E 00=405C	.110000E 02=405E	.850000E 01=4060
.350000E 01=4066	.900000E 02=4068	.105000E 00=406A	.106000E 01=406C
.247000E 01=4072	.219000E 01=4074	.113000E 01=4076	.176000E 01=4078
.148000E 01=407E	.700000E-01=4080	.204000E 01=4082	.141000E 01=4084
.637000E 01=408A	.694750E 01=408C	.525000E-01=408E	.150000E 02=4090

INTEGER CONSTANTS

2=4092	1=4093	0=4094	3=4095	498=4096	5=4097	8=4
21=409C	3042=409D	999=409E				

CORE REQUIREMENTS FOR -

COMMON- 0, VARIABLES AND TEMPORARIES- 16462, CONSTANTS AND PROGRAM- 16

END OF SUCCESSFUL COMPILATION

Computer Program for Model 2: Motion of Each Vehicle is Presented by its Mean Position.

PAGE 1

```
// JOB      0180 0181 0182 0183 0184
0000      0140      0180      0000
0001      0181      0181      0001
0002      0182      0182      0002
0003      0183      0183      0003
0004      0184      0184      0004
```

V2 M11 ACTLAL 32K CONFIG 32K

// FORTRAN

```
*NO JOCS
*IOCS(1132 PRINTER, CARD, DISK, TYPEWRITER)
*ONE WORD INTEGERS
*LIST ALL
```

C-ERRS...STNO.C..... F O R T R A N S O U R C E S T A T E M E N T S

```
C*****
C
C   PROGRAM TO PRODUCE A PLOT OF NOISE LEVEL CONTOURS. THIS PROGRAM
C   WAS PREPARED FOR ENGINEERING DYNAMICS INC. USING EQUATIONS
C   PROVIDED BY THEM.
C
C   SIMPLIFICATION 3A - THE SOURCE POSITIONS AS A FUNCTION OF
C                       TIME CAN BE REPLACED BY THEIR MEAN
C                       POSITION.
C*****
```

```
INTEGER TITL1(40),TITL2(40),TITL3(40)
REAL LS(500,5)
DIMENSION XS(5),YS(5)
DIMENSION X055(42),Y055(42),X065(42),Y065(42)
DIMENSION MAX(10),TIME(2),XLIN(10),YLIN(10)
DIMENSION SOURC(2)
DATA AL/'L'//,EQ/'EQ'//,EQUAL/'='//,FF/'55'//,SF/'65'//,SOJRC/'SOUR',
1  'CE' //
DATA BLANK/' ' //
DATA TOL/.01/
```

```
C   READ TITLE
READ(2,1)TITL1,TITL2,TITL3
READ(2,2)DEGRE,STEP,XCI,YCI
```

```
N=1
M=0
IFLAG=0
MMAX=0
XSUM =0.0
YSUM= 0.0
WRITE(3,21)
```


C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```

C      READ DATA
100    READ(2,3)TIME,X,Y,ALW
      IF (ALW)1000,200,200
200    M=M+1
      IFLAG=0
      XSUM=XSUM+X
      YSUM=YSUM+Y
      LS(M,N)=ALW
      WRITE(3,20)TIME,X,Y,ALW
      GO TO 100

C      END OF DATA SET
1000   IF (IFLAG)1100,1100,1200
1100   IFLAG=1
      WRITE(3,21)
      XS(N) = XSUM/M
      YS(N) = YSUM/M
      MAX(N)=M
      IF (M-498)1104,1104,1103
1103   WRITE(3,22)M
      CALL EXIT
1104   IF (M-MMAX)1110,1110,1105
1105   MMAX=M
1110   N=0
      N=N+1
      XSUM = 0.0
      YSUM = 0.0
      GO TO 100

C      END OF ALL DATA SETS
1200   NCONT=N-1
      IF (NCONT-5)1210,1210,1205
1205   WRITE(3,23)
      CALL EXIT
1210   MCONT=MMAX

C      BEGIN COMPUTATIONS OF CONTOURS
      ISTEP=360./DEGRE
      IX55=0
      IY55=0
      IX65=0
      IY65=0

      DO 5000 IRAD=1,ISTEP
      XC=XCI
      YC=YCI
      AVG=(IRAD-1)*DEGRE
      AVG = AVG *.017453293
      XINC=COS(ANG)*STEP
      YINC=SIN(ANG)*STEP
      ILEG=1

```

C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```

C      LOOP TO COMPUTE ENERGY AT A GIVEN POINT
1250  SJML=0.0
      DO 1300 N=1,NCONT
      MX=MAX(N)
      AMX=MX
      DO 1300 MM=1,NCONT
      AM=MM
      TEMP1=AM/AMX
      TEMP2=MM/MX
      M=(TEMP1-TEMP2)*AMX
      IF(M)1260,1260,1275
1260  M=MX
1275  SJML=SUML+10.**((LS(M,N)/10.)/((XC-XS( N))**2+(YC-YS( V))**2)
1300  CONTINUE
      SJML=10.0*ALOG(SUML/MCONT)/ALOG(10.)

C      BRANCH TO CORRECT SECTIONS BASED ON OBSERVER POSITION
      GO TO(1400,1700,1600,2000,3000,4100,4100,1575),ILEG

C      ILEG=1 OBSERVER AT ORGIN
1400  IF(SUML-55.)1550,1500,1600
1500  IX55=IX55+1
      IY55=IY55+1
      XO55(IX55)=XC
      YO55(IY55)=YC
      ILEG=2
      GO TO 4900

1550  ILEG=8
      GO TO 4900

1575  IF(SUML-55.)1580,1500,2020
1580  IF(SUML-SUMA)5000,5000,4900

1600  IF(SUML-65.)1660,1650,1670
1650  IX65=IX65+1
      IY65=IY65+1
      XO65(IX65)=XC
      YO65(IY65)=YC
      ILEG=3
      GO TO 4900

1660  ILEG=4
      GO TO 4900

1670  ILEG=5
      GO TO 4900
C      ILEG=2 ORSERVER AT 55 LEVEL
1700  IF(SUML-55.)5000,1500,1720
1720  ILEG=4

```

PAGE 4

C-ERRS...STNC.C..... F O R T R A N S O U R C E S T A T E M E N T S

```

      GO TO 4900

C      ILEG=3 OBSERVER AT 65 LEVEL
1200  IF(SUML-65.)1840,1650,1820
1820  ILEG=5
      GO TO 4900

1840  ILEG=4
      GO TO 4900

C      ILEG=4 OBSERVER BETWEEN 55 AND 65 LEVEL
2000  IF(SUML-55.)2020,1500,2040
2020  TARGT=55,
      ILEG=6
      GO TO 4000

2040  IF(SUML-65.)4900,1650,2050
2050  TARGT=65,
      ILEG=7
      GO TO 4000

C      ILEG=5 OVSSEVER AT LEVEL GREATER THAN 65
3000  IF(SUML-65.)2050,1650,4900

C      ITERATE AROUND TARGET POINT
4000  X3=XC
      Y3=YC
      SJMB=SUML
4010  XC=(XB+XA)/2.
      YC=(YB+YA)/2.
      GO TO 1250

C      ILEG=6 OR 7 ITERATING AROUND TARGET LEVEL
4100  IF(ABS(SUML-TARGT)-TOL)4500,4500,4120
4120  IF(SUML-TARGT)4130,4130,4140
4130  IF(SUMB-TARGT)4000,4137,4137
4137  XA=XC
      YA=YC
      SJMA=SUML
      GO TO 4010

4140  IF(SUMB-TARGT)4137,4137,4000

C      CONTOUR POINT FOUND
4500  ILEG=ILEG-5
      GO TO(1500,1650),ILEG

C      STEP OUT ON RADIUS
4900  XA=XC
      YA=YC
      SJMA=SUML
```


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C-ERRS...STNG.C..... F O R T R A N S O U R C E S T A T E M E N T S

```

      XC=XC+XINC
      YC=YC+YINC
      GO TO 1250

5000  CONTINUE

      WRITE(3,6)
      WRITE(3,4)(X055(I),Y055(I),I=1,IX55)
      WRITE(3,7)
      WRITE(3,4)(X065(I),Y065(I),I=1,IX65)

C     PRODUCE PLOT OF RESULTS
      PAUSE
      CALL RECT(-0.5,0.0,11.0,8.5,0.0,3)
      CALL SCALE(X055,6.,IX55,1)
      CALL SCALE(Y055,6.,IY55,1)
      FIRX=X055(IX55+1)
      DTX=X055(IX55+2)
      FIRY=Y055(IY55+1)
      DTY=Y055(IY55+2)
      CALL AXISN(1.0,3.5,BLANK,-1.6,0.0,0,FIRX,DTX,2)
      CALL AXISN(1.0,3.5,BLANK,1.6,0.0,0,FIRY,DTY,2)
      XLIN(1)=FIRX
      XLIN(2)=FIRX+6.0*DTX
      XLIN(3)=FIRX
      XLIN(4)=DTX
      YLIN(1)=0.0
      YLIN(2)=0.0
      YLIN(3)=FIRY
      YLIN(4)=DTY
      CALL PLOT(1.0,3.5,-3)
      CALL LINE(XLIN,YLIN,2,1,0,0)
      XLIN(1)=0.0
      XLIN(2)=0.0
      YLIN(1)=FIRY
      YLIN(2)=FIRY+6.0*DTY
      CALL LINE(XLIN,YLIN,2,1,0,0)
      CALL LINE(X055,Y055,IX55,1,-1,0)
      X065(IY65+1)=FIRX
      X065(IY65+2)=DTX
      Y065(IY65+1)=FIRY
      Y065(IY65+2)=DTY
      CALL LINE(X065,Y065,IY65,1,-1,1)
C     PLOT SOURCE LOCATIONS
      DO 6000 N=1,NCOUNT
      XPAGE=(XS( N)-FIRX)/DTX
      YPAGE=(YS( N)-FIRY)/DTY
      ISYM=N+1
      CALL SYMR(XPAGE,YPAGE,.105,ISYM,0.0,-1)
6000  CONTINUE
```

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C-ERRS...STNO.C..... FORTRAN SOURCE STATEMENTS

```

C      PLOT TITLE
      CALL PLOT(-1.0,-3.5,-3)
      CALL CNTR(TITL1,21,2)
      CALL CNTR(TITL2,21,2)
      CALL CNTR(TITL3,21,2)
      CALL SYMB(1.06,2.75,.14,TITL1,0.0,3042)
      CALL SYMB(1.06,2.47,.14,TITL2,0.0,3042)
      CALL SYMB(1.06,2.19,.14,TITL3,0.0,3042)
      CALL SYMB(1.13,1.76,.105,0.0,0,-1)
      CALL SYMB(1.34,1.69,.14,AL,0.0,1)
      CALL SYMB(1.48,1.69,.07,EQ,0.0,2)
      CALL SYMB(1.76,1.69,.14,EQUAL,0.0,1)
      CALL SYMB(2.04,1.69,.14,FF,0.0,2)

      CALL SYMB(1.13,1.48,.105,1.0,0,-1)
      CALL SYMB(1.34,1.41,.14,AL,0.0,1)
      CALL SYMB(1.48,1.41,.07,EQ,0.0,2)
      CALL SYMB(1.76,1.41,.14,EQUAL,0.0,1)
      CALL SYMB(2.04,1.41,.14,SF,0.0,2)

      DO 7000 N=1,NCONT
      AN=N
      ISYM=N+1
      YPAGE=1.69-.1575*(N-1)
      CALL SYMB(5.635,YPAGE,.105,SOURC,0.0,6)
      CALL NUMB(6.37,YPAGE,.105,AN,0.0,-1)
      CALL SYMB(6.9475,YPAGE+.0525,.105,ISYM,0.0,-1)
7000  CONTINUE
      CALL PLOT(15.,0.0,999)
      CALL EXIT
1      FORMAT(40A2)
2      FORMAT(8F10.0)
3      FORMAT(2A4,6F12.0)
4      FORMAT(4(F9.2,2X,F9.2,6X))
6      FORMAT(' COORDINATES OF LEG = 55 LEVEL')
7      FORMAT(' COORDINATES OF LEG = 65 LEVEL')
20     FORMAT(1X,2A4,3F10.2)
21     FORMAT(1H1)
22     FORMAT(1X,14('****ERROR'))/' DATA SET TO LARGE'/15,' POINTS'////////
23     FORMAT(1X,14('****ERROR'))/' TOO MANY DATA SETS'//////////
      END
VARIABLE ALLOCATIONS
XS(R) =0008-0000    YS(R) =0012-000A    X055(R) =0066-0014    Y055(R) =003A-0066
TIME(R) =0166-0164  XLIN(R) =017A-0168    YLIN(R) =018E-017C    SOURC(R) =0192-0190
STEP(R) =151E       XCI(R) =1520         YCI(R) =1522         XSUM(R) =1524
Y(R) =152A          ALW(R) =152C          XC(R) =152E          YC(R) =1530
YINC(R) =1536       SUML(R) =1536         AMX(R) =153A         AM(R) =153C
SUMA(R) =1542       TARGT(R) =1544        X9(R) =1546         Y9(R) =1548
YA(R) =154E         TOL(R) =1550         FIRX(R) =1552       DTX(R) =1554
BLANK(R) =155A      XPAGE(R) =155C        YPAGE(R) =155E      AL(R) =1560
FF(R) =1566        SF(R) =1568          AN(R) =156A        MAX(I) =157D-1574

```

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TITL3(I)=15F5-15CE	N(I)=15F6	M(I)=15F7	IFLAG(I)=15FA
ICONT(I)=15FB	ISTEP(I)=15FC	IX55(I)=15FD	IY55(I)=15FE
IRAD(I)=1601	ILEG(I)=1602	MX(I)=1603	MM(I)=1604

STATEMENT ALLOCATIONS

1=1650	2=1660	3=1663	4=1668	6=166F	7=1680	20=1
100=1733	200=1744	1000=1774	1100=1778	1103=17A4	1104=17A3	1105=1
1210=17DA	1250=1622	1260=165C	1275=1860	1300=188F	1400=19C2	1500=1
1600=1907	1650=1910	1660=1934	1670=193A	1700=1940	1720=1949	1800=1
2020=1960	2040=1977	2050=1980	3000=198A	4000=1995	4010=19A1	4100=1
4140=19CD	4500=19E6	4900=19F2	5000=1A0C	6000=1R79	7000=1C59	

FEATURES SUPPORTED

ONE WORD INTEGERS
STANDARD PRECISION
IOCS-
1132 PRINTER
DISK
TYPEWRITER
CARD

CALLED SUBPROGRAMS

FCOS	FSIN	FALOG	FABS	RECT	SCALE	AXISN	PLOT	LIVE	SYMB
FSUBX	FMPY	FDIV	FLD	FLOX	FSTO	FSTOX	FSBR	FQVR	FAXI
SRED	SWRT	SCOMP	SFIO	SIOAI	SIOAF	SIOFX	SIOF	SIOI	SURSC

REAL CONSTANTS

.000000E 00=160C	.360000E 03=160E	.174532E-01=1610	.100000E 02=1612
.200000E 01=1618	.500000E 00=161A	.110000E 02=161C	.850000E 01=161E
.350000E 01=1624	.900000E 02=1626	.105000E 00=1628	.106000E 01=162A
.247000E 01=1630	.219000E 01=1632	.113000E 01=1634	.176000E 01=1636
.148000E 01=163C	.700000E-01=163E	.204000E 01=1640	.141000E 01=1642
.637000E 01=1648	.694750E 01=164A	.525000E-01=164C	.150000E 02=164E

INTEGER CONSTANTS

2=1650	1=1651	0=1652	3=1653	498=1654	5=1655	8=1
21=165A	3042=165B	999=165C				

CORE REQUIREMENTS FOR -

COMMON- 0, VARIABLES AND TEMPORARIES- 5644, CONSTANTS AND PROGRAM- 16

END OF SUCCESSFUL COMPILATION

Computer Program for Model 3: Single Point Source Model

PAGE 1

```
// JOB      0180 0181 0182 0183 0184
0000      0180      0180      0000
0001      0181      0181      0001
0002      0182      0182      0002
0003      0183      0183      0003
0004      0184      0184      0004
```

V2 M11 ACTUAL 32K CONFIG 32K

// FORTRAN

```
*TRANSFER TRACE
*ASSIGNMENT TRACE
*NO IOCS
*IOCS(1132 PRINTER, CARD, DISK, TYPEWRITER)
*ONE WORD INTEGERS
*LIST ALL
```

C-ERRS...STNC.C.... FORTRAN SOURCE STATEMENTS

```
C*****
C
C PROGRAM TO PRODUCE A PLOT OF NOISE LEVEL CONTOURS. THIS PROGRAM
C WAS PREPARED FOR ENGINEERING DYNAMICS INC, USING EQUATIONS
C PROVIDED BY THEM.
C
C SIMPLIFICATION 3B - THE MEAN POSITIONS OF EACH SOURCE CAN BE
C REPLACED BY THE ACOUSTICAL CENTER OF
C THE SITE.
C*****
```

```
INTEGER TITL1(40),TITL2(40),TITL3(40)
REAL LS(500,5)
DIMENSION X055(42),Y055(42),X065(42),Y065(42)
DIMENSION MAX(10),TIME(2),XLIN(10),YLIN(10)
DIMENSION SOURC(2)
DATA AL/'L'//,EG/'EQ'//,EQUAL/'='//,FF/'55'//,SF/'65'//,SOJRC/'SOUR',
1 ICE '/'
DATA BLANK/' '/
DATA TOL/.01/
```

```
C READ TITLE
READ(2,1)TITL1,TITL2,TITL3
READ(2,2)DEGRE,STEP,XCI,YCI
```

```
N=1
M=0
IFLAG=0
MMAX=0
XASUM = 0.0
YASUM = 0.0
XSUM = 0.0
```

PAGE 2

C=ERRS...SINO.C..... FORTRAN SOURCE STATEMENTS

```
      YSUM= 0.0
      WRITE(3,21)

C      READ DATA
100    READ(2,3) TIME,X,Y,ALW
      IF (ALW) 1000,200,200
200    M=M+1
      IFLAG=0
      XSUM=XSUM+X
      YSUM=YSUM+Y
      LS(M,N)=ALW
      WRITE(3,20) TIME,X,Y,ALW
      GO TO 100

C      END OF DATA SET
1000   IF (IFLAG) 1100,1100,1200
1100   IFLAG=1
      WRITE(3,21)
      YSUM = YSUM/M
      XSUM = XSUM/M
      MAX(N)=M
      IF (M-498) 1104,1104,1103
1103   WRITE(3,22) M
      CALL EXIT
1104   IF (M-MMAX) 1110,1110,1105
1105   MMAX=M
1110   M=0
      N=N+1
      XASUM = XASUM + XSUM
      YASUM = YASUM + YSUM
      XSUM = 0.0
      YSUM = 0.0
      GO TO 100

C      END OF ALL DATA SETS
1200   NCONT=N-1
      XAC = XASUM / NCONT
      YAC = YASUM / NCONT
      IF (NCONT-5) 1210,1210,1205
1205   WRITE(3,23)
      CALL EXIT
1210   MCONT=MMAX

C      BEGIN COMPUTATIONS OF CONTOURS
      ISTEP=360./DEGRE
      IX55=0
      IY55=0
      IX65=0
      IY65=0

      DO 5000 IRAC=1,ISTEP
```

PAGE 3

C-ERRS...STNC.C..... F O R T R A N S O U R C E S T A T E M E N T S

```

      XC=XCI
      YC=YCI
      AVG=(IKAD-1)*DEGRE
      AVG = AVG *.017453293
      XINC=COS(ANG)*STEP
      YINC=SIN(ANG)*STEP
      ILEG=1

C      LOOP TO COMPUTE ENERGY AT A GIVEN POINT
1250  SJML=0.0
      DO 1300 N=1,NCONT
      MX=MAX(N)
      AM=MX
      DO 1300 MM=1,MCONT
      AY=MM
      TEMP1=AM/AMX
      TEMP2=MM/MMX
      M=(TEMP1-TEMP2)*AMX
      IF(M)1260,1260,1275
1260  M=MX
1275  SJML=SUML+10.**(LS(M,N)/10.)
1300  CONTINUE
      SJML = SUML/MCONT/((XC-XAC)**2+(YC-YAC)**2)
      SJML = 10.0 * ALOG(SUML)/ALOG(10.0)

C      BRANCH TO CORRECT SECTIONS BASED ON OBSERVER POSITION
      GO TO(1400,1700,1800,2000,3000,4100,4100,1575),ILEG

C      ILEG=1 OBSERVER AT ORIGIN
1400  IF(SUML-55.)1550,1500,1600
1500  IX55=IX55+1
      IY55=IY55+1
      XO55(IX55)=XC
      YO55(IY55)=YC
      ILEG=2
      GO TO 4900

1550  ILEG=8
      GO TO 4900

1575  IF(SUML-55.)1580,1500,2020
1580  IF(SUML-SUMA)5000,5000,4900

1200  IF(SUML-65.)1660,1650,1670
1650  IX65=IX65+1
      IY65=IY65+1
      XO65(IX65)=XC
      YO65(IY65)=YC
      ILEG=3
      GO TO 4900
```


PAGE 4

C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```
1660 ILEG=4
      GO TO 4900

1670 ILEG=5
      GO TO 4900
C     ILEG=2 OBSERVER AT 55 LEVEL
1700 IF(SUML-55.)15000,1500,1720
1720 ILEG=4
      GO TO 4900

C     ILEG=3 OBSERVER AT 65 LEVEL
1800 IF(SUML-65.)1640,1650,1820
1820 ILEG=5
      GO TO 4900

1840 ILEG=4
      GO TO 4900

C     ILEG=4 OBSERVER BETWEEN 55 AND 65 LEVEL
2000 IF(SUML-55.)2020,1500,2040
2020 TARGT=55.
      ILEG=6
      GO TO 4000

2040 IF(SUML-65.)4900,1650,2050
2050 TARGT=65.
      ILEG=7
      GO TO 4000

C     ILEG=5 OBSERVER AT LEVEL GREATER THAN 65
3000 IF(SUML-65.)2050,1650,4900

C     ITERATE AROUND TARGET POINT
4000 X3=XC
      Y3=YC
      SJMB=SUML
4010 XC=(XB+XA)/2.
      YC=(YB+YA)/2.
      GO TO 1250

C     ILEG=6 OR 7 ITERATING AROUND TARGET LEVEL
4100 IF(ABS(SUML-TARGT)-TOL)4500,4500,4120
4120 IF(SUML-TARGT)4130,4130,4140
4130 IF(SUMB-TARGT)4000,4137,4137
4137 XA=XC
      YA=YC
      SJMA=SUML
      GO TO 4010

4140 IF(SUMB-TARGT)4137,4137,4000
```

PAGE 5

C-ERRS...STND.C..... F O R T R A N S O U R C E S T A T E M E N T S

```
C      CONTOUR POINT FOUND
4500  ILEG=ILEG-5
      GO TO(1500,1650),ILEG

C      STEP OUT ON RADIUS
4900  XA=XC
      YA=YC
      SJMA=SUML
      XC=XC+XINC
      YC=YC+YINC
      GO TO 1250

5000  CONTINUE

      WRITE(3,6)
      WRITE(3,4)(X055(I),Y055(I),I=1,IX55)
      WRITE(3,7)
      WRITE(3,4)(X065(I),Y065(I),I=1,IX65)

C      PRODUCE PLOT OF RESULTS
      PAUSE
      CALL RECT(-0.5,0.0,11.0,8.5,0.0,3)
      CALL SCALE(X055,6.,IX55,1)
      CALL SCALE(Y055,6.,IY55,1)
      FIRX=X055(IX55+1)
      DTX=X055(1X55+2)
      FIRY=Y055(IY55+1)
      DTY=Y055(IY55+2)
      CALL AXISN(1.0,3.5,BLANK,-1.6,0.0,0.0,FIRX,DTX,2)
      CALL AXISN(1.0,3.5,BLANK,1.6,0.0,90.0,FIRY,DTY,2)
      XLIN(1)=FIRX
      XLIN(2)=FIRX+6.0*DTX
      XLIN(3)=FIRX
      XLIN(4)=DTX
      YLIN(1)=0.0
      YLIN(2)=0.0
      YLIN(3)=FIRY
      YLIN(4)=DTY
      CALL PLOT(1.0,3.5,-3)
      CALL LINE(XLIN,YLIN,2,1.0,0)
      XLIN(1)=0.0
      XLIN(2)=0.0
      YLIN(1)=FIRY
      YLIN(2)=FIRY+6.0*DTY
      CALL LINE(XLIN,YLIN,2,1.0,0)
      CALL LINE(X055,Y055,IX55,1,-1,0)
      X065(IY65+1)=FIRX
      X065(IY65+2)=DTX
      Y065(IY65+1)=FIRY
      Y065(IY65+2)=DTY
      CALL LINE(X065,Y065,IY65,1,-1,1)
```

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C-ERRS...STNC.C..... F O R T R A N S O U R C E S T A T E M E N T S

```

      C      PLOT SOURCE LOCATIONS
      XPAGE = (XAC-FIRX)/CTX
      YPAGE = (YAC-FIRY)/CTY
      ISYM = 2
      CALL SYMB(XPAGE,YPAGE,.105,ISYM,0.0,-1)

      C      PLOT TITLE
      CALL PLOT(-1.0,-3.5,-3)
      CALL CNTR(TITL1,21,2)
      CALL CNTR(TITL2,21,2)
      CALL CNTR(TITL3,21,2)
      CALL SYMB(1.06,2.75,.14,TITL1,0.0,3042)
      CALL SYMB(1.06,2.47,.14,TITL2,0.0,3042)
      CALL SYMB(1.06,2.19,.14,TITL3,0.0,3042)
      CALL SYMB(1.13,1.76,.105,0.0,0,-1)
      CALL SYMB(1.34,1.69,.14,AL,0.0,1)
      CALL SYMB(1.48,1.59,.07,ES,0.0,2)
      CALL SYMB(1.76,1.69,.14,EQUAL,0.0,1)
      CALL SYMB(2.04,1.69,.14,FF,0.0,2)

      CALL SYMB(1.13,1.48,.105,1.0,0,-1)
      CALL SYMB(1.34,1.41,.14,AL,0.0,1)
      CALL SYMB(1.48,1.41,.07,ES,0.0,2)
      CALL SYMB(1.76,1.41,.14,EQUAL,0.0,1)
      CALL SYMB(2.04,1.41,.14,SF,0.0,2)

      N=1
      YPAGE=1.69-.1575*(N-1)
      CALL SYMB(5.95,YPAGE,.105,SOURC,0.0,6)
      CALL SYMB(6.9475,YPAGE+.0525,.105,ISYM,0.0,-1)
      CALL PLOT(15.0,0.999)
      CALL EXIT
1     FORMAT(40A2)
2     FORMAT(8F10.0)
3     FORMAT(2A4,6F12.0)
4     FORMAT(4(F9.2,2X,F9.2,6X))
6     FORMAT(' COORDINATES OF LEO = 55 LEVEL')
7     FORMAT(' COORDINATES OF LEO = 65 LEVEL')
20    FORMAT(1X,2A4,3F10.2)
21    FORMAT(1H1)
22    FORMAT(1X,14('****ERROR'))/' DATA SET TO LARGE'/15,' POINTS'////////
23    FORMAT(1X,14('****ERROR'))/' TOO MANY DATA SETS'//////////
      END

VARIABLE ALLOCATIONS
X055(R) = 0052-0000  Y055(R) = 00A6-0054  X065(R) = 00FA-00A8  Y065(R) = 014E-00FC
YLIN(R) = 017A-0168  SOURC(R) = 017E-017C  LS(R) = 1506-0180  DEGRE(R) = 1509
YCI(R) = 150E        XASUM(R) = 1510        YASUM(R) = 1512        XSUM(R) = 1514
Y(R) = 151A          ALW(R) = 151C          XAC(R) = 151E          YAC(R) = 1520
ANG(R) = 1526        XINC(R) = 1528        YINC(R) = 152A        SUML(R) = 152C
TEMP1(R) = 1532      TEMP2(R) = 1534        SUMA(R) = 1536        TARGT(R) = 1538
SUMB(R) = 153E       XA(R) = 1540          YA(R) = 1542          TOL(R) = 1544

```


PAGE 7

FIRY(R)=154A	DTY(R)=154C	BLANK(R)=154E	XPAGE(R)=1550
EQ(R)=1556	EQUAL(R)=1558	FF(R)=155A	SF(R)=155C
TITL2(I)=155F-1598	TITL3(I)=15E7-15C0	N(I)=15E6	M(I)=15E9
MCONT(I)=15EC	MCONT(I)=15ED	ISTEP(I)=15EE	IX55(I)=15EF
IY65(I)=15F2	IRAD(I)=15F3	ILEG(I)=15F4	MX(I)=15F5
ISYM(I)=15F6			

STATEMENT ALLOCATIONS

1=1640	2=1650	3=1653	4=1658	6=165F	7=1670	20=1
100=172B	200=173C	1000=176C	1100=1771	1103=1797	1104=179E	1105=1
1210=17E9	1250=1831	1260=186C	1275=1870	1300=1886	1400=18CC	1500=1
1600=1911	1650=191A	1660=193E	1670=1944	1700=194A	1720=1953	1800=1
2020=1977	2040=1981	2050=198A	3000=1994	4000=199F	4010=19A3	4100=1
4140=19E7	4500=19F0	4900=19FB	5000=1A15			

FEATURES SUPPORTED

TRANSFER TRACE
 ASSIGNMENT TRACE
 ONE WORD INTEGERS
 STANDARD PRECISION
 IOCS-
 1132 PRINTER
 DISK
 TYPEWRITER
 CARD

CALLED SUBPROGRAMS

FCOS	FSIN	FALOG	FABS	RECT	SCALE	AXISN	PLOT	LINE	SY4B
FDIV	FLD	FLDX	FSTO	FSBR	FDVR	FAXI	SFAR	SFARX	SIAF
SFIF	SGOTO	CARDZ	PRNTZ	SREQ	SWRT	SCOMP	SFIO	SIOAI	SIOAF
SNR	SDFIO								

REAL CONSTANTS

.000000E 00=15FE	.360000E 03=1600	.174532E-01=1602	.100000E 02=1604
.200000E 01=160A	.500000E 00=160C	.110000E 02=160E	.850000E 01=1610
.350000E 01=1616	.900000E 02=1618	.105000E 00=161A	.106000E 01=161C
.247000E 01=1622	.219000E 01=1624	.113000E 01=1626	.175000E 01=1628
.148000E 01=162E	.700000E-01=1630	.204000E 01=1632	.141000E 01=1634
.694750E 01=163A	.525000E-01=163C	.150000E 02=163E	

INTEGER CONSTANTS

2=1640	1=1641	0=1642	3=1643	498=1644	5=1645	8=1
21=164A	3042=164B	999=164C				

CORE REQUIREMENTS FOR -

COMMON- C, VARIABLES AND TEMPORARIES- 5630, CONSTANTS AND PROGRAM- 15

END OF SUCCESSFUL COMPILATION

Computer Program for Model 4: Single-Point-Source and Utilization-Factor Model

PAGE 1

```
// JOB      n180 0181 0182 0183 0184
0000      0180      0180      0000
0001      0181      0181      0001
0002      0182      0182      0002
0003      0183      0183      0003
0004      0184      0184      0004
```

V2 M11 ACTUAL 32K CONFIG 32K

// FORTRAN

```
*NO 1005
*IOCS(1132 PRINTER, CARD, DISK, TYPEWRITER)
*ONE WORD INTEGERS
*LIST ALL
```

C-ERPS...STNO.C..... F O R T R A N S O U R C E S T A T E M E N T S

```
C*****
C
C   PROGRAM TO PRODUCE A PLOT OF NOISE LEVEL CONTOURS. THIS PROGRAM
C   WAS PREPARED FOR ENGINEERING DYNAMICS INC. USING EQUATIONS
C   PROVIDED BY THEM.
C
C   SIMPLIFICATION 4A - REPLACE THE ACTUAL SAMPLED TIME HISTORY
C                       BY A RECTANGULAR TIME HISTORY FOR EACH
C                       SOURCE
C*****
```

```
INTEGER TITL1(40),TITL2(40),TITL3(40)
REAL LS(6)
DIMENSION U(6)
DIMENSION XC55(42),Y055(42),XC65(42),Y065(42)
DIMENSION MAX(10),TIME(2),XLIN(10),YLIN(10)
DIMENSION SOURC(2)
DATA AL/'L',EQ/'EQ',EQUAL/'='/,FF/'55',SF/'65',SJJRC/'SOUR',
1      'CE' '/'
DATA BLANK/' '/
DATA TOL/.01/
```

```
C   READ TITLE
READ(2,1)TITL1,TITL2,TITL3
READ(2,2)DEGRE,STEP,XCI,YCI
```

```
N=1
M=0
IFLAG=0
MAX=0
XASUM = 0.0
YASUM = 0.0
XSUM = 0.0
YSUM = 0.0
```

PAGE 2

C-ERRS...STNC.C..... F O R T R A N S O U R C E S T A T E M E N T S

```
C      READ DATA
99      READ(2,2)U(N),LS(N)
        WRITE(3,24)U(N),LS(N)
100     READ(2,3)TIME,X,Y,ALW
        IF(ALW)1000,200,200
200     M=M+1
        IFLAG=0
        XSUM=XSUM+X
        YSUM=YSUM+Y
        WRITE(3,20)TIME,X,Y,ALW
        GO TO 100

C      END OF DATA SET
1000    IF(IFLAG)1100,1100,1200
1100    IFLAG=1
        YSUM = YSUM/M
        XSUM = XSUM/M
        MMAX(N)=M
        IF(M-498)1104,1104,1103
1103    WRITE(3,22)M
        CALL EXIT
1104    IF(M-MMAX)1110,1110,1105
1105    MMAX=M
1110    M=0
        N=N+1
        XASUM = XASUM + XSUM
        YASUM = YASUM + YSUM
        XSUM = 0.0
        YSUM = 0.0
        GO TO 99

C      END OF ALL DATA SETS
1200    NCONT=N-1
        XAC = XASUM / NCONT
        YAC = YASUM / NCONT
        WRITE(3,25)XAC,YAC
        IF(NCONT-5)1210,1210,1205
1205    WRITE(3,23)
        CALL EXIT
1210    MCONT=MMAX

C      BEGIN COMPUTATIONS OF CONTOURS
        ISTEP=360./DEGRE
        AL10=10.0/ALOG(10.0)
        IX55=0
        IY55=0
        IX65=0
        IY65=0

        DO 5000 IRAD=1,ISTEP
```


PAGE 3

C-EPRS...STNC.C..... F O R T R A N S O U R C E S T A T E M E N T S

```

      XC=XCI
      YC=YCI
      ANG=(IKAD-1)*DEGRE
      AVG = ANG *.017453293
      XINC=COS(ANG)*STEP
      YINC=SIN(ANG)*STEP
      ILEG=1

C      LOOP TO COMPUTE ENERGY AT A GIVEN POINT
1250  SJML=0.0
      DO 1300 N=1,NCONT
      SJML=SUML+U(N)*10.0**{(LS(N)/10.0)}
1300  CONTINUE
      SJML=SUML/((XC-XAC)**2+(YC-YAC)**2)
      SJML=ALOG(SUML)*AL10

C      BRANCH TO CORRECT SECTIONS BASED ON OBSERVER POSITION
      GO TO(1400,1700,1600,2000,3000,4100,4100,1575),ILEG

C      ILEG=1 OBSERVER AT ORIGIN
1400  IF(SUML-55.)1550,1500,1600
1500  IX55=IX55+1
      IY55=IY55+1
      X055(IX55)=XC
      Y055(IY55)=YC
      ILEG=2
      GO TO 4900

1550  ILEG=8
      GO TO 4900

1575  IF(SUML-55.)1580,1500,2020
1580  IF(SUML-SUMA)5000,5000,4900

1600  IF(SUML-65.)1660,1650,1670
1650  IX65=IX65+1
      IY65=IY65+1
      X065(IX65)=XC
      Y065(IY65)=YC
      ILEG=3
      GO TO 4900

1660  ILEG=4
      GO TO 4900

1670  ILEG=5
      GO TO 4900
C      ILEG=2 OBSERVER AT 55 LEVEL
1700  IF(SUML-55.)5000,1500,1720
1720  ILEG=4
      GO TO 4900
```

PAGE 4

C-ERRS...STNO.C..... FORTRAN SOURCE STATEMENTS

```
C      ILEG=3 OBSERVER AT 65 LEVEL
1800  IF(SUML-65.)1840,1650,1620
1820  ILEG=5
      GO TO 4900

1840  ILEG=4
      GO TO 4900

C      ILEG=4 OBSERVER BETWEEN 55 AND 65 LEVEL
2000  IF(SUML-55.)2020,1500,2040
2020  TARGT=55.
      ILEG=6
      GO TO 4000

2040  IF(SUML-65.)4900,1650,2050
2050  TARGT=65.
      ILEG=7
      GO TO 4000

C      ILEG=5 OBSERVER AT LEVEL GREATER THAN 65
3000  IF(SUML-65.)2050,1650,4900

C      ITERATE AROUND TARGET POINT
4000  X3=XC
      Y3=YC
      SUMB=SUML
4010  XC=(X3+XA)/2.
      YC=(Y3+YA)/2.
      GO TO 1250

C      ILEG=6 OR 7 ITERATING AROUND TARGET LEVEL
4100  IF(ABS(SUML-TARGT)-TOL)4500,4500,4120
4120  IF(SUML-TARGT)4130,4130,4140
4130  IF(SUMB-TARGT)4000,4137,4137
4137  XA=XC
      YA=YC
      SUMA=SUML
      GO TO 4010

4140  IF(SUMB-TARGT)4137,4137,4000

C      CONTOUR POINT FOUND
4500  ILEG=ILEG-5
      GO TO(1500,1650),ILEG

C      STEP OUT ON RADIUS
4900  XA=XC
      YA=YC
      SUMA=SUML
      XC=XC+XINC
```

PAGE 5

C-ERRS...STNC.C..... F O R T R A N S O U R C E S T A T E M E N T S

```
      YC=YC+YINC
      GO TO 1250

5000  CONTINUE

      WRITE(3,6)
      WRITE(3,4)(X055(I),Y055(I),I=1,IX55)
      WRITE(3,7)
      WRITE(3,4)(X065(I),Y065(I),I=1,IX65)

C     PRODUCE PLOT OF RESULTS
      PAUSE
      CALL RECT(-0.5,0.0,11.0,8.5,0.0,3)
      CALL SCALE(X055,6.,IX55,1)
      CALL SCALE(Y055,6.,IY55,1)
      FIRX=X055(IX55+1)
      DTX=X055(IX55+2)
      FIRY=Y055(IY55+1)
      DTY=Y055(IY55+2)
      CALL AXIS(1.0,3.5,BLANK,-1,6.0,0.0,FIRX,DTX,2)
      CALL AXIS(1.0,3.5,BLANK,1,6.0,90.0,FIRY,DTY,2)
      XLIN(1)=FIRX
      XLIN(2)=FIRX+6.0*DTX
      XLIN(3)=FIRX
      XLIN(4)=DTX
      YLIN(1)=0.0
      YLIN(2)=0.0
      YLIN(3)=FIRY
      YLIN(4)=DTY
      CALL PLOT(1.0,3.5,-3)
      CALL LINE(XLIN,YLIN,2,1,0,0)
      XLIN(1)=0.0
      XLIN(2)=0.0
      YLIN(1)=FIRY
      YLIN(2)=FIRY+6.0*DTY
      CALL LINE(XLIN,YLIN,2,1,0,0)
      CALL LINE(X055,Y055,IX55,1,-1,0)
      X065(IY65+1)=FIRX
      X065(IY65+2)=DTX
      Y065(IY65+1)=FIRY
      Y065(IY65+2)=DTY
      CALL LINE(X065,Y065,IY65,1,-1,1)

C     PLOT SOURCE LOCATIONS
      XPAGE = (XAC-FIRX)/DTX
      YPAGE = (YAC-FIRY)/DTY
      ISYM = 2
      CALL SYMB(XPAGE,YPAGE,.105,ISYM,0.0,-1)

C     PLOT TITLE
      CALL PLOT(-1.0,-3.5,-3)
      CALL CNTR(TITL1,21,2)
```


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C-ERRS...SYNO.C..... FORTRAN SOURCE STATEMENTS

```

CALL CNTR(TITL2,21,2)
CALL CNTR(TITL3,21,2)
CALL SYMB(1.06,2.75,.14,TITL1,0.0,3042)
CALL SYMB(1.06,2.47,.14,TITL2,0.0,3042)
CALL SYMB(1.06,2.19,.14,TITL3,0.0,3042)
CALL SYMB(1.13,1.76,.105,0.0,0,-1)
CALL SYMB(1.34,1.69,.14,AL,0.0,1)
CALL SYMB(1.48,1.69,.07,EO,0.0,2)
CALL SYMB(1.76,1.69,.14,EQUAL,0.0,1)
CALL SYMB(2.04,1.69,.14,FF,0.0,2)

CALL SYMB(1.13,1.48,.105,1.0,0,-1)
CALL SYMB(1.34,1.41,.14,AL,0.0,1)
CALL SYMB(1.48,1.41,.07,EO,0.0,2)
CALL SYMB(1.76,1.41,.14,EQUAL,0.0,1)
CALL SYMB(2.04,1.41,.14,SF,0.0,2)

N=1
YPAGE=1.69-.1575*(N-1)
CALL SYMB(5.95,YPAGE,.105,SOURC,0.0,6)
CALL SYMB(6.9475,YPAGE+.0525,.105,ISYM,0.0,-1)
CALL PLOT(15,0.0,999)
CALL EXIT

1  FORMAT(40A2)
2  FORMAT(6F10.0)
3  FORMAT(2A4,6F12.0)
4  FORMAT(4(F9.2,2X,F9.2,6X))
6  FORMAT(' COORDINATES OF LEQ = 55 LEVEL')
7  FORMAT('/// COORDINATES OF LEQ = 65 LEVEL')
20 FORMAT(1X,2A4,3F10.2)
22 FORMAT(1X,14('**ERROR'))/' DATA SET TO LARGE'/15,' POINTS'////////
23 FORMAT(1X,14('***ERROR'))/' TOO MANY DATA SETS'////////////////////
24 FORMAT(1H1,2F10.4)
25 FORMAT(' SOURCE LOCATED AT',F10.3,' ',F10.3)
END

VARIABLE ALLOCATIONS
U(R) =000A-JU00  X055(R) =005E-000C  Y055(R) =00B2-0060  X065(R) =0106-00B4
XLIN(R) =0172-0160  YLIN(R) =0186-0174  SOURC(R) =018A-0188  LS(R) =0196-018C
XCI(R) =01C  YCI(R) =019E  XASUM(R) =01A0  YASUM(R) =01A2
X(R) =01A8  Y(R) =01AA  ALW(R) =01AC  XAC(R) =01AE
XC(R) =0184  YC(R) =01B6  ANG(R) =01B8  XINC(R) =01BA
SUMA(R) =01C0  TARGT(R) =01C2  XB(R) =01C4  YR(R) =01C6
YA(R) =01CC  TCL(R) =01CE  FIRX(R) =01D0  DTX(R) =01D2
BLANK(R) =0108  XPAGE(R) =01DA  YPAGE(R) =01DC  AL(R) =01DE
FF(R) =01E4  SF(R) =01E6  MAX(I) =01F9-01F0  TITL1(I) =0221-01FA
N(I) =0272  M(I) =0273  IFLAG(I) =0274  MMAX(I) =0275
ISTEP(I) =0278  IX55(I) =0279  IY55(I) =027A  IX65(I) =0273
ILEG(I) =027E  I(I) =027F  ISYM(I) =0280

```

STATEMENT ALLOCATIONS
1=0205 2=0208 3=020B 4=02E0 6=02E7 7=02F8 20=0

PAGE 7

25=0361	99=03C1	100=03D7	200=03E8	1000=040D	1100=0411	1103=0
1200=0463	1205=0485	1210=048A	1250=04D9	1300=04F7	1400=0527	1500=0
1600=056C	1650=0575	1660=0599	1670=059F	1700=05A5	1720=05AE	1800=0
2020=05C2	2040=05LC	2050=05E5	3000=05EF	4000=05FA	4010=0505	4100=0
4140=0642	4500=0648	4900=0657	5000=0671			

FEATURES SUPPORTED
 ONE WORD INTEGERS
 STANDARD PRECISION
 IOCS-
 1132 PRINTER
 DISK
 TYPEWRITER
 CARD

CALLED SUBPROGRAMS

FALOG	FCOS	FSIN	FABS	RECT	SCALE	AXISN	PLOT	LIVE	SYMB
FMPYX	FDIV	FLD	FLDX	FSTO	FSTOX	FSBR	FDVR	FAXI	IFIX
SWRT	SCOMP	SFIO	SIOAI	SIOAF	SIOFX	SIOF	SIOI	SU35C	PAUSE

REAL CONSTANTS

.000000E 00=0296	.360000E 03=0288	.100000E 02=028A	.174532E-01=028C
.200000E 01=0292	.500000E 00=0294	.110000E 02=0296	.850001E 01=0298
.350000E 01=029E	.900000E 02=02A0	.105000E 00=02A2	.106001E 01=02A4
.247000E 01=02A4	.219000E 01=02AC	.113000E 01=02AE	.176003E 01=02B0
.148000E 01=02B6	.700000E-01=02B8	.204000E 01=02BA	.141003E 01=02BC
.694750E 01=02C2	.525000E-01=02C4	.150000E 02=02C6	

INTEGER CONSTANTS

2=02C8	1=02C9	0=02CA	3=02CB	498=02CC	5=02CD	8=0
21=02D2	30+2=02D3	999=02D4				

CORE REQUIREMENTS FOR -

COMMON- 0, VARIABLES AND TEMPORARIES- 646, CONSTANTS AND PROGRAM- 15

END OF SUCCESSFUL COMPILATION

Computer Program for Model 5: Base Equation Plus Barrier Attenuation

PAGE 1

```
// JOB      0180 0191 0182 0183 0184
0000      0180      0180      0000
0001      0191      0181      0001
0002      0182      0182      0002
0003      0183      0183      0003
0004      0184      0184      0004
```

V2 M11 ACTUAL 32K CONFIG 32K

// FORTRAN

```
*NO IOCS
*IOCS(1152 PRINTER, CARD, DISK, TYPEWRITER)
*ONE WORD INTEGERS
*LIST ALL
```

C-ERRS...STNC.C..... F O R T R A N S O U R C E S T A T E M E N T S

```
C*****
C
C PROGRAM TO PRODUCE A PLOT OF NOISE LEVEL CONTOURS. THIS PROGRAM
C WAS PREPARED FOR ENGINEERING DYNAMICS INC. USING EQUATIONS
C PROVIDED BY THEM.
C*****
```

```
INTEGER TITL1(40),TITL2(40),TITL3(40)
REAL LS(500,5)
DIMENSION XS(500,5),YS(500,5)
DIMENSION X055(42),Y055(42),X065(42),Y065(42)
DIMENSION MAX(10),TIME(2),XLIN(10),YLIN(10)
DIMENSION SOURC(2)
DATA AL/'L'//,EW/'EQ'//,EQUAL/'='//,FF/'55'//,SF/'65'//,SOJRC/'SOUR',
1 ICE ''//
DATA BLANK/' '//
DATA TOL/.01/
```

```
C READ TITLE
READ(2,1)TITL1,TITL2,TITL3
READ(2,2)STANG
READ(2,2)DEGRE,STLP,XC1,YC1
READ(2,2)XB1,YB1,XB2,YB2,H1,H2,H3
```

```
N=1
M=0
IFLAG=0
MMAX=0
WRITE(3,21)
```

```
C READ DATA
100 READ(2,3)TIME,X,Y,ALW
IF(ALW)1000,200,200
200 M=M+1
```


PAGE 2

C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```
      IFLAG=0
      XS(M,N)=X
      YS(M,N)=Y
      LS(M,N)=ALW
      WRITE(3,20)TIME,X,Y,ALW
      GO TO 100

C      END OF DATA SET
1000  IF(IFLAG)1100,1100,1200
1100  IFLAG=1
      WRITE(3,21)
      MAX(N)=M
      IF(M-498)1104,1104,1105
1103  WRITE(3,22)M
      CALL EXIT
1104  IF(M-MMAX)1110,1110,1105
1105  MMAX=M
1110  M=0
      N=N+1
      GO TO 100

C      END OF ALL DATA SETS
1200  NCONT=N-1
      IF(NCONT-5)1210,1210,1205
1205  WRITE(3,23)
      CALL EXIT
1210  MCONT=MMAX

C      BEGIN COMPUTATIONS OF CONTOURS
      ISTEP=360./DEGRE
      IX55=0
      IY55=0
      IX65=0
      IY65=0
      ITCNT = 0

C      DEFINE SLOPE OF BARRIER
      IF(XB1-XB2)1220,1225,1220
1220  ISH=1
      SBAR=(YB1-YB2)/(XB1-XB2)
      GO TO 1230
1225  ISB=0
      SBAR=0
1230  CONTINUE

      DO 5000 IRAD=1,ISTEP
      XC=XCI
      YC=YCI
      ANG=(IRAD-1)*DEGRE
      ANG=ANG+STANG
      WRITE(1,12)ANG
```

C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```

12  FORMAT('ANGLE =',F10.2)
    ANG = ANG *.017453293
    XINC=COS(ANG)*STEP
    YINC=SIN(ANG)*STEP
    ILEG=1

C    LOOP TO COMPUTE ENERGY AT A GIVEN POINT
1250 SJML=0.0
    DO 1300 N=1,NCONT
    MX=MAX(N)
    AM=MX
    DO 1300 MM=1,MCONT
    AM=MM
    TEMP1=AM/AMX
    TEMP2=MM/MMX
    M=(TEMP1-TEMP2)*AMX
    IF(M)1260,1260,1275
1260 M=MX
1275 XSC=XS(M,N)
    YSC=YS(M,N)
    IF(XSC-XC)1278,1279,1278
1278 ISL=1
    SLIN=(YSC-YC)/(XSC-XC)
    GOTO 1280
1279 SLIN=0
    ISL=0
1280 IF(SBAR-SLIN)1282,1281,1282
1281 FAC=1.0
    GOTO 1299
1282 IF(ISB)1284,1283,1284
C    SBAR = INF
1283 XI=XB1
    YI=SLIN*(XI-XC)+YC
    GO TO 1287

1284 IF(ISL)1286,1285,1286
C    SLIN = INF
1285 XI=XC
    YI=SBAR*(XI-XB1)+YB1
    GOTO 1287

1286 XI=(SLIN*XC - SBAR*XB1 - YC + YB1)/(SLIN-SBAR)
    YI=SBAR*XI - SBAR*XB1 + YB1
1287 CALL SEG(XB1,XB2,XI,ID)
    GO TO(1288,1281),ID
1288 CALL SEG(XC,XSC,XI,ID)
    GOTO(1290,1281),ID

C    DEFINE PARAMETERS FOR BARRIER CONDITION
1290 E47=((YI-YC)**2 + (XI-XC)**2)**.5
    U47 = ((YI-YSC)**2 + (XI-XSC)**2)**.5

```

C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```

      CMT = ((H1-H3)**2 + (EMT+DMT)**2)**.5
      BMT = ((H2-H3)**2 + EMT**2)**.5
      AMT = ((H2-H1)**2 + DMT**2)**.5
      GAMMA = AMT + BMT - CMT
      IF(GAMMA-.0514)1297,1298,1298
1297  GAMMA=.0514
1298  FAC = .0514/GAMMA
1299  SUML = SUML+FAC*10.0**((LS(M,N)/10.0)/((XC-XSC)**2 + (YC-YSC)**2)
1300  CONTINUE
      SUML=10.0*ALOG(SUML/MCONT)/ALOG(10.)
      WRITE(5,30)SUML,XC,YC
30    FORMAT(3F12.4)

C      BRANCH TO CORRECT SECTIONS BASED ON OBSERVER POSITION
      GO TO(1400,1700,1800,2000,3000,4100,4100,1575),ILEG

C      ILEG=1 OBSERVER AT ORIGIN
1400  IF(SUML-55.)1550,1500,1600
1500  IX55=IX55+1
      IY55=IY55+1
      XJ55(IX55)=XC
      YJ55(IY55)=YC
      ILEG=2
      GO TO 4900

1550  ILEG=8
      GO TO 4900

1575  IF(SUML-55.)1580,1500,2020
1580  IF(SUML-SUMA)5000,5000,4900

1600  IF(SUML-65.)1660,1650,1670
1650  IX65=IX65+1
      IY65=IY65+1
      XJ65(IX65)=XC
      YJ65(IY65)=YC
      ILEG=3
      GO TO 4900

1660  ILEG=4
      GO TO 4900

1670  ILEG=5
      GO TO 4900
C      ILEG=2 OBSERVER AT 55 LEVEL
1700  IF(SUML-55.)5000,1500,1720
1720  ILEG=4
      GO TO 4900

C      ILEG=3 OBSERVER AT 65 LEVEL
1800  IF(SUML-65.)1640,1650,1820

```


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C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```
1820 ILEG=5
      GO TO 4900

1840 ILEG=4
      GO TO 4900

C      ILEG=4 OBSERVER BETWEEN 55 AND 65 LEVEL
2000 IF(SUML-55.)2020,1500,2040
2020 TARGT=55.
      ILEG=6
      GO TO 4000

2040 IF(SUML-65.)4900,1650,2050
2050 TARGT=65.
      ILEG=7
      GO TO 4000

C      ILEG=5 OBSERVER AT LEVEL GREATER THAN 65
3000 IF(SUML-65.)2050,1650,4900

C      ITERATE AROUND TARGET POINT
4000 X3=XC
      Y3=YC
      SJMB=SUML
4010 XC=(XB+XA)/2.
      YC=(YB+YA)/2.
      WRITE(1,10)TARGT
10    FORMAT('START OF ITERATION',F10.2)
      GO TO 1250

C      ILEG=6 OR 7 ITERATING AROUND TARGET LEVEL
4100 ITCNT = ITCNT +1
      IF(ITCNT-15)4105,4105,4500
4105 IF(ABS(SUML-TARGT)-TOL)4500,4500,4120
4120 IF(SUML-TARGT)4130,4130,4140
4130 IF(SUMB-TARGT)4000,4137,4137
4137 X4=XC
      Y4=YC
      SJMA=SUML
      GO TO 4010

4140 IF(SUMB-TARGT)4137,4137,4000

C      CONTOUR POINT FOUND
4500 ILEG=ILEG-5
      ITCNT = 0
      WRITE(1,11)
11    FORMAT('END OF ITERATION')
      GO TO(1500,1650),ILEG

C      STEP OUT ON RADIUS
```

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C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```
4900  XA=XC  
      YA=YC  
      SJMA=SUML  
      XC=XC+XINC  
      YC=YC+YINC  
      GO TO 1250
```

```
5000  CONTINUE
```

```
      WRITE(3,6)  
      WRITE(3,4)(X055(I),Y055(I),I=1,IX55)  
      WRITE(3,7)  
      WRITE(3,4)(X065(I),Y065(I),I=1,IX65)
```

```
C      PRODUCE PLOT OF RESULTS
```

```
      PAUSE  
      CALL RECT(-0.5,0.0,11.0,8.5,0.0,3)  
      CALL SCALE(X055,6.,IX55,1)  
      CALL SCALE(Y055,6.,IY55,1)  
      FIRX=X055(IX55+1)  
      DTX=X055(IX55+2)  
      FIRY=Y055(IY55+1)  
      DTY=Y055(IY55+2)  
      CALL AXIS(1.0,3.5,BLANK,-1.6,0.0,0.0,FIRX,DTX,2)  
      XLIN(1)=FIRX  
      CALL AXIS(1.0,3.5,BLANK,1.6,0.0,90.0,FIRY,DTY,2)  
      XLIN(2)=FIRX+6.0*DTX  
      XLIN(3)=FIRX  
      XLIN(4)=DTX  
      YLIN(1)=0.0  
      YLIN(2)=0.0  
      YLIN(3)=FIRY  
      YLIN(4)=DTY  
      CALL PLOT(1.0,3.5,-3)  
      CALL LINE(XLIN,YLIN,2,1,0,0)  
      XLIN(1)=0.0  
      XLIN(2)=0.0  
      YLIN(1)=FIRY  
      YLIN(2)=FIRY+6.0*DTY  
      CALL LINE(XLIN,YLIN,2,1,0,0)  
      CALL LINE(X055,Y055,IX55,1,-1,0)  
      X065(IY65+1)=FIRX  
      X065(IY65+2)=DTX  
      Y065(IY65+1)=FIRY  
      Y065(IY65+2)=DTY  
      CALL LINE(X065,Y065,IY65,1,-1,1)
```

```
C      PLOT SOURCE LOCATIONS
```

```
      DO 6000 N=1,NCONT  
      NCONT=MAX(N)  
      XSIFCONT+1,N)=FIRX
```

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C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```
      YS(MCONT+1,N)=FIRY
      XS(MCONT+2,N)=DTX
      YS(MCONT+2,N)=DTY
      CALL LINE(XS(1,N),YS(1,N),MCONT,1,0,0)
      XPAGE=(XS(1,N)-FIRX)/DTX
      YPAGE=(YS(1,N)-FIRY)/DTY
      ISYM=N+1
      CALL SYMB(XPAGE,YPAGE,,105,ISYM,0,0,-1)
6000  CONTINUE
```

```
      C  PLOT BARRIER POSITION
      ISGN=(YB1-YB2)/ABS(YB1-YB2)
      IF(ISB)5200,5100,-200
5100  YB1=YB1+ISGN*H2
      YB2=YB2-ISGN*H2
      GO TO 5300
5200  ISGNX=(XB1-XB2)/ABS(XB1-XB2)
      YDIF=ABS(YB1-YB2)/(EMT+DMT)*H2
      XDIF=ABS(XB1-XB2)/(EMT+DMT)*H2
      YB1=YB1+ISGN*YDIF
      YB2=YB2-ISGN*YDIF
      XB1=XB1+ISGNX*XDIF
      XB2=XB2-ISGNX*XDIF
5300  XPAGE=(XB1-FIRX)/DTX
      YPAGE=(YB1-FIRY)/DTY
      CALL PLOT(XPAGE,YPAGE,3)
      XPAGE=(XB2-FIRX)/DTX
      YPAGE=(YB2-FIRY)/DTY
      CALL PLOT(XPAGE,YPAGE,2)
```

```
      C  PLOT TITLE
      CALL PLOT(-1.0,-3.5,-3)
      CALL CNTR(TITL1,21,2)
      CALL CNTR(TITL2,21,2)
      CALL CNTR(TITL3,21,2)
      CALL SYMB(1.06,2.75,.14,TITL1,0,0,3042)
      CALL SYMB(1.06,2.47,.14,TITL2,0,0,3042)
      CALL SYMB(1.06,2.19,.14,TITL3,0,0,3042)
      CALL SYMB(1.13,1.76,.105,0,0,0,-1)
      CALL SYMB(1.34,1.69,.14,AL,0,0,1)
      CALL SYMB(1.48,1.69,.07,E2,0,0,2)
      CALL SYMB(1.76,1.69,.14,EQUAL,0,0,1)
      CALL SYMB(2.04,1.69,.14,FF,0,0,2)

      CALL SYMB(1.13,1.48,.105,1,0,0,-1)
      CALL SYMB(1.34,1.41,.14,AL,0,0,1)
      CALL SYMB(1.48,1.41,.070,EQ,0,0,2)
      CALL SYMB(1.76,1.41,.14,EQUAL,0,0,1)
      CALL SYMB(2.04,1.41,.14,SF,0,0,2)
```

```
      DO 7000 N=1,NCONT
```


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C-ERRS...STNC.C..... FORTRAN SOURCE STATEMENTS

```

      AV=N
      ISYM=N+1
      YPAGE=1.69-.1575*(N-1)
      CALL SYMB(5.635,YPAGE,.105,SOURC,0,0,6)
      CALL NUMB(6.37,YPAGE,.105,AN,0,0,-1)
      CALL SYMB(6.9475,YPAGE+.0525,.105,ISYM,0,0,-1)
7000  CONTINUE
      CALL PLOT(15.,0,0,999)
      CALL EXIT
1      FORMAT(40A2)
2      FORMAT(8F10,0)
3      FORMAT(2A4,6F12,0)
4      FORMAT(4(F9,2,2X,F9,2,6X))
6      FORMAT(' COORDINATES OF LEG = 55 LEVEL')
7      FORMAT(' COORDINATES OF LEG = 65 LEVEL')
20     FORMAT(1X,2A4,3F10,2)
21     FORMAT(1H1)
22     FORMAT(1X,14('****ERROR'))/15,' POINTS'////////
23     FORMAT(1X,14('****ERROR'))/ ' TOO MANY DATA SETS'////////
      END

```

VARIABLE ALLOCATIONS

XS(R) =13E5-0000	YS(R) =270E-1388	X055(R) =2762-2710	Y055(R) =2766-2764
TIME(R) =2862-2860	XLIN(R) =2676-2664	YLIN(R) =288A-2678	SOURC(R) =268E-266C
DEGRE(R) =3C1A	STEP(R) =3C1C	XCI(R) =3C1E	YCI(R) =3C20
XB2(R) =3C26	YB2(R) =3C28	H1(R) =3C2A	H2(R) =3C2C
Y(R) =3C32	ALW(R) =3C34	SBAR(R) =3C36	XC(R) =3C38
XINC(R) =3C3E	YINC(R) =3C40	SUML(R) =3C42	AMX(R) =3C44
TEMP2(R) =3C4A	XSC(R) =3C4C	YSC(R) =3C4E	SLIN(R) =3C50
YI(R) =3C56	EMT(R) =3C58	DMT(R) =3C5A	CMT(R) =3C5C
GAMMA(R) =3C62	SUMA(R) =3C64	TARGT(R) =3C66	XB(R) =3C68
XA(R) =3C6E	YA(R) =3C70	TOL(R) =3C72	FIRX(R) =3C74
DTY(R) =3C7A	BLANK(R) =3C7C	XPAGE(R) =3C7E	YPAGE(R) =3C80
AL(R) =3C86	EQ(R) =3C88	EQUAL(R) =3C8A	FF(R) =3C8C
MAX(I) =3CA3-3C9A	TITL1(I) =3CC6-3CA4	TITL2(I) =3CF3-3CCC	TITL3(I) =3D13-3CF4
IFLAG(I) =3C1E	MMAX(I) =3D1F	MCONT(I) =3D20	MCONT(I) =3D21
IY55(I) =3C24	Ix65(I) =3C25	IY65(I) =3C26	ITCNT(I) =3D27
ILEG(I) =3C2A	MX(I) =3C28	MM(I) =3D2C	ISL(I) =3D2D
ISYM(I) =3C30	ISGN(I) =3C31	ISGNX(I) =3C32	

STATEMENT ALLOCATIONS

12=308C	30=3093	10=3096	11=30A2	1=30AC	2=30AF	3=3
20=30E3	21=30E9	22=30EC	23=30EE	100=30E90	200=30EA1	1000=3
1105=3EF9	1110=3EFD	1200=3F09	1205=3F15	1210=3F1A	1220=3F40	1225=3
1275=3FL4	127A=3FLC	1279=4000	1280=4009	1281=4010	1282=4016	1283=4
1287=4068	128A=4074	1290=4080	1297=40F4	1298=40F8	1299=40FE	1300=4
1575=419A	1580=41A3	1600=41AC	1650=41B5	1660=4109	1670=410F	1700=4
1840=4203	2000=4209	2020=4212	2040=421C	2050=4225	3000=422F	4000=4
4120=4278	4130=427F	4137=4286	4140=4294	4500=429D	4900=42B1	5000=4
5300=451A	7000=461B					

FEATURES SUPPORTED

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ONE WORD INTEGERS
STANDARD PRECISION

IOCS-

1132 PRINTER

DISK

TYPEWRITER

CARD

CALLED SUBPROGRAMS

FCCS	F2IN	SEG	FALOG	FARS	RECT	SCALE	AXISN	PLDT	LINE
FSUB	FMPY	FDIV	FLO	FLDX	FSTO	FSTOX	FSBP	FDVR	FAXI
SRED	SWRT	SCOMP	SFIO	SIOAI	SIOAF	SIOFX	SIOF	SIOI	SUBSL

REAL CONSTANTS

.360000E 03=3038	.174532E-01=303A	.000000E 00=303C	.100000E 01=303E
.100000E 02=3044	.550000E 02=3046	.650000E 02=3048	.200000E 01=304A
.600000E 01=3050	.350000E 01=3052	.900000E 02=3054	.105000E 00=3056
.140000E 00=305C	.247000E 01=305E	.219000E 01=3060	.113000E 01=3062
.169000E 01=306A	.148000E 01=306A	.700000E-01=306C	.204000E 01=306E
.563500E 01=3074	.637000E 01=3076	.694750E 01=3078	.525000E-01=307A

INTEGER CONSTANTS

2=307E	1=307F	0=3080	3=3061	498=3082	5=3083	8=3
15=3068	21=3089	3042=308A	999=308B			

CORE REQUIREMENTS FOR -

COMMON- C, VARIABLES AND TEMPORARIES- 15672. CONSTANTS AND PROGRAM- 22

END OF SUCCESSFUL COMPILATION

APPENDIX C:

ACCURACY OF A SINGLE-POINT-SOURCE MODEL

Nomenclature

L_{or} —sound level of noise source at distance D_r

L_{sr} —sound level of source at 50 ft (15 m)

D_r —distance to noise source

D_1, D_2 —distances

Estimation of the degree of accuracy sacrificed by adoption of a point-source model as a function of the amount of vehicle motion perpendicular to an observer point may be calculated by assuming an arbitrary reference sound level (L_{or}) at an observer point located an arbitrary reference distance (D_r) from the source which produces a reference sound level (L_{sr}) at 50 ft (15 m). Given these variable definitions, the following relationship is true:

$$L_{or} = 10 \log_{10} \frac{50^2 \times 10^{L_{sr}/10}}{D_r^2} \quad (\text{Eq C1})$$

The question may then be asked: at what distance D_1/D_r or D_2/D_r will the sound level at the observer point be less than or greater than L_{or} by X amount?

$$X = L_{or} - 10 \log_{10} \frac{50^2 \times 10^{L_{sr}/10}}{D_1^2} \quad (\text{Eq C2})$$

and

$$X = 10 \log_{10} \left[\frac{50^2 \times 10^{L_{sr}/10}}{D_2^2} \right] - L_{or} \quad (\text{Eq C3})$$

Substituting the equality set forth for L_{or} in Eqs C2 and C3 gives:

(Eq C4)

$$X = 10 \log_{10} \left[\frac{50^2 \times 10^{L_{sr}/10}}{D_r^2} \right] - 10 \log_{10} \left[\frac{50^2 \times 10^{L_{sr}/10}}{D_1^2} \right]$$

and

(Eq C5)

$$X = 10 \log_{10} \left[\frac{50^2 \times 10^{L_{sr}/10}}{D_2^2} \right] - 10 \log_{10} \left[\frac{50^2 \times 10^{L_{sr}/10}}{D_r^2} \right]$$

From Eqs C4 and C5, the following relationships can be derived:

$$D_1 = D_r \sqrt{10^{X/10}} \quad (\text{Eq C6})$$

$$D_2 = D_r / \sqrt{10^{X/10}} \quad (\text{Eq C7})$$

If values of X are substituted into Eqs C6 and C7, the following relationships of D_1 and D_2 to D_r may be derived:

X	D_1/D_r	D_2/D_r
1.0	1.122	.891
1.5	1.189	.841
2.0	1.259	.794
2.5	1.334	.750
3.0	1.413	.708
3.5	1.496	.668
4.0	1.585	.631
4.5	1.679	.596
5.0	1.778	.562
5.5	1.884	.531

From these relationships, the degree of accuracy sacrificed by the point-source model may be provided as a function of the amount of movement relative to a given distance to observer position (D_r) in feet.*

Accuracy	Movement Acceptable Around Center Point
± 1 dB	.347 D_r
2 dB	.583 D_r
3 dB	.827 D_r
4 dB	1.082 D_r
5 dB	1.352 D_r

*1 ft = .3048 m

APPENDIX D:

DEVELOPMENT OF A SIMPLIFIED BARRIER EQUATION AND ASSESSMENT OF ITS APPLICABILITY TO A POINT-SOURCE MODEL

Nomenclature

- α — constant equal to 20
- δ — difference in sound path distance with and without barrier
- λ — wavelength
- L_{BA} — barrier attenuation
- FR_f — frequency f
- L_B — A-weighted sound level at observer position with barrier
- L_A — A-weighted sound level at observer position without barrier
- A_f — A-weighting correction for frequency f
- L_f — sound pressure level at frequency f

Barrier Equation Development

A barrier equation was derived from a simplified form of Makawa's equation:

$$L_{BA} = 10 \log_{10} \left(\frac{\alpha \delta}{\lambda} \right) \quad [\text{Eq D1}]$$

α = a constant which equals 20

$\lambda = (1130 \text{ ft/sec } [344 \text{ m/sec}]) / FR$

δ = the difference in sound path distance travel with and without the barrier (Figure A5), $\delta = a+b-c$.

FR = frequency in Hz

Given the above definitions, the equation can be rewritten as:

$$L_{BA} = 10 \log_{10} \frac{FR_f}{28.25} + 10 \log_{10} \delta \quad [\text{Eq D2}]$$

If L_A and L_B are the A-weighted sound levels at the observer position without and with a barrier, respectively, and A_f equals the A-weighting correction for each frequency f , then the following relationship is true:

$$L_A = 10 \log_{10} \sum_{f=1}^F 10^{(L_f - A_f - L_{BA})/10} \quad [\text{Eq D3}]$$

Substituting the equality presented for L_{BA} in Eq D2 into Eq D3 gives:

$$L_A = 10 \log_{10} \left[\sum_{f=1}^F \frac{10^{(L_f - A_f)/10}}{FR_f} \times \frac{28.25}{\delta} \right] \quad [\text{Eq D4}]$$

Eq D4 can be rewritten as:

$$L_A = 10 \log_{10} \left[\frac{28.25}{\delta} \sum_{f=1}^F \frac{10^{(L_f - A_f)/10}}{FR_f} \right] \quad [\text{Eq D5}]$$

At this point the assumption is made that all construction vehicles have a frequency spectrum which is similar enough to allow acceptance of a single representative spectrum (which can be weighted to yield the total sound level measured for each vehicle). Given this assumption, a new variable (FS_f) is defined as that value which when added to the total A-weighted sound level (L_A), will yield the quantity of the sound level (L_f) of frequency f minus the A-weighting component (A_f):

$$L_A + FS_f = L_f - A_f \quad [\text{Eq D6}]$$

Substituting this relationship into Eq D5:

$$L_B = 10 \log_{10} \left[\frac{28.25}{\delta} \sum_{f=1}^F \frac{10^{(L_A + FS_f)/10}}{FR_f} \right] \quad [\text{Eq D7}]$$

from which Eq D8 can be derived:

[Eq D8]

$$L_B = 10 \log_{10} \left[\frac{28.25}{\delta} \times 10^{L_A/10} \sum_{f=1}^F \frac{10^{FS_f/10}}{FR_f} \right]$$

Since it has been assumed that the same relative spectrum applies to all construction vehicles, then the quantity

$$\sum_{f=1}^F \frac{10^{FS_f/10}}{FR_f}$$

is a constant, which is calculated to equal 0.001 when the spectrum depicted by Figure D1 is selected as representative. Substituting this value into Eq D8 we have:

$$L_B = 10 \log_{10} \frac{0.3 \times 10^{L_A/10}}{\delta} \quad [\text{Eq D9}]$$

Eq D9 can be rewritten as:

$$L_B = L_A + 10 \log_{10} \frac{0.0514}{\delta} \quad [\text{Eq D10}]$$

Given that the difference in the A-weighted sound levels at the observer with and without the barrier equals the excess attenuation due to the barrier L_{BA} , then:

$$L_{BA} = L_A - L_B \quad [\text{Eq D11}]$$

Replacing the term L_B in Eq D11 with the equality presented in Eq D10 gives:

$$L_{BA} = 10 \log_{10} (\delta/0.0514) \quad [\text{Eq D12}]$$

Application of Barrier Equation to a Point-Source Model

A procedure was developed for applying this barrier Eq D12 to a point-source construction-site model. A series of simple hypothetical situations was postulated where a vehicle was moved in discrete, equally spaced steps behind a barrier. The variables investigated were the distance from the observer to the barrier, the closest vehicle approach to barrier, the farthest distance from the barrier to the vehicle, the median distance of the vehicle to the barrier, and the total distance of vehicle movement.

The results of the analyses of these hypothetical situations indicate that a fixed-point-source model located at the median position of vehicle travel behind a barrier will estimate the barrier-attenuated sound level to within approximately 1 dB given that the quotient of the total distance of vehicle movement divided by the distance from the observer to the barrier is 2 greater than the quotient of the nearest approach of the vehicle to the barrier divided by the distance from the observer to the barrier.

Derivation of a Simple Table of Barrier Attenuation Levels

In order to derive a simple table of barrier attenuation levels, a program was developed to calculate the excess attenuation resulting from several combinations of barrier and vehicle heights, for various distances from barriers to vehicle and to observer, for various fractions of vehicle path shielding, and for two conditions of vehicle noise levels. From these scenarios (2400 in all), three tendencies were observed:

Difference Between Barrier and Vehicle Heights

The first trend which became apparent was the excess attenuation only ranged a maximum of 1.1 dB for any given difference between barrier and vehicle heights, regardless of the actual barrier and vehicle heights. The relationship held for all barrier-to-vehicle and barrier-to-observer distances modeled.

Distance Between Barrier and Observer

Another relationship investigated was excess attenuation as a function of the distance between barrier and observer for a constant barrier-to-vehicle distance. For any given barrier to vehicle distance, excess attenuation was found to be relatively constant (within 1.2 dB) for barrier to observer distances of 2500 ft (762 m) and beyond. Excess attenuation increases as the distance from barrier to observer decreases from 2500 ft (762 m). No simplifying relationship was found for these shorter distances.

Percentage of Vehicle Path Shielded by Barrier

The third relationship investigated is excess attenuation as a function of the percentage of the vehicle path shielded by the barrier. It was determined that for every 25 percent decrease in the percentage of the vehicle path shielded by the barrier, the excess attenuation values provided in Table D1 should be halved. This procedure is accurate within 1 dB for all conditions investigated (vehicle distance from 50 to 400 ft (15 to 122 m) behind the barrier and barrier-vehicle height differences ranging from 0 to 13 ft (0 to 4 m)), except when the vehicle was 50 ft (15 m) behind the barrier and the barrier-vehicle height was greater than 10 ft (3 m). In these cases, when this procedure is used, the excess attenuation is overestimated by as much as 1.9 dB.

Table D1
Number of Decibels Attenuation Provided by Barrier
Shielding as a Function of (1) Distance between Vehicle and
Barrier and (2) Difference between Barrier and Vehicle Heights*

Barrier Ht Minus Vehicle Ht (ft) ⁺	Median Distance between Vehicle and Barrier (ft) ⁺				
	50	100	150	200	400
0-2	0.0dB	0.0dB	0.0dB	0.0dB	0.0dB
3	0.0	0.0	0.0	0.0	0.0
4	3.0	0.0	0.0	0.0	0.0
5	5.0	2.0	0.0	0.0	0.0
6	6.5	4.0	2.0	1.0	0.0
7	8.0	5.0	3.5	2.0	0.0
8	9.0	6.0	4.5	3.5	1.0
9	10.0	7.0	5.5	4.5	1.5
10	11.0	8.0	6.5	5.0	2.0
11	12.0	9.0	7.0	6.0	3.0
12	12.5	9.5	8.0	7.0	4.0
13	13.0	10.0	9.5	7.5	4.5

*This table is most accurate when applied to points 2,500 ft (762 m) or more behind the barrier. For points closer to the barrier than 2500 ft (762 m), more attenuation than indicated by the table will be obtained.

⁺1 ft = .3048 m

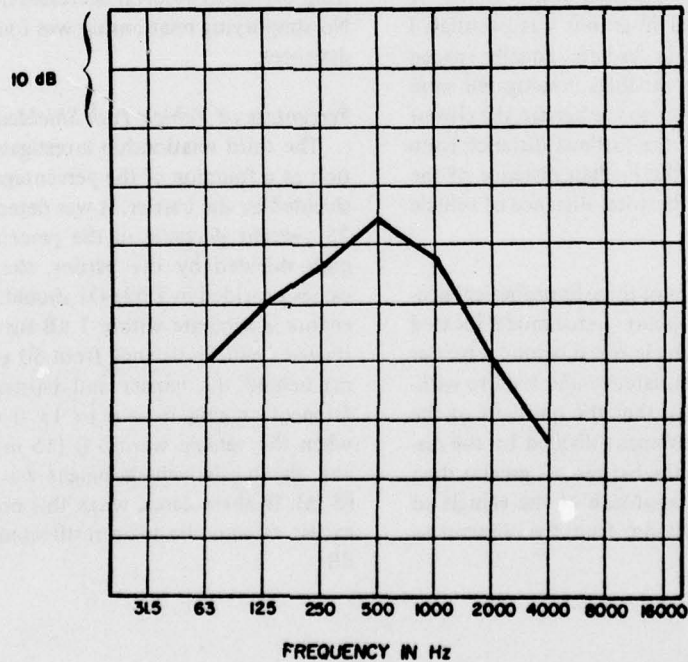


Figure D1. Relative spectrum for typical engine powered construction equipment.

APPENDIX E:

EQUIPMENT NOISE LEVELS

Construction Equipment at Fort Hood and Fort Carson Construction Sites

Noise measurements of construction equipment were made at Fort Hood and Fort Carson construction sites. Table E1 summarizes data relating to these pieces of equipment, such as equipment types, manufacturers, model numbers, modes of operation, noise levels, and usage factors.

Donaldson Tests

Donaldson Company, Inc., of Minneapolis, MN, has conducted numerous noise level tests on construction equipment. More than 90 noise-level measurements of construction equipment with varying machine sizes and noise control features were made. A summary of the test results is presented in Table E2. Linear regressions of the maximum sound level versus engine horsepower ($L_p = 80.8 + .01 \text{ hp}$) and sound level versus the logarithm of the engine horsepower ($L_p = 64.1 + 9.05 \log_{10} \text{ hp}$) are presented in Figures E1 and E2 respectively.

Table E1
Equipment Noise Data

Equipment Type	Manufacturer	Model No.	Operation	L_p (dBA) at 15 m (50 ft)	Usage Factor
Backhoe	Case	530	Used as trencher—filling in telephone trench	80	
		580B	Filling in plumbing trench using front loader	66	
			Idling	59-70	
			Setting up in sandy soil	68	
			Ditching and emptying shovel	69-71	
Bulldozer	John Deere	410	Ditching with faster idle	72-74	
			Digging trench for sewer line	82	
	Case	450	Moving light sand	80	
			Idling	68	
	Caterpillar		Backing	74	
		D3		82.5	
		D4D		81.5	
		D5		83.5	
		D6	Moving forward and backward	88	
			Passby with moderate load	84	
		D6C	Backing	84	
			Forward scraping	85	
		D76		85.5	
		D8H	With sheepsfoot attachment	99.1	.06
			Forward	88.1	.31
			Backward	89	.23
		D8K	Digging furrows	88	
			Backing up	89	
			Passby	79	
		D9H		88.8	
	International Harvester	TD-15C		87	
		TD-20E		87	
		TD-25C		89	
	John Deere	350-B	Forward	81	.10
			Backward	79	
		450-B		82.5	

**Table E1 (Cont'd)
Equipment Noise Data**

Equipment Type	Manufacturer	Model No.	Operation	L _p (dBA) at 15 m (50 ft)	Usage Factor
Compactor	Caterpillar	DW20 815	Road preparation	81-82 91	.10
Compressor	Ingersoll-Rand	DRAIF 160 cfm*	Testing plumbing for leaks	82	
	Unidentified		Idling	69-70	
			Rear	75-86	
			Right side	67-68	
Concrete Batch Plant			Loading truck	95.5	
Concrete Mixer (small)			Mixing mortar for brick facade	67-68	
Concrete truck				69-79	
Crane	Skyhook	5-section telescope	Raising framed trusses to second story	75-78	
Forklift	John Deere	480	Passby - no load	81	
Front-End Loader	Caterpillar	910 920 930		80.5 85.5 87	
			Removing piles of hard dirt	87	
			Forward	79-88	
			Leaving site	83	
			Scooping dirt from pile - near idle	84	
			Backing	79-83	
			Scooping dirt from pile, then leaving	81	
			Dumping dirt into dump truck	81	
		930C	Picking up dirt	73 82	
		931		81.8	
		941B		82.3	
		950		81.5-82.5	.1
			Handling 4-ft. tile sections	78	
			Backing - no load	80	
			Picking up tile	82	
			Backing	74	
		951C		82.3	
		955L		85	
		966C		86	
		977L		83.5-85.9	.1
		980B		89	
		988		90.5	
		992B		89.5	
	Clarke	M610	Picking up sand	73-75	
			Forward	73	
			Passby	72	
	John Deere	644B	Removing piles of hard dirt - lifting	89	
			- lifting	85	
			- backwards while scraping	82-89	
			- leaving site	73	
Excavator	Caterpillar	235		84.8	.10
Grader	Allis Chalmers	M65	Forward - road preparation	71-72	
			Backward - road preparation	70-76	
	Caterpillar	12F	Grading - road preparation	85	
			Road grading - moderate load	80-82	
			Backing	79-81	.8

*1 cfm = 35.31 m³/min

Table E1 (Cont'd)
Equipment Noise Data

Equipment Type	Manufacturer	Model No.	Operation	L _p (dBA) at 15 m (50 ft)	Usage Factor
Hy Hoes	Caterpillar	12G	Forward	88.4	.04
			Backwards	95.5	.03
			Forward—leveling sandy soil	75	
			Backwards	86	
			Idling	67-74	
		14E	Road grading—finishing	82	
			Leveling sandy soil	73	
				80	
				65	
			Grading roadway	80	
	John Deere	120	Slow	79	
			Idling	78	
				80	.33
		235	Trenching in hard clay	80	
			Steady	76	
			Digging, clanking	81	
			Idling	65	
			Digging plumbing trench—scooping	73	
			Impulsive	87	
			Moving	79	
Hydraulic Hammer Self Propelled Roller	BMC		Scraping	85	
			Tamping fill over sewer line—peak	99-105	
	Ingram Flat		Passby upgrade	86	
			Passby downgrade	72	
			Finishing roadbed—slow	77	
			Finishing roadbed	84	
			Passby	80	
	Ingram Pneumatic		Downhill 5° grade	75	
			Uphill	71	
			Uphill—revving engine	81	
			Downhill	78	
			Uphill full speed	80	
Scraper	Allis Chalmers	260B	Fully loaded traveling down 10° slope	83	
			Unloaded traveling up 10° slope	89	
			Backing	78	
			Idle	72	
			Starting up	87	
			Dumping dirt for roadbed	87	
		633C	Unloaded	89.2	.09
			Loaded	86.5	.13
			Digging	90.7	.24
	John Deere	760A		82	
		860A	Unloaded	87.3	.12
			Loaded	82.8	.21
			Digging	88.6	.44
			Dumping	88.6	.37
Hand Tamper	Wacker	51005	Side	87	
			Front	88	
			Shielded	85	
Trenchers	Ditchwitch	R65	Trenching for telephone cable—hard clay subsoil	81-83	
			Continuous	81	1.0
				85	1
			Rock	83	

Table E2
Summary of Donaldson Company, Inc., Test Results

EQUIPMENT		Year	ENGINE		HP	RPM	WORK CYCLE		Sound Level @ 15 m (50 ft)	Passby Loaded	Muffler Orten- tation	Usage Factor %
Manufacturer	Type		Model	Model			Hrs/Day	Hrs/Week				
Caterpillar	FEL	75	992B	12-cyl. turbo D-348	550	2000	10	50	89	89	H	50
Caterpillar	Crawler- Tractor	72	D9H	D353E	385	1330	10	50	86	86	V	60
Caterpillar	Road Grader	70	12F	2904 Series F D333	125	2000	10	50	85	85	V	65
Terex	Scrapper	67	524	Detroit Diesel DD	432	2100	10	50	93	93	H	50
Terex	Scrapper	67	524	12V71 MA	432	2100	10	50	93	93	H	65
Ingersoll-Rand	Compressor	73	160 Gyro	2711E	74	2500	10	50	78	78	V	98
Unit Rig	Truck	74	Mark 30	DD12V149T1	1200	1900	8	40	88	88	X	50
Euclid	Truck	74	R-170	DD16V149T1	1492	1900	8	40	91	91	X	50
Unit Rig	Truck	74	Mark 36	DD16V149T1	1492	1900	8	40	93	93	X	50
Caterpillar	Tractor	67	D9G	D353	385	1330	8	40	95	95	X	60
Drott	Excavator	74	40	4-cyl. DD 4-53	123	2500	8	40	83	83	V	70
Caterpillar	Grader	74	14G	3305	180	2000?	8	40	80	80	V	35
Caterpillar	FEL	67	988	6-cyl. turbo D343	325	2060	8	40	95	95	X	50
Caterpillar	Scrapper	64-69	651	D346	500	1900	8	40	91	91	X	60
Kenworth	Mixer	72	C525	V555	—	—	8	40	82	82	V	50
Diamond Rio	Truck	—	—	—	—	—	—	—	82	82	H	50
Caterpillar	Scrapper	74	651B	V8 turbo D546	500	1900	8	40	87	87	V	60
Caterpillar	Grader	70	14E	D333	125	2000	8	40	85	85	V	35
Caterpillar	FEL	73-75	C920	3304	80	2200	8	40	79	79	V	40
Peterbilt	Truck	—	—	555	—	—	—	—	84	84	V	—
White	Concrete Mixer	—	4564WD Western	V8210	188	3000	8	40	83	83	V	50
P&H	Shovel	56	Star	D397	427	1000	8	40	95.5	95.5	X	—
Caterpillar	FEL	71	1400	D333-TA	—	—	8-10	—	86	86	V	—
Kenworth	Concrete Mixer	—	980B C923	C190	—	—	8	40	85	85	V	50
Peterbilt	Concrete Mixer	—	—	V555	202	3000	8	40	84	84	V	50
I-H	Truck	73	65,200 lb. Dump Body F85 OM	1160	206	2800	8	40	82	81	V	50
I-H	Truck	—	559646	8 cyl. V7087-7093	301	2100	8	40	84	84	V	50
I-H	Tractor	72	4200	V903	299	2600	8	40	78	78	V	50
I-H	Mixer	74	F4270	81-71?	300	2100	8	40	83	83	V	50
John Deere	Grader	70	JD570	M63VA	83	2300	8	40	79	79	V	40
Caterpillar	Scrapper	74	623B	6-cyl. turbo 3H06	330	1900	8	40	81	81	H	—

Table E2 (Cont'd)
Summary of Donaldson Company, Inc., Test Results

Manufacturer	EQUIPMENT		Year	Manufacturer	Model	ENGINE	HP	RPM	WORK CYCLE		Sound Level at 15 m (50 ft)	Passby Loaded	Muffler Orientation	Usage Factor %
	Type	Model							Hrs/Day	Hrs/Week				
WABCO	Truck	120C	75	GM-DD	12V149T	1000	1900	1900	20	140	91	91	X	50
WABCO	Truck	120B	71	GM-DD	12V149T	1000	1900	1900	20	140	93.5	93.5	X	50
WABCO	Truck	120B	71	Caterpillar	D348	960	2000	2000	20	140	86.5	86.5	X	50
Unit Rig	Truck	M100	68	Caterpillar	D348	950	2100	2100	20	140	86	86	X	50
K.W. Dart	Truck	65-ton D4655	65	Cummins	VT41710C	650	—	—	20	140	79	79	X	50
Caterpillar	Grader (#77)	D16G	70	Caterpillar	D343	225	1900	1900	16	80	77.5	77.5	V	50
Caterpillar	Grader	16G	68	Caterpillar	D343	225	1900	1900	16	80	88	88	X	50
Caterpillar	Grader	D16G	75	Caterpillar	3406	250	2000	2000	16	80	86	86	V	40
BLH Austin-	Crane	410 Senior	—	G11-DD	4-53N	—	—	—	16	80	87	77	H	50
W. Stern	Crane	RT75S	75	Caterpillar	320B	185	2600	2600	16	80	85	85	V	50
Caterpillar	Tractor	D8	57	Caterpillar	—	—	—	—	8	40	82	—	X	90
Caterpillar	Crawler- Tractor	D9G	74	Caterpillar	D353	385	1330	1330	16	80	81	81	V	30
Caterpillar	Crawler- Tractor	D8H	69	Caterpillar	D342	270	1280	1280	16	80	87	87	X	20
Caterpillar	Dozer	955K	70	Caterpillar	330	130	2185	2185	8	40	86	—	V	—
Allis Blake	Crawler- Tractor	HD41	72	Cummins	VT1710-C	524	2100	2100	16	80	96	96	X	30
Joy	Compressor	RPO-1200D	—	Caterpillar	D343-TA	380	2000	2000	8	40	90	—	H	50-100
Gardner-Denver	Compressor	SM61	—	Caterpillar	D343A	282	1800	1800	8	40	102	—	X	60
Gardner-Denver	Compressor	SP600F/1	65	Detroit Diesel	6-71	202	2100	2100	8	40-80	82	—	H	60
Caterpillar	Generator	D336	65	Caterpillar	D336	235	2200	2200	8	40	87.5	—	X	100
Caterpillar	Gen Set	SRCR	74	Caterpillar	3304	74	1800	1800	8	40	81.5	—	V	100
Case	FEL	580B	72	Case	188	188	2100	2100	8	40	78	—	V	—
Caterpillar	FEL	920	71	Caterpillar	330	130	2185	2185	3	15	80	—	V	—
Trojan	Wheel FEL	304A	63-65	GM Detroit Diesel	GV53N	185	2500	2500	8	40	84	—	H	20
Trojan Eaton	Wheel FEL	6000	71	Cummins	NT855C335	335	2100	2100	8-16	40-80	86	84	H	60
Caterpillar	Wheel FEL	988	71	Caterpillar	D343	325	2060	2060	8	40	86	—	V	30
R. G. Letoveneau	Wheel FEL	L-700	74	Detroit Diesel	16V71T	700	2100	2100	16	80	85	85	H	50
Trojan Eaton	WFEL	8000	—	Detroit Diesel	12V71N	456	2100	2100	8-16	40-80	91	—	H	70-80
Caterpillar	WFEL	950	65-72	Caterpillar	D330	130	2150	2150	8	40	86	—	V	—
Caterpillar	WFEL	980	67	Caterpillar	D336	235	2200	2200	8	40	88	84	X	60-80
Michigan	WFEL	175-111A	67	GM Detroit Diesel	8V71N	290	2100	2100	8	40	85	—	H	20
Trojan Eaton	WFEL	404	63-68	GM Detroit Diesel	8V71N	318	2100	2100	8	40	88	—	H	20

Table E2 (Cont'd)
Summary of Donaldson Company, Inc., Test Results

Manufacturer	EQUIPMENT		Year	Manufacturer	ENGINE Model	HP	RPM	WORK CYCLE		Sound Level (@ 15 m 50 ft)	Passby Loaded	Muffler Orienta- tion	Usage Factor %
	Type	Model						Hrs/Day	Hrs/Week				
Hyster	Roller	C530A	-	GM 4-cylinder	GM230-G	-	2800	8	40	82	-	V	-
Ingersoll-Rand Caterpillar	Steel Roller Gen Set	SP54	74	Detroit Diesel Caterpillar	4-5 3N 8-cyl. W22 3208	140 210	2500 2800	16 16	80 80	83 81	83	H V	100 100
Caterpillar	Tractor	D8H	63	Caterpillar	46A 2065 R9D347	235	1200	16	80	90	90	X	50
Caterpillar	FEL	966C	73	Caterpillar	2P6300 3306	170	2200	10	50	89	89	V	60
Ingersoll-Rand	Compressor	Super Spiro Flo XL750	72	Diesel Allison Div.	6V71	228	2100	10	50	83	83	H	70
International- Harvester Caterpillar	Truck	Pay Hollar	70	General Motors	12V71	456	2100	10	50	96	92	X	50
	Scraper	J619	63	Caterpillar	4-cyl. turbo D340	250	1900	8	40	89	-	X	55
WABCO General Tractors Caterpillar Caterpillar	Scraper Water Pump Backhoe Excavator	D 8V71 245 235	67 70 75 74	GM DD General Motors Caterpillar Caterpillar	4-71 8V-71 Straight 6 6-cyl. turbo 3306	148 318	2100 2100	8 10 8	40 50 40	87 80 ?	- - - 77	H V H V	50 100 75 70
Caterpillar Michigan-Clark Equip. Co. Dynapac Caterpillar	Backhoe Backhoe FEL Steel Roller Tractor	225 475B CA25D D8H	74 72	Caterpillar Cummins	3208 VTA1710C700	-	-	8 8	40 40	78 85	78	H H	60 50
Terex A H & D	30-ton truck Crawler crane	3305 7250	73	Caterpillar	3145	-	-	16	80	82	82	X	100
	Tractor	D8H	73	-	-	-	-	-	-	86	-	X	-
	30-ton truck	3305	74	DD	8V-71T	-	-	8	40	92	-	X	50
	Crawler crane	7250	73	DO AD	6-87N	-	-	8	40	85.5	-	-	-
Caterpillar WABCO Unit Rig WABCO WABCO Dart Ingersoll-Rand	Compactor Truck Truck Truck Truck FEL Air	824B 120B M100 170C 120B 600 DL1200	69	Caterpillar Caterpillar Caterpillar Detroit Diesel DD DD DD	- D348 D348 DD16V149T1 DD12V149T 16V-71 12V-71	- 950 950 1492? 1000	- 2100 2100 1900 1900	8 20 20 20 15 8-24	40 140 140 140 140 105 -	80 - 90 - - 85 99	- - - - - - -	V X X X H H H	- 50 50 - - 40 -
Ingersoll-Rand	Compressor	DXL1200	70	DD	12V-71	-	1800	8-24	-	98	-	H	-
Hough Hughes Tool Rex	FEL Drill Rig Slip Form Paver	400 LLHD100 -	72 75 74	Cummins DD Caterpillar	V1710C 6-71 3304T	635 238 125	2100 2100 2100	8 8 8	40 40 40	92-99 90 80	- - -	X V X	- - 100

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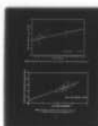
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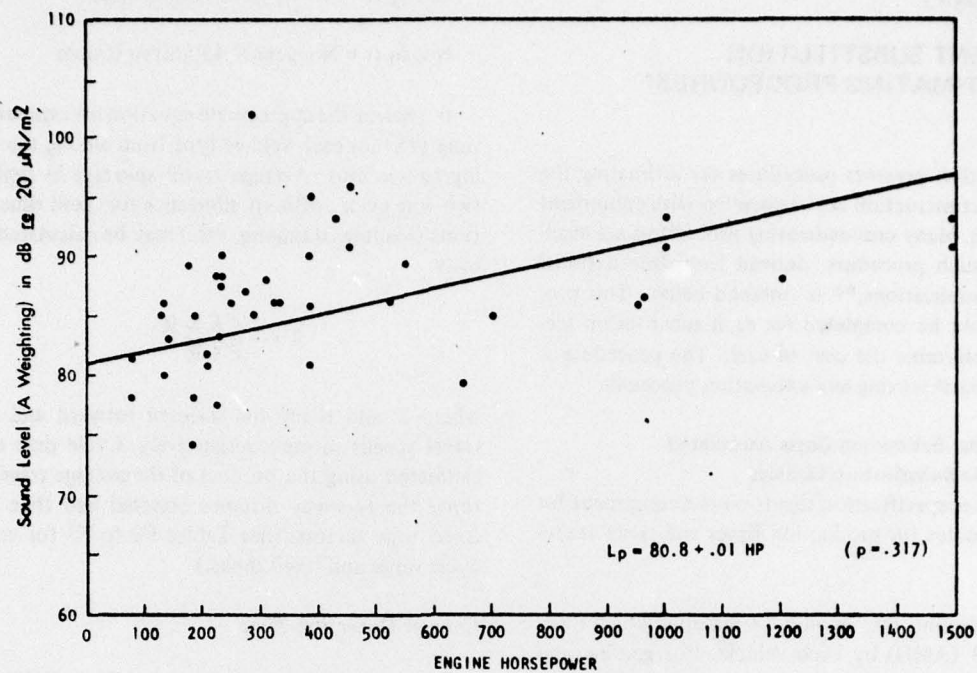


Figure E1. Equipment sound level (at 50 ft [15 m]) as a function of engine horsepower (Donaldson tests).

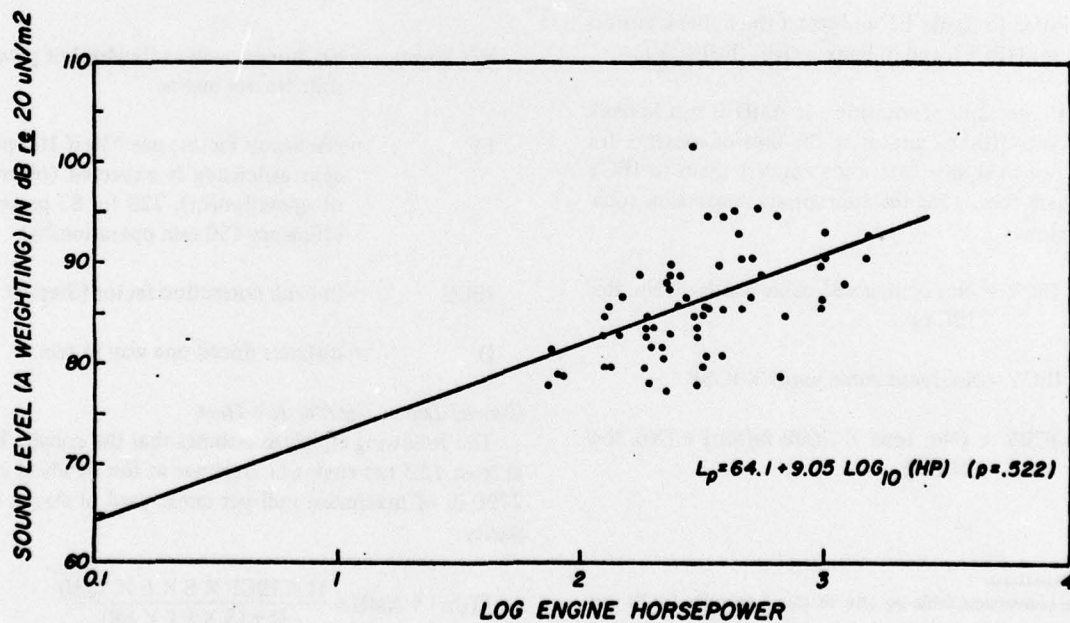


Figure E2. Equipment sound level (at 50 ft [15 m]) as a function of logarithm of engine horsepower (Donaldson tests).

APPENDIX F:

EQUIPMENT SUBSTITUTION COST-ESTIMATING PROCEDURES*

This section presents procedures for estimating the increase in construction cost associated with equipment substitution. Many cost-estimating procedures are available. One such procedure, derived from International Harvester publications,** is outlined below. This procedure would be completed for each substitution scenario to determine the cost of each. The procedure is specific to earthmoving and excavation processes.

Procedure for Estimating Costs Associated with Vehicle Substitution Choices

1. Gather specification sheets on the equipment for which estimates for production times and costs are required.

2. Determine the amount of material which must be handled (AMH) by each vehicle. For grading and plowing activities, estimate the area to be graded or plowed.

3. Determine the type of material to be moved or excavated.

4. Refer to Table F1 and select the in-bank correction factor (IBCF), and in-bank weight (lb/IBCY).

5. If the unit of measure for AMH is not in-bank cubic yards (IBCY) and/or if the unit of measure for area is not in square feet, then convert them to IBCY and square feet, using the appropriate conversion equations below:

$$\text{No. IBCY} = \text{No. compacted cubic yards} \div (\text{No. lbs/IBCY})$$

$$\text{No. IBCY} = \text{No. loose cubic yards} \times \text{ICBF}$$

$$\text{No. ICBY} = (\text{No. tons} \times 2000 \text{ lb/ton}) \div (\text{No. lbs/IBCY})$$

*See conversion table pg 104 of this Appendix for SI conversions.

**Basic Estimating, Construction Equipment Division (International Harvester). *Earthmoving Principles: A Guide to Production and Cost Estimating* (International Harvester, 1975).

$$\text{No. sq ft} = \text{No. sq yd} \times 9 \text{ sq ft/sq yd}$$

$$\text{No. sq ft} = \text{No. acre} \times 43,560 \text{ sq ft/acre}$$

6. Select the appropriate equation for estimating job time (JT) for each vehicle type from among the following subsections. Average travel speed(s) in mph for a two-way cycle, without allowance for fixed time operations (loading, dumping, etc.) may be calculated as follows:

$$S = \frac{2 \times F \times R}{F + R}$$

where F and R are the selected forward and reverse travel speeds in mph, respectively. Cycle time may be estimated using the product of the average travel speed times the two-way distance traveled and then adding fixed time factors. (See Tables F2 to F5 for common cycle times and fixed times.)

Crawler Dozer Job Time

$$\text{JT(hr)} = \text{AMH} \div \frac{\text{Net Power} \times \text{EF} \times \text{IBCF}}{D + 50}$$

where AMH = total amount of job material to be handled in in-bank cubic yards (Step 5)

Net Power = net horsepower at flywheel of power shift tractor engine

EF = efficiency factor, use 330 if 100 percent efficiency is expected (60 min of operation/hr), 220 for 83 percent efficiency (50 min operation/hr)

IBCF = in-bank correction factor (Step 4)

D = distance dozed one way in feet.

Crawler-Drawn Scraper Job Time

The following equation assumes that the crawler has at least 12.5 net engine horsepower at the flywheel and 2700 lb of maximum pull per cubic yard of struck capacity.

$$\text{JT(hr)} = \text{AMH} \div \frac{H \times \text{IBCF} \times S \times E \times 5280}{D + (S \times \text{FT} \times 88)}$$

AMH = total amount of job material to be handled in in-bank cubic yards (Step 5)

- H = SAE heaped capacity in loose cubic yards
- IBCF = in-bank correction factor (Step 4)
- S = travel speed in mph; a suggested speed is 4.9 mph, which requires 12.5 net flywheel horsepower per pay yard of scraper capacity at approximately 200 lb/ton of rolling resistance. This speed may be replaced by the product of the maximum speed adjustment factor provided by Table F6
- E = efficiency; fraction of each hour that machine is engaged in productive operation (example: 55 min of productive operation out of every hour would equal 0.92)
- d = distance of two-way round trip haul in feet
- FT = fixed cycle time related to loading, dumping, acceleration, turning; an estimate of 1.85 min per cycle is suggested
- 5280 = conversion factor = 5280 ft/mi
- 88 = conversion factor = 5280 ft/mi ÷ 60 min/hr.

Tractor Ripper Job Time

$$JT(\text{hr}) = \frac{AMH}{DP \times W \times S \times E \times 196}$$

- AMH = total amount of job material to be handled in in-bank cubic yards (Step 5)
- DP = depth of penetration per pass, in feet
- W = effective width of ripper in feet
- S = travel speed in mph, usually 1.2 to 1.5 mph
- E = efficiency; fraction of each hour that machine is engaged in productive operation (example: 55 min of productive operation out of every clock hour would equal 0.92).

Motor Grader Job Time

$$JT(\text{hr}) = \frac{\text{Area} \times NP}{BL \times AA \times S \times E \times 3520}$$

- Area = job to be graded in square feet (Step 5)

- NP = number of passes required to achieve the desired grade
- BL = blade length in ft
- AA = blade angle adjustment factor (Table F7)
- S = travel speed in mph
- E = efficiency; fraction of each hour that vehicle is operated productively (example: 55 min of productive operation out of every hour would equal 0.92)
- 3520 = adjustment factor of 2/3 (because of overlap of Y_3 for each pass) times the conversion factor of 5280 ft/mi.

Pay Loader Job Time

$$JT(\text{hr}) = AMH \div \frac{H \times IBCF \times E \times 60}{C}$$

- AMH = total amount of job material to be handled in in-bank cubic yards (Step 5)
- H = heaped capacity in loose cubic yards
- IBCF = in-bank correction factor (Step 4)
- E = efficiency; fraction of hour that vehicle is operated productively (example: 55 min of productive operation out of every clock hour would equal 0.92)
- C = cycle time in minutes
- 60 = conversion factor: 60 min/hr.

Self-Propelled Scraper Job Time

$$JT(\text{hr}) = AMH \div \frac{H \times IBCF \times S \times E \times 5280}{D + (S \times FT \times 88)}$$

- AMH = total amount of job material to be handled in in-bank cubic yards (Step 5)
- H = heaped capacity of scraper bowl in loose cubic yards
- IBCF = in-bank correction factor (Step 4)

- S = travel speed in mph; 22.7 mph is suggested; this speed requires 15 hp/cu yd of scraper capacity at 65 to 75 lb/ton of gross vehicle weight rolling resistance. S may be replaced by the product of the maximum speed time. The speed adjustment is provided in Table F6
- E = efficiency, fraction of hour that vehicle is operated productively (example: 55 min of productive operation per clock hour would equal 0.92)
- D = two-way, round trip haul distance in feet
- FT = fixed time constant, in minutes, for loading, acceleration, turning and dumping; 2 min per cycle is suggested.
- 5280 = conversion factor = 5280 ft/mi
- 88 = conversion factor = 5280 ft/mi ÷ 60 min/hr.

Job Time of Tractor Drawn Harrows, Plows and Cultivators Used in Construction Work

$$JT(\text{hr}) = \frac{\text{Area}}{5280 \times S \times E \times W}$$

- Area = job area to be plowed in square feet (Step 5)
- S = travel speed in mph
- W = effective width of implement in feet
- E = efficiency; fraction of each hour that vehicle is operated productively (example: 55 min of productive operation out of every clock hour would equal 0.92)
- 5280 = conversion factor = 5280 ft/mi.

Job Time for Sheepsfoot Compactors or for Tractor Drawn Sheepsfoot Rollers

Drawbar Pull necessary to pull a sheepsfoot roller(s)
= total weight of roller(s) × .25

$$JT(\text{hr}) = \frac{AMH \times W \times D \times S \times E \times 16.3}{SHF \times NP}$$

- AMH = total amount of job material to be compacted in in-bank cubic yards (Step 5)
- W = effective width of roller in feet (for compactors, it equals 2 times the width of one wheel). If two rollers are pulled, one behind the other, W equals the width of just one of the rollers: what changes is that half the number of passes which must be made to achieve the desired compaction.
- D = depth of compacted lift in inches
- S = travel speed of vehicle in mph
- E = efficiency; fraction of each hour that vehicle is operated productively (example: 55 min of operation out of every clock hour would equal 0.92)
- SHF = shrinkage factor; relationship of compacted cubic yards divided by in-bank cubic yards. This factor should be provided by job specifications
- NP = number of passes required to achieve the desired compaction; this depends on type and moisture content of soil and weight of roller
- 16.3 = conversion factor = 5280 ft/mi ÷ 12 in./ft ÷ 27 ft³/cu yd.

Job Time for Wheel Tractor Backhoe Production

$$JT(\text{hr}) = \frac{AMH}{E \times H \times IBCF \times DDF \times SAF \times MLF \times 8.3}$$

- AMH = total amount of material to be handled in in-bank cubic yards (Step 5)
- E = efficiency; fraction of each hour that vehicle is operated productively; (example: 55 min of productive operation out of every clock hour would equal 55/60 or 0.92)
- H = heaped capacity of bucket in cubic feet
- IBCF = in-bank correction factor (Step 4)
- DDF = digging depth factor, see Table 8

SAF = swing angle factor, see Table 9

MLF = material loadability factor, see Table 10

8.3 = conversion factor equal to 225 cycles/hr ÷ 27 cu ft/cu yd. 225 = the standard number of cycles per hour; deviations from this standard are adjusted for by the variables: DDF, SAF, and MLF.

Job Time for Truck-Type Excavator

$$JT(\text{hr}) = \frac{AMH}{H \times IBCF \times E \times DDF \times SAF \times MLF \times 155}$$

AMH = total amount of material to be handled in in-bank cubic yards (Step 5)

H = heaped capacity in cubic yards

IBCF = in-bank conversion factor (Step 4)

E = efficiency; fraction of each hour that vehicle is operated productively (example: 55 min of productive operation out of every clock hour would equal 55/60 or 0.92)

DDF = digging depth factor, see Table F11

SAF = swing angle factor, see Table F12

MLF = material loadability factor, see Table F13

155 = standard number of cycles per hour; deviations from standard are accounted for by the DDF, SAF, and MLF variables.

Job Time for Off-Highway Haulers

$$JT(\text{hr}) = \frac{AMH \times CT}{H \times IBCF \times E}, \text{ where } CT = \frac{D}{MS \times SF \times 5280}$$

AMH = total amount of material to be handled in in-bank cubic yards (Step 5)

CT = total cycle time in hours and equals the sum of the time required for each road section as defined above

H = heaped capacity in loose cubic yards

IBCF = in-bank correction factor (Step 4)

E = efficiency; fraction of each hour that the vehicle is operated productively (example: 55 min of productive operation out of every clock hour would equal 0.92)

D = distance of each road section in feet

MS = maximum speed in mph

SF = speed factor, Table F6

5280 = conversion factor = 5280 ft/mi.

7. Determine the hourly costs associated with owning or renting and operating each vehicle (HC_V) including hourly operator's wages. Procedures for estimating these costs can be obtained from equipment manufacturers.

8. Determine the hourly operator's costs (HC_O).

9. Multiply the job time (JT) calculated for each vehicle by its hourly costs (HC_V) and sum the results to get the total job cost associated with each vehicle (JC_V).

10. Multiply the job time (JT) calculated for each vehicle (JT) times the hourly wages paid to each vehicle's operator (HC_O) to calculate the total job cost associated with the operator of each vehicle.

11. Add the JC_O and JC_V calculated for each vehicle to get the job cost of each vehicle (JC) and sum the results to get the total job cost (TJC).

Table F1
Material Type Correlation Factors*

Material Type	In-Bank	
	Correction Factor (IBCF)	Unit Weight (lb/BCY)
Ashes (hard coal)	0.93	700-1000
Ashes (soft coal)	0.93	1080-1215
Bauxite	0.75	2700-4325
Clay, dry	0.85	2300
Clay, light	0.80	2800
Clay, wet	0.75	3000
Coal, anthracite	0.74	2450
Coal, bituminous	0.74	2000
Coal, steam (compacted)	0.72	1890
Copper ore	0.74	3800
Earth, dry	0.80	2700
Earth, moist	0.80	3000
Earth, wet	0.85	3370
Earth, with sand and gravel	0.90	3100
Gypsum	0.57	4300
Gravel, dry	0.89	3250
Gravel, wet	0.88	3600
Granite	0.56-0.67	4600
Iron ore, hematite	0.45	6500-8700
Limestone, blasted	0.57-0.60	4200
Loam	0.83	2700
Mud, dry	0.83	2160-2970
Mud, moderately packed	0.83	2970-3510
Rock and stone, crushed	0.74	3240-3920
Sand, dry	0.89	3050
Sand, wet	0.87	3500
Shale, soft rock	0.60	3000
Slate	0.60	4590-4860
Trap rock	0.61	5075

*The material presented in Tables F1 through F13 is taken from *Earthmoving Principles: A Guide to Production and Cost Estimating*, with permission of International Harvester.

Table F2
Pusher Cycle Time (min)

	Condition		
	Favorable	Average	Unfavorable
Back-track loading	0.9	1.3	1.7
Chain loading	0.7	0.9	1.2
Shuttle loading	0.7	0.9	1.2

Table F3
Scraper Loading Time (min)

Condition	Open Bowl			Elevating	
	Single Engine	Dual Engine	Pay Mate	Single Engine	Dual Engine
Favorable	0.40	0.35	0.90	0.70	0.45
Average	0.60	0.50	1.20	1.00	0.60
Unfavorable	0.80	0.70	1.50	1.30	0.75

Table F4
Front-End Loader Cycle Time (min)

Conditions	Rubber-Tires		Crawler
	0-5 cu yd	5+ cu yd	All
Favorable	0.30	0.42	0.42
Average	0.33	0.50	0.50
Unfavorable	0.42	0.66	0.58

Table F5
Turn and Dump Time (min) for Haulers and Scrapers

Conditions	Haulers		Scrapers	
	Bottom Dump	End Dump	Open Bowl	Elevating
Favorable	0.3	0.7	0.3	0.4
Average	0.6	1.0	0.4	0.5
Unfavorable	1.5	1.5	0.6	0.7

Table F6
Speed Factors (SF) for Off-Highway Haulers and Scrapers

Length of 2-Way Round Trip in ft	Starting from or Coming to a Stop in Haul Section	Moving when Entering Haul Road Section
400-1000	0.33-0.51	0.56-0.80
1001-2000	0.43-0.67	0.65-0.83
2001-3000	0.53-0.75	0.78-0.90
3001-4000	0.59-0.80	0.84-0.93
4001-5000	0.62-0.84	0.88-0.96
5001-6000	0.65-0.85	0.90-0.97
6001-7000	0.68-0.87	0.92-1.00
7001-above	0.71-0.95	0.95-1.00

Table F7
Blade Angle Adjustment (AA) Factor

Blade Angle	AA Factor
90	1.00
80	.98
70	.94
60	.87
50	.77
40	.64
30	.50
20	.34
10	.17

Table F8
Digging Depth Factor (DDF) for Backhoes

Depth (in ft)	DDF
4	1.00
6	0.95
8	0.90
10	0.85
12	0.80
14	0.75

Table F9
Swing Angle Factor (SAF) for Backhoes

Angle of Swing in Degrees	SAF
40-60	1.00
60-70	0.95
over 70	0.90

Table F10
**Material Loadability Factor (MLF)
For Backhoes**

Conditions	MLF
Favorable	1.00
Average	0.85-0.95
Unfavorable	0.50-0.80

Table F11
**Digging Depth Factor (DDF) for Track
Excavators**

Depth in feet	DDF
5	1.00
10	.95
15	.87
20	.78

Table F12
**Swing Angle Factor (SAF) for Track
Excavators**

Angle of Swing (degrees)	SAF
45	1.00
60	.95
75	.90
90	.86
120	.81
180	.71

Table F13
**Material Loadability Factor (MLF) for Track
Excavators**

Conditions	Type of Material	MLF
Favorable	loam, sand, gravel	0.85-1.00
Average	general earth, clay	0.65-0.85
Unfavorable	rock, roots, gumbo	0.50-0.65

SI Conversion Table

1 in.	= 25.4 mm
1 ft	= .3048 m
1 yd	= .9144 m
1 in. ²	= 6.54 cm ²
1 ft ²	= .092 m ²
1 yd ²	= .836 m ²
1 yd ³	= .764 m ³
1 mi	= 1.609 km
1 sq mi	= 2.589 km ²
1 acre	= .404 ha = 40.46 m ²
1 lb	= .453 kg
1 ton	= 907 kg = .907 tonne

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