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STATE OF THE PRACTICE: ENVIRONMENTAL NOISE MEASUREMENTS

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State of the Practice
Environmental Noise Measurements

Transportation Research Board Committee A2H01
Instrumentation Systems, Principles and Applications
Noise Subcommittee
July 1983

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1.0 INTRODUCTION

One important role of the Transportation Research Board (TRB) is to keep its committee members abreast of current activities in other member agencies. This report serves that purpose in the area of noise measurement.

Since the promulgation of Federal Highway Administration (FHWA) noise standards in 1973, state departments of transportation (DOTs) have been required to assess the existing noise environment in the area of a proposed highway project. While this assessment may be done by use of a traffic noise prediction model, it has traditionally been done by measurement.

When the FHWA noise standards were first promulgated, there was little standardization in noise measurement equipment or procedures as they pertained to traffic noise. Since then, FHWA training courses and demonstration project workshops have provided a more consistent picture of the field and have served as "technology transfer" agents. However, no comprehensive assessment of the state-of-the-practice had been made.

A questionnaire was circulated in December, 1982, by TRB Committee A2H01, Instrumentation Systems, Principles and Applications, to gather and synthesize this information. Responses were received from 44 state DOTs (including the District of Columbia and Puerto Rico), four Canadian provinces, two counties, the Federal Aviation Administration, and the Colorado Department of Health, for a total of 52 responses. This report presents the results of the survey. It should be noted that while questionnaires were not returned by eight state DOTs, that lack of response should not be taken as an indication of the absence of measurement equipment or programs in those states. Indeed, at least two have a good deal of measurement equipment.

This report is divided into six additional sections. Sections 2, 3 and 4 address personnel, equipment and measurement procedures. Section 5 blends much of the information from the previous sections as it discusses monitoring experience in nine separate areas such as ambient noise, noise barrier effectiveness, aviation noise, and vibration. Section 6 summarizes comments on research reports and other items of interest to the respondents, while Section 7 discusses research needs as seen by the respondents. Section 8 provides a summary.

In addition, two appendices provide detailed information on measurement reports and manuals and research needs.

In order for this survey to be effective, it was necessary to make use of brand names. The Transportation Research Board nor the National Research Council endorse commercial products and no such endorsements are stated or implied in this document.

2.0 PERSONNEL

Information was requested on the use of both in-house staff and people outside the agency for noise measurements. Additionally, the questionnaire asked for information on training of personnel. A detailed chart on this is presented in Table 1. One DOT did not respond to this question; therefore, only 43 states will be referenced in the following discussion.

2.1 In-House Forces

a. Where assigned?

Agency Location of Noise Monitoring Staff

	In Environmental Unit	In Planning Unit	In Design Unit	In Materials Unit
Among States (43)	29	7	3	2
Among Provinces (4)	1	1	0	0
Among Other Agencies (4)	2	0	0	0
	32	8	3	2

b. Personnel with training

Twenty of the 43 states, three of the provinces, and one county have four or fewer trained or experienced personnel. Eleven states, one province, and one county have five to ten, while seven states and the Colorado Department of Health have 11 to 20 trained personnel. California has over 100 and Texas at least 50 trained or experienced personnel.

c. Personnel making measurements routinely

Twenty-nine of the 43 states, four of the provinces, and two counties have four or fewer personnel who are making measurements routinely. Eight states and the FAA have five to ten, and three states and the health department have 11 to 20 personnel making measurements routinely. California and Texas have the largest numbers of 28 and 26 people respectively making measurements routinely.

2.2 Use of Non-agency Personnel

a. Percentage of work

The percent work done by outsiders has a very wide range, with from zero to 100 percent being reported. Eighteen states, one province, and one county reported zero percent; ten states - 1 to 9 percent; seven states and the FAA - 10 percent; three states, three provinces, one county and the health department - 60 to 100 percent with the highest percentages (90-100) reported by two provinces, one county, and the health department.

b. By whom?

Two states did not supply this information. Of the 50 respondents, 23 states and two provinces use consultants. New Mexico uses the services of the city of Albuquerque; while two provinces, the FAA and the health department

Table 1 - Noise Measurement Personnel

Agency	Office	# People with Training	# People Measuring Routinely
AL	Environmental	3	2
AK	Environmental		
AZ	Environmental Planning	3	2
	Research	1	0
AR	Environmental	4	2
CA	District Environmental	100	26
	Transportation Lab (research)	5	2
CO	District Environmental	11	7
	Central Environmental	4	0
CT	Environmental Planning	4	2
DC	Planning	1	0
FL	Central Environmental	7	1
	District Project Development and Environmental	21	10
	Central Aviation	3	1
GA	Environmental Analysis	4	2
HI	Materials	8	8
IL	District Planning	21	9
	Central Environmental	1	0
IN	Environmental	12	6
IA	Project Planning (Central Ofc)	4	3
KS	Environmental (Bureau of Design)	8	4
KY	Environmental	2	1
LA	Environmental		
	(Materials Testing Lab)	2	1
ME	Locational and Enviroment	6	3
MD	Environmental Design (Bureau of Landscape Architecture	3	2
MI	Research Services (Testing and Research Division)	4	3
MN	District Prelminary Design	4	2
	Central Office Environmental	4	2
MS	Transportation Planning	4	2
	District Office	9	6
MO	Surveys and Plans Division	7	2
MT	Traffic Unit	2	2
NB	Noise and Air Section (Project Development)	3	2
NV	Environmental	3	2
NJ	Environmental (Bureau Quality Control)	4	2
	Division of Research	0	3
NM	Environmental	2	1
OH	Environmental	3	1
	Districts (12)	24	12
OK	Environmental	5	4
OR	Environmental	5	4
PA	Environmental Quality Division	3	1
	Districts	11	11
PR	Environmental Studies Division	5	3
SC	Environmental	2	1
SD	Environmental Planning	1	1
TN	Environmental	3	3
TX	District Design Offices	50	26
UT	Environmental Studies	3	3
	District Design	6-10	?
	Central Office Roadway Design	3	?
VT	Design	5	2
VA	Environmental Quality	5	2
	Research	2	2
WS	Environmental	10	6
WV	Materials	2	1
WI	Transportation Districts (8)	10-15	8
WY	Environmental	4	2
BRO	Air Enforcement	7	0
COH	Central Office Noise Control Program	2	1
	Health Department	13	13
CUY	Environmental	1	0
FAA	Environment and Energy	18	8
	Airports (APP)	1	1
	FAA Regions	10	0
ALB	Systems Training	1	0
MAN	Environmental	2	2
NOV	Operations	1	1
ONT	Research Laboratory	3	2
	Planning and Design Regions	2	2

ABBREVIATION KEY

Code	Agency*	Code	Agency	Code	Agency
AL	Alabama	MD	Maryland	RI	Rhode Island
AK	Alaska	MA	Massachusetts	SC	South Carolina
AZ	Arizona	MI	Michigan	SD	South Dakota
AR	Arkansas	MN	Minnesota	TN	Tennessee
CA	California	MS	Mississippi	TX	Texas
CO	Colorado	MO	Missouri	UT	Utah
CT	Connecticut	MT	Montana	VT	Vermont
DE	Delaware	NB	Nebraska	VA	Virginia
DC	District of Columbia	NV	Nevada	WS	Washington
FL	Florida	NH	New Hampshire	WV	West Virginia
GA	Georgia	NJ	New Jersey	WI	Wisconsin
HI	Hawaii	NM	New Mexico	WY	Wyoming
ID	Idaho	NY	New York	ALB	Alberta
IL	Illinois	NC	North Carolina	BRO	Broward County, FL
IN	Indiana	ND	North Dakota	COH	Colo. Dept. of Health
IA	Iowa	OH	Ohio	CUY	Cuyahoga Cty, OH
KS	Kansas	OK	Oklahoma	FAA	Fed. Aviation Admin.
KY	Kentucky	OR	Oregon	MAN	Manitoba
LA	Louisiana	PA	Pennsylvania	NOV	Nova Scotia
ME	Maine	PR	Puerto Rico	ONT	Ontario

*Highway or transportation agency, unless otherwise indicated use other public agencies.

2.3 Training

Thirty of 51 respondents listed more than one source (usually two). Thirty-nine states listed either the FHWA/NHI training courses or FHWA Demonstration Project workshops. Four states, two counties, and the health department use in-house training, while one province noted use of on-the-job training. One province reported no training, while two provinces and the FAA use other agencies or schools.

3.0 MEASUREMENT EQUIPMENT

Agencies were asked to supply information on the types, brands, models and quantities of sound measurement equipment in their possession. Additionally, they were asked to describe configuration of this equipment as measurement systems, and to describe support equipment, problems, desirable equipment improvements, and purchase plans.

3.1 Types

The categories of equipment listed in the questionnaire were:

- sound level meters
- strip chart recorders
- tape recorders
- self-contained portable analyzers
- digital cassette monitors
- real time analyzers
- data acquisition/reduction/analysis systems
- other

Table 2 summarizes the response by category in terms of number of agencies, brands, and items. While not shown, most of the equipment in each category is from four manufacturers. For example, 261 of the 324 sound level meters are from two companies, with many agencies having both brands. Forty seven of the 63 level recorders are from the same two companies. Twenty two of the tape recorders are from one manufacturer, while 32 of the 57 portable analyzers are made by two companies.

Finally, while not shown in table, many agencies reported owning miscellaneous items of related equipment for noise measurement and data reduction and analysis. For example, most agencies included their sound level meter calibrators in this category. All agencies that listed possession of sound level meters did not list calibrators. It is assumed that these agencies have calibrators and therefore the total number of them would be greater than reported.

3.2 Systems

The questionnaire next requested information on how these various pieces of equipment were configured into measurement systems. Thirty-eight of the 44 state DOTs and five other respondents described their instrumentation set-ups used for collecting noise data. Equipment configurations ranged from a simple microphone and sound level meter to elaborate data collection systems.

One of the more popular types of systems uses the newer portable environmental sound level analyzers (also called environmental noise classifiers, noise monitors, etc.) described in Section 3.1. These analyzers provide a number of noise descriptors which are typically printed on a paper tape. The units are self-contained and require only connection of a microphone as shown in Figure 1. Connection of a graphic level recorder can also provide a time history of the analog data.

A typical simple system used years ago and still used today by several states consists of a microphone, sound level meter, and portable tape recorder for data collection and a graphic level recorder and statistical distribution analyzer for data reduction. The system used by Maryland is shown in Figure 2. Montana, New Jersey, and Virginia use similar systems. (Other states use similar data collection configurations; however, for data reduction, a variety of analyzers are used). For 24-hour noise surveys for prediction model validation, New Jersey collected data at up to four microphone positions and simultaneously reduced the data. Figure 3 illustrates that system for one microphone position.

Minnesota also simultaneously records data at up to four microphone positions using precision sound level meters and instrumentation tape recorders. Data reduction and analysis is performed using the system as shown in Figure 4. As seen in the figure, this system is extremely versatile and capable of providing various L_n descriptors, chart recordings, octave and 1/3-octave analysis, data storage and printed data output. The connection to an external mainframe computer provides additional analysis and output capabilities.

Wyoming utilizes equipment specifically made to provide a printed output of sound level, traffic, and meteorological information. The equipment digitizes analog information for input to a printer. A block diagram of Wyoming's system is shown in Figure 5.

Manitoba and New Jersey use similar data collection and reduction instrumentation consisting of a digital data recorder, data translator, interface, and programmable calculator. New Jersey's system is shown in Figures 6a and 6b.

Another system utilized by New Jersey to reduce recorded data is shown in Figure 7. The system utilizes a maximum level detector which enables determination to be made of the maximum noise level of an individual vehicle pass-by. The system was used to determine medium and heavy truck noise reference levels for input into noise prediction models as replacements for national average levels.

The FAA uses the system shown in Figure 8 for data collection. A community noise analyzer, sound level meter, and graphic level recorder provide immediate information. Data is simultaneously recorded with the instrumentation tape recorder and a time code generator supplies input to the cue channel.

3.3 Problems

Of the 52 respondents, 29 had complaints or experienced some problems with equipment utilized for noise measurement, reduction and analysis. Twenty-three respondents reported no problems or none of any major significance. Some states caution that irrespective of whether problems are experienced, extreme care should be exercised when operating and handling sensitive electronic equipment used for field noise measurements.

Problems ranged from breakdown of specific pieces of equipment to complaints about the difficulties in operating older, more cumbersome equipment compared to newer self-contained units.

A common problem reported by Maine, Minnesota,

Table 2 - Measurement Equipment by Type

Type	Number of Agencies	Number of Brands	Number of Items
Sound Level Meters	45	11	324
Strip Chart Recorders	35	11	63
Tape Recorders	23	8	51
Self Contained Portable Analyzers	28	2	57
Digital Cassette Monitors	3	1	9
Real Time Analyzers	7	4	9
Data Acquisition Reduction Analysis Systems	15	7	15

Figure 1. Portable Sound Level Analyzer

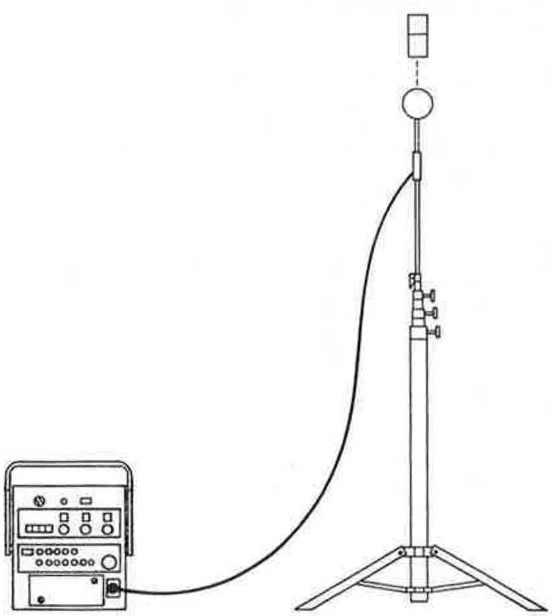


Figure 2. Typical Measurement and Data Reduction System (Maryland)

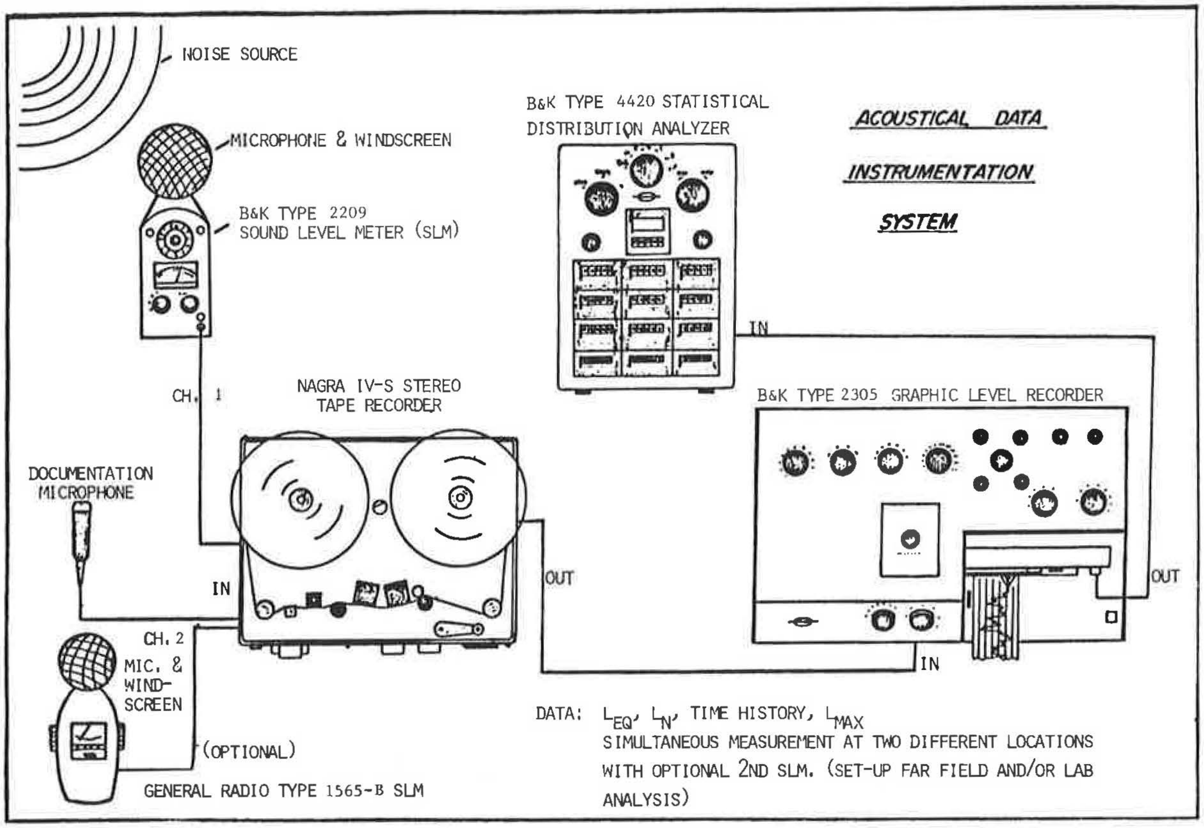


Figure 3. System for 24-Hour Surveys in New Jersey

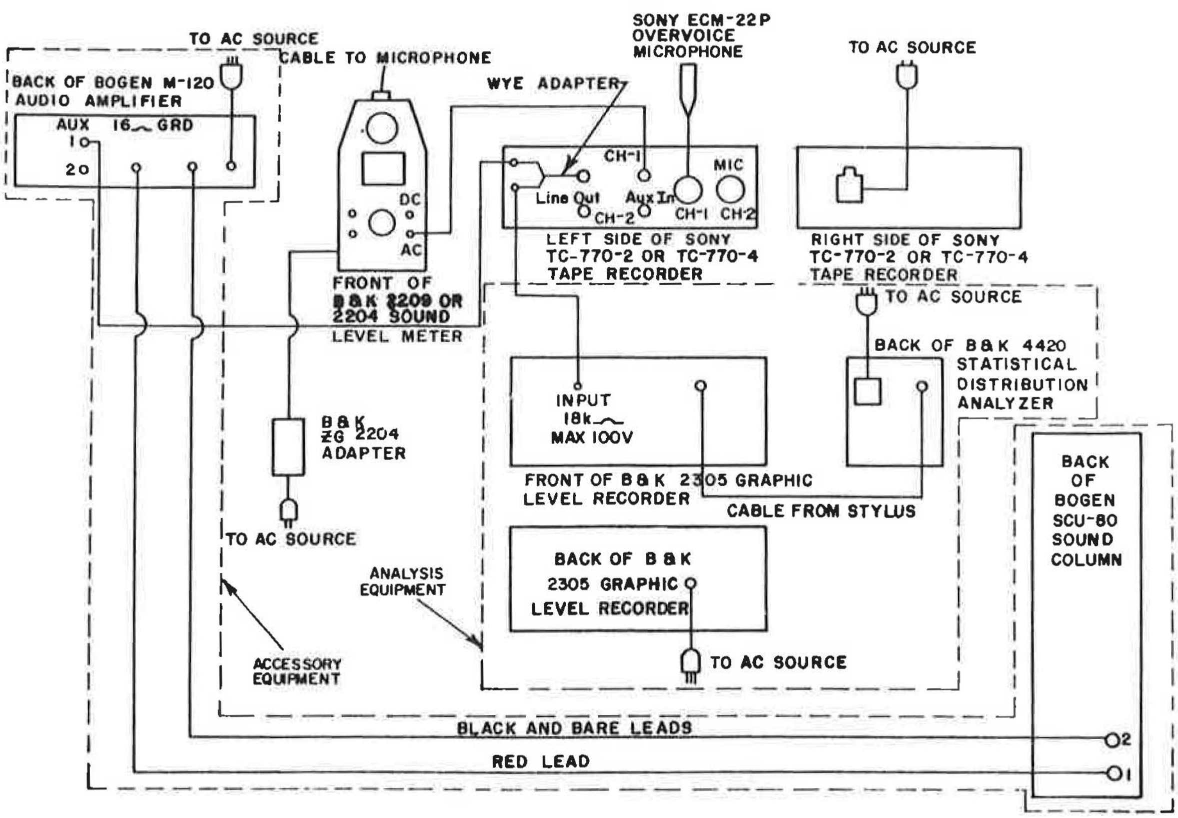


Figure 4. Data Reduction and Analysis System used by Minnesota

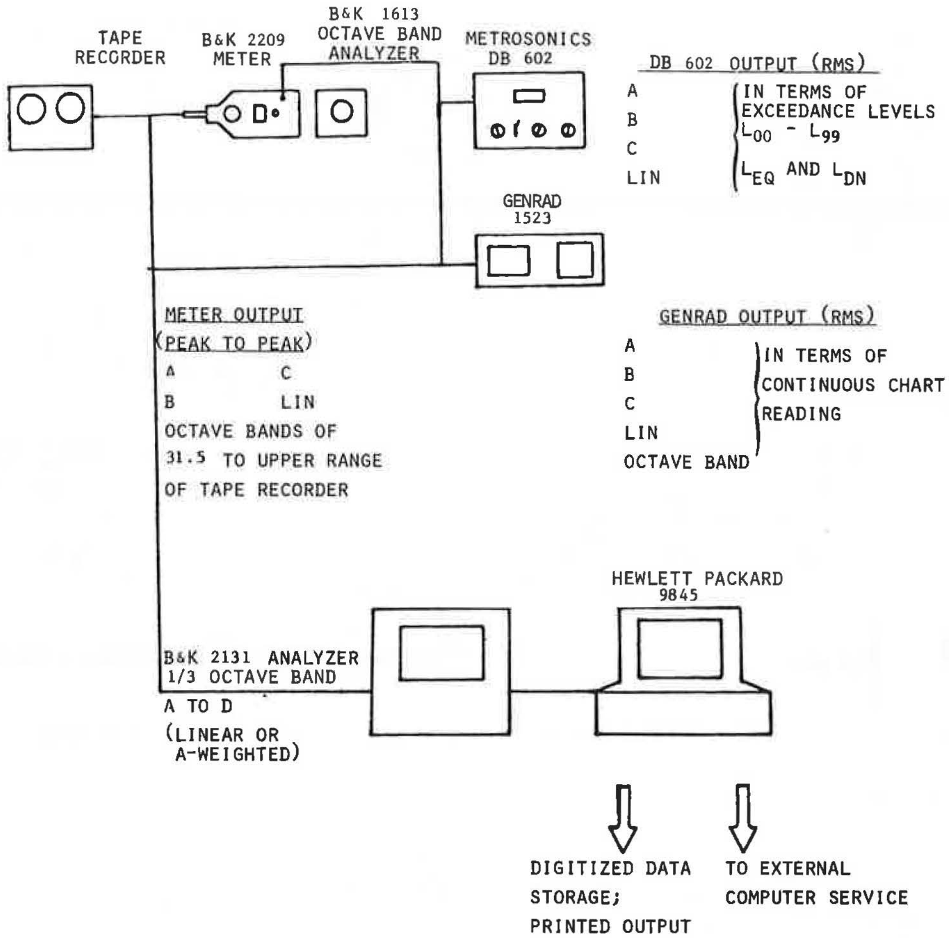


Figure 5. Wyoming Sound Level, Traffic and Meteorological Data Collection System

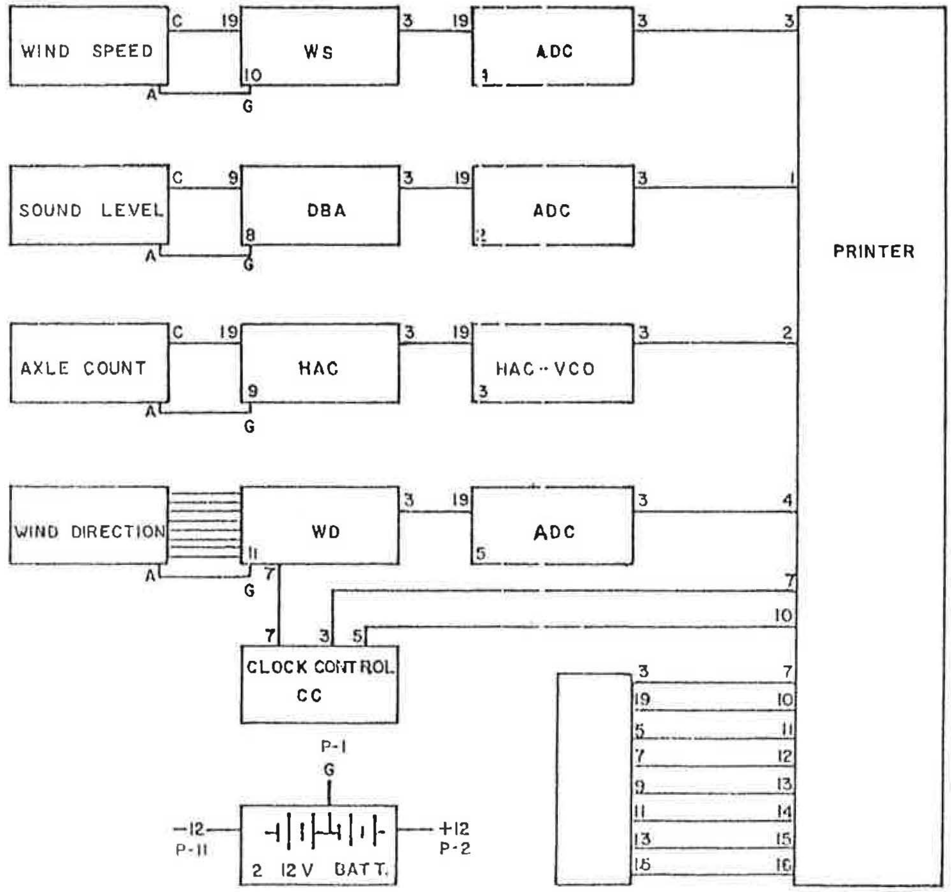


Figure 6a. Data Logging Instrumentation System (New Jersey)

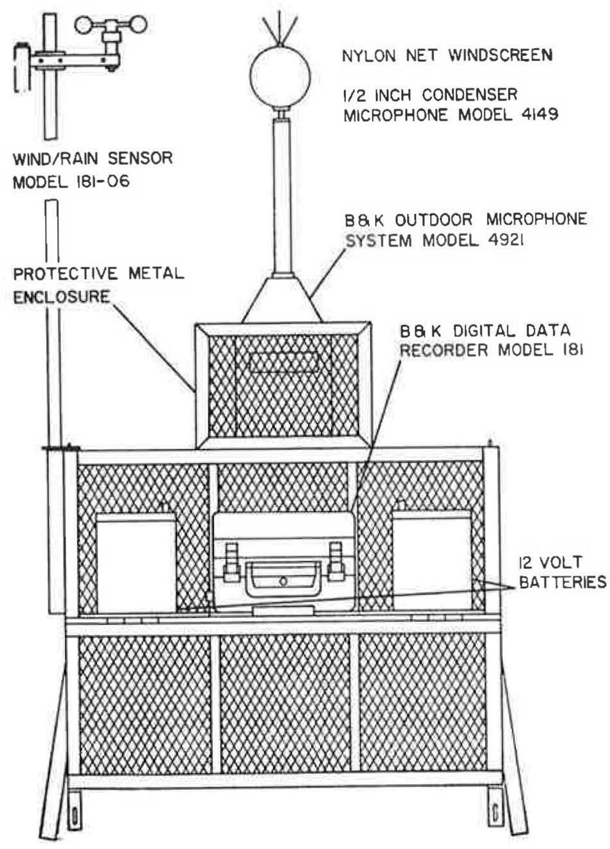


Figure 6b. Data Reduction Instrumentation System (New Jersey)

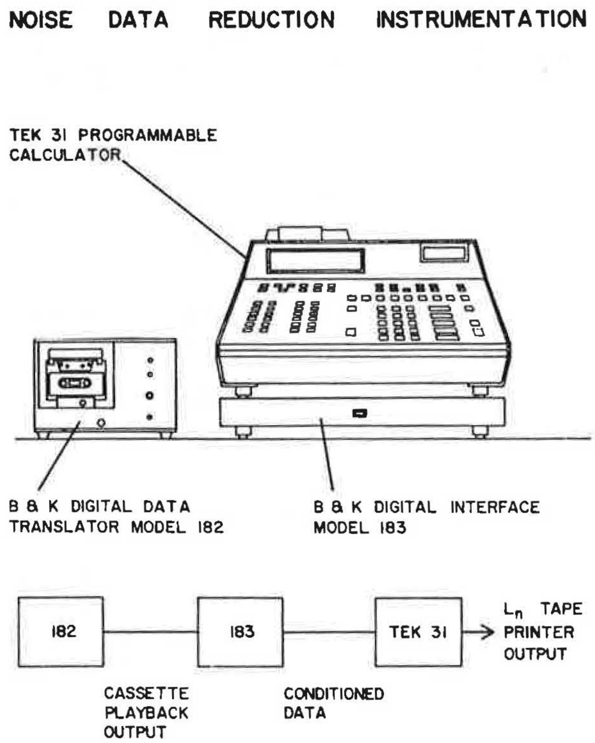


Figure 7. New Jersey System for Reduction of Vehicle Pass-by Data for Maximum Noise Level

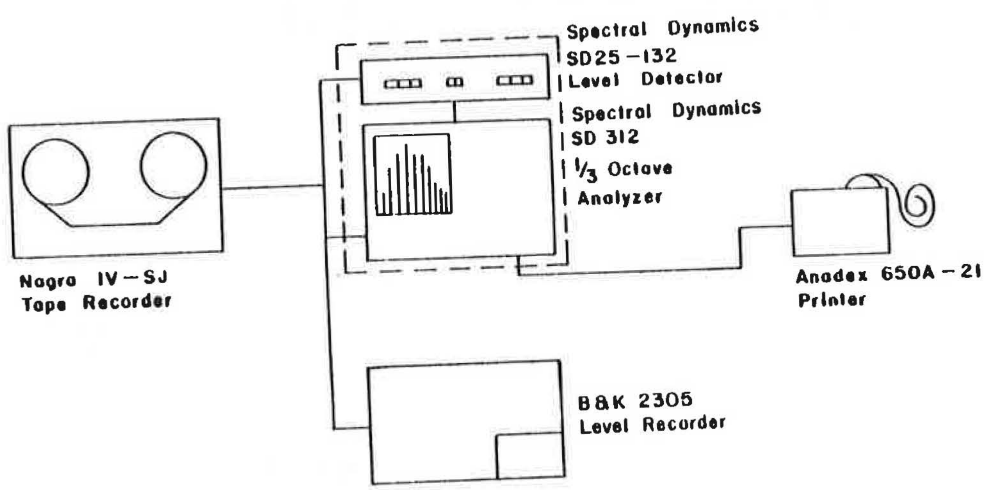
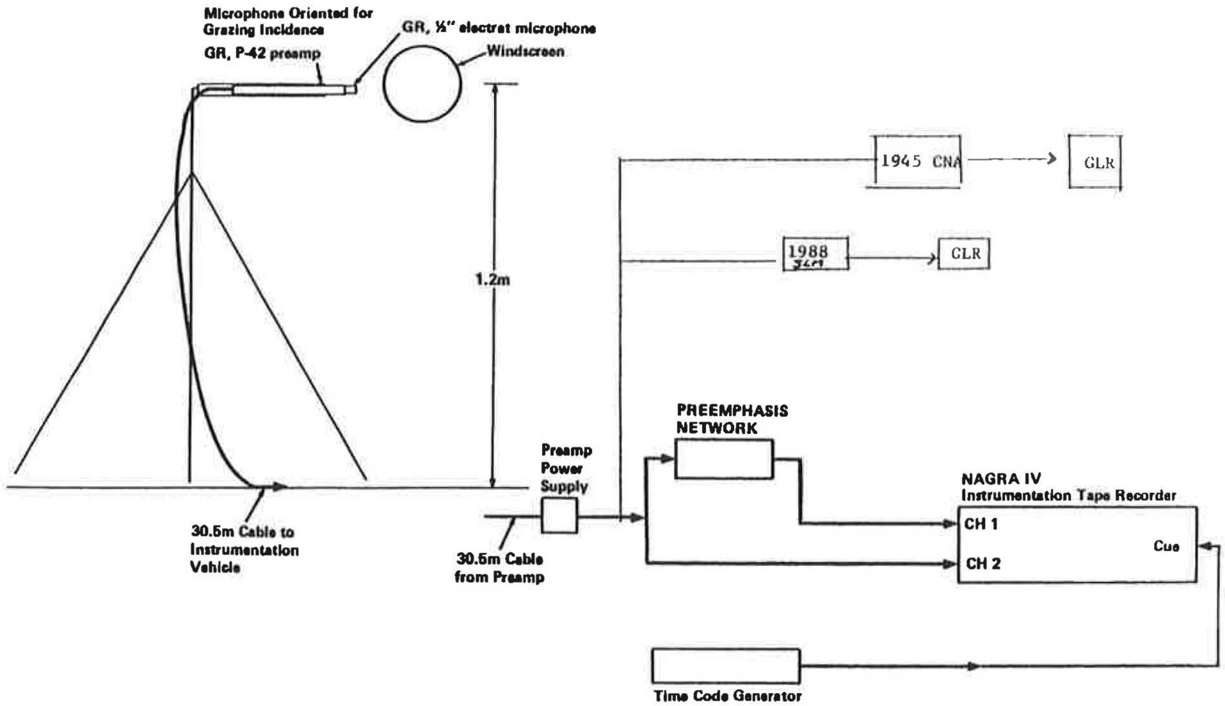


Figure 8. Federal Aviation Administration Data Collection System



Manitoba, and the FAA is the effect of extremely cold temperatures in reducing instrument sensitivity and accuracy. Electro-mechanical equipment with moving parts, such as tape recorders are also adversely affected by cold temperatures. These effects should be considered whenever measurements are taken at cold temperatures.

Another common problem related to weather conditions is humidity. Minnesota, New Jersey, and the FAA reported that condenser microphones were sensitive to high humidity with current arcing causing momentary loss of signal. Similar condensation problems can be caused by removing equipment from buildings with air-conditioning for use in warmer outdoor environments.

3.4 Support Equipment

Thirty-six of the state DOTs and five other respondents reported using support equipment to gather data to supplement noise measurements. The equipment includes manual and automatic vehicle counters and classifiers, radar speed measuring devices, portable meteorological instruments, stop watches, headphones, inverters, walkie-talkies, microphone tripods and masts, tape measures, clipboards, etc.

Twenty-six states and Alberta reported performing traffic counts while taking noise measurements. The types of counters were not always specified by the respondents; however, most obtained vehicle classification counts by using hand held counters. Seven states reported using machine counters to obtain data. Vehicle speed data is collected solely by portable radar devices as reported by 20 state transportation departments.

Meteorological data is collected by using a variety of instruments including portable weather stations, hand held anemometers, sling psychrometers, and barometers. Seventeen state DOTs and four other respondents reported collecting meteorological data during noise measurements.

3.5 Needed Improvements

Of the 52 respondents, 17 state DOTs and three others identified needed improvements in existing equipment or needed development of new equipment for noise measurements. Five state DOTs reported that additional or newer existing equipment was needed in their states, reflecting tight fiscal constraints for monitoring equipment.

Six respondents reported that generally they desired equipment that was more portable, versatile, durable, and field worthy under a variety of environmental and weather conditions. Ontario reported that a small portable monitor with a partitioned memory for both L_{eq} and L_n and capable of operating a minimum of 24 hours was needed. Manitoba reported that equipment capable of noise source identification would be useful. The Colorado Health Department reported that an instrument with an audible warning signal indicating that maximum allowable noise levels have been exceeded would be useful for enforcement purpose. Arizona indicated compatibility of existing equipment from different manufacturers would be desirable. Utah identified a need for an inexpensive portable system consisting of a real-time analyzer, tape recorder, and chart recorder.

3.6 Purchase Plans

Despite the previously-noted desires for equipment improvements, most agencies did not have plans for purchasing additional equipment. Five of the eight non-state agencies and 30 of 44 state DOTs indicated they did not have any such plans.

For those responding positively, there was a range in the type of planned new equipment purchases. The most common equipment were portable noise analyzers and sound level meters. Also listed more than once were graphic level recorders and accelerometers. Other equipment included a frequency analyzer, noise source, calibrator, and microphone.

4.0 PROCEDURES

Agencies were asked to list any manuals or procedures that they followed in their programs, to discuss quality assurance, and to address questions on frequency and duration of measurements.

4.1 Measurement Manuals

Most of the agencies listed measurement manuals used in their program, with the large majority involving published manuals. Ten state and two non-state agencies listed in-house manuals or procedures that were used. Many published manuals were listed, and a summary is given in Appendix A. There was only one document that was mentioned very often: the FHWA report Sound Procedures for Measuring Highway Noise: Final Report (Report No. FHWA-DP-45-1R) was listed by 21 respondents. The next most common publication was the FHWA report on Fundamentals and Abatement of Highway Traffic Noise, which was listed by four respondents.

4.2 Quality Assurance

Twenty-three of the 44 state DOTs and four of the eight other agencies indicated they had no formal quality assurance program. In addition, nine state DOTs and one other agency listed equipment calibration as the only quality assurance measure used.

Equipment calibration was the most common type of quality assurance used with about one half of the respondents indicating a regular program of calibration. This involved sending the equipment back to the factory for calibration, usually on an annual basis, or regular calibration by agency personnel.

The second most frequent form of quality assurance was recordkeeping and checking. This could consist of updating project files, preparing status reports, periodic review of data, or logging all pertinent information during data collection for later review. Examples of information logged include equipment used, meteorological data, traffic data, experimental set-up, calibration, site geometry and irregularities that occurred.

Other examples of quality assurance included comparing measured noise levels with predicted levels, taking duplicate readings, and maintaining permanent recordings of measurements.

4.3 Traffic Noise Measurements: Number and Duration

Of the 40 responses to this question, 19 stated that the noise level was measured once at each site. This was qualified in some instances to state that more measurements were taken if irregularities occurred, or if measured and predicted values did not correspond. In addition, nine stated they measured the noise level either two or from one to two times at each site. Four measured each site from one to three times, two either two or 2-3 times, and two from one to five times. One indicated five measurements per site and one stated they collected at least 24 one-hour samples.

The most common duration of noise measurements was in the 10 to 15 minute range. The duration of measurements range from one respondent giving a low range of five minutes to one giving 24 hours. Of 25 responses to this question, only three indicated measurement durations of greater than one hour. In addition, five respondents indicated measurement duration of either one hour or up to one hour. Twelve respondents gave a duration of 15 minutes less, fourteen listed 20 minutes or less, and seventeen noted 30 minutes or less.

Many factors influenced the selection of the duration of the measurement. Obtaining a 95 percent confidence level was mentioned several times while obtaining a 99 percent confidence level was given once. Other factors included traffic volume, type of traffic, ambient noise, time of day, type of noise parameter sought, land use or type or receptors, uniformity of noise level, length of peak or off-peak period, distance from source, and traffic speed. In some instances, a measurement manual was referenced. These included the report Sound Procedures for Measuring Highway Noise: Final Report, Federal Aid Highway Program Manual 7-7-3, and the report Fundamentals and Abatement of Highway Traffic Noise.

5.0 NOISE MONITORING EXPERIENCE

5.1 Overview

The questionnaire listed eight specific monitoring areas and also inquired about "other" applications:

- ambient noise levels
- vehicle "emission" levels
- noise barrier effectiveness
- construction equipment or site noise
- aircraft noise
- railroad yard or line noise
- building noise reduction
- vibration
- other

Respondents were asked to address questions on number of projects in the past year, number of sites per project and measurements per site, procedures, measurement parameters, equipment, and problems. Table 3 indicates which respondents had experience in which areas.

Nearly all of the 52 respondents indicated experience in ambient noise level measurement, while roughly one-third indicated experience in monitoring emission levels, noise barriers, construction noise or building noise reduction. Only 7-9 state DOTs and 1-3 of the other respondents listed experience in the areas of aviation noise, rail noise, or vibration.

"Other" monitoring areas included OSHA worker exposure, noise control of a mower tractor, noise from overhead highway sections, input to a retrofit noise barrier planning study, tire/pavement noise and property line nuisance.

The following sections summarize the results in each monitoring area. The numbers listed at different times for the state DOTs are from the pool of 44 respondents, and the numbers for the non-state DOTs are from a total of eight respondents.

5.2 Ambient Measurements

Of the 40 state DOTs with ambient level experience, 29 conducted these measurements of 15 or fewer projects in the previous year. Six of the states listed 19-30 projects per year. Five states -- Oregon, Pennsylvania, Georgia, Ohio, and California

Table 3 - Areas of Monitoring Experience of Respondents

AGENCY	AMBIENT	EMISSION	BARRIER	CONSTRUCTION	AIRCRAFT	RAIL	BUILDING N.R.	VIBRATION	OTHER
AK	X								
AL	X								
AR	X		X			X	X		
AZ	X	X	X		X				
CA	X	X	X	X	X		X	X	
CO	X	X	X	X	X	X	X	X	
CT	X	X		X					X
DC	X								
FL	X		X	X	X		X		
GA	X	X							
HI	X		X						
IA	X		X	X					
IL	X		X			X			
IN	X								
KS		X							
KY	X	X		X			X		
LA	X					X		X	
MD	X		X	X	X				
ME	X	X							X
MI	X	X	X					X	
MN	X		X	X	X	X	X		X
MO	X								
MS	X								
MT	X								
NB	X					X	X		
NJ	X	X	X	X	X		X		
NM									
NV	X			X			X		
OH	X		X						
OK	X								
OR	X		X	X		X	X		
PA	X		X				X	X	
PR	X	X		X			X	X	
SC	X								
SD									
TN	X			X					
TX	X	X							X
UT	X	X		X		X	X		X
VA	X		X				X		
VT	X								
WI									
WS	X		X	X					
WV	X							X	
WY	X	X							
ALB									
BRO	X		X	X					
COH	X	X	X	X	X	X	X		X
CUY	X	X							
FAA	X				X				X
MAN	X	X	X	X	X	X		X	X
NOV	X			X			X		
ONT	X	X	X	X					X

-- listed from 40 to "over 200."

Twenty of the state DOTs reporting measuring at an average of five or fewers sites per project, seven reported between six and ten, and seven noted more than ten, including New Jersey which made 24 contiguous one-hour measurements of 20 sites. Iowa also indicated that it makes at least one 24-hour measurement per project. Eleven state DOTs specifically mentioned a typical number of measurements at a site, which ranged from one to six, with "one" or "two" accounting for seven answers.

Of the 40 state DOT respondents, ten noted that they measured L_{eq}, three measured L_{10}, and 14 measured both L_{eq} and L_{10}; two noted that they additionally measured L_{dn}. The other respondents did not indicate a particular descriptor.

Sixteen state DOTs use sound level meters for ambient measurements (five in conjunction with graphic level recorders); fifteen use sound level analyzers; seven use both meters and analyzers; two noted use of tape recorders.

Twenty-three states specifically noted that no major problems were encountered during the measurements. Nine states mentioned problems relating to weather (wind, cold), equipment (calibration drift with temperature, malfunctions), and site choice (location, "typical" conditions).

Of the non-state DOT respondents, all but Alberta reported ambient level monitoring experience in the past year. The number of projects per year ranged from one to five, with the Colorado Health Department noting 20 projects. The number of sites per project varied from one to 20, and the number of measurements per site ranged from one to three, or in terms of time, from several hours to several days. Measurement descriptors included L_n values and L_{eq}, with Colorado Health measuring L_{max} at source/property lines. Equipment use was split between meters and analyzers, with the FAA also using graphic level recorders.

Ontario noted problems in getting repeatable results.

5.3 Vehicle Emission Levels

Thirteen of the 44 state DOTs indicated they had made vehicle emission level measurements.

California reported a current study using ten sites, with four microphones and 300 measurements per site, where data is taped and logged. Michigan indicated a study including 34 measurements per site at nine sites using a sound level meter with a maximum level display feature. It noted a possible problem with recreation vehicles adding to car noise, while subtracting from medium truck noise. Texas indicating a study at one site where 45 trucks were measured from overhead, noting problems in adjusting for values out to the side. New Jersey measured 4500 trucks at 35 sites in a research study using tapes and a 1/3 octave band analyzer. Utah made 80 measurements of three buses at different speeds on an airport runway. Kentucky reported a major research study that resulted in levels currently used in their modeling.

The other six respondents described emission level measurements that appeared to be done in conjunction with their ambient level sampling as a check on prediction model validity.

Four non-state respondents conducted emission level measurements in the past year on between one and five projects. The number of sites per project ranged from three to ten. L_{eq}, L_n values and L_{max} were measured, while Ontario also studied interior levels and operator doses. Equipment included meters and analyzers.

5.4 Noise Barrier Effectiveness

Fifteen of the 44 responding state DOTs indicated they have measured the effectiveness of traffic noise barriers. Additionally, Georgia mentioned plans to study vegetative barriers, while Kentucky noted that a research study is planned in 1983. Twelve of the 15 reported one or two projects per year; Oregon noted ten. Nine states study one to four sites per project; five mentioned 7-11 sites. The number of microphones per site ranged from two to nine, while the number of measurements per site ranged from three to twenty.

Self-contained analyzers were the most commonly used equipment, sometimes supplemented by tape recording or sound level meters. Most states use L_{eq} for the sound level descriptor although L_{10} was mentioned four times, once by itself (Ohio), twice in combination with L_{eq}, and once in combination with maximum levels (Florida). Of interest, Iowa noted use of 24-hour measurements supplemented with shorter duration spot measurements. Two techniques that were mentioned included use of a high/low microphone system and microphones atop and behind the barrier.

Four non-state DOT respondents studied noise barrier effectiveness in the previous year (Manitoba - one project; Colorado Health - two; Broward County, Florida - three; Ontario - eight). Ontario studied 15 sites per project; the others studied three or less. Measurement descriptors included L_{eq}, L_{max} and L_n values. Equipment included meters and analyzers, with Colorado Health also using strip chart recorders. Manitoba noted a problem in calibration variation among three instruments.

5.5 Construction Noise

Sixteen state DOTs reported construction noise measurement experience, with all but two noting three or fewer projects in the previous year. Hawaii reported 12 projects and Florida noted nine. Generally, one or two sites were studied per project with anywhere from two to twenty measurements per site.

L_{eq} and L_{max} were the most commonly mentioned descriptors, along with L_{10}, L_{90}, L_{dn} (New Jersey), and SEL (Maryland). New Jersey and Iowa noted making 24-hour measurements while Minnesota has done spectral analysis work. Minnesota has also studied OSHA compliance while Oregon has measured noise barrier effectiveness. Published FHWA reports were the most commonly cited sources of procedures.

Either sound level meters or analyzers were typically used, often in conjunction with taping and level recorders. Minnesota uses its real time analysis system.

Florida noted problems in isolating equipment for measurement, while Connecticut mentioned that its results had limited applications due to varying levels. Utah reported that pile driver noise is "greatly influenced" by soil type.

Five of the non-state DOT respondents monitored construction noise in the previous year (Ontario - one project; Colorado Health - five; Broward County - five; Manitoba - 10; and Nova Scotia - 12). The number of sites per project ranged from one to five. L_{max}, L_{eq}, L_{10} and ambient levels were measured. Measurements were made of operator and ambient levels (with and without equipment operating) using meters and analyzers.

5.6 Aircraft Noise

Eight state DOTs monitored aircraft noise in the past year, with six reporting only one project. Six of the eight also reported studying three or fewer sites per project, with one to five measurements per site.

Most of the data was collected by sound level meter or analyzer, with three instances of tape recording. Descriptors included L_{eq} (five states), and L_{10} and SEL (one state each).

New Jersey reported using 24-hour data while California has studied octave band levels and Arizona measured controlled helicopter maneuvers.

Colorado noted problems with wind.

Three non-state DOT respondents had aircraft noise monitoring projects last year. The FAA measured about 40 operations a day at four sites for 20 projects in addition to its continuous 24-hour monitoring at 23 sites in the Washington, D.C. area. Manitoba and Colorado Health had one and two projects, respectively, with one and two sites per project, respectively. All respondents measured L_{eq}; other descriptors included SEL, L_n values, and L_{dn}.

Equipment included meters, analyzers, level recorders, and tape recorders. Additionally, the FAA continuous monitoring system uses hydrophones, signal processors and a PDP-11 computer. The FAA noted problems with its system in being able to detect false signals.

5.7 Rail Noise

Nine state DOTs made rail noise measurements in the previous year, although six noted only one project. Also, two only studied rail noise in conjunction with highway project studies. Of the respondents, four studied one site per project, one studied four sites and two studied five.

Equipment use divided evenly among sound level meters and analyzers, with occasional tape or graphic level recorder back-up. L_{eq} was the most common descriptor, with L_{10} and L_{max} (for horns) also noted.

Problems included dealing with the episodic nature of the events (Colorado), horns during ambient measurements (Nebraska) and personnel safety in rail yard measurements (Utah). Louisiana reported that its study was in response to a lawsuit over an accident at rail-highway grade crossing.

Of the non-state DOT respondents, Manitoba and Colorado Health each noted one rail noise project (one site) in the previous year. Manitoba measured L_{eq} and L_n values using an analyzer, while Colorado Health measured L_{max}, L_{eq} and L_{dn} via a meter, real time analyzer and sound level recorder.

5.8 Building Noise Reduction

Fourteen of the 43 state DOTs reported experience in determining how much building facades reduced exterior sound levels in interior spaces. Eleven noted one to three projects in the past year, while California reported eight. Six states indicated only one site per project, while five used two or three sites; Nevada reported using eight sites.

In most cases, only two microphones were used per site -- one indoors and one outdoors. Several states mentioned use of FHWA measurement techniques, with Nebraska noting placement of the outdoor mike to the side of the building. Half of the states used only sound level meters or analyzers for the measurements, while the rest augmented the equipment system with tape recorders, graphic level recorders, or more sophisticated data acquisition systems. Minnesota reported using loudspeakers to broadcast the outdoor noise.

L_{eq} was studied in all cases, often in conjunction with L_{max} or L_{10} values. Minnesota also noted determining articulation index, speech interference level, and sound transmission class.

The only problem was noted by Minnesota in assuring that the outdoor source will produce a level that is above the indoor ambient. Utah reported studying the reduction of a diesel engine testing room with indoor levels at 117 dB.

Of the non-state DOT respondents, Nova Scotia and Colorado Heath studied building noise reduction (four and six projects in the previous year, respectively). The latter studied six sites per project, measuring L_{max}, and L_{eq} using a meter, level recorder and real time analyzer for octave band analysis.

5.9 Vibration

Seven state DOTS reported making vibration measurements in the past year. Four had only one or two projects while West Virginia, Michigan and California reported three, four and six projects, respectively. Louisiana noted studies of highway and pile driver vibration problems. Four of the respondents studied four or fewer sites per project with three to twenty measurements/site. Michigan studied 16 sites per project and Louisiana 10-50 in its projects (making 200-1000 measurements).

Regarding descriptors, Louisiana, Michigan, Puerto Rico and West Virginia used peak particle velocity, with Louisiana also using amplitude and frequency, and Puerto Rico also using acceleration and amplitude. Michigan noted that it used department-designed and built equipment for three-dimensional velocity measurements, while California used seismometers and level recorders.

The only problem was mentioned by Louisiana, which was the difficultly in "mounting the velocity geophone to the ground."

Of the non-state respondents, only Manitoba had vibration monitoring experience in the previous year. It studied three sites per project on three projects, measuring peak particle velocity and peak dB (linear) via U.S. Bureau of Mines procedures. It used a B&K vibration meter and a Dallas Instruments blast monitor.

5.10 Other Monitoring Experience

Six state DOTs and three non-state DOT respondents listed measurement applications beyond what was covered in Sections 5.2 - 5.9, as described below.

Connecticut studied mitigation of mower tractor through insulation, using a sound level meter to measure maximum levels at various frequencies at the operator's ear.

Colorado noted a measurement survey for assessing for feasibility and planning Type II Projects (retrofit noise barriers, per previous FHWA noise standards).

Maine listed a special project to monitor "machine gun test effect" on the I-195 Spur, using sound level meters.

Minnesota and Utah reported studies for OSHA work place compliance. Minnesota used tape recorders or hand held meters, while Utah used an integrating sound level meter. The Utah work was a statewide survey involving 25 sites with measurements of individual pieces of equipment as well as 30-minute histories of 15-second L_{eq} values.

Texas studied noise from overhead highway sections at three sites using sound level analyzers but reported problems in microphone positioning.

Among the non-state DOT respondents, Ontario reported a study of tire/pavement interface noise over all types of pavement with three measurements per pavement using a meter and tape recorder. Manitoba also noted five projects measuring air conditioner noise per city by-law procedures, using a sound level meter. Finally, Colorado Health reported a 22 studies of property line nuisance measuring L_{max} and L_{eq} with a meter, level recorder, and real time analyzer.

6.0 OTHER ITEMS

The questionnaire provided an opportunity to identify areas of concern that warrant consideration for future research study, to list agency reports on noise measurements and to make other comments. This section deals with the latter two items, while future research is addressed in Section 7.0. Twenty-one of the 44 state DOTs, two provinces, and one county did not respond to any of the three items. Two states and one province used "other comments" to explain about their operations.

6.1 Research Reports

Ten states, one province, and the FAA listed 23 reports. Three states -- California, Kentucky, and Virginia -- listed more than one report each. Based on the titles, the reports were categorized according to subject, and are summarized below by category and state.

Subject	Agency
Construction Noise	AZ
Noise Barriers Experience/Evaluation	CA, CO, MD, MN, VA, ONT
Pavement Grooving-Tire Noise	IA, VA, MN
Evaluation of Model or Program	KY, VA
Vehicular Emission	KY, WV

Considering the frequent use of barriers for noise abatement, it is not surprising that five states and one province have reported on their experience with or evaluation of noise barriers. Pavement grooving as it affects roadway noise, the evaluation of noise models or computer programs, and vehicular emissions were each the subjects of research in two states. Appendix A contains a listing of the reports.

6.2 Other Comments

Seven of the 52 respondents made other comments. Among them, the Colorado Department of Health suggested that, when a Type II barrier is built, the community should commit itself to a noise ordinance and the necessary enforcement. Alberta predicts noise levels, relates them to land use and suggests mitigation techniques to the community. They encourage the control of development along their highways. Cuyahoga County and South Dakota both noted little need for noise measurement. The former said that few of its arterials needed widening, extension or relocation, while the latter noted that most of its work is on low volume roads. Wisconsin also noted that it uses FHWA prediction models in most instances to determine existing noise levels. Finally, Texas noted that it is continuing research on noise from overhead roadways.

7.0 RESEARCH NEEDS

Eighteen state DOTs, Ontario, the Colorado Department of Health, and the FAA submitted 35 expressions of concern for future research. Six subjects of concern were expressed by more than one respondent. In order of number of mentions, they are:

a. reflections off barriers and natural surfaces;
b. time as related to maximum noise levels and annoyance (nighttime);
c. urban noise (intersections, stop-and-go, propagation);
d. construction noise;
e. pavement/tire noise; and
f. vibration.

Several subjects for research that were only mentioned once, but which may be of interest are:

a. ANSI specifications for modern instrumentation
b. Uniform measurement procedures
c. Quality assurance programs
d. A model that will accommodate all area noise components so that mitigative strategies might be developed.

Appendix C lists all of the expressions of concern by the respondents.

8.0 SUMMARY

A questionnaire was circulated in December, 1982, by TRB Committee A2H01, Instrumentation Systems, Principles and Applications, to gather and synthesize information on noise measurement equipment and procedures in state highway agencies. Responses were received from 44 such agencies (including the District of Columbia and Puerto Rico), four Canadian provinces, two counties, the Federal Aviation Administration, and the Colorado Department of Health, for a total of 52 responses. Information was received on personnel, equipment, procedures, measurement experience, and research needs.

The responses indicated that most noise measurement personnel are assigned to the environmental, planning, design or materials offices, with the majority being in the environmental office. Nearly half of the respondents have four or fewer trained or experienced personnel, while over half have four or fewer personnel making measurements routinely. Over half of the respondents reported that at least ninety percent of their work was done in-house, although several respondents indicated that most work was done by outsiders. These outsiders include consultants, city agencies, or other public agencies. Most respondents indicated that the main sources of training were FHWA/NHI training courses or FHWA Demonstration Project workshops, although several respondents used in-house training.

While a wide variety of types, brands and models of noise measurement equipment are owned by the respondents, most of the equipment was obtained from only a few major manufacturers. The percentage of respondents having various types of equipment may be summarized as follows:

- ninety percent have sound level meters
- seventy percent have strip chart recorders
- forty-five percent have tape recorders
- fifty-five percent have self-contained portable analyzers
- five percent have digital cassette monitors
- sixteen percent have real time analyzers.

Typical measurement system arrangements include the self-contained analyzers connected to graphic level recorders, and sound level meters connected to tape recorders with a laboratory graphic level recorder and statistical distribution analyzer for data reduction.

Over half of the respondents had complaints or had experienced some problems with equipment including malfunctioning, difficulty in operating older equipment, and effects of low temperatures and high humidity.

Eighty percent of the respondents reported using support equipment to gather data to supplement the noise measurements. One half of the respondents reported performing traffic counts while making noise measurements. Meteorological data is collected by forty percent of the respondents during noise measurements.

In commenting on needed equipment improvements and purchase plans, respondents generally reported that they desired equipment that was more portable, versatile, durable, and field-worthy. Despite the desires for equipment improvements, most agencies did not have plans for purchasing additional equipment. Of those respondents planning to purchase new equipment, the types most often mentioned were portable noise analyzers and sound level meters.

In discussing measurement procedures, nearly half of the respondents listed published FHWA reports, while one-quarter listed in-house manuals, as references. The most common types of quality assurance were equipment calibration and record keeping and checking. Regarding practices, half of the respondents indicated that noise levels were measured only once at each site. The most common measurement duration was in the ten to fifteen minute range. Nearly all respondents indicated experience in monitoring emission levels, noise barrier, construction noise or building noise reduction. Less than twenty percent of the respondents listed experience in the areas of aviation noise, rail noise or vibration.

The questionnaire provided an opportunity to identify areas of concern that warrant consideration for future research. Six subjects of concern were expressed by more than one respondent:

- sound reflection
- noise impact as a function of time of day
- urban noise
- construction noise
- pavement/tire noise
- vibration.

A number of respondents also provided references on state measurement manuals and research reports.

APPENDIX A - RESPONDENTS' LISTS OF REPORTS

A. PUBLISHED MANUALS OR REPORTS ON NOISE MEASUREMENT

While over 30 reports were listed by respondents, only those specifically addressing noise measurement are listed below.

1. Acoustic Noise Measurements, Bruel and Kjaer Instruments, Inc., 1973.
2. Agent, K.R., Vehicle Noise Emission Levels in Kentucky, Kentucky Transportation Research Program, Report UKTRP-81-13, July 1981.
3. Beranek, L.L., Noise and Vibration Control, McGraw-Hill, New York, 1971.
4. Bowlby, W. (ed.), Sound Procedures for Measuring Highway Noise: Final Report, Report No. FHWA-DP-45-1R, Federal Highway Administration, Arlington, Virginia, August 1981.
5. Davy, B.A., and S.R. Skale, Insulation of Buildings Against Highway Noise, Report No. FHWA-TS-77-202, Federal Highway Administration, Washington, D.C., 1977.
6. "Evaluation of Traffic Noise Barrier Design Methods," New Jersey DOT.
7. Fundamentals and Abatement of Highway Traffic Noise, Volumes 1, 2, and 3, Report No. FHWA-HHI-HEV-73-7976-1, Federal Highway Administration, Washington, D.C., June 1973.
8. Guide on Evaluation and Attenuation of Traffic Noise, AASHTO, Washington, D.C., 1974.
9. Harris, C.M., Handbook of Noise Control, McGraw-Hill, New York, 1979.
10. Highway Noise Analysis, Demonstration Project 45, (workshop notes), Report No. FHWA-DP-45-2, Federal Highway Administration, Arlington, Virginia.
11. Kugler, B.A., D.F. Cummins, and W.J. Galloway, "Highway Noise - A Design Guide for Prediction and Control," NCHRP Project 174, 1976.
12. Kugler, B.A., and A.G. Piersol, "Highway Noise - A Field Evaluation of Traffic Noise Reduction Measures," NCHRP Report 144, 1973.
13. Ma, Y.Y., and F.F. Rudder, Jr., Statistical Analysis of FHWA Traffic Noise Data, Report No. FHWA-RD-78-64, Federal Highway Administration, July 1978.
14. Mange, G.E., S.R. Skale, and L.C. Sutherland, Background Report on Outdoor/Indoor Noise Reduction Calculation Procedures, Report No. FHWA-TS-77-220, Federal Highway Administration, Washington, D.C., 1977.
15. "Motor Vehicle Noise Control," TRB Special Report 152, Washington, D.C.
16. "NANCO Technical Report 1," National Association of Noise Control Officials, Ft. Walton Beach, Florida.
17. "Noise Measurements," New Jersey DOT.
18. Peterson, A., and E.E. Gross, Handbook of Noise Measurement, General Radio, Concord, MA, 1972.
19. Procedures for Abatement of Highway Traffic Noise and Construction Noise, Federal Aid Highway Program Manual 7-7-3, Federal Highway Administration, Washington, D.C., 1982.
20. Reagan, J.A., Determination of Reference Energy Mean Emission Levels, Federal Highway Administration, Washington, D.C., 1978.
21. Reagan, J.A., and C.A. Grant, Highway Construction Noise: Measurement, Prediction and Mitigation, FHWA Special Report, Washington, D.C., 1974.
22. Sasor, S.R., Determination of Truck Noise

Levels for New Jersey, NJDOT Report 81-606-7791, July 1979.
23. Webster, W.J., "Use of Graphic Level Recorders as Indicator Instruments," New York State Department of Environmental Conservation, Albany, NY, 1973.

B. IN-HOUSE NOISE MEASUREMENT DOCUMENTS

1. Alberta Surface Transportation Noise and Attenuation Study.
2. Caltrans Noise Manual, Cal Test 703.
3. Colorado Department of Highways Policy/Procedural Directives on Noise.
4. Illinois Traffic Noise and Vibration Manual.
5. Indiana Division of Location and Environment, Noise Prediction Manual.
6. Kentucky Division of Environmental Analysis Guidance Manual.
7. Ohio Department of Transportation Noise Manual.
8. Ontario Ministry of Environment, Acoustics Technology, Training Manuals.
9. State of Wisconsin Facilities Development Manual, Chapter 23, (Noise).
10. Texas State Noise Quality Guidelines.
11. Virginia Procedures for Noise Measurements.
12. West Virginia Department of Highways, Materials Procedure 712.40.01.

Areas of Concern to Respondents

Agency	Area of Concern
AZ	Model refinement for "soft" barriers.
CO	Off-peak intermittent noise standards; Property values related to abatement; How to measure/predict reflections off rock, canyon walls, and water; Effectiveness of non-barrier mitigation; Auto tire noise.
CT	Securing equipment for long and short term monitoring.
FL	Simplified monitoring and prediction of construction noise; Simple, accurate insertion loss analysis for barrier effect.
IA	Degradation of effectiveness due to parallel barriers.
KY	Construction noise.
LA	Noise attenuation through residential areas.
MD	Emission levels as a function of pavement type; Actual truck noise compared to predicted levels;

C. AGENCY RESEARCH REPORTS

Agency	Report Title
AZ	A Construction Noise Abatement Incentive.
CA	Noise Measurement Quality Assurance.
	Evaluation of Noise Barriers.
CO	Noise Barrier Experience.
IA	Transverse Grooving - Effect on Roadway Noise.
KY	Evaluation SNAP 1.
	Propagation of Traffic Noise.
	Effect of Interrupted Flow on Traffic Noise.
	Vehicle Noise Emission Levels in Kentucky.
MD	Evaluation of I-495/Georgia Avenue Noise Barrier.
MN	Traffic Noise Tire/Pavement Interaction I-90, Albert Lea, Minnesota: Five Year Summary 1978-1982.
	Traffic Noise Tire/Pavement Interaction I-90, Albert Lea, Minnesota: 1978, 79, 80, 81, and 82.
	Traffic Noise Tire/Pavement Interaction T.H., 12, Willmar, Minnesota: 1978, 79, 80, 81, and 82.
	Objective Traffic Noise Barrier Measurements.
TX	Traffic Noise from Overhead Sections.
VA	Effect of Pavement Textures on Tire-Road Noise -- Exterior and Interior.
	Effectiveness of Computer Programs in Design of Noise Barriers -- Part I: The Data Acquisition System, Part IIA: The Final Report, Part IIB: The Noise Level Data.
	Computer Program Validations.
	Barrier Effectiveness Measured.
WV	Sampling and Analysis Used in Determining Vehicular Acoustical Emission Levels.
FAA	Operation and Maintenance of Airport Noise Monitoring Systems.
ONT	A considerable number of unspecified reports have been issued.

APPENDIX B - DETAILS ON EQUIPMENT OWNERSHIP

This appendix lists the equipment reported by each respondent by type, model and number of pieces. The tables are:

B.1 - Sound level meters
B.2 - Strip chart recorders
B.3 - Tape recorders
B.4 - Self-contained portable analyzers
B.5 - Digital cassette monitors
B.6 - Real time analyzers
B.7 - Data acquisition/reduction/analysis systems
B.8 - Other

APPENDIX C - AREAS OF CONCERN TO RESPONDENTS

Agency	Area of Concern
AZ	Model refinement for "soft" barriers.
CO	Off-peak intermittent noise standards; Property values related to abatement; How to measure/predict reflections off rock, canyon walls, and water; Effectiveness of non-barrier mitigation; Auto tire noise.
CT	Securing equipment for long and short term monitoring.
FL	Simplified monitoring and prediction of construction noise; Simple, accurate insertion loss analysis for barrier effect.
IA	Degradation of effectiveness due to parallel barriers.
KY	Construction noise.
LA	Noise attenuation through residential areas.
MD	Emission levels as a function of pavement type;

	Actual truck noise compared to predicted levels; On-site differentiation of airborne noise, noise induced vibration and ground transmitted vibration.
MI	Effect of sloping (battered) retaining walls on reflection; Effect of reflection on opposing barrier walls; Determine noise levels from recreational vehicles.
MN	ANSI specifications for modern instrumentation.
MS	Determine if maximum noise levels occur during peak traffic hour.
NJ	Establish uniform measurement procedures; Establish quality assurance programs.
OR	Develop all-weather noise monitoring equipment.
PA	Stop-and-go measurement procedures and coordination with valid prediction model; Need for vibration course.
TN	Nighttime readings when impact is more of concern.
TX	Noise from overhead roadways; Joint noise; Reflective dampening.
UT	Intersection noise (highways); American freight train noise model.
WV	Correlation of time versus traffic mix and volume to acoustical levels.
COH	Develop a model to identify all area noise components (sources), then develop mitigative strategies.
FAA	Influence of "time of day" weighting on cumulative noise metrics.
ONT	Effects of weather conditions on sound propagation.