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DOT HS-802 083

AN AUDIBLE AUTOMOBILE BACK-UP PEDESTRIAN WARNING DEVICE - DEVELOPMENT AND EVALUATION

Contract No. DOT-HS-5-01185
November 1976
Final Report

PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Washington, D.C. 20590

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16. Abstract

The purpose of this study was to develop and field-test an audible back-up warning device for use on automobiles. Detailed criteria of pedestrian age and hearing ability combined with noise characteristics of typical accident sites provide the basis for selection of a warning signal format. The warning signal (a tone at 1250 Hz pulsed on for 0.1 sec and off for 0.2 sec) is generated by a small loudspeaker mounted at the rear of the vehicle. An essential element of the design, that the system sense the ambient level and adjust its output accordingly, results in a warning signal level approximately equal to the A-weighted noise level throughout the danger zone. This is comparable to a level at least 10 dB above the pedestrian's detection threshold.

Evaluation of a prototype system was conducted in typical parking sites using pedestrian subjects of opportunity. Results comparing the normal situation with a test sequence using the warning signal indicated a tenfold improvement in the number of pedestrians warned of the presence of a backing vehicle.

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Unclassified	Unclassified	165	

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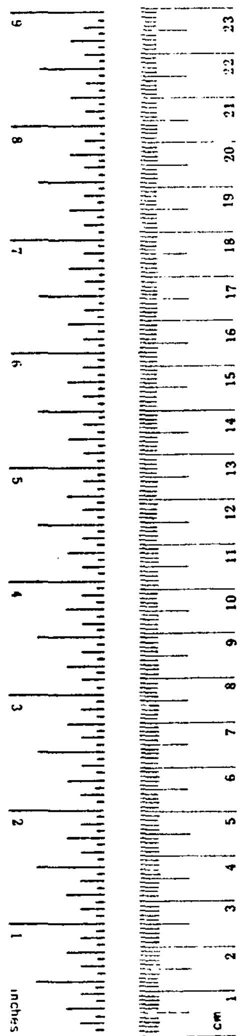
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

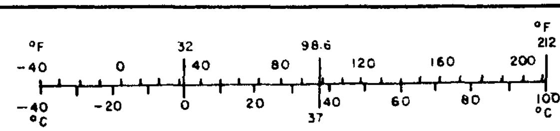
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

TECHNICAL SUMMARY

CONTRACTOR	Wyle Laboratories, Wyle Research 128 Maryland Street, El Segundo CA 90245	CONTRACT NUMBER DOT-HS-5-01185
REPORT TITLE	An Audible Automobile Back-Up Pedestrian Warning Device — Development and Evaluation.	REPORT DATE July 1976
REPORT AUTHOR(S)	Ron Brown, Louis C. Sutherland	

Each year an estimated 260 pedestrians are killed and over 5,000 are injured by backing vehicles. This type of accident is classified as preventable, as an effective warning signal could eliminate a large majority from the accident rolls. To verify this thesis, the National Highway Traffic Safety Administration authorized a program to

- Estimate the potential effectiveness of an audible warning signal.
- Study the factors related to the ability of a pedestrian to detect a warning signal.
- Analyze the noise environment of potential back-up accident sites.
- Select an optimum warning signal format.
- Design a prototype warning device.
- Evaluate the effectiveness of the device.

This program has now been completed and all goals have been successfully reached. This report details the results of the program and, as outlined below, summarizes the essential conclusions from the study. A noteworthy result of the study predicts a change from a potential 50 percent accident rate, if unawareness is the main cause of accidents, to only 6 percent when the audible warning signal is used.

Pedestrian Back-Up Accident Data Analysis — An examination of existing back-up accident data was made to determine whether the pedestrian would have successfully detected the vehicle in time to avoid the accident if the vehicle had been equipped with an audible back-up warning device. An estimated 73 percent of these accidents would have been prevented if the pedestrian could have heard a warning signal. Data from these accident cases were also used in later sections to identify factors related to potential accident victims and the type of sites where these accidents may occur.

The Target Population — This section identifies the distribution of accident victims by age and sex, and defines their critical characteristics — hearing ability and reaction time being the primary factors. Over 37 percent of the back-up accident victims are 45 or older and over 18 percent are over 65. Thus, older segments of the population comprise the primary "population at risk" and, therefore, the main benefactors of a warning signal system.

(Continue on additional pages)

"PREPARED FOR THE DEPARTMENT OF TRANSPORTATION, NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION UNDER CONTRACT NO.: DOT-HS-5-01185. THE OPINIONS, FINDINGS, AND CONCLUSIONS EXPRESSED IN THIS PUBLICATION ARE THOSE OF THE AUTHORS AND NOT NECESSARILY THOSE OF THE NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION."

HS Form 321
July 1974

The Accident Site — The distribution of back-up accidents at different types of sites and the time of occurrence were derived from the accident data. Background information is presented which defines the ambient noise variations and typical spectra to be expected at various potential accident sites, and noise data is presented from eight specific site locations. Analyses of the vehicle self-noise, the limiting ambient level, and the elapsed time of driver actions preparatory to backing are also discussed. A design ambient noise level exceeded less than 5 percent of the time (L_5) between 63 dBA and 87 dBA is projected.

Selection of the Warning Signal — An integration of the preceding factors results in development of the optimum warning signal format. An analysis of possible accident scenarios illustrates the geometry of backing accidents. A brief discussion of the signal detection process and correlation of the levels and spectra of all pertinent factors result in the selection of 1250 Hz as an optimum warning signal. Subjective tests of various warning signal formats identify a timing sequence of 100 msec on and 200 msec off at a level approximately 17 dB above the detection threshold as an optimum signal.

The Warning Signal System — The peak warning signal level, as heard by the pedestrian, will be approximately equal to the A-weighted ambient noise level throughout the danger zone. Propagation of the warning signal, including potential annoyance which is projected as minimal due to the ambient sensing feature of the system, is also discussed. Detailed descriptions of the warning signal system, including a complete schematic of the prototype system, are presented. System installation and operation instructions, and a specification for the warning signal are also included.

Evaluation of the Warning Signal System — Finally, the most important objective of the program - measuring the effectiveness of an actual system - is described. It has been found that approximately 95 percent of the subjects "noticed" the warning device. This was based on subject response as observed by the investigator and/or a verbal response from the subject elicited during an interview. Analyses of the evaluation test data by walking speed and by type of site, along with ambient noise level data, are also presented. Noise levels measured compare favorably with earlier projections.

The final results of the warning system evaluation predict that a vast improvement in the pedestrian's ability to avoid injury would ensue if an audible warning signal were present. Specifically, the percentage of those who did not notice a vehicle backing was decreased from 55 percent to 5.6 percent — a factor of 10 improvement in potential accident rate.

It is obvious from these results that an audible warning would substantially reduce the accident risk for pedestrians walking near vehicles about to back up. At least two unknown factors should be examined and resolved prior to considering adopting the system for use on all passenger cars:

- The cost of producing the device, including installation and servicing, may affect public acceptance of its adoption. Cost estimates of this type must, of necessity, be provided by the potential manufacturer to be realistic. However, based on current technology in electronics, the initial cost is expected to be low compared to the potential benefits.
- Based upon measurements, subjective tests, and theoretical predictions, annoyance to the general public should be minimal. However, an accurate assessment of this aspect will require a greater effort than could be expended on this program.

A recommendation for future adoption of the device should thus be tempered by the results of an analysis of these two issues. Nevertheless, a simple device such as tested, which can save perhaps 200 lives a year and reduce the number of people injured from 5,000 per year to a much lower number, is considered worthy of consideration.

ACKNOWLEDGEMENTS

This program has benefited from the experience and expertise of many individuals. The authors wish to acknowledge the support of NHTSA personnel, especially Dr. Robert L. Henderson, Contract Technical Manager, who has provided technical guidance during the conduct of the program.

Sincere appreciation is given to members of the Wyle Laboratories Staff who have made significant contributions to the program. In particular, Dr. Norman J. Meyer, Director of the Research Staff, who took particular interest in solving several challenging problems which developed during the one year program. Mr. C. Christian Stiehl contributed to the system evaluation and analysis of the experimental data; Mr. Bob R. Beavers consulted on the system circuit design; and Mr. Gary E. Mange and Mr. Richard E. Stambaugh served ably during the experimental evaluation phase of the program. The support of these and many other Wyle personnel, helped to achieve the goals successfully reached.

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1.0 INTRODUCTORY SUMMARY

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Pedestrian Back-Up Accident Data Analysis - An examination of existing back-up accident data was made to determine whether the pedestrian would have successfully detected the vehicle in time to avoid the accident if the vehicle had been equipped with an audible back-up warning device. An estimated 73 percent of these accidents would have been prevented if the pedestrian could have heard a warning signal. Data from these accident cases were also used in later sections to identify factors related to potential accident victims and the type of sites where these accidents may occur.

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In summary, the primary program results may be reviewed as follows: Figure 1-1 presents the relationship between the noise levels affecting detection of the warning signal and the warning signal itself. The hearing threshold of the target population, which is seldom a limiting factor, is shown. Spectrum levels (1/3 octave) of the vehicle engine noise, often the controlling ambient for the warning system, are approaching the community ambient levels heard by the pedestrian. The range of community noise levels exceeded 5 percent of the time (L_5) to be expected at potential accident sites is shown and in relation to this, the warning signal level at the extent of the danger zone.

The final results of the warning system evaluation are shown in Figure 1-2. These data, extracted from Table 7-6, predict that a vast improvement in the pedestrian's ability to avoid injury would ensue if an audible warning signal were present.

Test	Noticed	Did Not Notice
With Device	94.4%	5.6%
Without Device	45%	55%

Figure 1-2. Percentage of Effectiveness of the Back-up Warning Device (74 subjects)

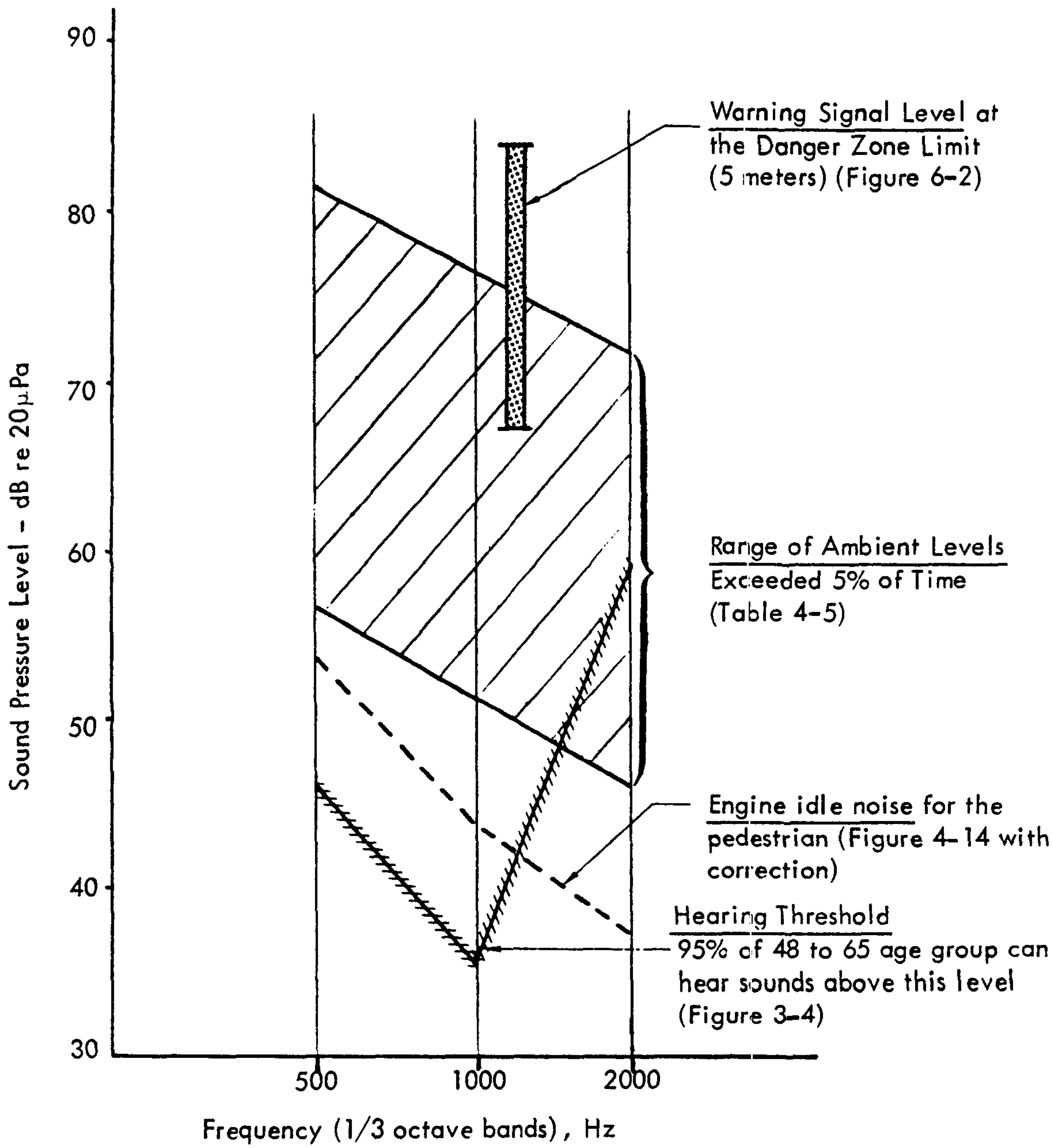

Figure 1-1. Relationship Between the Factors Governing Selection of the Warning Signal Level.

Specifically, the percentage of those who did not notice a vehicle backing was decreased from 55 percent to 5.6 percent - a factor of 10 improvement in potential accident rate.

It is obvious from these results than an audible warning would substantially reduce the accident risk for pedestrians walking near vehicles about to back-up. At least two unknown factors should be examined and resolved prior to considering adopting the system for use on all passenger cars.

- The cost of producing the device, including installation and servicing may affect public acceptance of its adoption. Cost estimates of this type must, of necessity, be provided by the potential manufacturer to be realistic. However, based on current technology in electronics, the initial cost is expected to be low compared to the potential benefits.

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2.0 PEDESTRIAN BACK-UP ACCIDENT DATA ANALYSIS

Prior to the selection of a warning signal and designing the device, a study was made of 160 back-up accidents involving pedestrians in order to determine whether an audible warning device would have been effective in preventing these accidents. This section presents the results of the accident data review and related statistics are shown to provide a basis for evaluating the study results. Also, although the research necessary to prepare meaningful cost estimates is beyond the scope of this program, some relevant economic costs are presented to provide insight into the viability of the program.

2.1 Study by Operations Research, Inc. – 1971

An examination was made of 34 vehicle back-up accident cases involving 37 pedestrians.* This examination was made to determine the effectiveness that an audible warning device would have in preventing these back-up accidents. In some instances, the data was inadequate to determine whether the pedestrian saw the vehicle prior to being struck, but many pedestrians obviously had inadequate time to avoid being hit.

The study, of which the reviewed accident data was a part, identified the accident precipitating factors – the details of which were listed in Table 4.1 of Reference 9. For all pedestrian accidents, 71 percent of the precipitating factors were assigned to pedestrian failures with the remaining 29 percent assigned to the driver. A similar tabulation of back-up accident precipitating factors, derived from the reviewed accident data, indicated 40 percent of the factors were assigned to the pedestrian and 60 percent were assigned to the vehicle driver.

The accident data was analyzed to determine if the pedestrian would have successfully detected the vehicle in time to avoid the accident if each vehicle had been equipped with an audible back-up warning device. A summary of the detailed pertinent facts from the original data is shown in Table A-1 of Appendix A. These data were

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* The original accident data from Reference 9.

analyzed and pedestrians were classified according to (1) those who would not have been helped by an audible warning, and (2) those who would likely have responded to an audible warning. Table 2-1 summarizes the results of this analysis and identifies a few of the specific classes of identified accident causations. Examination of this data indicates that 79 percent of all the pedestrians involved in these back-up accidents would have benefited from an audible warning device.

Table 2-1

Summary of Back-up Accident Causation
(Accident Cases from Table A-1)

Pedestrians who would not benefit from an audible warning

Code	Accident Cause	Number of Cases
a.	Pedestrian saw vehicle, unable to avoid	3
b.	Pedestrian saw vehicle, did not avoid	2
c.	Young child (less than 5 years of age)	2
	Total	7

Pedestrians who would likely benefit from an audible warning

Code	Accident Cause	Number of Cases
d.	Pedestrian was not aware the vehicle was backing	21
e.	Pedestrian saw vehicle too late to avoid	6
	Total	27

2.2 Accident Data from Bio-Technology Study, 1973 and 1974 (Urban)

A similar examination was made of 99 vehicle back-up accident cases involving 102 pedestrians. Table A-2 in Appendix A contains the detailed pertinent data derived from these accident cases. An analysis of these accident cases revealed that 73 percent of the accidents probably would not have occurred if a back-up warning device had been operational. The factors relating to the pedestrians' possible help from a warning device are enumerated in Table 2-2 with the number of cases falling within each category.

Table 2-2

Summary of Back-up Accident Causation
(Accident Cases from Bio-Technology Study,
1973 & 1974, Urban, Reference 17)

Pedestrians who would not benefit from an audible warning

Code	Accident Cause	Number of Cases
a.	Pedestrian saw vehicle, unable to avoid	13
b.	Pedestrian saw vehicle, did not avoid	2
c.	Young child (less than 5 years of age)	11
f.	Unoccupied vehicle	2
	Total	28

Pedestrians who would likely benefit from an audible warning

Code	Accident Cause	Number of Cases
d.	Pedestrian was not aware the vehicle was backing	50
e.	Pedestrian saw vehicle too late to avoid	21
	Total	71

2.3 Study by Bio-Technology – Rural Accidents

Accident data from a study currently being performed by Bio-Technology, Inc. produced 27 cases of vehicle back-up accidents involving 28 pedestrians. Summary data extracted from the reports are shown in Table A-3 of Appendix A. A determination of the effectiveness an audible device would have had was made and the results are shown in Table 2-3. This analysis indicates 67 percent of the pedestrian accidents could have been prevented if an audible warning signal had been operational.

Table 2-3

Summary of Back-up Accident Causation
(Accident Cases from Bio-Technology Study, Rural, Reference 17)

Pedestrians who would not benefit from an audible warning

Code	Accident Cause	Number of Cases
a.	Pedestrian saw vehicle, unable to avoid	2
b.	Pedestrian saw vehicle, did not avoid	
c.	Young child (less than 5 years of age)	7
	Total	9

Pedestrians who would likely benefit from an audible warning

Code	Accident Cause	Number of Cases
d.	Pedestrian was not aware the vehicle was backing	9
e.	Pedestrian saw vehicle too late to avoid	9
	Total	18

2.4 Summary of the Accident Data Analysis

Table 2-4 is a tabulation of the total pedestrian accident cases in each of the studies and the number of back-up accident cases reviewed. Analysis of the accident causation related to the pedestrian indicates that 73 percent of the vehicle back-up pedestrian accidents would have been prevented if all pedestrians could have heard a warning device. Of course, some pedestrians – particularly those in their later years – may have inadequate hearing ability and may fail to respond to an audible warning signal.

Table 2-4

Summary of Back-up Accident Data Analysis

Accident Cases	ORI Study (Urban)	BTI Study (Urban)	BTI Study (Rural)	Total Number
Pedestrian Accident Cases	2,157	3,827	1,632	7,616
Back-up Accident Cases	34	99	27	160
Pedestrian Fatalities	2	4	1	7
Pedestrian Injuries	26	94	24	144
Accident Cases Preventable by an Audible Warning Device	27	71	18	116

Back-up accident data statistics derived –

Back-up Accidents = 2.1 percent of Pedestrian Accidents
Back-up Fatalities = 4.4 percent of Back-up Accidents
Back-up Injuries = 90 percent of Back-up Accidents

Urban Pedestrian Accidents (BTI Study) –

1973 Back-up Accidents = 2.5 percent of Urban Pedestrian Accidents
1974 Back-up Accidents = 2.7 percent of Urban Pedestrian Accidents

2.5 Estimated Benefit of a Warning Device

The determination of costs to produce and install a warning device on all new automobiles on a high-volume production basis is complex and was deemed not feasible within the scope of the program. As an alternative, a brief analysis was performed to evaluate the benefits to be derived by implementing the program, and thereby determine the maximum amount to be committed to the program, using normal cost-benefit criteria. Table 2-5 lists information used to perform this calculation. These data – in conjunction with approximate dollar loss-per-accident values supplied by NHTSA – yield an economic loss of $106 million due to back-up accident fatalities and injuries.

The review of the 160 back-up accidents in this study indicates approximately 70 percent could have been prevented if the vehicles had been equipped with warning devices. Using an economic loss value of $240,000 per fatality and $8,000 per injury, the annual value (benefit) of prevented accidents – once the national automobile fleet is fully equipped – is approximately $74 million. Assuming that no more than $74 million would be committed annually and assuming a yearly production rate of 10 million automobiles, a maximum unit cost of $7.40 is derived.

It should also be pointed out that the benefits will lag the costs until the national fleet is fully equipped. A previous Wyle study of vehicle registrations for the year 1973 indicated that 50 percent of the automobile fleet were over 5 years old and 12 percent were over 10 years old.[16] Therefore, assuming a similar retirement rate in the future, it is expected to take approximately 5 years to equip one-half the fleet (assuming no used-car retrofit) and over 10 years to reach full implementation.

Table 2-5

Back-up Accident Economic Loss — Worksheet

Relevant Accident Statistics			Ref.
Total Accidents Per Year	25.6 million	(1973)	15
Total Traffic Fatalities	55,800	(1973)	15
Total Traffic Injuries	5.2 million	(1973)	15
Pedestrian Accidents	286,500	(1973)	14
Pedestrian Fatalities	10,500	(1973)	14
Pedestrian Injuries	277,000	(1972)	15
Back-up Accidents (2.1% of Ped. Accidents*)	6,017		17
Back-up Fatalities (4.4% of Back-up Accidents*)	263		17
Back-up Injuries (90% of Back-up Accidents*)	5,417		17
Total Loss Due to Accidents	$19 billion	(1972)	15

Total Economic Loss Computation:

Back-up Accident Fatalities - 263 at $240,000 each	$ 63 million
Back-up Accident Injuries - 5,417 at $8,000 each	$ 43 million
Total -	$106 million

Potential Benefit Computation:

Estimated prevention rate of 70% x $106 million = $ 74 million

References — 14: Accident Facts, 1974
15: Statistical Abstracts, 1974
17: Data from Bio-Technology Study
* Table 2-4 derived from BTI and ORI Studies

3.0 THE TARGET POPULATION

There are several factors bearing on the success of an audible automobile back-up warning device. Of course, the primary concern is to alert pedestrians in the danger zone behind the automobile soon enough for them to take evasive action. However, a number of pedestrian back-up accidents occur which would not be prevented by an audible warning; among these are:

- Pedestrians who see the vehicle but are unable to avoid it;
- Pedestrians who see the vehicle but do not feel evasive action is necessary; and
- Young children who may not recognize the danger.

These categories of pedestrians are beyond the ability of any warning device to help, although the audible signal may enhance the importance of a dangerous situation and thus prevent additional accidents. The present program was directed toward those pedestrians - the target population - who would not normally see the backing automobile soon enough to avoid injury, but would be alerted in time by an audible warning device.

Our primary goal is to evoke an appropriate response from members of the target population when they hear the warning signal. Their complete response is relatively complex, but primarily includes the following:

- Audibly detecting a warning signal;
- Visually confirming the direction of the impending danger; and
- Taking physical action to minimize the danger.

3.1 Reaction Time of the Population

The reaction time of people depends on many variables[4], some of which will be considered here. The mean reaction time of both the male and female population as a function of age (shown in Figure 3-1) indicates a range of approximately 2 to 1 between young and old pedestrians. There are also minor differences in reaction time depending on the initial cue, whether it is visual or audible, an audible cue yielding approximately 20 percent faster reaction times.

3.2 Acoustic Perception by the Population

The pedestrian's ability to be alerted by an audible alarm is, of course, dependent on his ability to perceive the warning signal. The acoustic characteristics of the warning signal - its frequency content and intensity - are paramount, but we must also consider the pedestrian's hearing ability.

The standard (reference) threshold of hearing represents the level of sound in a free progressive sound field just audible to a hypothetical young adult with no history of medical problems of the ear. This reference hearing threshold, in Figure 3-2 shows that the normal ear can hear sounds with the lowest sound pressure level at frequencies in the vicinity of 1000 Hz. The actual hearing ability of people is specified in terms of their "hearing level" - the difference in the level of a just audible sound relative to the standard reference threshold in Figure 3-2. The "hearing level" of the average person decreases (rather the difference between his threshold and the standard threshold increases) as one grows older - a process apparently due to normal aging (presbycusis) and possibly to progressive hearing loss suffered by normal exposure to high level noise in our society (sociocusis).[6] Figure 3-3 shows this trend in decreased hearing ability with age; each curve represents the hearing level exceeded by no more than 10 percent of the population.

If these hearing levels are added to the standard threshold given in Figure 3-2. the hearing threshold for two age groups are obtained as illustrated in Figure 3-4. These data. considered representative of the most reliable information on hearing levels available, show the sound level as a function of frequency which can be heard by the specified percent of the population for the age groups indicated.

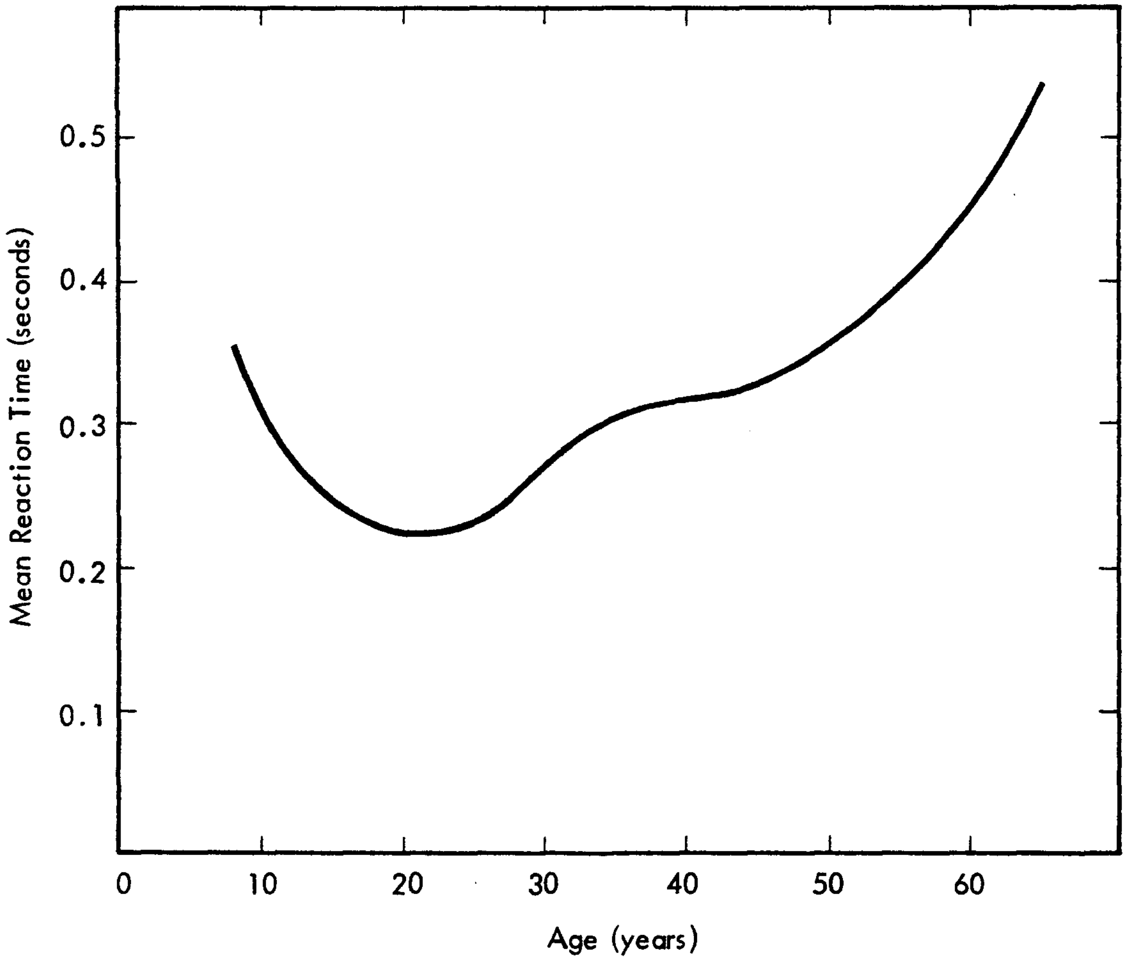


Figure 3-1. Approximate Mean Reaction Time of the Male and Female Population for Audible and Visual Stimuli (Reference 13)

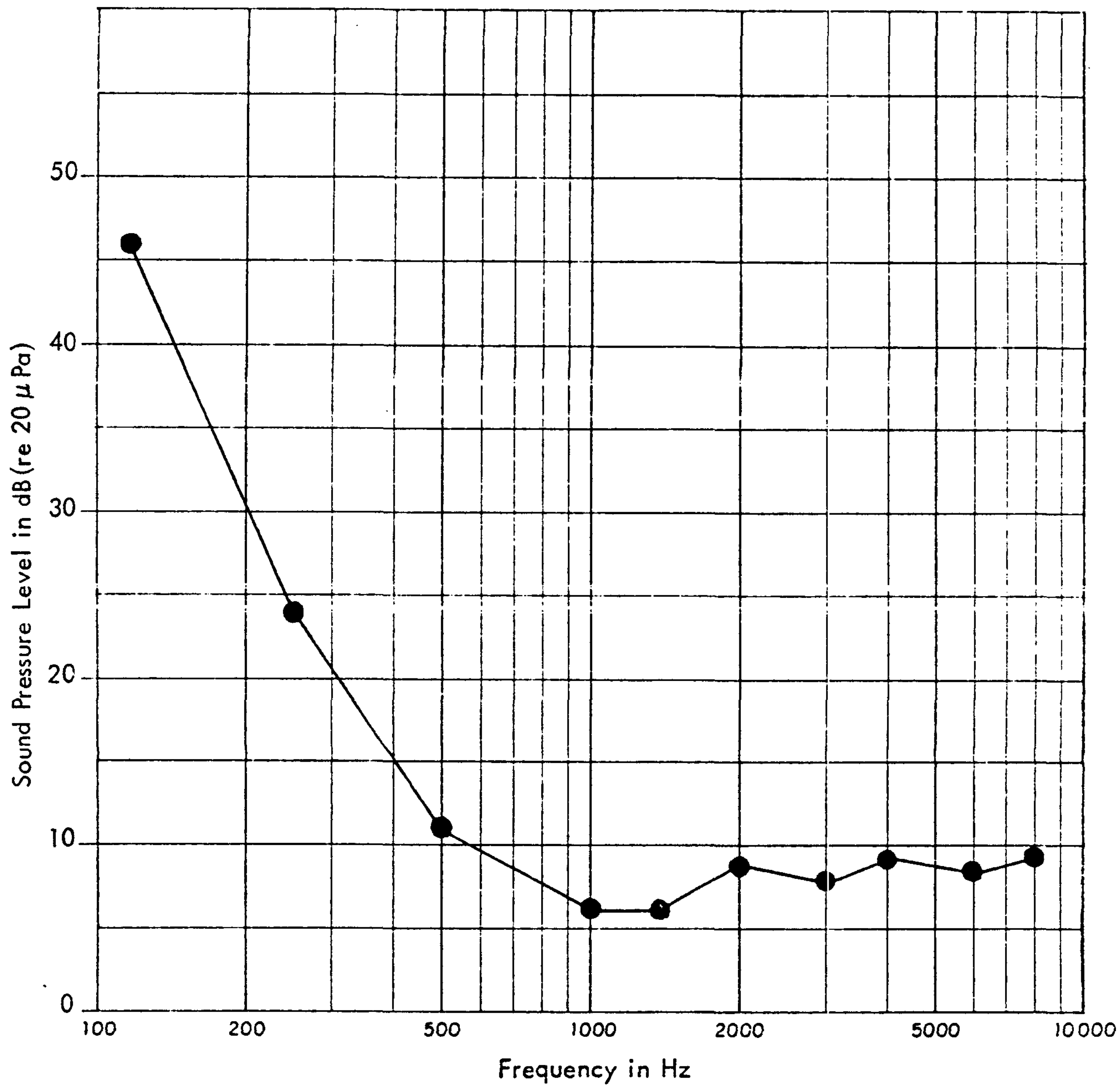


Figure 3-2. Standard Reference Threshold Sound Pressure Levels ISO (1963) (Reference 12)

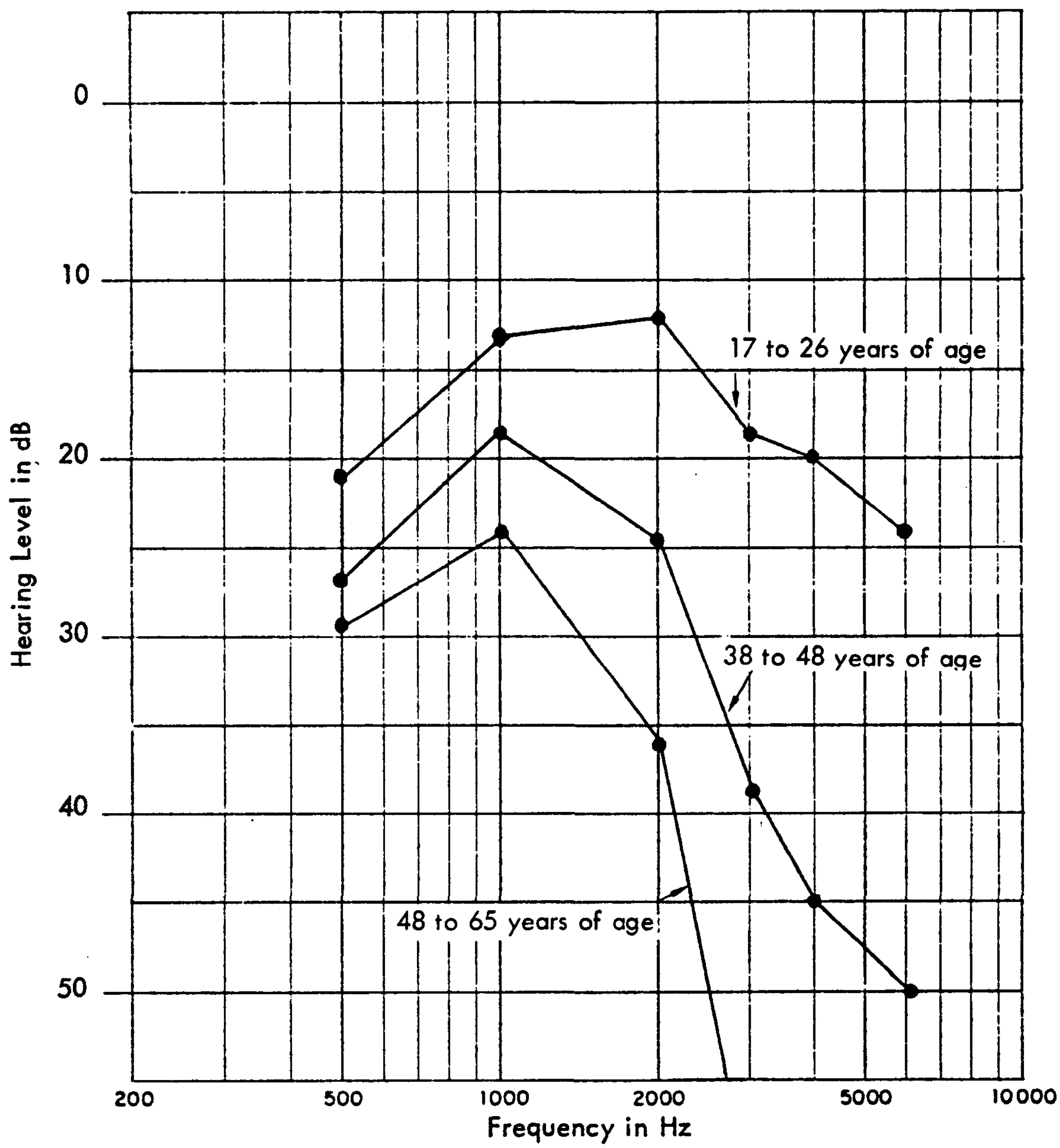


Figure 3-3. Hearing Level of 90 Percent of the Population Within Each Indicated Age Group (Reference 1)

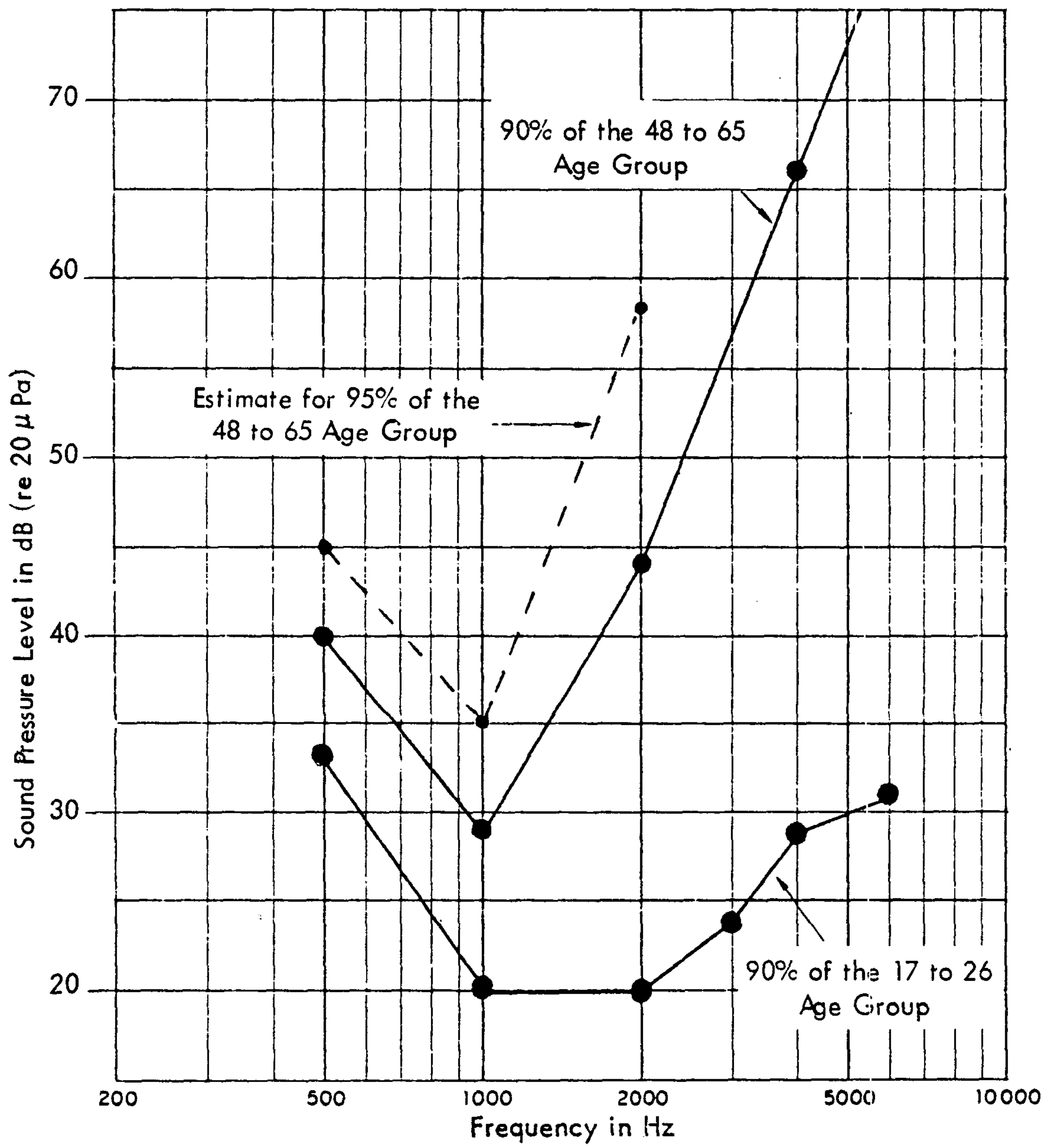


Figure 3-4. Comparison of Hearing Thresholds for Two Age Groups

The differences in the hearing ability of the male and female population are also of interest. Figure 3-5 illustrates the differences at two frequencies as a function of age. It is interesting to note the reversed hearing capability of men and women at the two frequencies shown.

3.3 Age Distribution of Accident Victims

To establish an approximate profile of the target population, comparisons were made between the distribution of ages and sex for: 1) pedestrian back-up accident victims, 2) all pedestrian accident victims, and (3) the total U.S. population. Table 3-1 lists the details derived from three different sources showing the age distribution and percentages of each sex. These data show that approximately 10 percent of the total population is 65 years of age or older and a similar percentage of the pedestrian accident victims are in this age group. However, over 18 percent of the back-up accident victims are 65 or older. Based on the limited sample of the latter, age appears to be a unique added risk factor for the target population. This may be due to such factors as reduced reaction time, and lowered hearing and visual acuity.

Figure 3-6 shows graphs of the three categories – total population, pedestrian victims, and back-up victims. These graphs illustrate the dissimilarity among these three categories and the fact that back-up accident victims may not be identified with a particular age group.

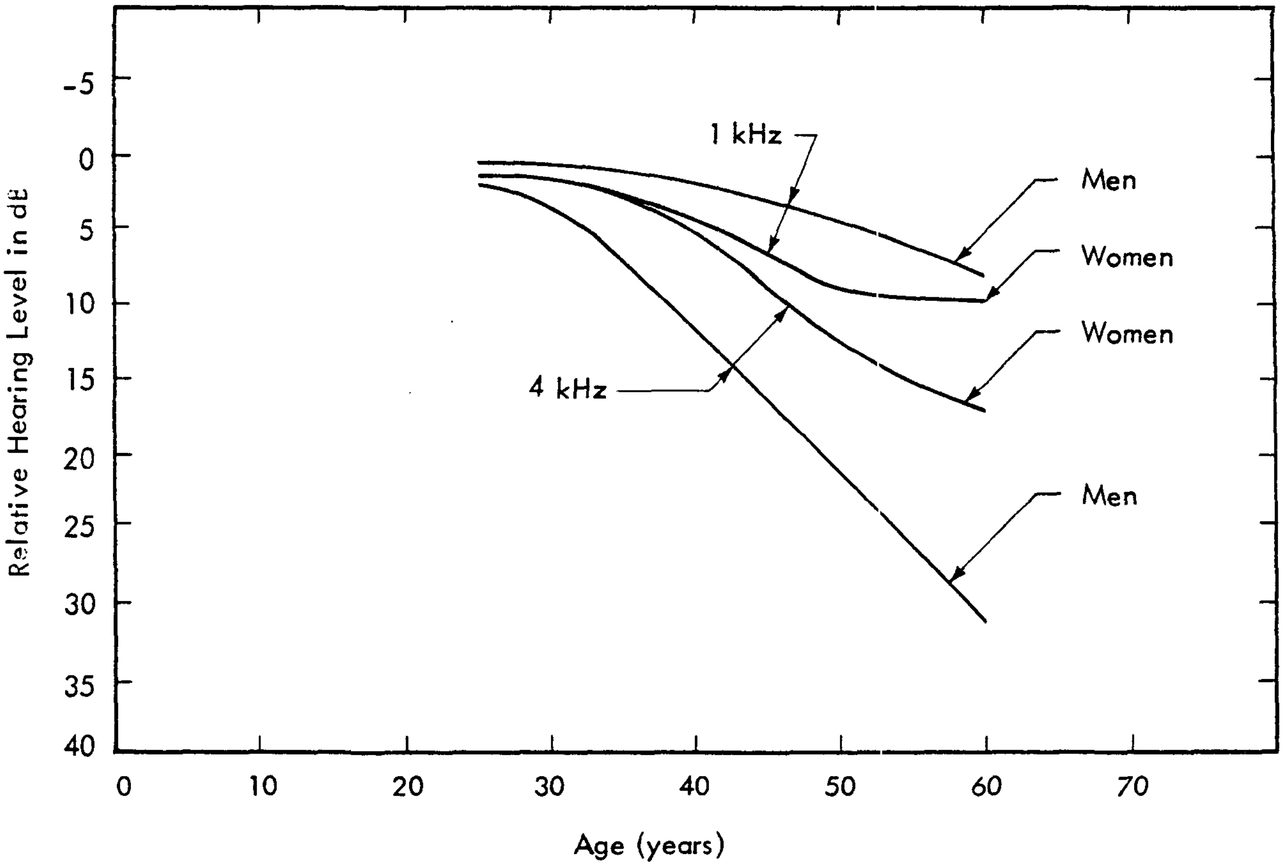


Figure 3-5. Comparison of the Hearing Ability of the Male and Female Population (Reference 18)

Table 3-1

Age and Sex of the Population and Accident Victims
(See Figure 3-6 for Graphical Presentation)

Age Group	1972 U.S. Population		Pedestrian Accident Victims – Fatalities and Injuries		Back-up Accident Victims – Fatalities and Injuries	
	Total Population (%)	Males in each Category (%)	Total (%)	Males in each Category (%)	Total (%)	Males in each Category (%)
0-4	8.3	51.1	10.0	71.2	12.7	66.7
5-9	9.0	50.9	29.5	65.5	9.7	56.3
10-14	10.0	51.0	10.7	65.6	2.4	50.0
15-19	9.6	50.9	6.5	61.2	4.2	85.7
20-24	8.7	50.4	5.7	64.1	7.9	38.5
25-29	7.2	49.7	4.9	61.4	8.5	85.7
30-34	5.9	49.4	2.9	69.4	7.9	46.2
35-39	5.3	49.0	2.9	53.3	6.1	50.0
40-44	5.6	48.8	3.6	67.1	1.2	100.0
45-49	11.3 (45-54)	48.1 (45-54)	2.8	70.7	3.6	33.3
50-54			2.8	61.4	9.1	40.0
55-59	9.1 (55-64)	47.1 (55-64)	2.9	54.2	4.2	57.1
60-64			3.0	48.2	3.6	83.3
65-69	6.2 (65-74)	43.5 (65-74)	3.5	54.2	3.6	50.0
70-74			3.6	51.4	4.2	71.4
75-79	3.9 (75-100)	38.1 (75-100)	2.6	51.9	2.4	25.0
80-84			1.2	62.5	4.8	62.5
85-89			0.6	53.8	1.8	33.3
90-100						
Unknown					1.8	66.7
Total Number	208 Million Population		2,072 Victims		165 Victims	
Source	Reference 15		Reference 9		Section 2.0	

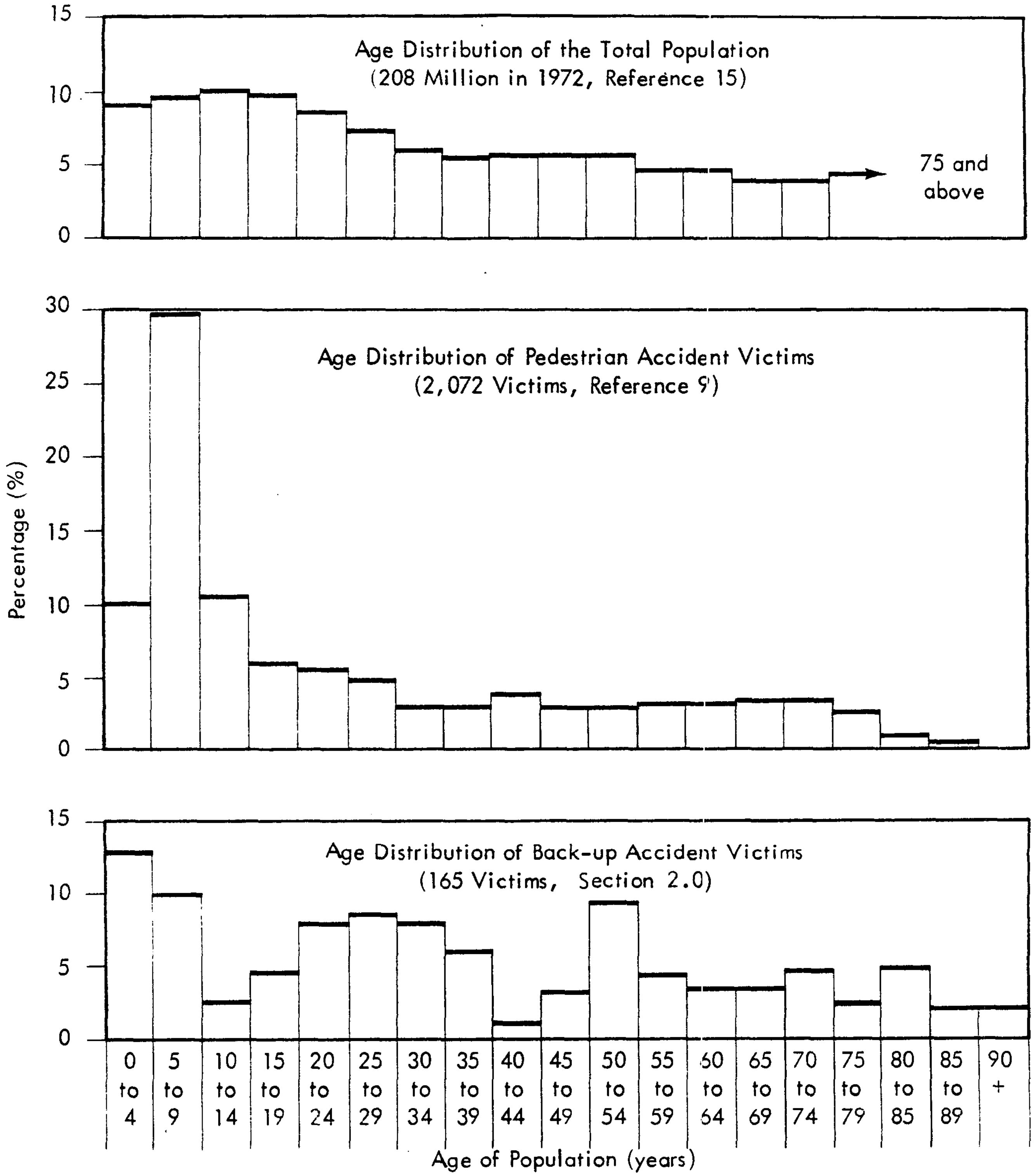


Figure 3-6. Age Distribution of the Population and Accident Victims

4.0 THE ACCIDENT SITE

An analysis of vehicle back-up accidents in which pedestrians were involved was performed early in the program to determine the potential effectiveness of an audible warning signal. A total of 160 accident cases were studied and details pertinent to the task of designing a warning system were identified. This study (described in Section 2.0) of accident data provided information regarding the location and time of occurrence of back-up accidents. The most important facts describing a potential accident site related to the present study are:

- The site location
- The time of accident occurrence
- The ambient noise level in the vicinity

These aspects of the site description have been analyzed in detail and results are presented to substantiate the warning signal design goals, based upon the environment it must operate within.

4.1 Location of the Accident Site

A review of available pedestrian back-up accident data revealed that a bare majority (58 percent) of the back-up accidents occurred in residential areas as opposed to commercial areas as illustrated in Table 4-1.[9, 17] However, this fact may be misleading since the residential classification includes multifamily dwelling areas and areas which are mixed but predominantly residential. Also, the residential areas mainly comprise a quiet type of location, where an audible warning would be most effective, but also most annoying. This aspect of the problem may lack adequate data to resolve completely, but a brief discussion is contained in Section 6.5.

Figure 4-1 illustrates the distribution of different types of motor vehicle accidents throughout the day. If the back-up accidents reviewed in the referenced studies are a representative sample, this type of accident seems to be somewhat more

Table 4-1

Summary of the Locations of 160 Pedestrian Back-Up Accidents (Section 2.0)

Accident Site	Number of Back-Up Accidents		
Commercial/Industrial	– Total		63
Intersection		17	
Mid-Block		17	
Driveway or Alley		13	
Off Street Area		16	
Residential/Rural	– Total		93
Intersection		14	
Mid-Block		40	
Driveway or Alley		33	
Off Street Area		6	
Other	– Total		4
Total Accident Cases			160

evenly spread through the day than other types of pedestrian accidents (compare Figures 4-1b and 4-1c). Based on the limited data, late morning and late afternoon periods seem to be the most critical for back-up pedestrian accidents. As shown in Figure 4-2a and Figure 4-2b, the early morning time corresponds to a period of reduced travel activity for people and fairly high outdoor noise levels, while for the late afternoon period, both travel and outdoor noise levels are relatively high. The late afternoon or early evening period, therefore, is clearly the most hazardous for pedestrians.

The remainder of this section discusses the acoustic noise aspects of the back-up accident or parking sites. Detailed descriptions of various types of sites and related acoustic measurements and data are presented.

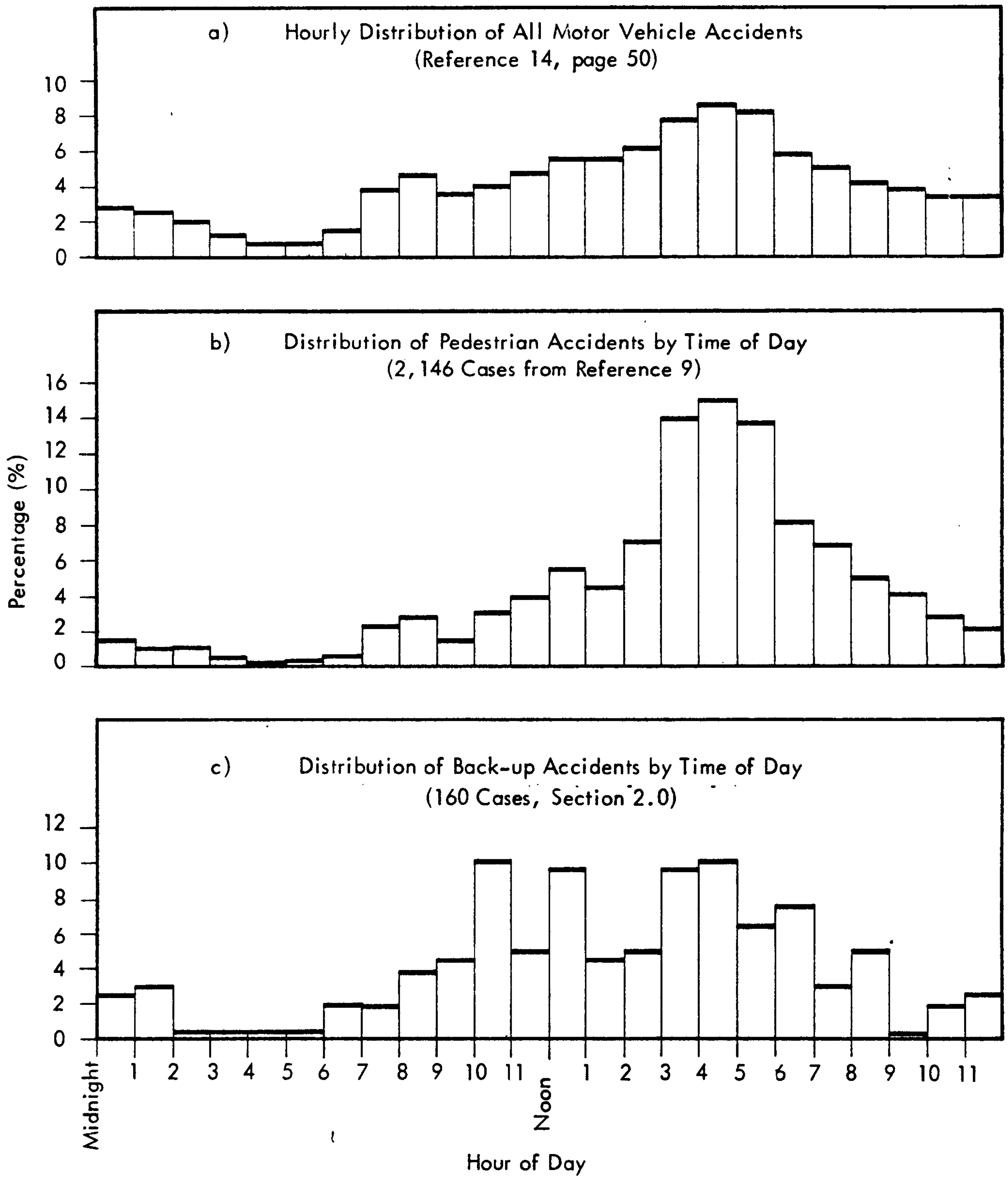


Figure 4-1 Distribution of Accidents by Time of Day

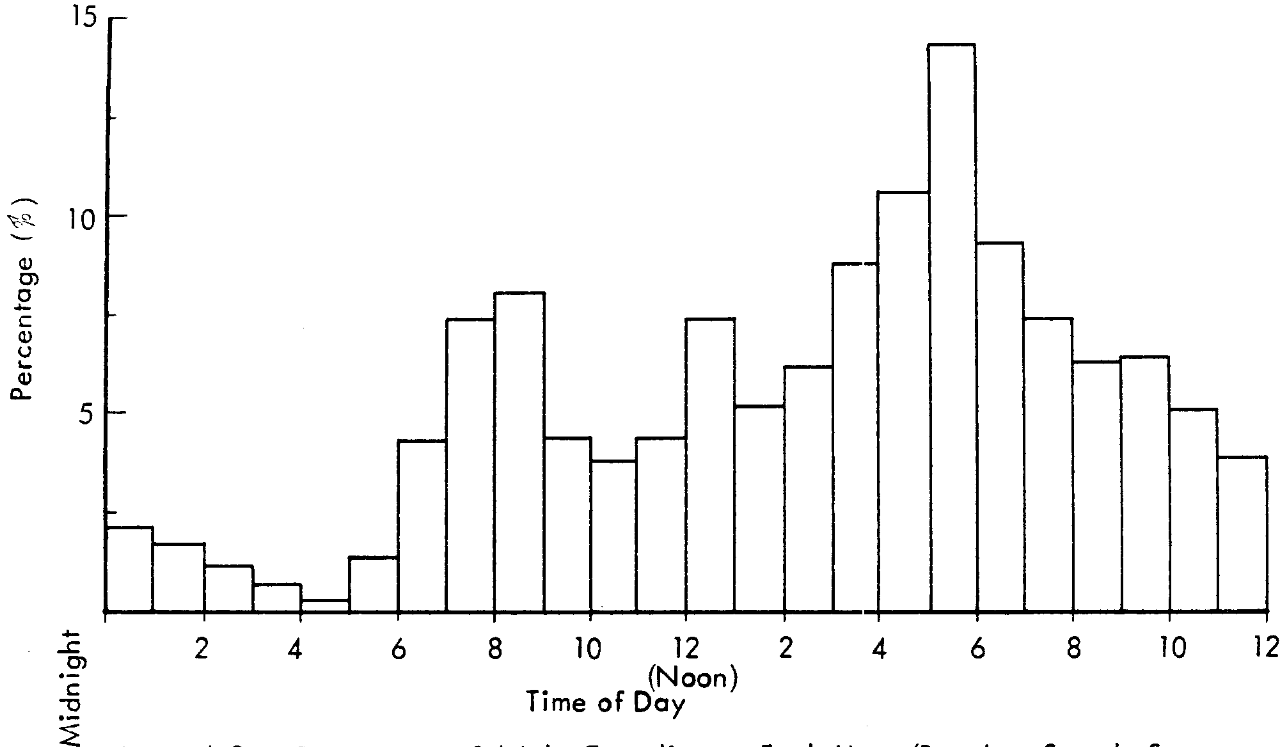


Figure 4-2a. Percentage of Adults Traveling on Each Hour (Based on Sample Survey of 1197 Adults in 44 U.S. Cities.) Pertains to All Forms of Traveling, i.e., Public Transport, Private Automobile, and Walking[21]

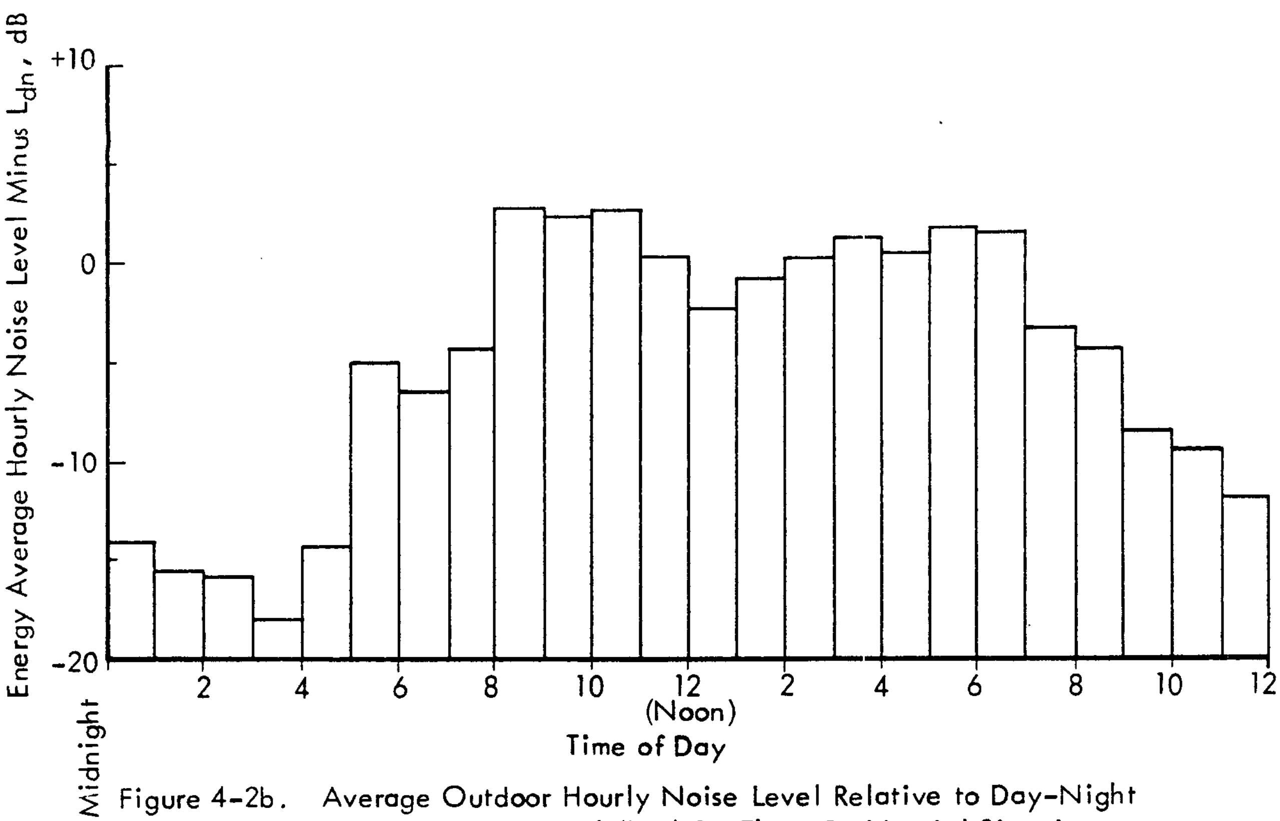


Figure 4-2b. Average Outdoor Hourly Noise Level Relative to Day-Night Average Noise Level (L_{dn}) for Three Residential Sites in Los Angeles[3]

4.2 Parking Site Background Noise Levels

Potential back-up accident sites exist wherever vehicles are present, where the background noise levels range from the quietest residential neighborhood to the noisiest downtown business district. Figure 4-3 illustrates the extreme range of noise levels experienced in various outdoor locations during the daytime period.[20] The levels shown are statistical levels which are exceeded the stated percentage of time. For most practical purposes L_{90} is considered as the residual noise level, L_{50} the median level, with L_{10} and L_1 describing the approximate level of primary intrusive noises. The maximum noise levels will often exceed the L_1 value by 10 to 15 dB.

4.2.1 Typical Statistical Levels at Back-Up Accident Sites

To provide a more definitive picture of the potential noise levels at accident sites, it is desirable to examine in detail, the extensive statistical data available on outdoor noise levels available from previous community noise studies. These data may be used to estimate the detailed statistical variation over space and time of outdoor noise levels. From this broad data base, and the limited sample of noise levels actually measured in parking areas for this program, it is possible to estimate a design ambient noise level for the back-up warning device – a level exceeded not more than 5 percent of the time in parking areas.

The cumulative probability distribution, over space (or sites) of the median (in time) L_{50} levels observed in a wide range of outdoor locations in typical urban areas is shown in Figure 4-4.[3,22] These distributions based on studies covering about 2000 sites in the U.S. and over 11,200 sites outside the U.S., tend to fall into two groups. One group is for all of the sites studied except those in the largest cities – New York City and London. The other group consists of the approximate distribution in these two very large cities. There are, of course, exceptions, but the trend is quite evident and verifies that the design ambient noise level for back-up warning devices may be significantly higher for large, densely populated cities than for the

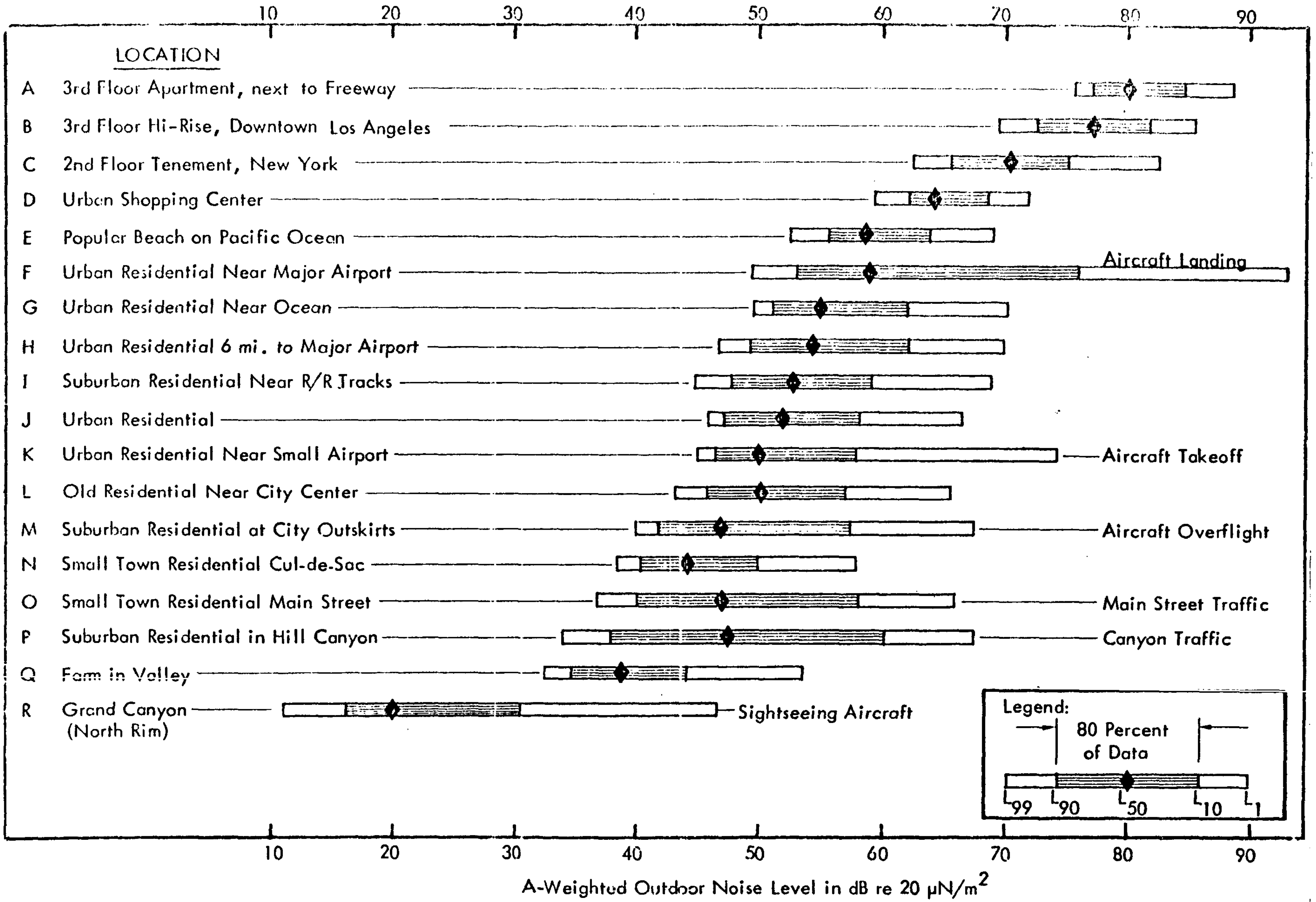


Figure 4-3. Daytime Outdoor Noise Levels Found in 18 Locations Ranging Between the Wilderness and the Downtown City, with Significant Intruding Sources Noted. Data are Arithmetic Averages of the 12 Hourly Values in the Daytime Period (7:00 a.m. - 7:00 p.m.) of the Levels Which are Exceeded 99, 90, 50, 10 and 1 Percent of the Time (Reproduced from Ref. 20)

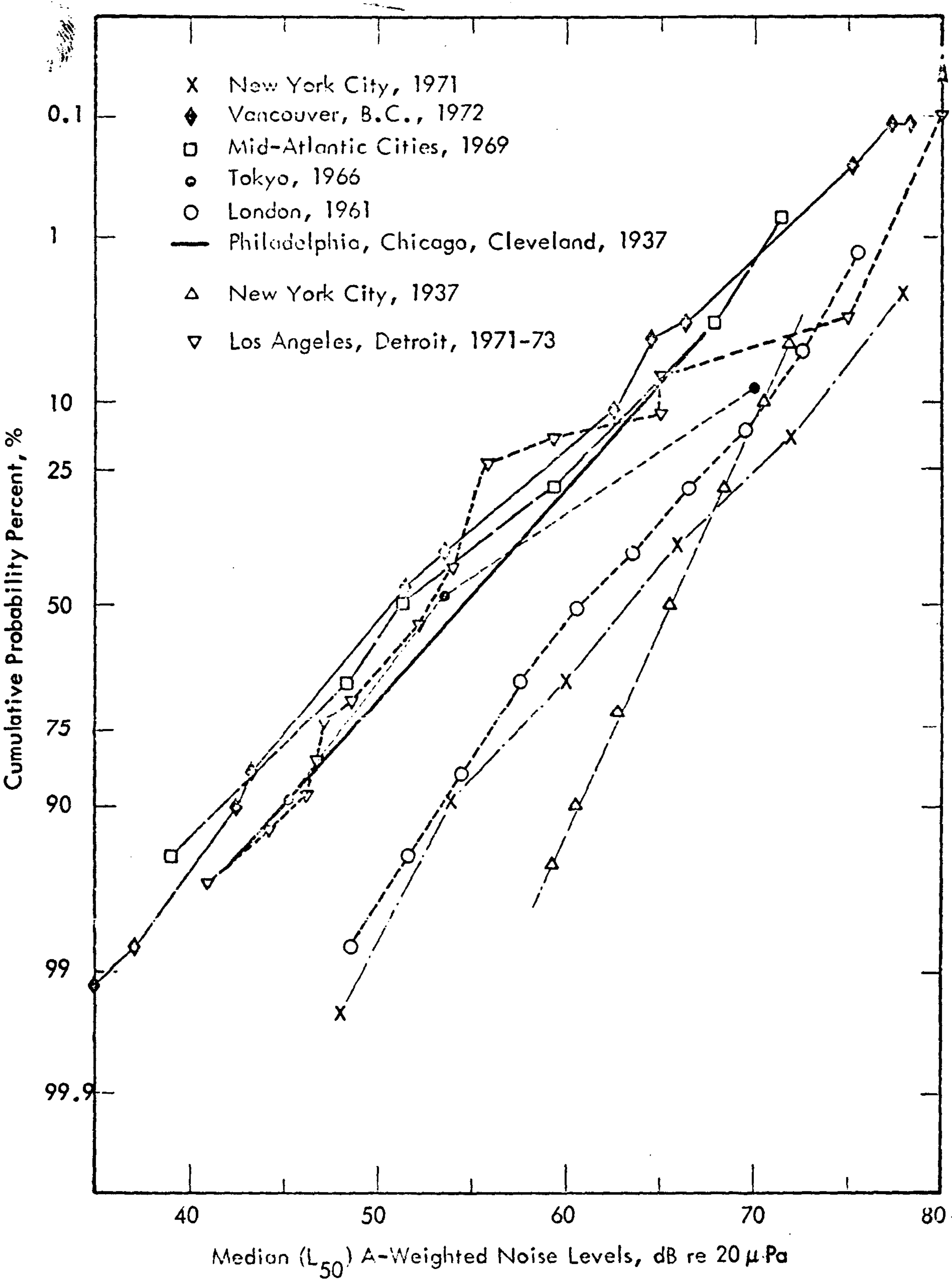


Figure 4-4. Comparison of Data on Probability Distribution of Median Outdoor (L_{50}) Noise Levels Measured in Residential Areas in Daytime (Reproduced from Ref. 3)

average medium density city. This range in design ambient level is, as, of course, anticipated by the automatic ambient-sensing feature required for the back-up warning device.

In order to estimate the range of noise characteristics of actual back-up accident sites, a group of eight sites (listed in Table 4-2) were selected and noise data samples recorded. (Noise characteristics at sites where field tests of the warning system were conducted are contained in Section 7.0.) A microphone was mounted at a height of 6 feet, close to the rear of an automobile. Ten to 15 minute samples of noise were recorded and subsequently analyzed in the laboratory to compute noise descriptors and describe the intrusive noise events. Table 4-3 lists the results of this analysis and for comparison purposes a graph of the data in the same format as the community noise data shown in Figure 4-3 is shown in Figure 4-5. The sites examined obviously represent examples of noisier community locations. While the data is strictly only valid for a 10 to 15 minute measurement period during the noisy part of the day, the hour-to-hour variation at any one back-up accident site is expected to be substantially less than the variation between sites.

The cumulative distribution median (L_{50}) noise levels for this sample of back-up accident sites is compared, in Figure 4-6 to the distribution in L_{50} levels in comparable urban areas shown earlier in Figure 4-4. A straight line for a cumulative distribution on this probability graph implies a normally distributed sample where the slope of the line is proportional to the standard deviation. This comparison indicates that the noise levels over all back-up accident sites (or at least parking lot sites) will tend to have a higher mean value than that for all types of outdoor locations in the typical low to medium density city (64 dBA versus 52 dBA respectively) The estimated distribution for the parking area noise levels has a somewhat steeper slope corresponding to a standard deviation of 7.2 dB as compared to a standard deviation of about 8 dB for noise levels in all outdoor sites in low to medium density cities.

Table 4-2

Parking Sites for Acoustic Noise Measurements
(Greater Los Angeles Area)

Site Number	Type of Site	Time of Day	Location
1	Residential Off Street Area	1230	Carl's Jr. Parking Lot, Brookhurst & Warner, Fountain Valley (Restaurant)
2	Commercial Off Street Area	1315	Sears Parking Lot, Westminster Mall, San Diego Freeway & Golden West, Westminster
3	Commercial Mid-Block	1545	Downtown Los Angeles, Broadway between 4th and 5th Streets
4	Commercial Mid-Block	1640	Downtown Hollywood, Hollywood Boulevard, West of Ivar
5	Commercial Off Street Area	1710	Universal Studios Tour Parking Lot, Universal City
6	Commercial Mid-Block	1025	Los Angeles International Airport, Baggage Check-in Area, Los Angeles
7	Commercial Off Street Area	1045	Los Angeles International Airport Tower Parking Lot
8	Commercial Off Street Area	1130	May Company Parking Lot, South Bay Center, Artesia & Hawthorne Blvds., Redondo Beach

Table 4-3

Summary of the Statistical Levels Measured at the Parking Sites Listed in Table 4-2

Site	L_{eq} (1)	L_{90}	L_{50}	L_{10}	L_1	$L_{.1}$	σ (2)
1	62.5	56.5	59.0	63.9	72.1	78.1	4.42
2	61.2	57.7	59.6	62.9	67.4	72.0	4.72
3	74.7	67.7	71.2	77.1	82.5	88.3	4.82
4	76.0	65.3	70.6	76.4	86.9	96.2	3.87
5	58.1	55.3	56.5	59.7	64.6	67.6	4.72
6	72.8	65.7	70.2	75.3	80.8	84.3	3.83
7	66.4	62.4	64.5	68.7	72.9	75.4	4.49
8	58.8	55.1	56.7	60.6	65.7	70.7	4.62
Average Site	66.3	60.7	63.5	68.1	74.1	79.1	4.44

(1) Energy-average noise level during 10 to 15 minute sample period.

(2) Standard deviation of noise level during sample period.

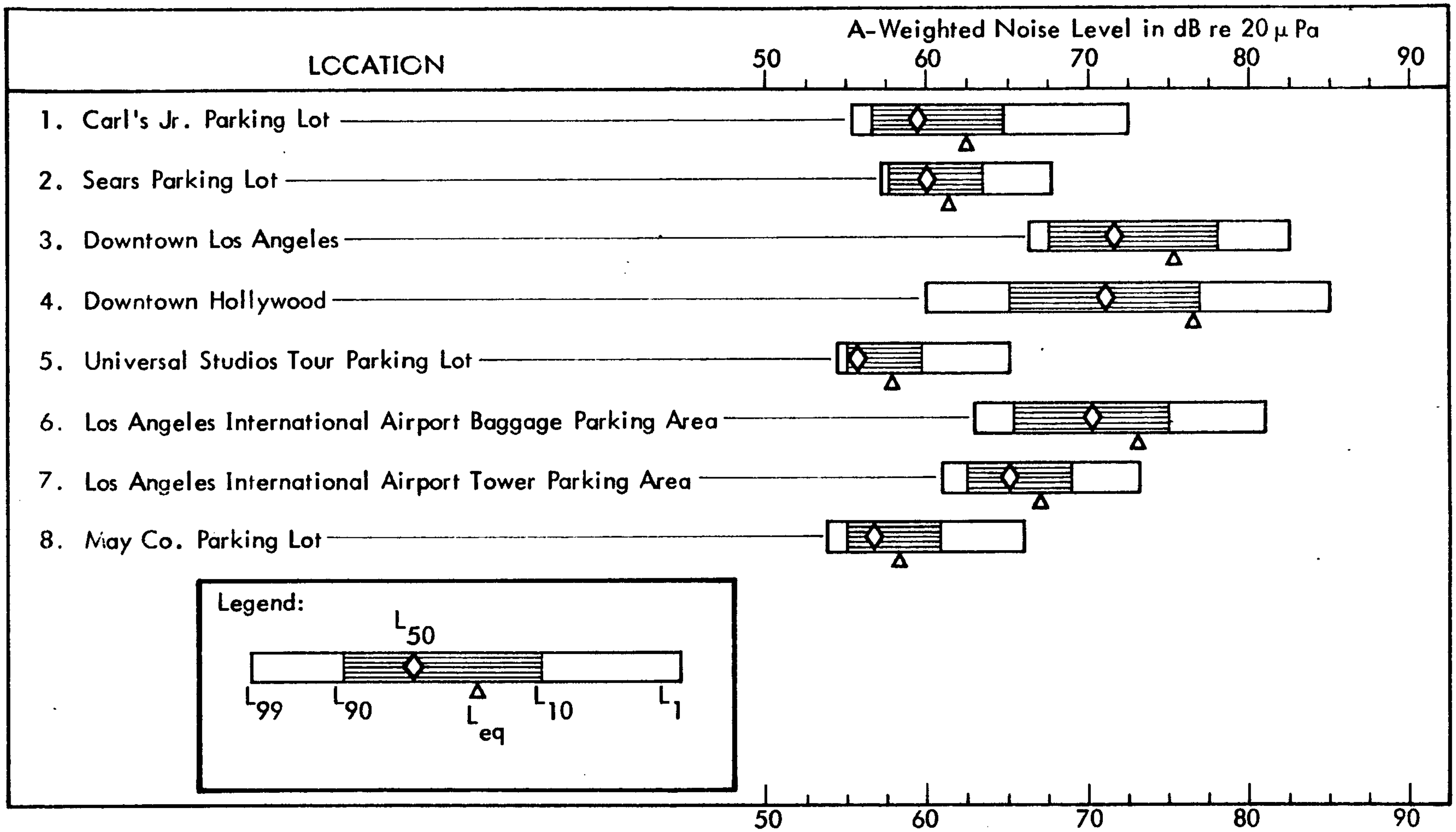


Figure 4-5. Daytime Sample of the Outdoor Noise Level at Eight Parking Locations (for comparative data, see Figure 4-3)

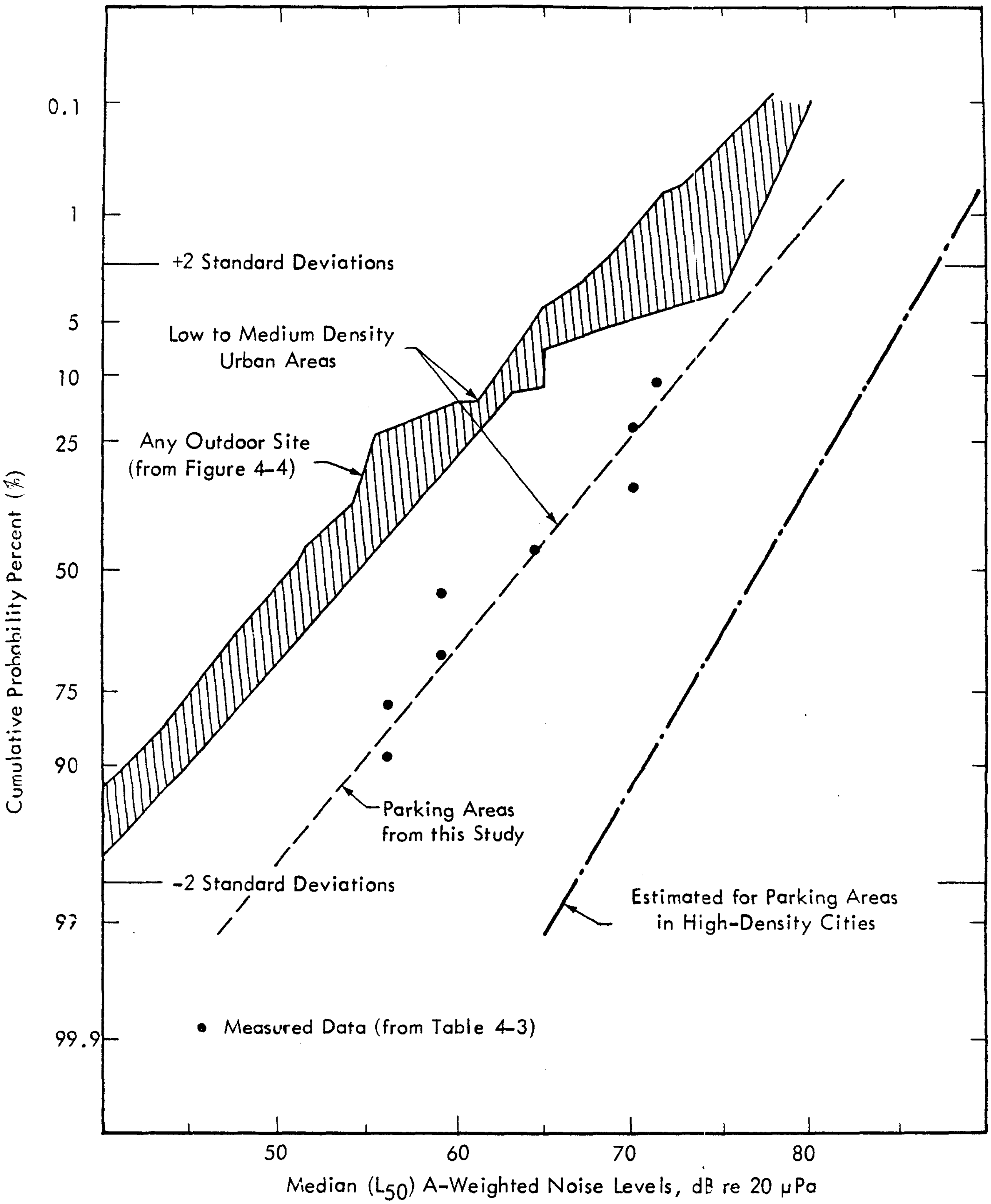


Figure 4-6. Comparison of Median (L_{50}) Noise Levels at Back-up Accident Sites to Urban Areas

Figure 4-6 also shows an estimate of the distribution of L_{50} noise levels in parking areas in large, densely populated cities, such as New York. For this latter estimate, it was assumed that the mean (over sites) L_{50} (median in time) level for parking areas was also 12 dB higher (i.e., 64 to 52 dBA) than the mean noise level for all outdoor sites in large, densely populated areas. Based on the data in Figure 4-4, this indicated that the mean L_{50} level for parking areas in such cities would be about 65 + 12 = 77 dBA. The standard deviation for this estimated distribution was also assumed to be slightly less by the ratio (7.2/8.0) than for all sites in densely populated areas. The resulting estimate of the standard deviation was 5 dB for the parking areas as compared to an estimated standard deviation of 5.6 dB for all sites.

Table 4-4

Estimated Distribution of Median (L_{50}) Levels in Parking Areas in Typical Medium Density Cities and in Large High Density Cities

City Type	L_{50} Level in Parking Areas, dBA Exceeded at:				
	95 Percent of Sites	80 Percent of Sites	50 Percent of Sites	20 Percent of Sites	5 Percent of Sites
Low-Medium Density(1)	52	58	64	70	76
High Density(2)	68.5	72.5	77	81	85

(1)Like Denver, Los Angeles.
(2)Like New York City.

Table 4-4 summarizes these estimates of the distribution of the median L_{50} daytime levels in parking areas in typical medium-density and large, very dense cities. It will be assumed, for conservatism, that back-up accident sites in purely residential areas have a distribution of noise levels comparable to those estimated for commercial parking areas.

Now having established estimates of the distribution of L_{50} noise levels over accident sites, it remains to establish the estimated variation over time at these sites in order to determine the "5 percent of the time" design level.

From previous analyses of the statistics of time variation in outdoor noise levels, the following empirical model has been established.[3,23]

In contrast to the usual assumption of a normal distribution for time variation in outdoor noise levels, it was found, as illustrated in Figure 4-7 that a Rayleigh distribution provides a better, albeit empirical, fit to the distribution over time of outdoor noise levels. The solid data points shown in Figure 4-7 are from three separate studies of outdoor noise involving continuous noise measurement, over 24 hours and encompassing 116 sites in urban areas. The open symbols represent the average of the data measured at the eight parking sites (see Table 4-3). The latter generally fall reasonably close, and on the conservative side of the "empirical" Rayleigh distribution curve so that the latter is used for design. Note that in Figure 4-7, these cumulative distributions are plotted in normalized form; i.e., the statistical level at X percent $(L_x) - (L_{50})$ is normalized by the standard deviation (σ) of the time distribution. The theoretical form for this distribution is given by:[3]

$$\frac{L_x - L_{50}}{\sigma} = \left\{ \left[Ln_e (100/x) \right]^{\frac{1}{2}} - \left[Ln_e (2) \right]^{\frac{1}{2}} \right\} \Big/ \left[1 - \pi/4 \right]^{\frac{1}{2}}$$

From additional analysis of the data cited in Figure 4-4, it has been found possible to roughly estimate the standard deviation (over time) (σ) of the daytime outdoor levels by the empirical expression:

$$\sigma \simeq \begin{cases} 12.9 - 0.141\ L_{50},\ \text{dB} & L_{50} > 49\ \text{dBA} \\ 6\ ,\ \text{dB} & L_{50} \leq 49\ \text{dBA} \end{cases}$$

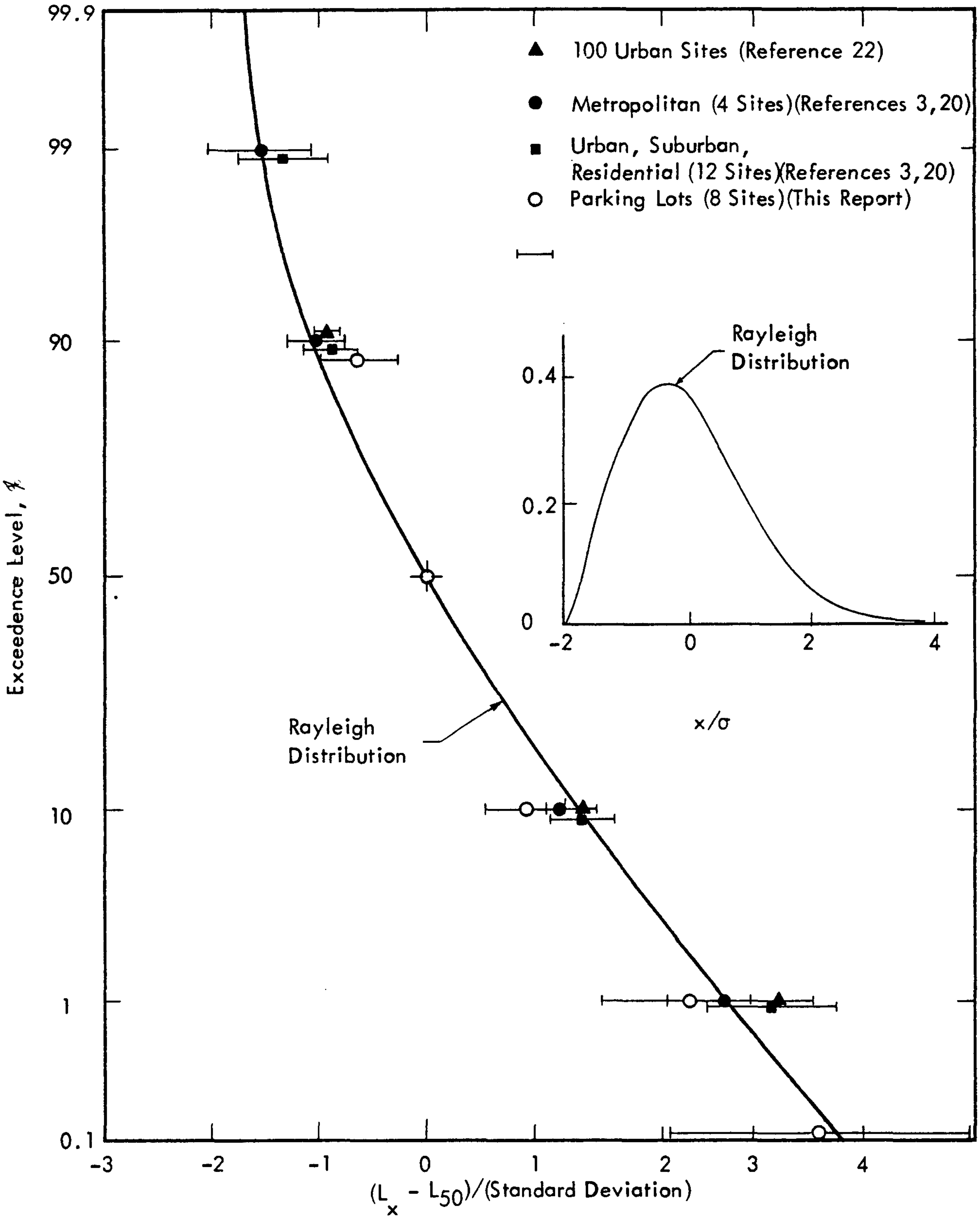


Figure 4-7. Average Normalized Statistical Levels Over 15 Hour Daytime Period (0700-2200) at 16 Residential Sites (Airport Sites Excluded)

With these expressions, and the values of median levels (L_{50}) specified earlier in Table 4-3, it is now possible to provide estimates of the L_5 design level – the noise level not exceeded more than 5 percent of the time – at any of the sites. The results of this evaluation are presented in the following table:

Table 4-5

Estimated (L_5) A-Weighted Noise Levels Not Exceeded More Than 5 Percent of the Time in Back-Up Accident Sites

City Type	L_5 Level, dBA Exceeded at				
	95 Percent of Sites	80 Percent of Sites	50 Percent of Sites	20 Percent of Sites	5 Percent of Sites
Low-Medium Density	63	67	72	76	80
High Density	75	78	81	84	87

According to the values in Table 4-5, the L_5 design ambient level for the back-up warning device will vary from the quietest conditions of 63 dBA (arbitrarily taken as the level exceeded 5 percent of the time at 95 percent of the sites in low to medium density cities) to the noisiest conditions of 87 dBA (taken as the level exceeded 5 percent of the time at only 5 percent of the sites in high-density cities). This range in the design ambient level of 63 to 87 dBA should be accommodated by the variable output feature to be built into the back-up warning device. Later, it will be shown that when the self-noise of the backing automobile is taken into account, this dynamic operating range is not really altered.

4.2.2 Typical Noise Spectra in Back-up Hazard Areas

Characterization of the noise at each location must also include spectrum analyses of the noise to define its frequency content. In terms of the parameters most important for the warning signal system, the spectrum should be averaged over a relatively short period of time. This is consistent with the way the ear perceives a warning signal which must effectively penetrate the background ambient. The data recorded at three parking locations were analyzed with a B&K 3347 Real Time Analyzer (RTA) to obtain plots of the one-third octave band spectrum levels. Figures 4-8, 4-9, and 4-10 illustrate the variations in these one-third octave band noise levels at the three locations. Spectrum analysis samples are shown for periods close to the minimum level and also for typical periods when intrusive events occur producing the maximum levels. These samples were obtained using the "fast random" time constant of the RTA, an averaging time which very roughly corresponds to the averaging time of the ear (see Section 5.0).

Just as was done for the A-weighted noise levels, it is desirable to augment this limited sample of spectral content of outdoor noise levels from previous community noise studies. By normalizing all of the spectral plots in the three previous figures to their respective A-weighted noise levels, the average relative one-third octave band level spectra shown in Figure 4-11 is obtained. This average is indicated by the solid line drawn through the mean of the normalized measured data. Note that the relative spectra are very nearly the same for both residual and intrusive events for the frequency range of interest for the back-up warning device.

The dashed line represents the average (over surveys), median (in time) 1/3 octave band levels during daytime hours from several extensive outdoor noise surveys conducted in the past. These data, taken from the summary in Reference 3, are also normalized in the same way to the A-weighted level and show very nearly the same average spectra. Since they are conservative for frequencies below 1000 Hz, are realistic above 1000 Hz, and are based on a much broader data base than was attempted in this study, the dashed line in Figure 4-11 will be used to define the spectral content for the design ambient levels. Note, however, that without the benefit of the limited sample of spectral data recorded at actual parking areas in this study, it would not have been possible to be certain of the utility of the earlier data. By simply adding the relative one-third octave band levels from the

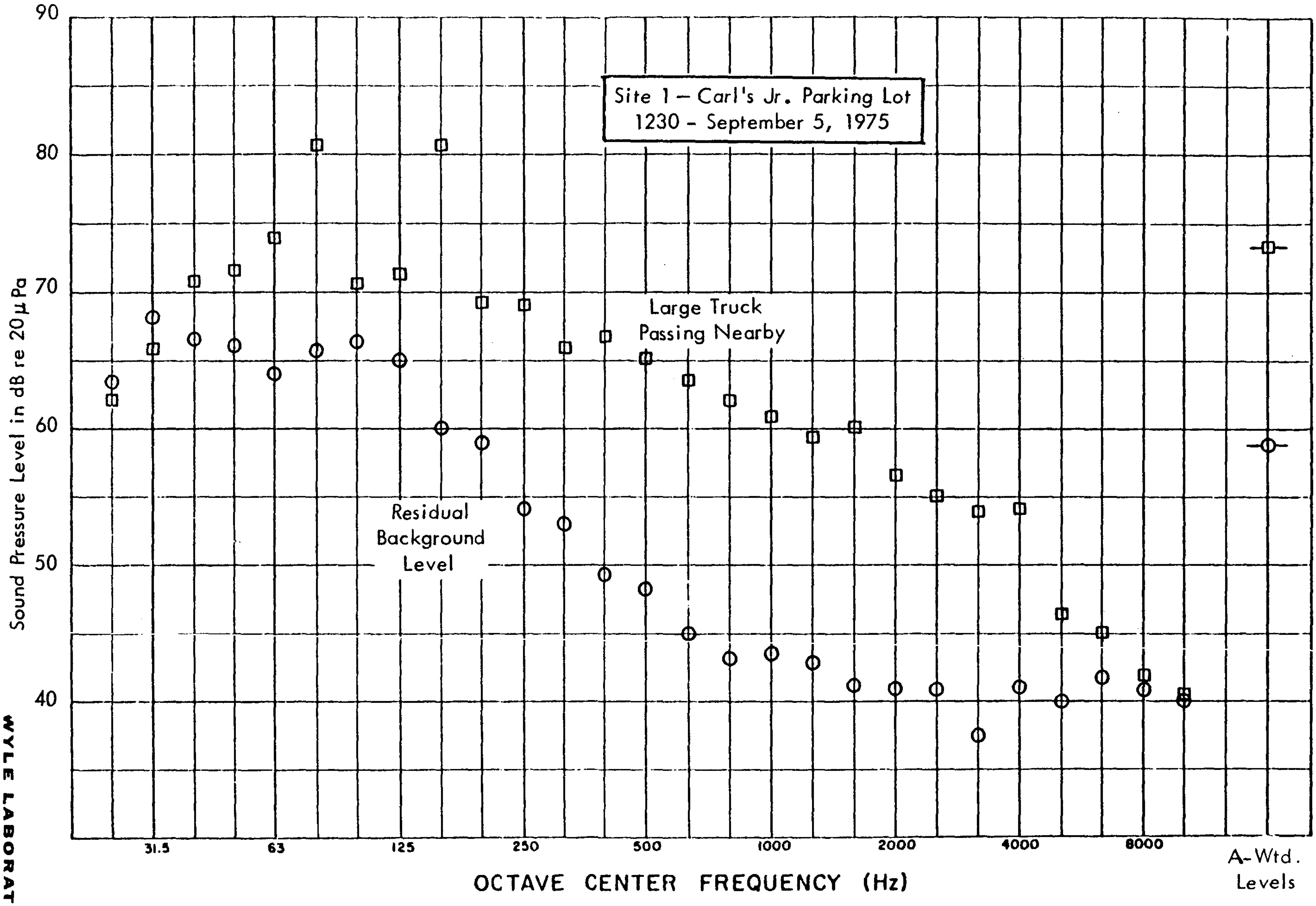


Figure 4-8. Typical Spectra of the Ambient Noise Level at Site 1

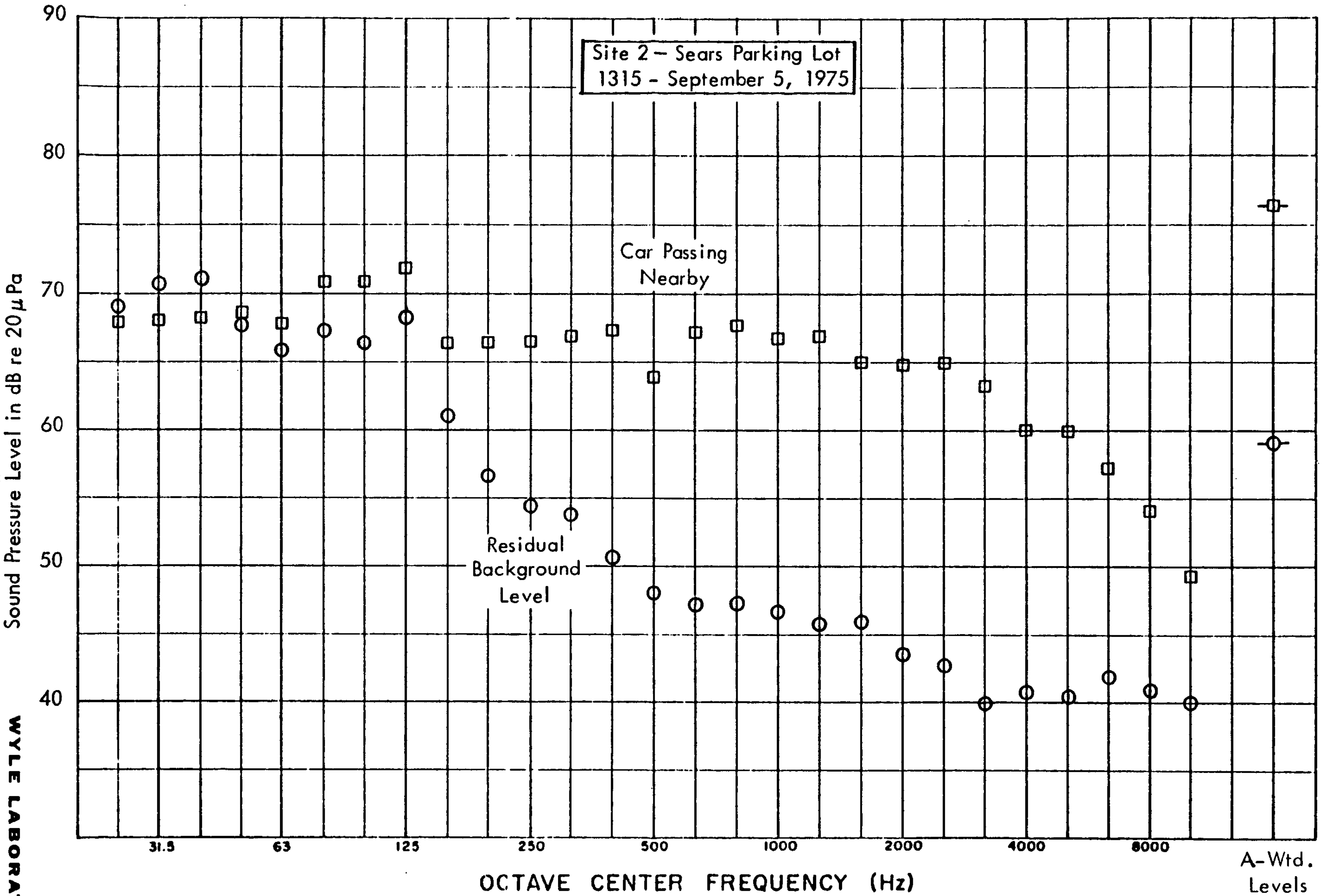


Figure 4-9. Typical Spectra of the Ambient Noise Level at Site 2

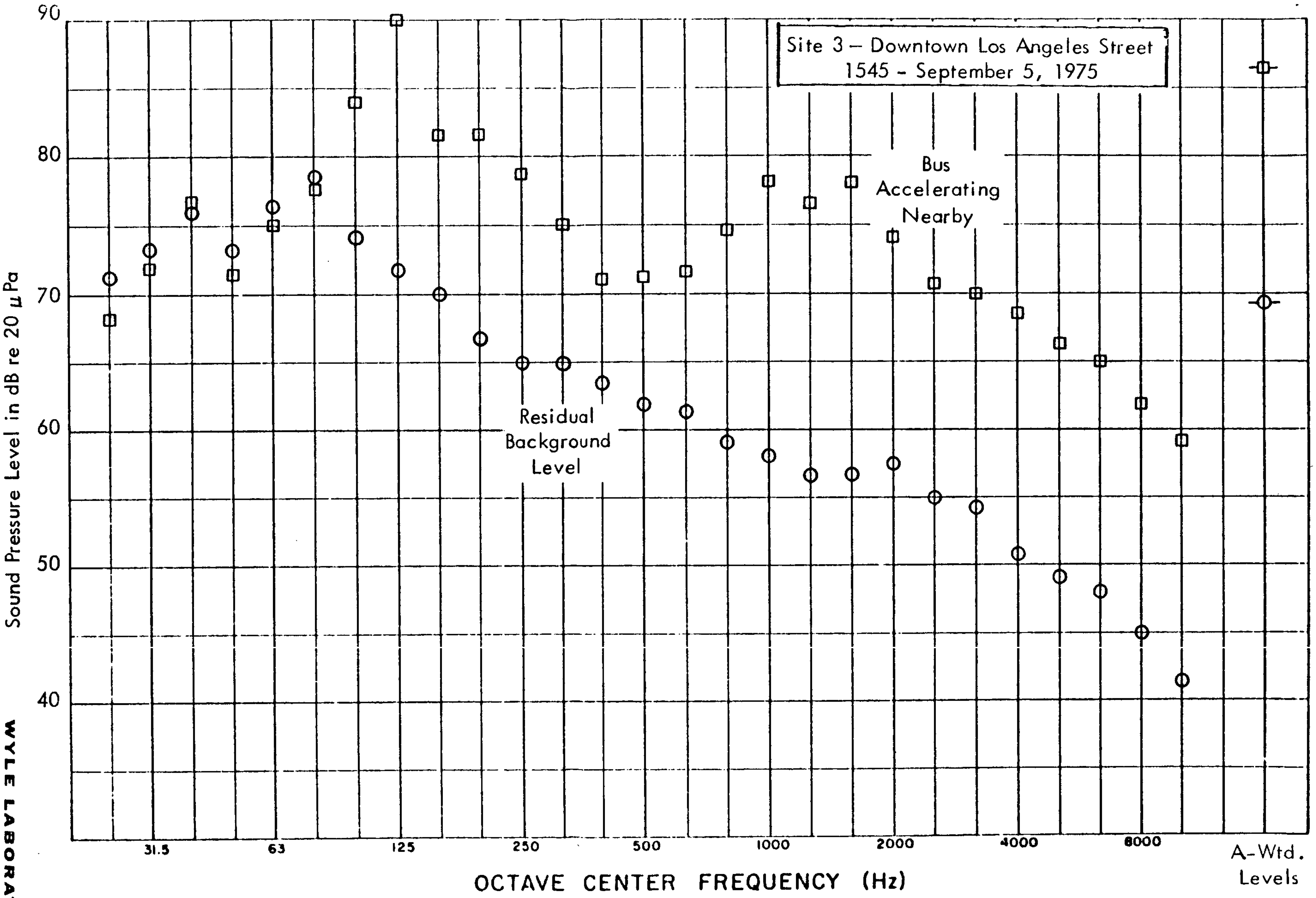


Figure 4-10. Typical Spectra of the Ambient Noise Level at Site 3

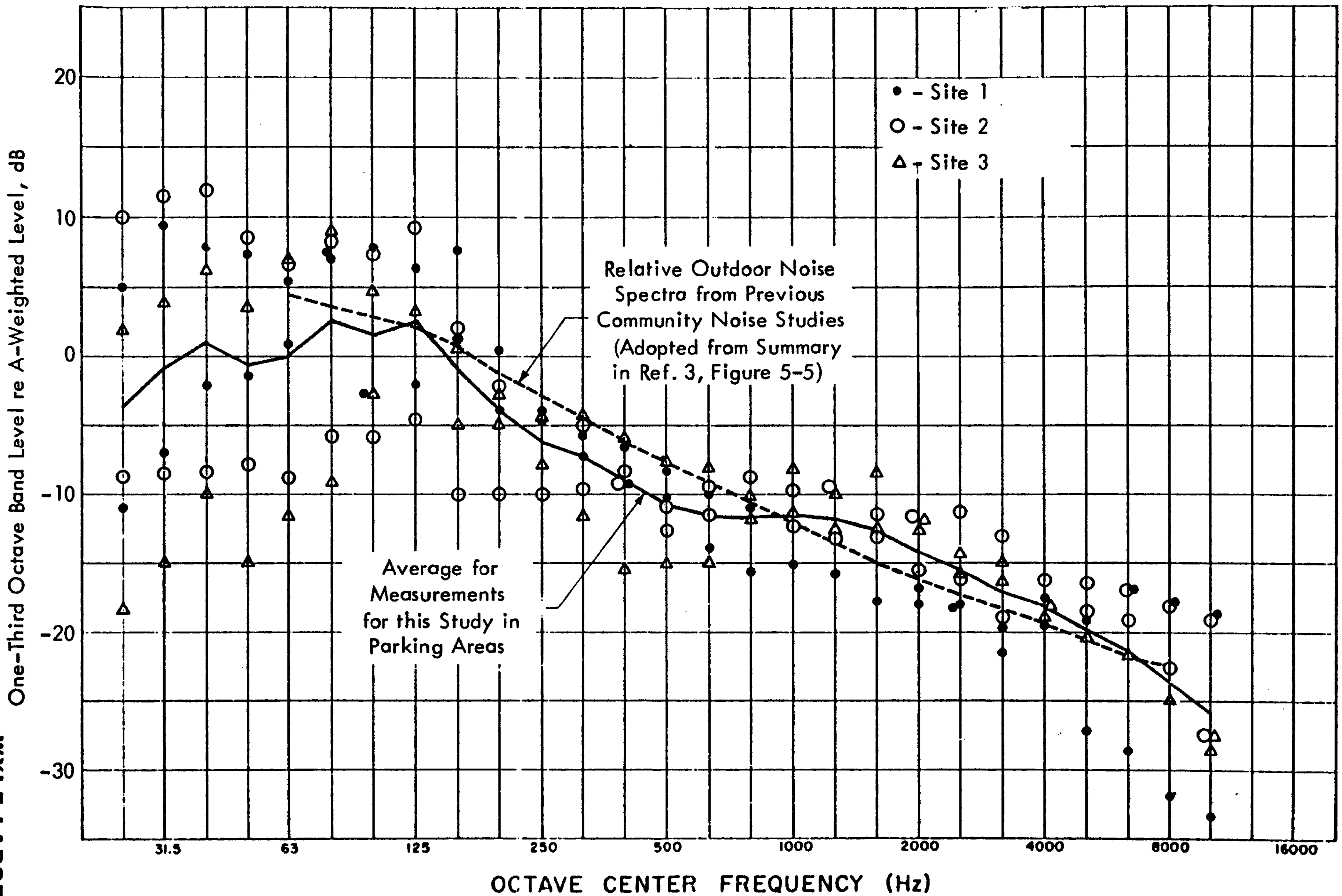


Figure 4-11. Relative One-Third Octave Band Spectra at Outdoor Sites

dashed line in this figure to the design values for L_5 specified earlier in Table 4-5, one can obtain the desired one-third octave band spectra for any of the sites defined by this table.

Table 4-6 lists the relative one-third octave band correction factors which will be utilized to help define audible signal characteristics of the warning device.

Table 4-6

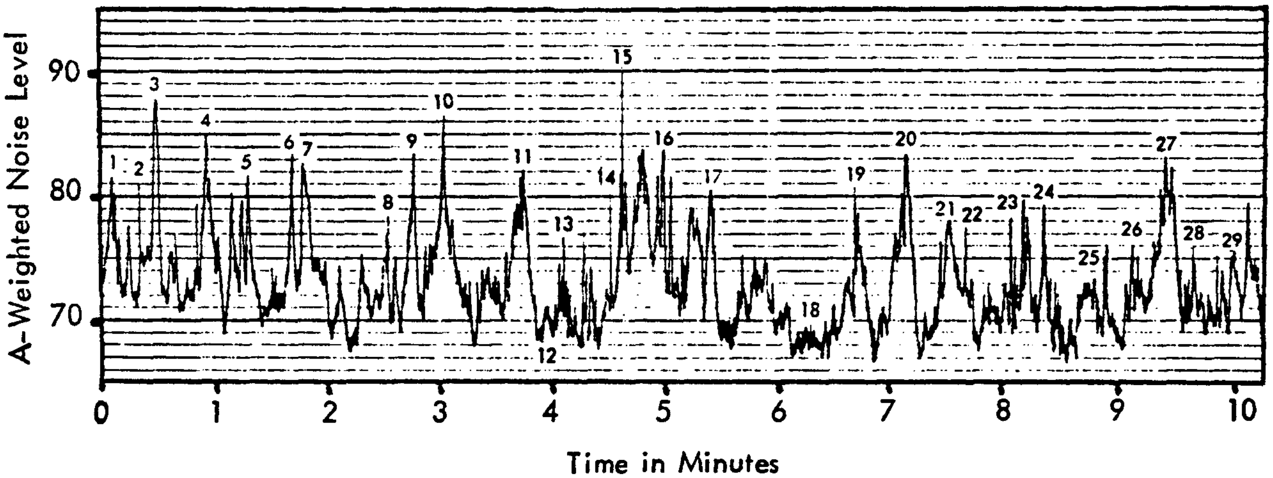
Relative One-Third Octave Band Spectra to be Applied to L_5 Levels in Table 4-5 to Define Ambient Spectrum

Frequency, Hz	63	80	100	125	160	200	250	315
Relative One-Third Octave Band Level, dB	4.5	3.5	3	2	1	-1	-2.5	-4.5
Frequency, Hz	400	500	630	800	1000	1250	1,600	2000
Relative One-Third Octave Band Level, dB	-6.5	-7.5	-9	-10.5	-12	-13.5	-15	-16
Frequency, Hz	2500	3150	4000	5000	6300	8000	10,000	
Relative One-Third Octave Band Level, dB	-17	-18.5	-19.5	-20.5	-22	-23.5	-25	

To illustrate the variable nature of the noise level at a potential accident site, Figure 4-12 shows a time history of the noise level in a noisy business district. In this figure all major intrusive events are identified and listed. This recording was obtained with the car parked at the curb and the microphone behind it at a 6 foot height.

4.3 Self Noise of the Automobile

So far we have considered only the ambient noise exclusive of the backing vehicle. Consider now the noise source which will control the minimum ambient level in the area of the automobile, the automobile itself. This will negate the need



1 Bus Passing
2 Horn
3 Bus Pulling Away
4 Truck Passing
5 Bus Passing
6 Car Passing
7 Bus Pulling Away
8 Voice – Yelling
9 Bus Passing
10 Truck Passing
11 Truck Passing
12 Voices on Sidewalk
13 Car Passing
14 Horn
15 Tire Screech – Braking
16 Vehicles Passing – Several
17 Motorcycle Passing – Slowly
18 Ambient – No Vehicles Passing
19 Car Passing
20 Bus Passing
21 Car Passing
22 Children Yelling
23 Children Yelling
24 Truck Passing
25 Car Starting-up Nearby
26 Car (VW) Passing
27 Bus Passing
28 Children's Voices
29 Bus Pulling Away in Distance

Figure 4-12. Time History of the Noise Level at Location 3 – Downtown Los Angeles. Intrusive events are identified by numbers for a detailed examination of the quietest potential accident sites since the warning signal may be held constant at some minimum ambient noise level.

The noise originates from the engine and the exhaust pipe and in very quiet areas, it is the dominant noise source. In extremely quiet areas the automobile's noise will likely provide an adequate audible warning for nearby pedestrians, but as the ambient level increases, the automobile noise ceases to be a distinct identifiable noise source. At this point an audible warning signal is necessary.

Measurements were made at the rear of seven different automobiles which would be representative of later model cars and the noise they produce. The microphone was placed above the bumper near the car at a point where the final warning system might be mounted. Recordings were made while each car was started and the engine was run-up and idled. Figure 4-13 shows time histories of the A-weighted noise level during each of these starting sequences and Table 4-7 lists the average noise level for the different conditions. The minimum noise level measured during the time any of the cars were running was 62 dBA. The average level for both the starting noise and engine idling noise is 67 dBA, indicating a possible limiting noise threshold for the system microphone to be around 65 dBA.

As an illustration of the acoustic noise spectrum present at the rear of an automobile while it is running, Figure 4-14 shows data typical of the automobiles investigated. The one-third octave band spectra shown here represent samples taken before the automobile was started (ambient), while the starter was turning, and while the engine was idling. Level fluctuations below 100 Hz are primarily due to ambient variations but at higher frequencies the one-third octave band levels and consequently the A-weighted levels, are controlled by the automobile noise. For comparison, the statistical ambient noise levels and relative spectra of Tables 4-5 and 4-6, respectively

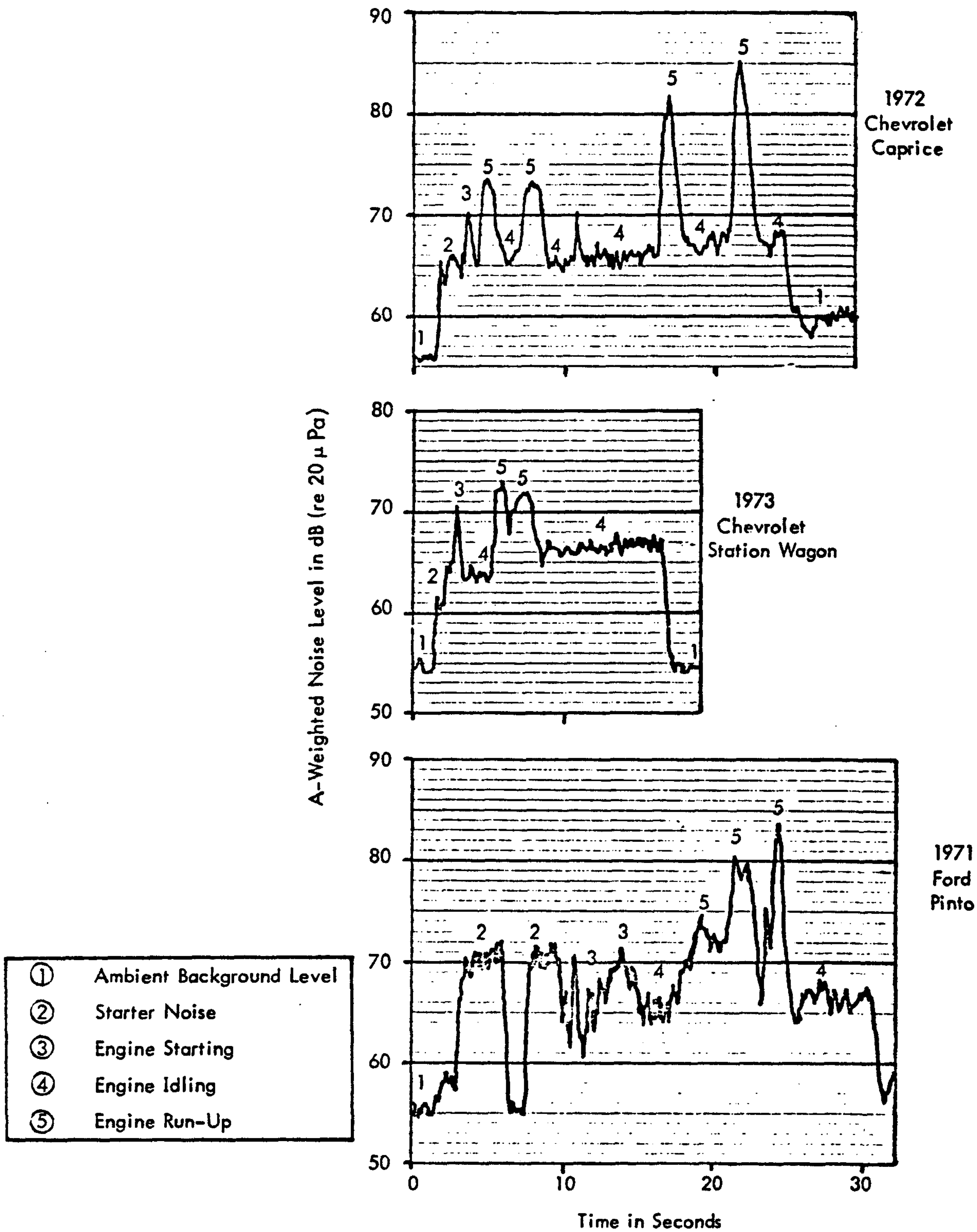


Figure 4-13a. Comparison of Starting and Running Noise Measured at the Rear of Typical Automobiles

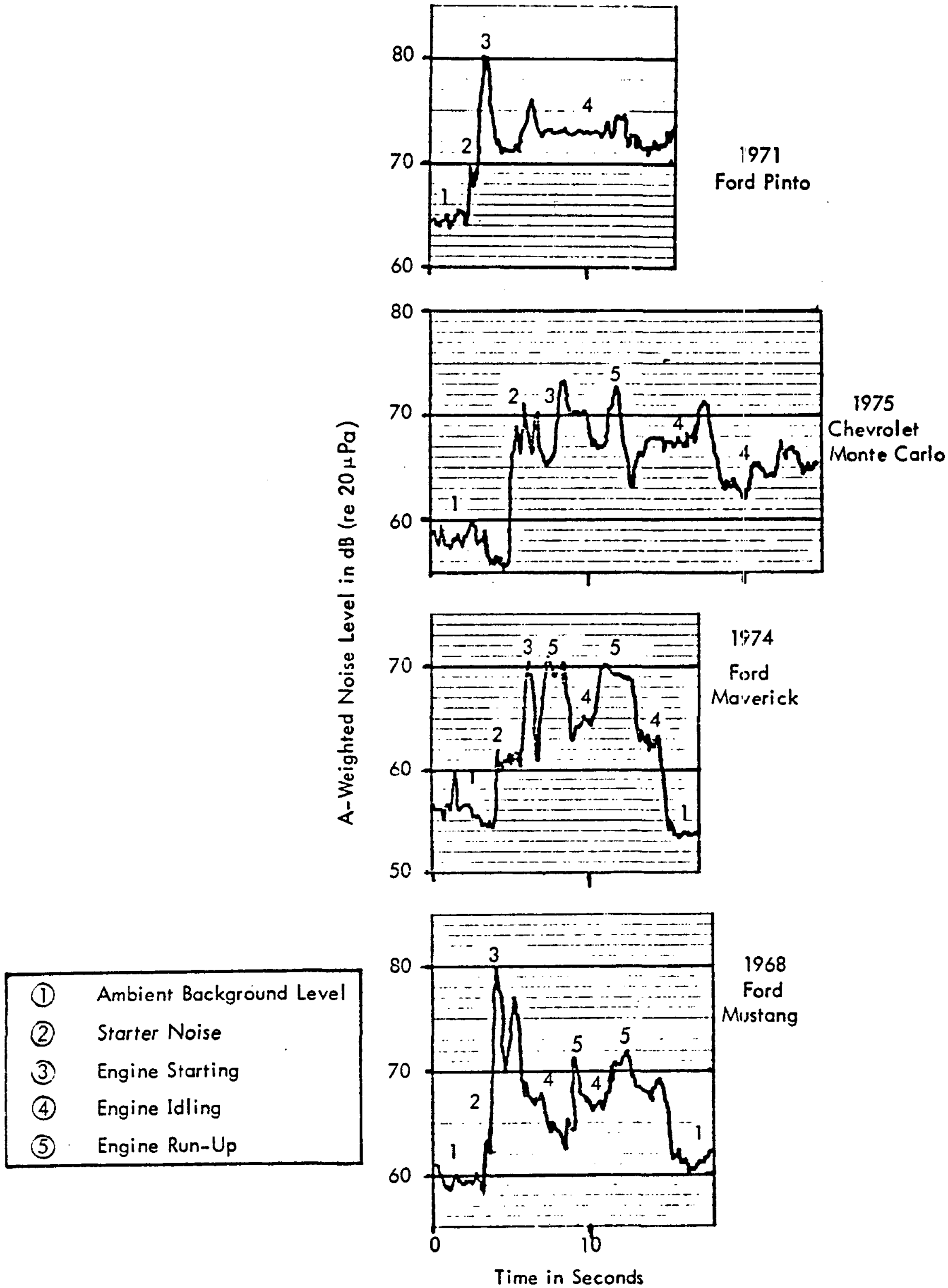


Figure 4-13b. Comparison of Starting and Running Noise Measured at the Rear of Typical Automobiles

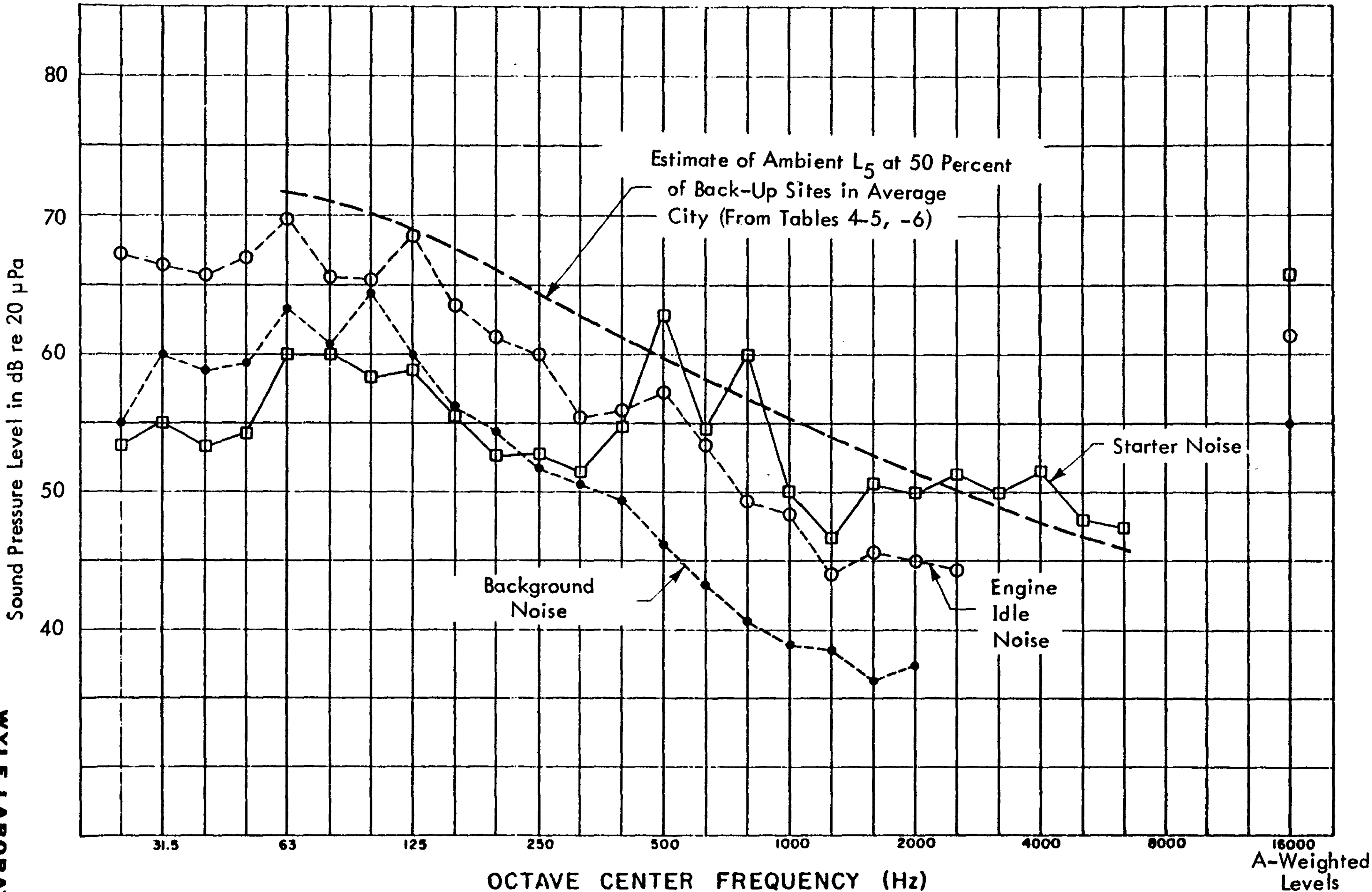


Figure 4-14. Starting Noise Spectra Measured at the Rear of a 1975 Chevrolet Monte Carlo Compared to Estimates of Ambient Noise Exceeded 5 Percent of Time (L_5) at 50 Percent of Back-Up Sites in Average (Low-Medium Density) Cities

Table 4-7

Summary of Starting and Running Noise Measured at the Rear of Typical Automobiles.* Values shown are average maximum levels from Figure 4-13

Automobile	A-Weighted Noise Level (dBA)			
	Ambient	Starting Noise	Engine Idle Noise	Engine Run-Up
72 Chevrolet	56	71	66	83
73 Chev. Wagon	55	62	64	73
71 Pinto	56	72	66	82
71 Pinto	65	70	73	80
75 Chevrolet Monte Carlo	58	70	67	75
74 Maverick	57	62	68	71
68 Mustang	60	63	68	80
Average	58	67	67	78

* Measured above rear bumper near anticipated location of audible warning device.

have been used to construct the estimated ambient L_5 level (exceeded 5 percent of the time) at 50 percent of the backing sites in the average (low to medium density) city. This estimate shown in Figure 4-14 by the upper dashed line, indicates that only the starter noise would tend to exceed this L_5 ambient noise level. More significant, however, is that with the rare exception of the manual transmission automobile started with the car in reverse (and the clutch in), the starting action will usually have stopped before the average driver engages the car in reverse – usually while the car is idling.

According to the limited self-noise data in Table 4-7 and Figure 4-13, engine idle noise levels will have an average value of about 67 dBA and an estimated standard deviation over all cars of about 4 dB. From this estimated distribution of engine starting noise and the data on statistical variation of ambient noise levels given earlier, it was possible to construct the three-way distribution profile shown in Figure 4-15 of the ambient noise distributed over sites and over time and the idling self-noise distributed over automobiles.

Based on these data, the dynamic range for the background noise (site ambient noise or automobile idling noise) which the warning system will monitor and adjust the signal level to, can now be confirmed.

The minimum A-weighted background noise level is again selected as 63 dB based on the estimated idling self-noise level of 63.5 dB exceeded by 80 percent of the automobiles. This level is consistent with the earlier choice based on the fact that only 5 percent of the sites are expected to have an L_5 level lower than this. The maximum background noise level for the average low-medium density city can be taken as 80 dB – it is exceeded only 5 percent of the time at 5 percent of the sites. However, as indicated earlier in Table 4-5, this maximum level increases to 87 when ambient levels in high density cities are included. Thus, the previously estimated dynamic range for the background noise of 63 to 87 dB is confirmed even when the self-noise levels of the automobile are considered.

However, it is clear from these data that the limiting background noise level will tend to actually be the self-noise of the automobile for quieter sites and the site ambient noise for less quiet sites. The ambient-sensing characteristic of the back-up warning device must therefore be capable of responding to either type of time-varying environment. The former tends to have a fairly uniform noise level with time for the few seconds between engine start-up and reversing operation while the normal outdoor ambient may vary drastically with time.

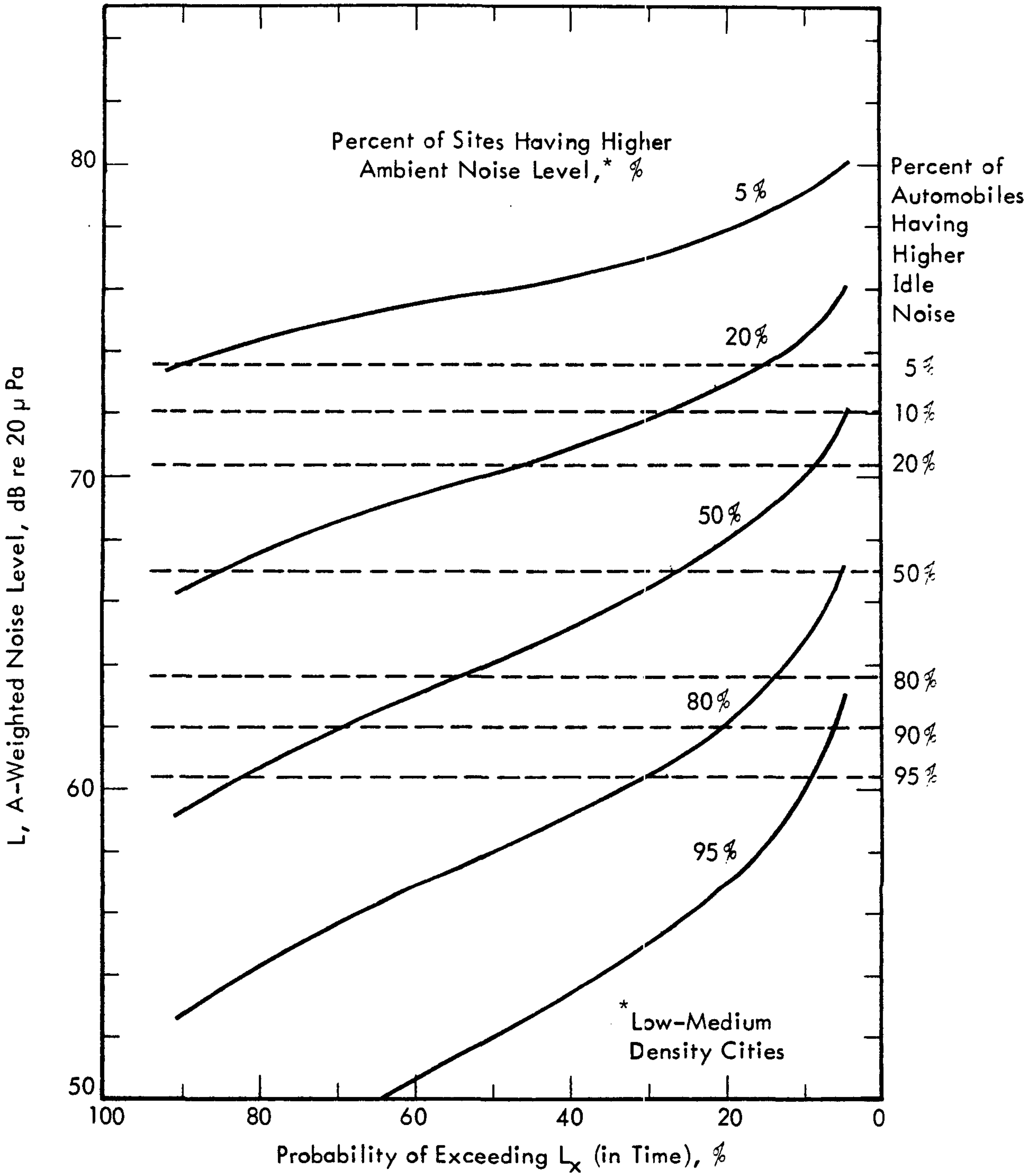


Figure 4-15. Estimated Distribution Profile of Ambient Noise in Parking Areas over Sites in Average (Low-Medium Density) Cities and Over Time Compared to the Estimated Distribution of Idling Self-Noise of Automobiles

4.4 The Automobile Driver

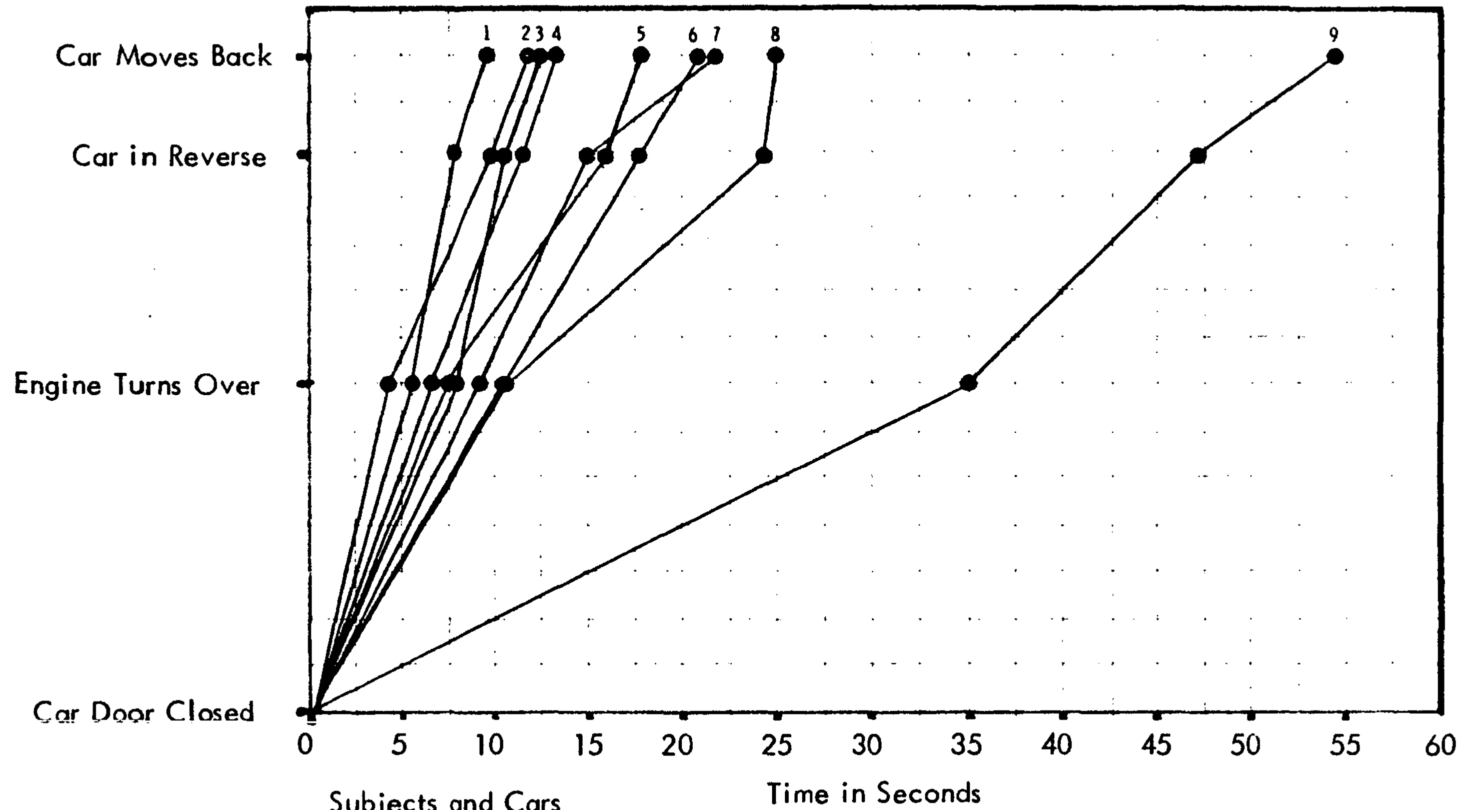
Although it was not intended to study the detailed vehicle operations related to back-up accidents, a few observations were made on a sample of eight drivers (selected at random) to determine the typical sequence of events and elapsed time between particular actions of these drivers. Figure 4-16 illustrates the results of these observations made in a typical commercial parking lot. A narrative recording was made describing the four events with indications of their time of occurrence and this recording was later analyzed to determine the elapsed time between each event. Subject Number 9 appeared to exhibit atypical behavior well removed from the majority of the events, and was discounted. If the time intervals between events for the other seven subjects are examined, the following values are obtained:

Interval Events	Time Interval, seconds[1]		
	Minimum	Average	Maximum
Car door closed to starting engine	4.0	7.5	11.0
Starting engine to car in reverse	2.0	6.1	13.0
Car in reverse to car moving back	1.0	2.8	6.5

[1]Excluding Subject No. 9.

Although the values shown are not derived from a large number of observations, they are probably a good representation of the time variations to be expected. It should be mentioned, the data shown was obtained in a shopping center parking lot where the engines were probably still warm, so longer time intervals would likely be observed where cars are started cold.

The time interval between the engine turning over and the car being placed in reverse will be utilized by the warning system to determine the acoustic background level. The minimum time observed for this interval was 2 seconds, suggesting an upper limit for the averaging time of the microphone circuit of approximately 1 second. This



Subjects and Cars

1 - Woman in Chevrolet El Camino
2 - Man In Van
3 - Man in Cadillac
4 - VW Minibus
5 - Woman in Mercury Station Wagon
6 - Average of All Events (Straight Line)
7 - Man in Chevrolet El Camino
8 - Woman in Ford Pinto
9 - Old Pick-up Truck

Figure 4-16. Observed Sequence of Events Preparatory to Backing Up would allow sufficient time for determination of the background level before the microphone circuit is de-energized and the warning signal activated when the car is placed in reverse.

The interval between placing the car in reverse and the cars motion to the rear is a crucial time for the pedestrian. The endangered pedestrian must evaluate the situation and take action to avoid being struck within a very short period of time. Motion of the automobile to the rear occurs within 1 second after being placed in reverse, in some cases. The warning signal should thus be activated and audible immediately upon the automobile being placed in reverse to provide the pedestrian with the maximum time to respond.

5.0 SELECTION OF THE WARNING SIGNAL

The characteristics of the potential target population and accident site have been defined in the preceding sections. It remains now to integrate these features into a model for the design requirements of the warning signal. The objective is to provide a warning device which has a 95 percent probability of alerting a target population which is within a danger zone near a backing automobile with ambient noise that would not be exceeded more than 5 percent of the time. The "danger zone" is nominally identified as extending 5 meters from the rear of the automobile. However, it is desirable to define this danger zone more carefully in order to clearly establish the range requirements for the warning signal.

5.1 Possible Accident Scenarios

Figure 5-1 illustrates four general scenarios for possible back-up accidents. Cases A and B involve a pedestrian walking directly toward an automobile backing out of a perpendicular parking slot or at 90 degrees to its path, respectively. Case C corresponds to a pedestrian who is walking parallel and in the same direction as an automobile backing away from a parallel parking slot next to a curb. He then suddenly turns into its path. Case D involves a pedestrian standing directly in the path of an automobile backing out of a long driveway or alley. While this is by no means an exhaustive sample of possible back-up accident scenarios, it serves to illustrate the basic types from which one can construct a reasonable model for the "danger zone." First of all, it should be noted that the accident zone — the actual location where an impact could occur — is indicated in Figure 5-1 by the cross-hatched area. This is intended to identify an envelope of the area that could be actually occupied by the backing automobile. The size of the fan-shape accident zone shown in Figure 5-1 for Cases A and B can be estimated as having a radius to the end of the "fan" as much as two car lengths (8.7 to 11.9 meters) for most 1975 U.S. cars and

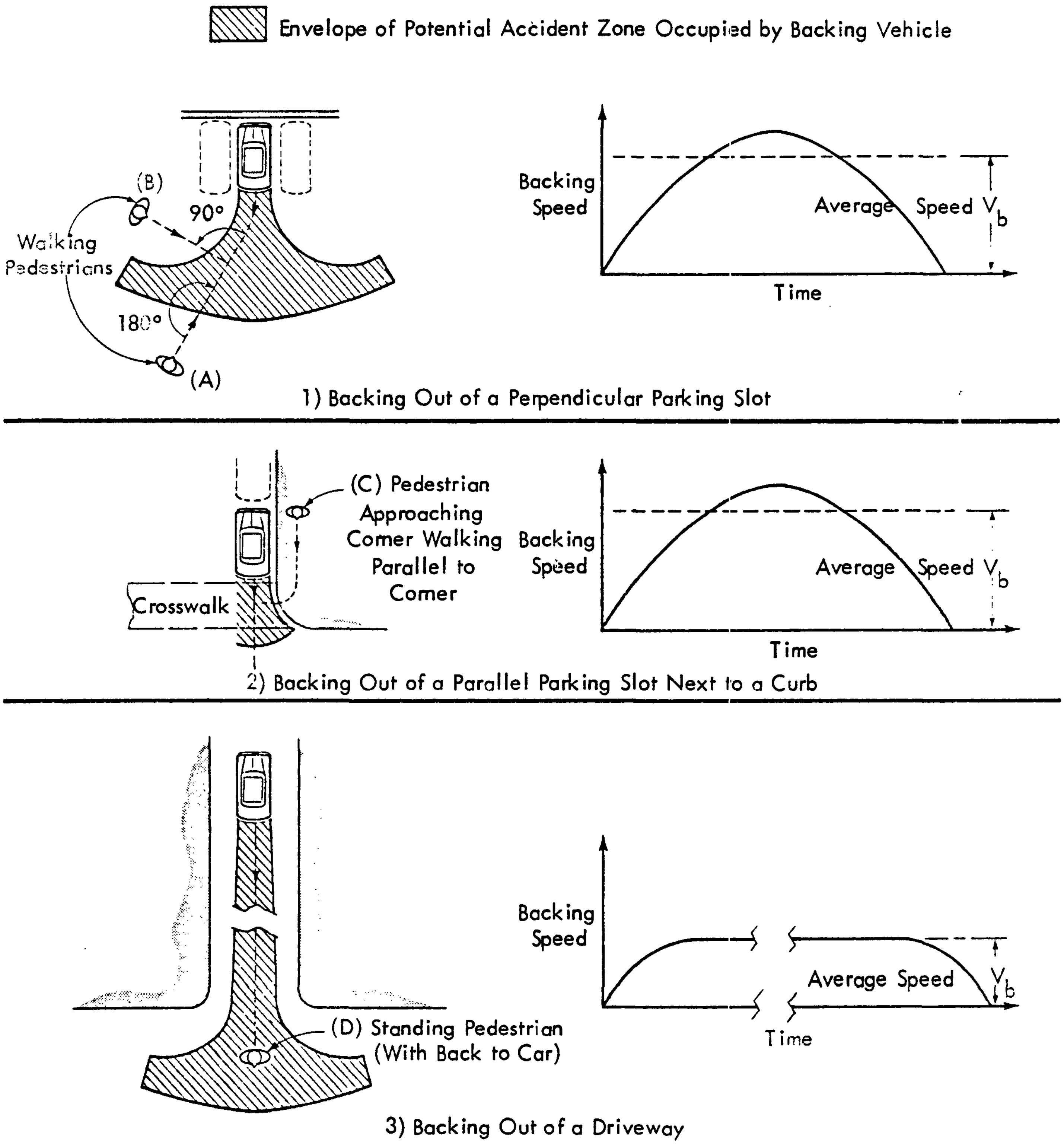
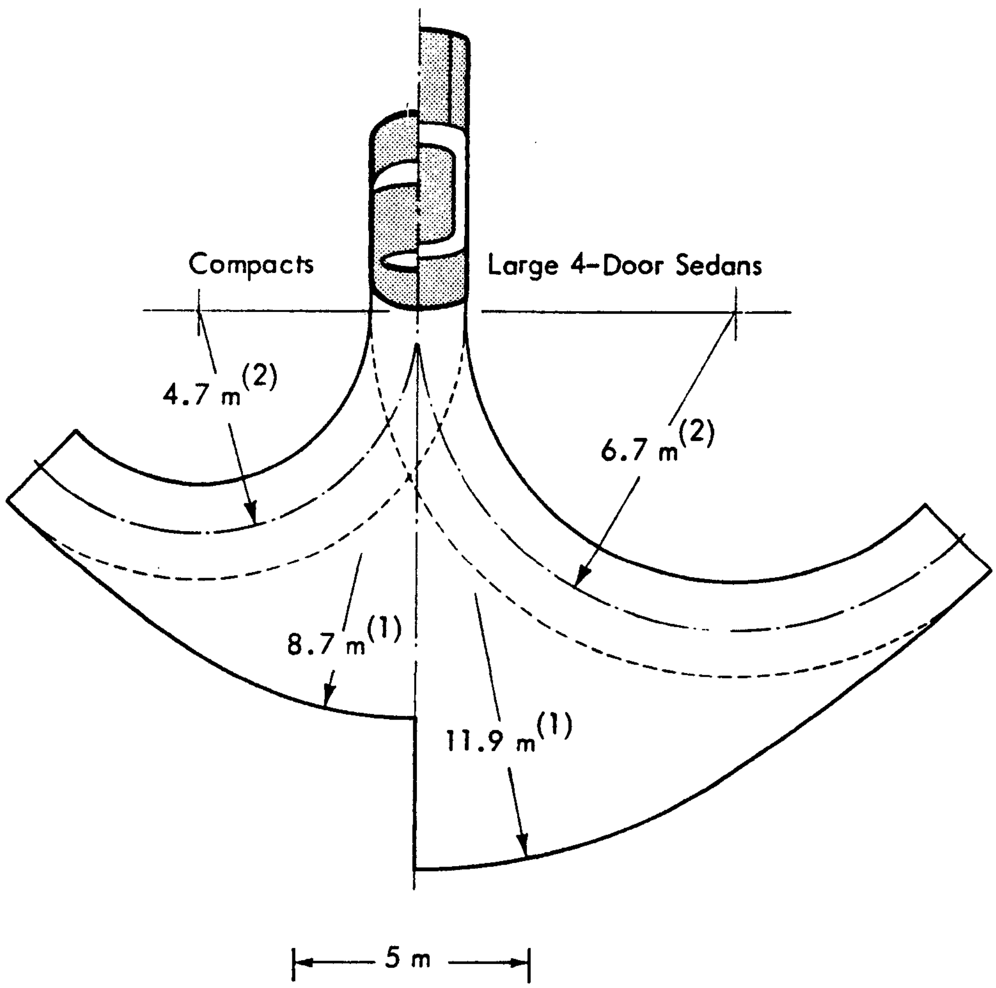


Figure 5-1. Possible Back-Up Accident Scenarios

having a minimum radius on the side of the fan equal to the minimum turning radius of an automobile (4.7 to 6.7 meters) for most 1975 U.S. cars. This envelope of the accident zone for Case A or B is illustrated in more detail in Figure 5-2.



(1) Two car lengths.

(2) Minimum turning radius

Figure 5-2. Approximate Envelope of Potential Back-Up Accident Zone for Most 1975 U.S. Automobiles for Case A in Figure 5-1

The actual danger zone for the pedestrian can extend beyond the boundaries of this accident zone since the pedestrian must be warned in time to take evasive action before entering the accident zone. Thus, a critical warning distance (D_c) can be defined as the separation between the automobile and the pedestrian at the moment he hears the warning signal, at a time just sufficient to allow him to take the necessary avoidance action. The following simple model provides a means of estimating this critical distance D_c.

5.1.1 The "Critical Distance" Model

Examination of the various scenarios in Figure 5-1 indicates that they can all be represented, analytically, by the general case illustrated in Figure 5-3. The curved backing paths indicated in Figure 5-1 are reduced here to equivalent linear paths.

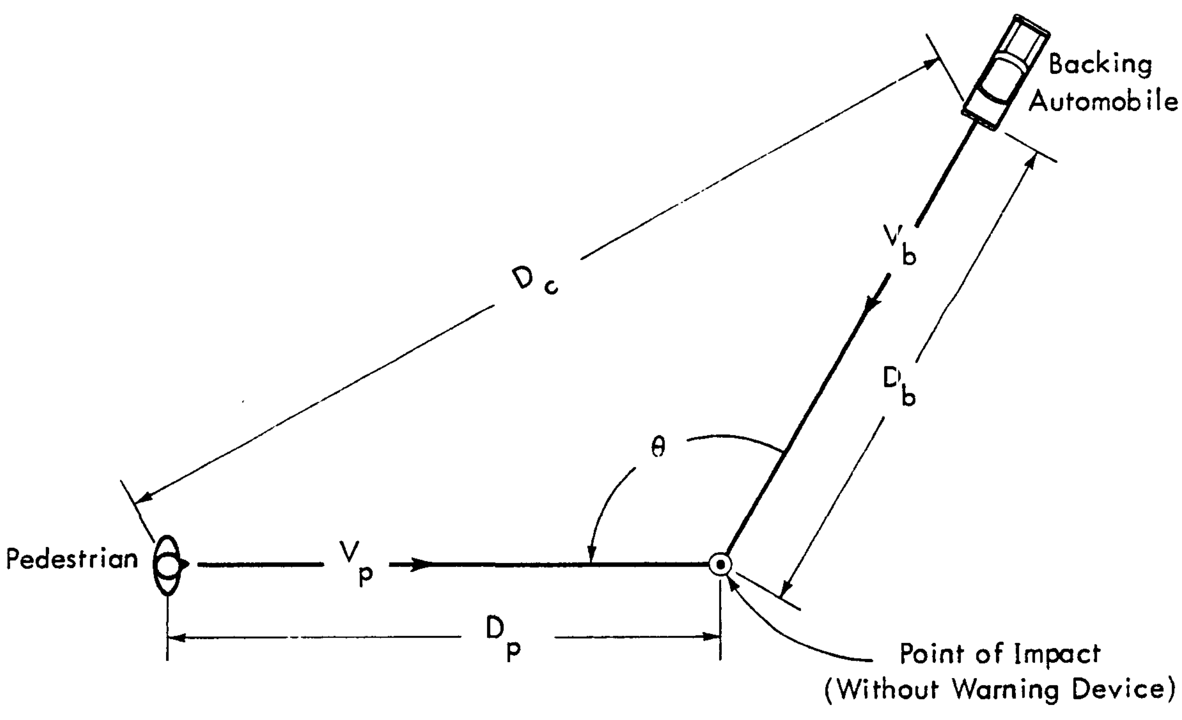


Figure 5-3. Geometry of General Back-Up Accident Case

This sketch shows the backing automobile at an initial distance D_b from the potential impact point. It is assumed that it travels along this line with a constant (average) velocity V_b. Lying at an angle θ from the automobile path is the path of motion of the unwarned pedestrian traveling at a velocity V_p. Had he been warned when he was a distance D_p from the point of impact, or the critical distance D_c from the automobile, he would just have had sufficient time to avoid the impact.

The independent time sequences involved in this model for the automobile and pedestrian motion can be defined as follows:

Automobile			Pedestrian		
Time	Duration of Interval	Event	Time	Duration of Interval	
0	t_b	Auto in Reverse (Warning Signal On)	0	t_r	Pedestrian Position When Auto in Reverse (Warning Signal Received)
2	t_i	Auto Starts to Back Up	1	t_a	(Pedestrian Starts to React if Warned)
3		Impact (If Warning Signal is Not Used)	3		Impact (If Warned, Pedestrian Just Completes Avoidance Action)

where: $t_i + t_b = t_r + t_a$

At time 0, the automobile is engaged in reverse and if a warning signal is present, the signal is turned on and (neglecting the finite sound propagation time) received by the pedestrian.

At time 1 (t_r seconds after time 0), if a warning signal is on, the pedestrian starts to act. According to the reaction time data shown previously in Figure 3-1, this reaction time t_r can be as short as 0.25 to 0.5 seconds, depending on the pedestrian's age.

At time 2 (t_b seconds after time 0), the automobile starts to move in reverse. According to the typical backing time sequences defined in Section 4.4, this backing delay time t_b can vary from typically 1 to 6.5 seconds.

At time 3 (t_i seconds after time 2 or t_a seconds after time 1), the auto and pedestrian impact, or, if a successful warning has occurred, the pedestrian has enough time (t_a) to complete a safe avoidance action. It is estimated that this action time (t_a) would not be less than 1 to 2 seconds.

Based on these time periods and the motion diagram in Figure 5-3, the distances traveled by the auto (D_b) and pedestrian (D_p) along their respective paths will be:

For the auto, $$D_b = V_b t_i = V_b(t_r + t_a - t_b) \qquad (5\text{-}1)$$

since $$t_i = t_r + t_a - t_b \geq 0$$

For the pedestrian, $$D_p = \begin{cases} V_p(t_r + t_a) & \text{- Pedestrian initially in motion} \\ V_p t_a & \text{- Pedestrian initially standing still} \end{cases}$$

From Figure 5-3, applying the law of cosines, the critical warning distance D_c can be given as:

$$D_c = \left[D_b^2 + D_p^2 - 2D_b D_p \cos\theta\right]^{\frac{1}{2}} \qquad (5\text{-}2)$$

Applying this expression to each of the four cases illustrated in Figure 5-1 gives the following expressions for the critical distances subject to the constraint that the total pedestrian response time ($t_r + t_a$) cannot be less than the backing delay time t_b, to yield a sensible value of the critical distance.

Case A, $\theta = 180°$, $$D_c = (V_b + V_p)(t_r + t_a) - V_b t_b \quad (5\text{-}3)$$

Case B, $\theta = 90°$, $$D_c = \left\{ V_b^2 \left[t_r + t_a - t_b \right]^2 + V_p^2 \left[t_r + t_a \right]^2 \right\}^{\frac{1}{2}} \quad (5\text{-}4)$$

and $$D_p = V_p(t_r + t_a) \quad (5\text{-}5)$$

Case C, $\theta \simeq 0°$, $$D_c \simeq (V_b - V_p)(t_r + t_a) - V_b t_b \quad (5\text{-}6)$$

Case D, $\theta = 180°$, $$V_p = 0 \text{ from time 0 to time 1} \quad (5\text{-}7)$$

$$D_c = (V_b + V_p) t_a + V_b(t_r - t_b) \quad (5\text{-}8)$$

Examination of these equations reveals that the critical distance will be greatest for $\theta = 180°$, minimum values of the backing delay time t_b and maximum values of the velocities and the pedestrian reaction and action times t_r and t_a respectively. Figure 5-4 illustrates the variation in the critical warning distance D_c with the total pedestrian response time $(t_r + t_a)$ for idealized versions of Case A ($\theta = 180°$) and Case B ($\theta = 90°$) and for two different values of the backing speed and backing delay time.

A design range for audibility of 5 meters will cover a large percentage of back-up accident scenarios. However, it is suggested that under "maximum hazard" conditions, with a maximum backup speed of 5 m/s (11.2 mph) a minimum back-up delay time of 1 second and total pedestrian response time of 2.5 seconds (say, $t_r = 0.5$ seconds and $t_a = 2$ seconds – reasonable values for an elderly pedestrian). The critical warning distance D_c for a Case A or Case D scenario would be about 10 meters. Therefore, consideration should be given in the design of the audible warning signal to extending its range of effectiveness to as much as 10 meters. It is not unreasonable to postulate, however, that this type of extreme case might occur when (1) the automobile is backing out of a blind driveway bounded by buildings on each side so that the normal propagation loss of the warning signal from source to receiver would tend to be reduced, or (2) when the automobile is backing out of a long

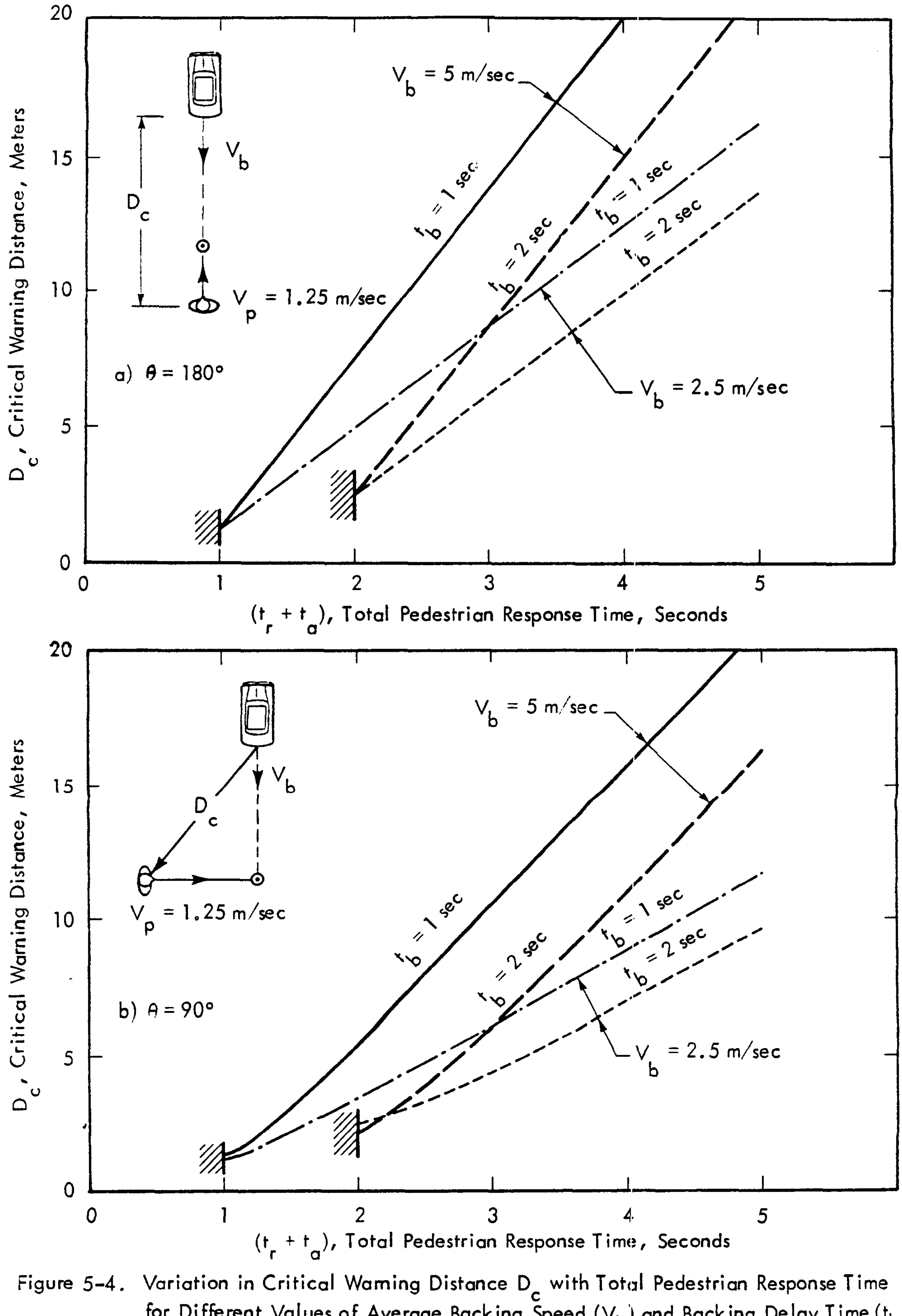


Figure 5-4. Variation in Critical Warning Distance D_c with Total Pedestrian Response Time for Different Values of Average Backing Speed (V_b) and Backing Delay Time (t_b)

driveway in a residential area where lower ambient noise levels would tend to make the warning signal effective at a greater distance. Nevertheless, the tentative design range of 5 meters is considered a minimum with potential extension to as much as 10 meters desirable. All other things being equal, this extension of the range would require an increase in the source level of approximately 6 dB – a 4-to-1 increase in acoustic power. Clearly, seemingly small changes in the effectiveness design range can have a substantial influence on the system performance requirements.

To provide some guidance relative to the desired directivity of the back-up warning device, the locus of the critical distances for all approach angles of the pedestrian and for two different values of the backing speed and backing delay time is shown in Figure 5-5. For any one case, the circular locus of the critical distance is centered at a distance $D_b = V_b(t_r + t_a - t_b)$ from the rear of the automobile and has a radius $D_p = V_p(t_r + t_a)$. It defines the boundary of the danger zone within which the pedestrian would not receive a warning signal in time to take evasive action. The envelope of these loci for these various cases is roughly defined, for the worst case, by a rectangle with a maximum length $[V_b + V_p]_{max} \cdot [t_r + t_a]_{max} - V_b t_{b\,min}$ and a width equal to $2 \cdot V_{p\,max} [t_r + t_a]_{max}$. In any event, an elongated directivity pattern is clearly desirable with the greatest range in the direction of backing.

Finally, it should be pointed out that a strict interpretation of one of the design goals of this audible warning system – performance with a 95 percent probability of alerting – would require a detailed statistical evaluation of the dynamics of backing automobiles and pedestrians potentially subject to impact. Such an effort was beyond the scope of this study. The preceding analysis has served, however, to clearly define the desired range of the warning device. Now it remains to utilize all of the preceding design constraints to establish its required acoustical characteristics.

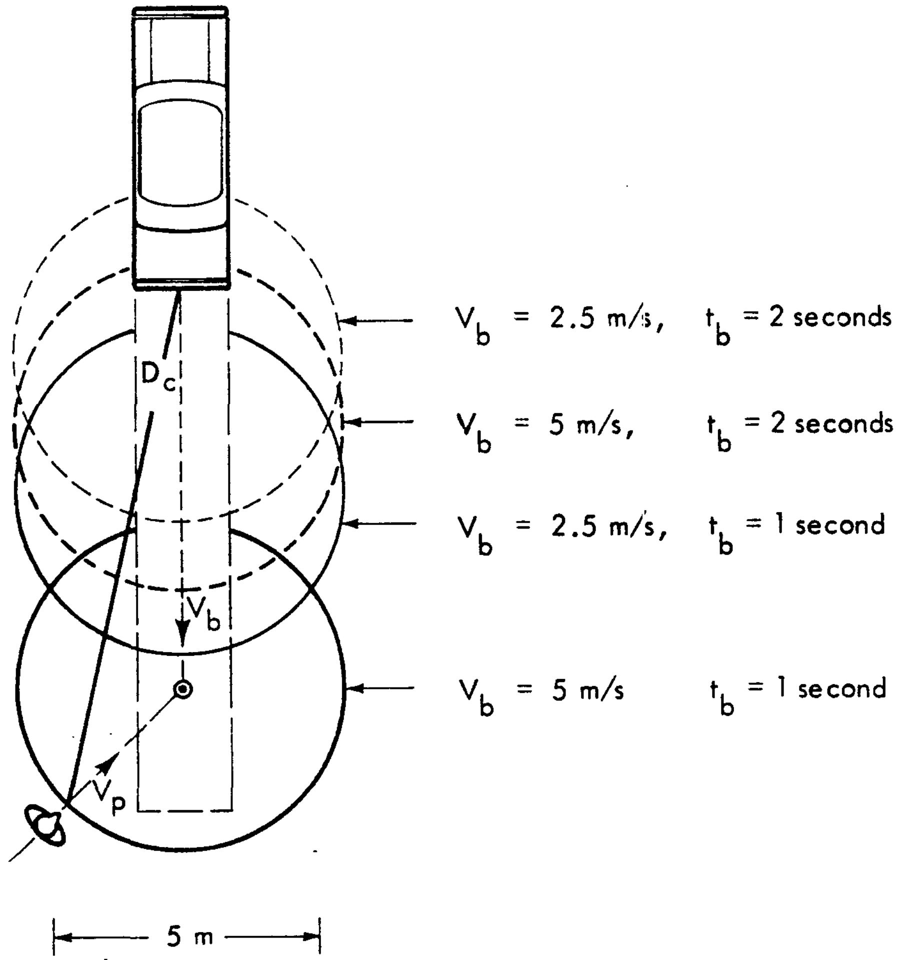


Figure 5-5. Locus of Critical Warning Distances for Several Variations of Back-Up Accident Scenarios – Case A. Pedestrian Speed and Total Response Time = 1.25 m/s (2.8 mph) and 2.5 seconds Respectively

5.2 General Acoustical Requirements

The general acoustic features of an effective acoustic warning signal suitable for this program should include the following:[18]

- Concentrate its frequency spectrum in the vicinity of 1000 Hz where the ear of any pedestrian is most sensitive.
- Provide some degree of complexity to the signal through the use of periodic interruption, level modulation, and/or addition of multiple tones. (This requirement must be carefully balanced against the economic constraint for simplicity and low mass-production cost.)
- If possible, project a directional beam.
- Select a level to ensure effective alerting of the pedestrian, but limited to minimize community annoyance.

Each of these general features will be considered in this section by analyzing the acoustic characteristics required of an effective acoustic warning signal.

To be effective, the audible signal must be presented at a level significantly above the masking background noise. Just how much above is a function, essentially, of the following two basic factors.

1. The detection threshold of the signal in the presence of the masking background noise.
2. The relative increase in intensity above this detection threshold to elicit a subjective "alarm" response just sufficient to motivate positive avoidance action by a pedestrian.

5.2.1 Detection of a Signal in the Presence of Noise

The threshold of audibility (or hearing threshold) of a sound is defined as its sound pressure level which is just audible (detectable 50 percent of the time) to the human ear in silence. Actually, the silence can really be considered as consisting of the internal masking noise inside the ear which limits our own threshold of audibility in the absence of any other sound. The hearing thresholds applicable to 90 or 95 percent of the population within different age groups in the target population were presented earlier in Section 3 (see Figure 3-4).

In the presence of background noise, the normal threshold of audibility will rise due to the masking effect. The amount of masking (i.e., the increase in the signal level above the normal threshold in quiet) can be determined by the spectral analysis characteristics of the human ear in terms of "critical bands." In the simplest possible sense, "critical bands" represent the ear's internal spectral analysis filters whose bandwidths correspond to the minimum frequency separation of two tones whose excitation regions on the basilar membrane in the inner ear do not overlap to any significant degree. This model explains masking the following way.[6]

When a pure tone is masked by a very narrow band of noise, i.e., one whose bandwidth is only a few Hz wide and whose center frequency coincides with the pure tone frequency, the amount of masking increases, up to a specific limit, as the bandwidth of the masking noise increases. The critical bandwidth is reached when any further increase in the width of the band of masking noise has little or no influence on the amount of masking produced on the pure tone at the center of the band. The addition of noise energy outside the critical band may be unpleasant, but it does not increase the masking of the pure tone.

This critical bandwidth model, first proposed by Fletcher in 1946, has since provided a basic foundation for most of the observed characteristics of the sensation of sounds.[25-35] The only major source of disagreement between researchers is in the exact dimensions of the critical bands themselves.

Plotted in Figure 5-6 are critical bandwidths from various researchers as a function of the frequency of the pure tone being masked. The apparent discrepancies between the curves begin to disappear, however, when differences in the measurement method of the critical bands are taken into account. Fletcher,[25] and Hawkins and Stevens[26] used an indirect method based on assuming that a pure tone was just masked by a critical band of noise centered on the same frequency and having the same intensity. The more direct measurements of the critical bands by noting changes in masking for changes in the masking noise bandwidth, outlined earlier, produced the larger values of the width of the critical bands observed by Zwicker[29] and Greenwood.[31] Note that the results from these two experimenters agree quite well at frequencies of interest for this study.

Based on the concepts outlined in the preceding discussion, it is possible to construct a model for aural detectability of warning signals. This model was first derived by Ollerhead[7] and has been extensively tested in laboratory and field experiments on aural detectability of helicopter sounds.[7, 8]

The first step in applying the model is to define the "critical band levels" of the masking noise. Ideally, this is best accomplished by first obtaining a narrow band spectrum of the background masking signals and then mathematically converting this into critical band spectra as described in Reference 8. For the present purposes, however, it is simpler to use the available spectrum levels of the masking noise. These may be converted into approximate critical band levels (according to Greenwood's experimental values) by adding the following constants contained in Table 5-1.[31]

In the above discussion it has been assumed that the masking noise level was significantly above the threshold of audibility. Since this is not always the case, it is necessary to add the critical band levels of the masking noise to the equivalent internal noise levels of the threshold of audibility to establish a true masked threshold. This summation must be performed on an energy basis.

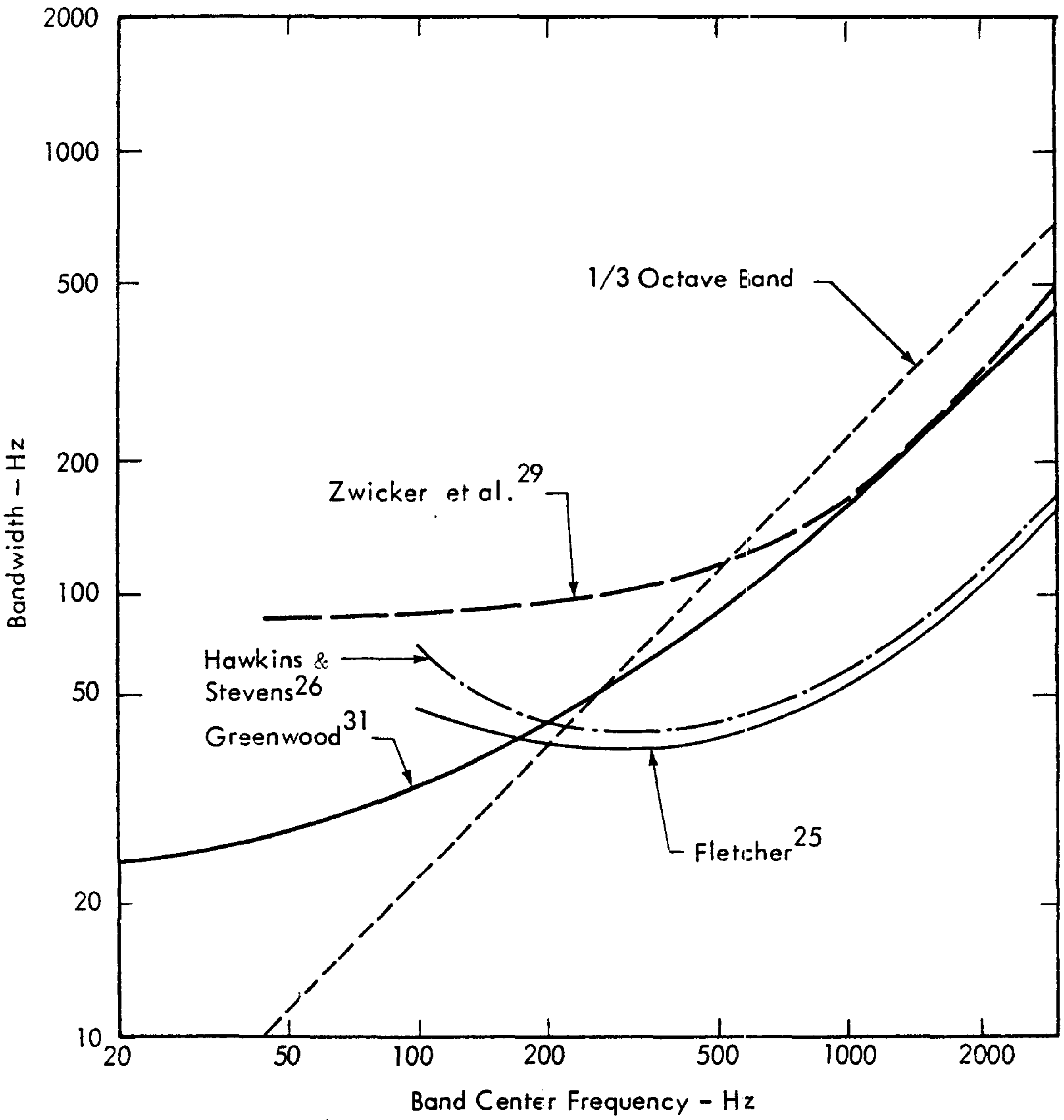


Figure 5-6. Comparison of Various Critical Bandwidth Measurements

Table 5-1

Correction Factors to Determine Approximate Critical Band Levels By Adding to One-Third Octave Band Levels (According to Greenwood's Experimental Values)[31]

	Add to One-Third Octave Band Levels To Obtain Critical Band Levels							
Frequency, Hz	50	63	80	100	125	160	200	250
Correction, dB	4	3.5	3	2	1.5	1	0.5	0
Frequency, Hz	315	400	500	630	800	1000	1250	1600-10,000
Correction, dB	-5	-.5	-1	-.1	-1.5	-1.5	-1.5	-2.0

Based on the preceding discussion, the equation for predicting the sound level (L_k) in the k^{th} critical band of a signal detectable 90 percent of the time in a background noise can be given as:[8]

$$L_k = 10 \log \left[10^{T_k/10} + 10^{(M_k + X)/10} \right] + 1.0 \quad , \text{dB} \qquad (5\text{-}9)$$

where

L_k = warning signal level in k^{th} critical band (dB)

T_k = sound pressure level at the threshold of audibility corresponding to center frequency of k^{th} critical band (dB)

M_k = level of masking signal in k^{th} critical band (dB)

X = "fine tuning parameter" ($\approx$ -5 dB for detection by 50 percent of individuals, $\approx$ 0 dB for detection by 90 percent of individuals)

A 1 dB constant has been added to the above equation to ensure correct results for low levels of masking noise near the threshold of audibility.[8] For the "fine tuning parameter," however, a value of -5 dB is used to provide a threshold level corresponding to the usual 50 percent response level which will be the starting point for the increase in level required to achieve a "warning" quality.

One minor simplification has been made in proposing this model for this study; namely, that the effective bandwidth of the critical band is independent of the level of the masked threshold. Zwicker[36] shows significant broadening of the critical band characteristics at high noise levels (above 85 dB). However, for this program, this is expected to be a second order effect and the linear equation specified above is used for computing the signal threshold for all levels of masking noise.

Based on the preceding expression, the range of masking noise levels and spectra defined in Section 4.0 and the threshold of audibility not exceeded by 95 percent of the target population in the 48 to 65 year age group from Figure 3-4 in Section 3.0, the threshold levels for the warning signal have been computed. The results are summarized in Table 5-2, assuming the warning signal would consist of only a single pure tone within any one-third octave band in the frequency range 500 to 2500 Hz.

The three frequencies giving the lowest threshold levels for the quietest ambient design level of 63 dBA (taken from Table 4-5) are 800, 1000, and 1250 Hz for which the threshold levels of the pure tone warning signals would be 47.7, 46, and 46.8 dB respectively. For the highest ambient design level of 87 dBA, the selected frequencies with the lowest threshold levels are 1250, 1600, and 2000 Hz, providing threshold levels of 68, 66.2, and 66.1 dB respectively. The 1250 Hz frequency band is the only one common to these two extreme ranges, so in order to provide one optimum design for all sites, this frequency should be selected as the basic warning signal frequency.

A tentative selection for the threshold level of the warning signal at the ear of the pedestrian is thus defined as ranging from 47 to 68 dB at a frequency of 1250 Hz. It remains to define the additional characteristics of this tone required to establish it as an effective warning signal.

Table 5-2

Computation of Threshold Levels of Pure Tone Warning Signals for Specified Sites and for 95 Percent Percentile of 48 to 65 Year Age Group

Site	Parameter	k^{th} Frequency, Hz								
		500	630	800	1000	1250	1600	2000	2500	L_A
Low-Medium Density City	$T_k^{(1)}$, dB	45	(42)	(38.5)	35	(42.5)	(51)	(58.5)	(65)	-
	$\Delta L_A^{(2)}$, dB	-7.5	-9	-10.5	-12	-13.5	-15	-16	-17	-
	$L_M^{(3)}$, dB	55.5	54	52.5	51	49.5	48	47	46	63
	$\Delta CBL^{(4)}$, dB	-1	-1	-1.5	-1.5	-1.5	-2	-2	-2	-
	$M_k^{(5)}$, dB	54.5	53	51	49.5	48	46	45	44	-
	M_k-(4), dB	49.5	48	46	44.5	43	41	40	39	-
	$L_k^{(6)}$, dB	51.8	50	[47.7]	[46.0]	[46.8]	52.4	59.6	66	-
High-Density City	$\Delta L_A^{(2)}$, dB	-7.5	-9	-10.5	-12	-13.5	-15	-16	-17	-
	$L_M^{(3)}$, dB	79.5	78	76.5	75	73.5	72	71	70	87
	$\Delta CBL^{(4)}$, dB	-1	-1	-1.5	-1.5	-1.5	-2	-2	-2	-
	$M_k^{(5)}$, dB	78.5	77	75	73.5	72	70	69	68	-
	M_k-(4), dB	73.5	72	70	68.5	67	65	64	63	-
	$L_k^{(6)}$, dB	74.5	73	71	69.5	[68]	[66.2]	[66.1]	68.1	-

(1) T_k = Hearing threshold for 95 percent percentile age 48 to 65 group, ( ) interpolated.

(2) ΔL_A = Relative one-third octave band level for ambient levels from Table 4-6.

(3) L_M = One-third octave band ambient level = A-weighted design level plus (2).

(4) ΔCBL = Correction factor for critical band levels from Table 5-1.

(5) $M_k = L_M + \Delta CBL$.

(6) L_k = Threshold level of pure tone in k^{th} band, dB re 20 μPa, computed from Equation 5-9 in text - lowest three bands are enclosed.

5.2.2 Warning Signal Parameters

Since the signal defined above would be only detected about 50 percent of the time in the environmental conditions specified, it must be modified to achieve an effective warning capability. The simplest modification is to increase the level until the signal is clearly noticeable and then to change its presentation by either adding additional components or by interrupting the signal to increase its alerting qualities. The "critical band" model again plays a useful role in establishing a minimum rate of interruption to avoid degrading the loudness of the tone.

Whenever a broadband noise spectrum is analyzed by a filter (such as one may consider the "critical bands" within the ear), the output of the filtered band of noise should be examined for a minimum period of time (T) of the order of $40/2\Delta f$, where Δf is the bandwidth of the filter in Hz. This relationship provides at least 40 degrees of freedom for the analysis and ensures that the filtered output will not fluctuate excessively.[37] Thus, if the signal frequency is 1250 Hz. the critical bandwidth (Δf), from Greenwood's data in Figure 5-6, is 200 Hz, then the ear should have $40/(2 \cdot 200) = 0.1$ second to look at each burst of the tone. Thus, an interruption rate less than 10 per second is desired. A rate of 3 per second has been selected.

The anticipated increase in level of about 15 dB required beyond the threshold values was verified in a brief experiment conducted during this program. The results, to be discussed in the next section, indicated that a pure tone signal of 1000 Hz or 2000 Hz presented at three bursts per second at an average level of 17 dB above the threshold level in a noise background of 65 to 70 dBA achieved a satisfactory "warning signal" quality according to the subjective judgment of the subjects. Therefore, a tentative design range for the warning signal level at the ear of the pedestrian is:

Minimum Level for Low-Medium Density Cities

$$47 + 17 = 64 \text{ dB}$$

Maximum Level for High Density Cities

$68 + 17 = 85$ dB

Finally, assume a 1 meter reference point for rating the source output and allow for simple inverse square law propagation loss from that point to the minimum desired critical distance of 5 meters ($\Delta L = 20 \log 5/1 = 14$ dB) or the desired range capability of 10 meters ($\Delta L = 20$ dB).* Thus, the reference source level at a 1 meter distance would range from 64 + 14 = 78 dB for the quietest conditions and minimum critical distance of 5 meters to 85 + 20 = 105 dB for the noisiest conditions and the maximum (10 meters) range. In both cases, a pure tone of 1250 Hz interrupted at three times per second is assumed.

Literature on the desirable acoustic characteristics of warning devices has been reviewed and the following criteria have been identified:[38]

- The warning signal frequency should be greater than 700 Hz
- Maximum audibility of a signal in a noise field is attained if the frequency is greater than 1000 Hz
- Pulsing a signal does not detract from its alerting potential and it does not appear to enhance it. It does however, make the signal more distinctive.

In conclusion, an optimum alerting signal (one which attracts attention) must:

1. be audible
2. have attention getting characteristics
3. be distinctive

There is one additional aspect regarding subjective judgments of a signal in the presence of a masking noise that has not been discussed. This is the phenomenon of loudness recruitment which is illustrated in Figure 5-7. With loudness recruitment, the apparent loudness of a tone, masked by noise, grows more rapidly than it would in the absence of the masking noise. This effect is illustrated in Figure 5-7 by the solid line which shows the increased rate of growth of loudness observed for normal ears

*There is no need to consider any other loss effects over such a short range.

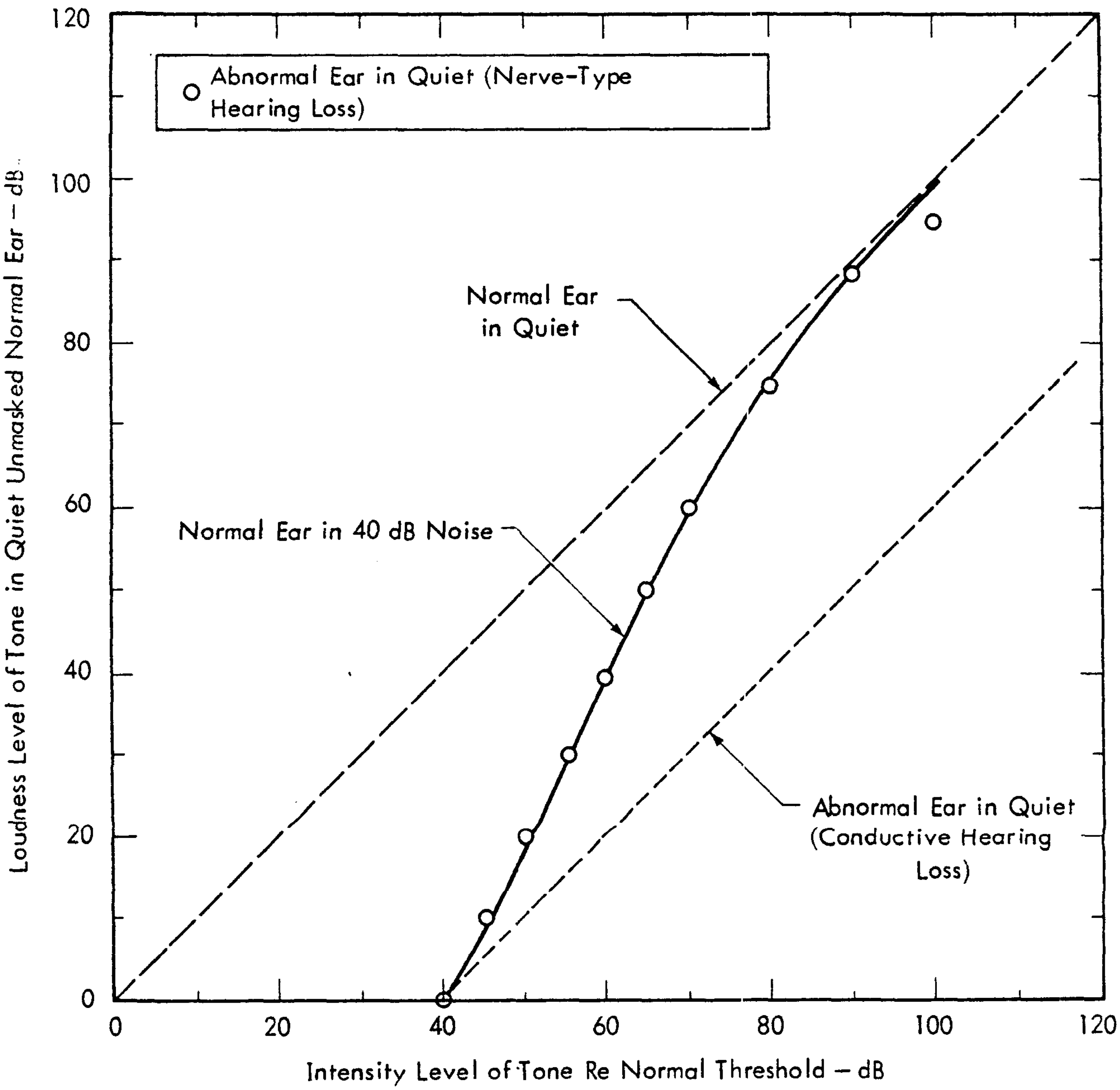


Figure 5-7. Growth of a Partially Masked Tone for Normal and Abnormal Ears to Illustrate the Phenomenon of Recruitment

listening to a tone masked by 40 dB noise. The data points show that people with nerve-deafness (inner ear loss similar to the type of hearing loss observed for older people) exhibit exactly the same type of behavior when listening to a tone in the quiet. In other words, their nerve-type hearing loss acts like an external masking noise does to the normal ear as far as loudness growth is concerned.

Also illustrated in Figure 5-7 is the loudness growth curve that would be observed for a person with conductive-type hearing loss due to disfunction of the middle ear. The point is that for people with normal ears and those with nerve-type hearing loss, the way the ear perceives the growth of loudness of a tone in the presence of noise is very nonlinear compared to the normal ear in quiet. Although this effect could possibly be utilized to improve the effectiveness of a warning signal, the added complexity of a nonlinear amplitude control was not deemed a cost effective design criteria.

5.3 Subjective Evaluation

Based upon an early brief examination of the important warning signal parameters, a subjective evaluation of warning signal characteristics was conducted. A group of eight subjects was first tested to determine their hearing thresholds and then asked to judge the level of detection and the level at which a signal attained a warning quality, both with the signal masked by noise.

Audiometric pure tone threshold hearing tests were performed using a Beltone Model 9D portable audiometer. The audiometric testing was performed using earphones with a circumaural cushion, used in lieu of the standard earphone cushion. The audiometer had been calibrated approximately to ANSI S3.6-1969, considered adequate for our purposes since the results were intended for comparison purposes only. Results of these tests are illustrated in Figure 5-8 where the best hearing level of either ear is shown.

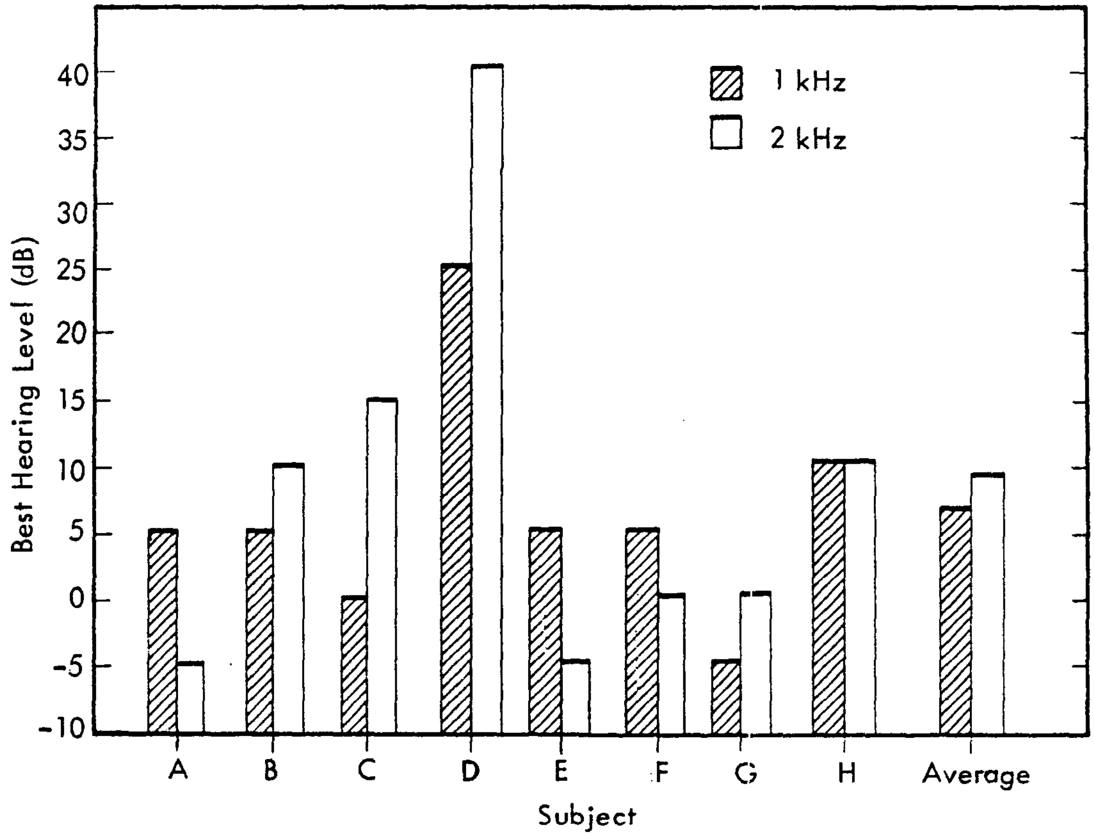


Figure 5-8. Hearing Level of Eight Subjects at 1 kHz and 2 kHz. Beltone Model 9D Portable Audiometer Used

Directly following the audiometric testing, the subjects were asked to perform a second task. A simulated warning signal was mixed with broadband pink noise and played through a loudspeaker in the test room. The broadband level of the pink noise alone for the subject in the room was 65 to 70 dBA. While this noise level was held constant, the signal level was increased until the subject indicated its audibility. This sequence was repeated for each of the signal formats listed in Table 5-3 at both 1 kHz and 2 kHz. Regarding the relative detectability of any one format over another, there were no consistent results to portray. The detectability of both 1 kHz and 2 kHz were almost identical based on the data shown in Figure 5-9a. If the corrections shown earlier in Table 5-1 are applied to the data in Figure 5-9a, the audibility thresholds obtained are in excellent agreement with expected levels.

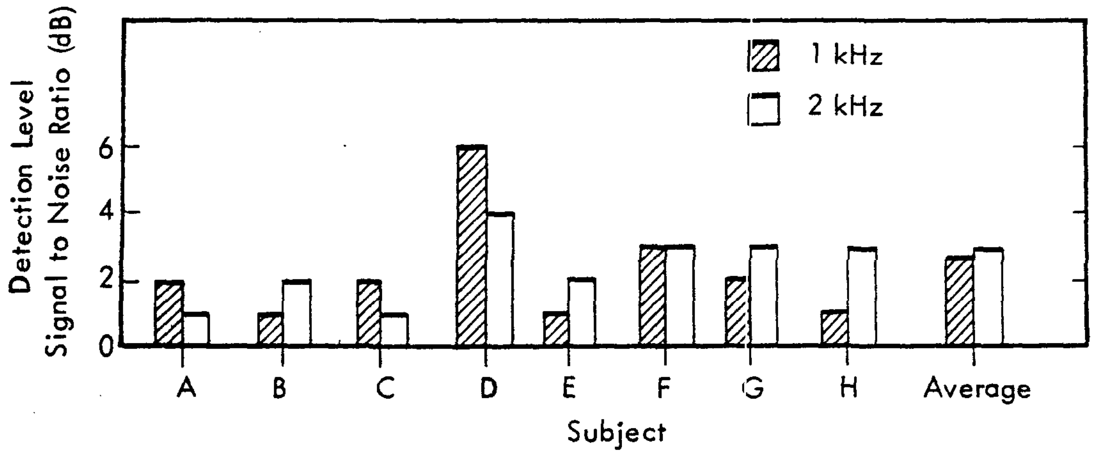
Table 5-3

Warning Signal Formats Tested

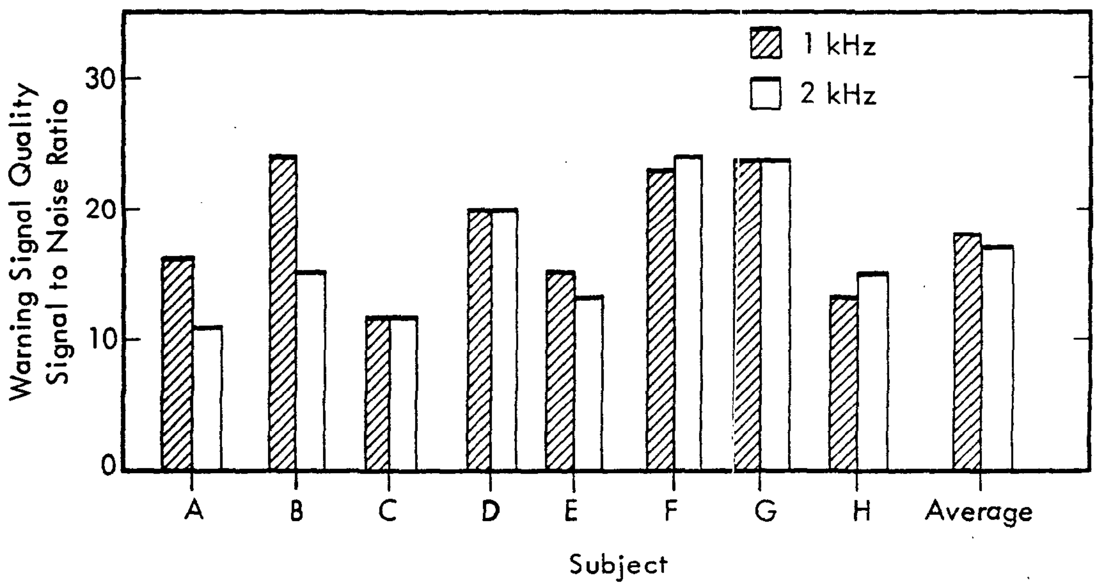
Signal Duration	Signal Off Time	Relative Level Slow RMS Meter
Continuous	0	0 dB
50 m sec	0.3 sec	-8 ±0.2 dB
100 m sec	0.3 sec	-5.5 ±0.2 dB
100 m sec	0.5 sec	-8 ±0.7 dB
100 m sec	0.2 sec	-5 ±0.2 dB

The subjects were also asked to select a level at which the signal attained a warning or alarm quality. Results of this test are portrayed in Figure 5-9b. There appears to be a slight advantage in using 2 kHz since a lower level is required, but the majority of the subjects selected 1 kHz as a preferred warning signal.

It is significant to note the almost complete lack of correlation between the subjects' hearing level and their ability to detect the warning signal in the presence of a moderate intensity level of noise. These results are not unexpected, as discussed in earlier sections; once the noise and signal exceed the subjects' threshold of hearing, they will detect the warning signal with equal ease.



(a) Detection Level (Signal to Noise Ratio) of a 1 kHz and 2 kHz Warning Signal of 100 msec Duration and 200 msec Off Time



(b) Warning Signal Quality Level (Signal to Noise Ratio) of a 1 kHz and 2 kHz Warning Signal of 100 msec Duration and 200 msec Off Time

Figure 5-9. Detection Level and Warning Quality of the Warning Signal in the Presence of Noise. Pink Noise Level in the Room was 65 to 70 dBA. Signal Levels are Shown Relative to the One-Third Octave Band Level of the Noise at Each Frequency

6.0 THE WARNING SIGNAL SYSTEM

The preceding sections of this report define the desirable characteristics of the warning signal. A system has been designed which fulfills all the program objectives. It has been constructed with controls to allow signal timing and level variations to be made if further evaluation studies or demonstrations are desired. If, in the future, the system is adopted for use in passenger cars, minor circuit design changes will be required to incorporate the major circuit elements into a single chip.

It was recognized that the system could be designed in several ways and still perform the same identical functions. Basically, the system was developed from the following requirements:

- The device must sense the ambient acoustic level (such as A-weighted) in the near vicinity of the vehicle.
- The device must generate an acoustic warning signal proportional to the measured ambient level when the gearshift is placed in reverse.

These fundamental requirements were satisfied by a circuit with functions as illustrated in Figure 6-1.

The final system design utilized a single inexpensive loudspeaker to perform both receiver and audio output functions. In the block diagram of Figure 6-1, both the acoustic sensor and loudspeaker are common.

When ignition power is applied, the system monitors the ambient level, producing a control voltage which continues to track the ambient until the gearshift is placed in reverse. At this time the control voltage is held and a signal proportional to the ambient is generated. The signal, a pulsed tone at 1250 Hz, is generated at a level approximately 15 dB above the A-weighted noise level at the source speaker.

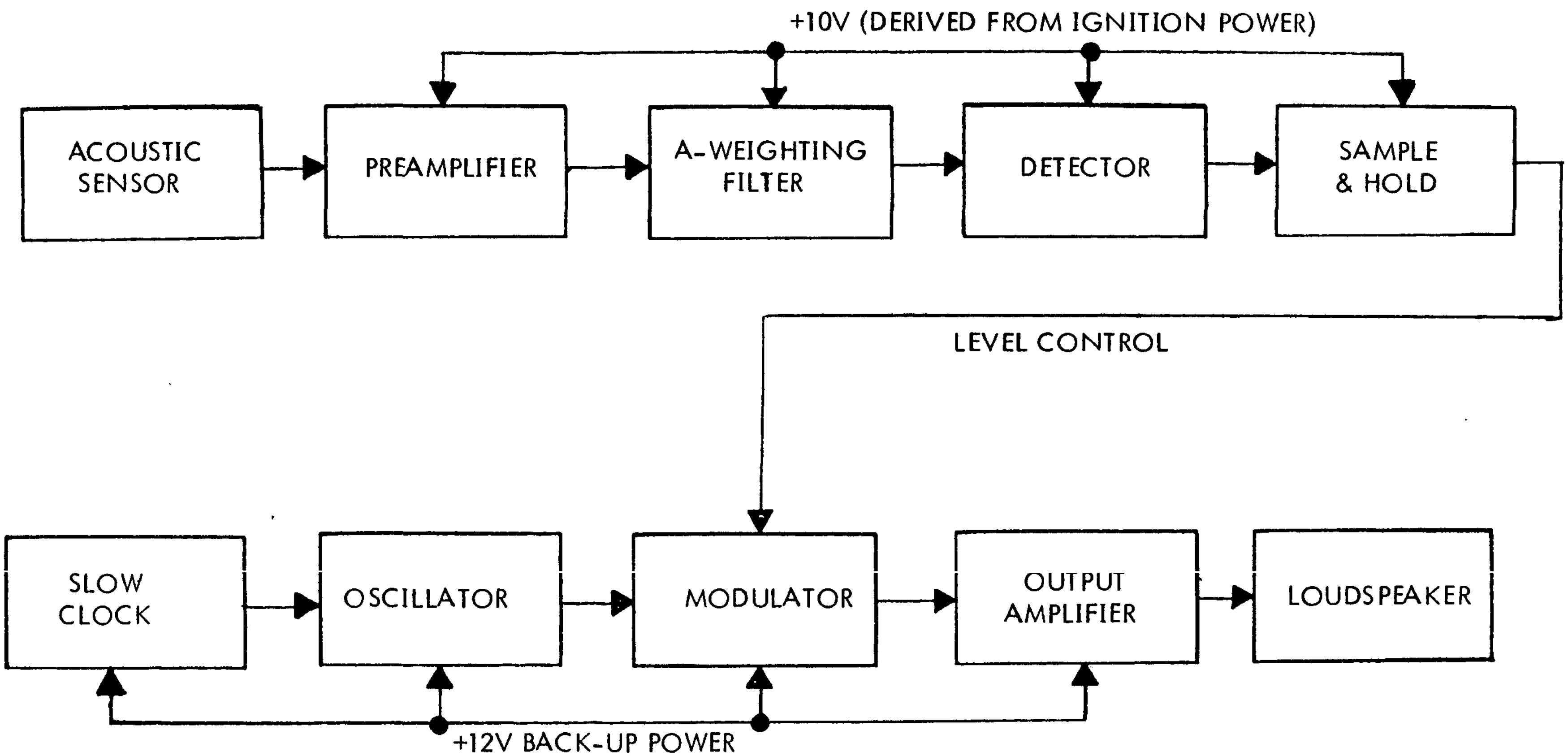


FIGURE 6-1. FUNCTIONAL BLOCK DIAGRAM OF THE WARNING SIGNAL SYSTEM

Figure 6-2 illustrates the peak warning signal levels behind the vehicle relative to the detected ambient level and the threshold of audibility. The levels shown appear to represent an increase over earlier design levels; this is primarily due to the change to a linear relationship between the ambient and signal, but also due to signal reinforcement from pavement reflections. Other characteristics of the system will be discussed following the circuit description, a diagram of which is shown in Figure 6-3.

6.1 Circuit Description

The input stage is a differential amplifier biased about the +6V point. The two 0.047 μF capacitors are needed to isolate the bias from the output transistors when they are off, and are the first stage of the input signal filter. The 10K input resistors are necessary to limit the input current to a safe level when the output stage is on. The cutoff frequency of this first stage is approximately 300 HZ to limit the low-frequency response. The gain of this stage is set to 20 dB.

The second stage is a single-ended gain stage producing approximately 28 dB gain, with a cutoff frequency of 200 HZ controlled by the 0.03 μF capacitor and the 33K input resistor of the second stage.

The third stage has a variable gain which ranges from 21 to 37 dB which controls the ambient to signal ratio of the system. The 0.1 μF capacitor with the 10K resistor is the final stage of the input signal filter. Detection is accomplished in this stage by biasing the output to zero volts. This eliminates the 0.6V offset that would occur if a diode had been used, and increases the dynamic range of the DC signal.

The fourth stage is a DC amplifier stage used to optimize the DC signal for the sample and hold circuit. An integrating filter is included in this stage to provide a smoothing time constant. The 0.1 μF used gives a value of 0.03 second which, being quite short, keeps the decay time short enough that signals will not build up if the device is rapidly switched on and off. The output of this stage is also biased to zero volts to give the maximum dynamic range of DC values. The diode in the feedback loop serves to allow the output to reach exactly zero volts.

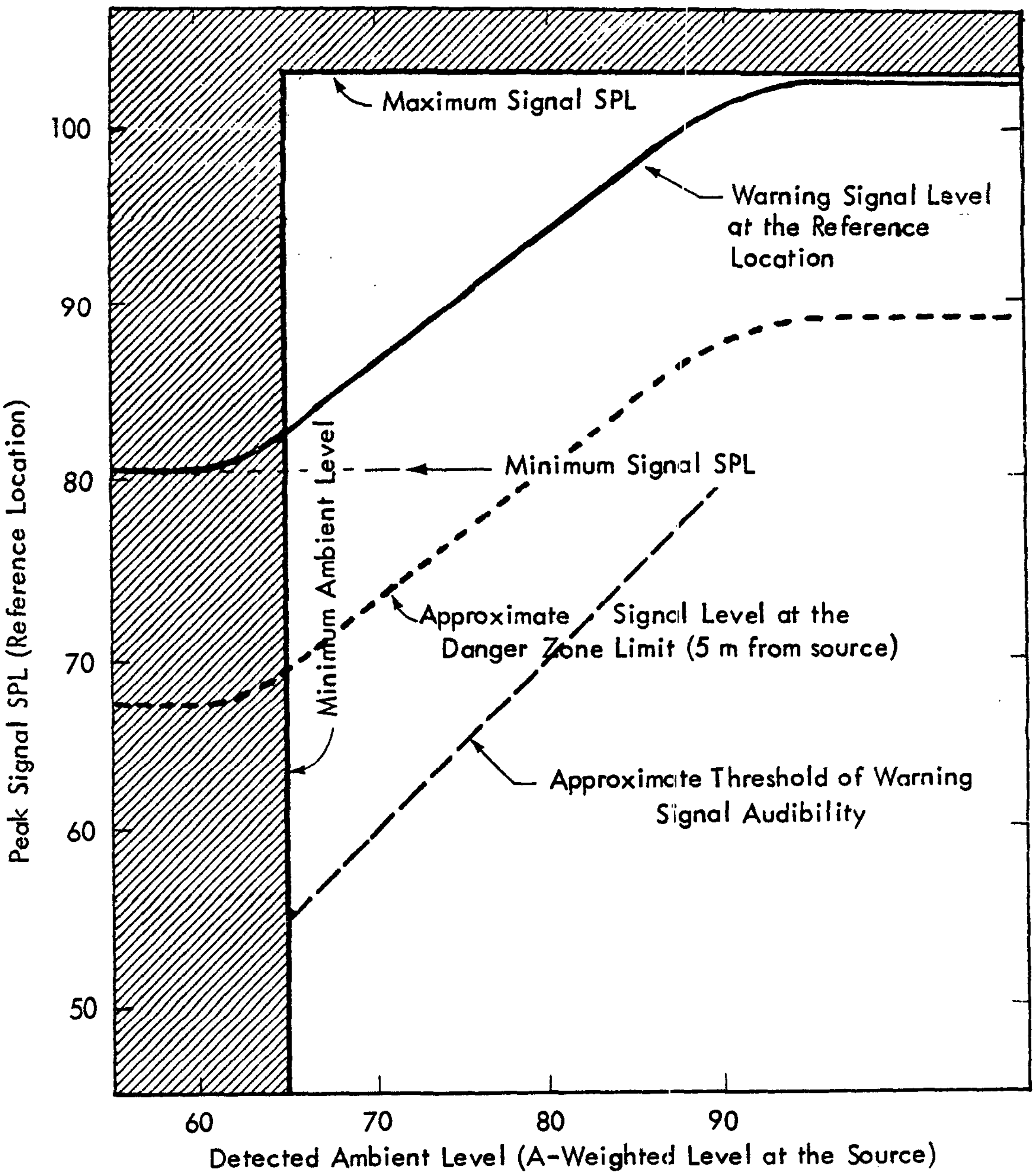


Figure 6-2. Illustration of the Warning Signal Level Parameters

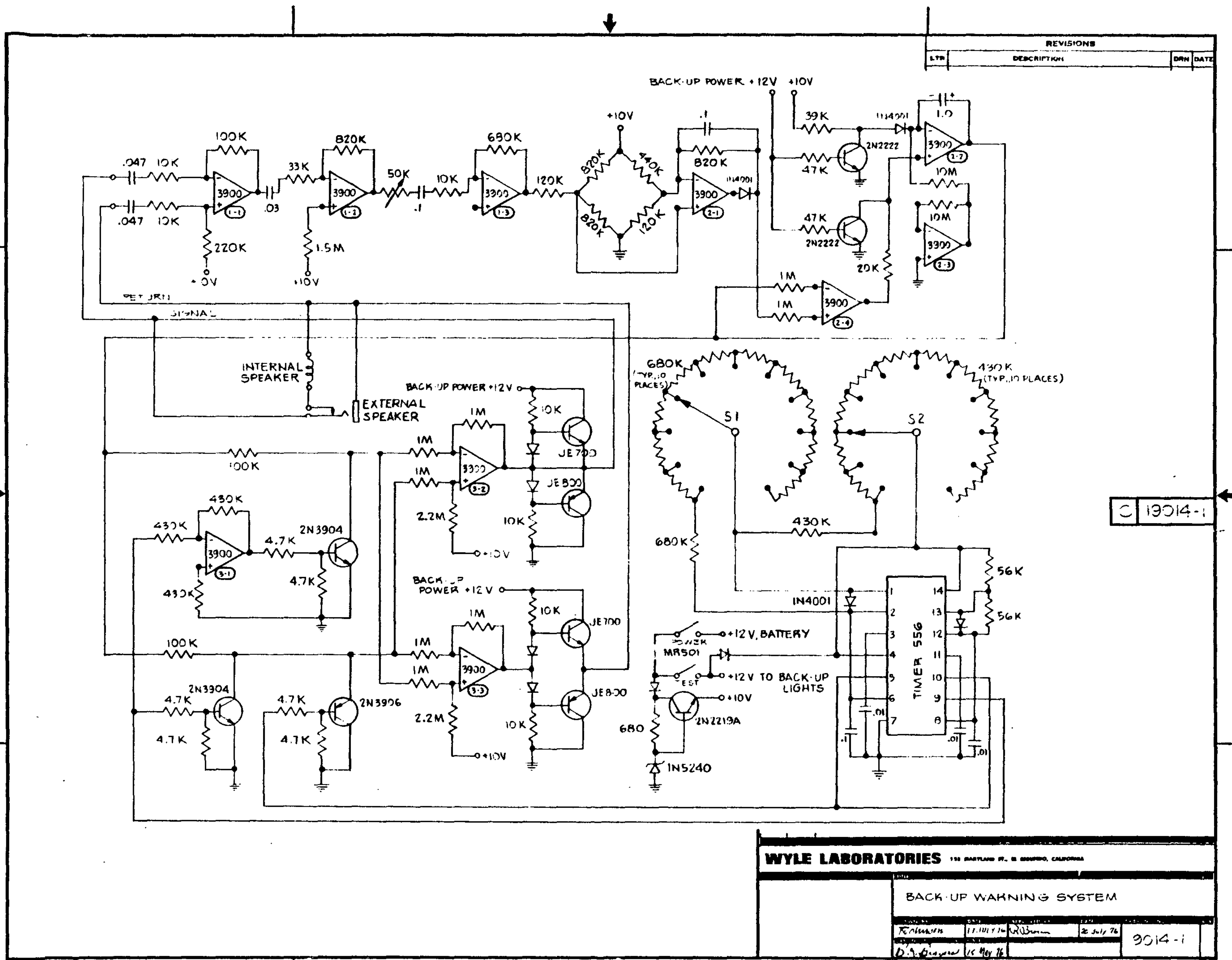


Figure 6-3. Circuit Diagram of the Warning System

The sample-and-hold circuit is composed of three operational amplifiers designated Q2-2, Q2-3, and Q2-4. Amplifier Q2-3 is used to balance the current flowing into Q2-2. Since they are on the same monolithic chip, their input current will closely match. This technique reduces the external input current into Q2-2 to a very low level and can be trimmed if necessary by adjusting the midpoint of the two 10 MΩ resistors. The input is switched by the two 2N2222 transistors. Q2-4 buffers the input and compares the output of Q2-2 with the input and causes it to track. The sampling capacitor is a 1.0 μF tantalum which allows hold times of several minutes.

The 1250 Hz oscillator and the timing circuit are constructed utilizing a 556 timer IC. This chip contains two separate timer circuits which are used to produce the square wave and control the on-off times.

The first half of the 556 timer (pins 1 thru 6) is used to control the on-time and off-time of the square wave tone. Two rotary switches have been utilized to provide varying resistances R_{a1} and R_{b1}. The diode across R_{b1} allows duty cycles of less than 50%. The on time and off time for the circuit are given by:

$$T_{on} = (0.69)\,(R_{a1})\,(C_1)$$

$$T_{off} = (0.69)\,(R_{b1})\,(C_1)$$

The output of this "slow clock" is fed to the reset (pin 10) of the other half of the 556 timer to turn the 1250 Hz oscillator on and off. This oscillator is constructed with two 56K resistors producing a 50% duty cycle. The output of this "fast clock" is a 1250 Hz square wave.

The actual square wave output tone is generated by modulating the DC output of the sample-and-hold circuit with the two 2N3904 switching transistors. The operational amplifier Q3-1 is used to invert the output of the fast clock with unity gain so as to produce equal but out-of-phase inputs to the next amplifier stage. The 2N3906 transistor turns off the second output when the oscillator is turned off by the slow clock.

The modulator is followed by a pair of differential drivers Q3-2 and Q3-3. These are biased at 1/2 the supply voltage and drive the bridge connected Darlington outputs. The bridge connection quadruples the output power available at 12V into 8Ω and eliminates the need for a large DC blocking capacitor in series with the speaker. This amplifier is capable of delivering over 6 WATTS at 12V supply levels.

A simple 10V regulator is used to supply IC-1 and IC-2 and eliminate electrical noise on the battery line. IC-3 and the 556 timer are operated directly off the 12V back-up supply to maximize output; because of this, the supply must be a low impedance as the current pulses drawn by the output circuit are quite large.

6.2 Warning System Characteristics

Important characteristics of the warning signal system will be described. The parameters shown are derived from measurements of the system used for the evaluation tests.

The frequency response of the loudspeaker operating as a microphone is shown in Figure 6-4. The response is not smooth, an expected result for an inexpensive loudspeaker, but is more than adequate for the application.

Directivity of the warning signal in the region behind the vehicle is a relatively complex parameter. The signal is essentially a pure tone, thus it is subject to severe reinforcement and cancellation due to reflections, especially from the hard pavement. The horizontal directivity was measured with the device mounted on the test vehicle at a height of 15" from the pavement. The directivity pattern is illustrated in Figure 6-5, with variations caused by ground reflections illustrated in Figure 6-6. The combined effects of attenuation, signal reflections, and directivity variations will be discussed further in Section 6.5.

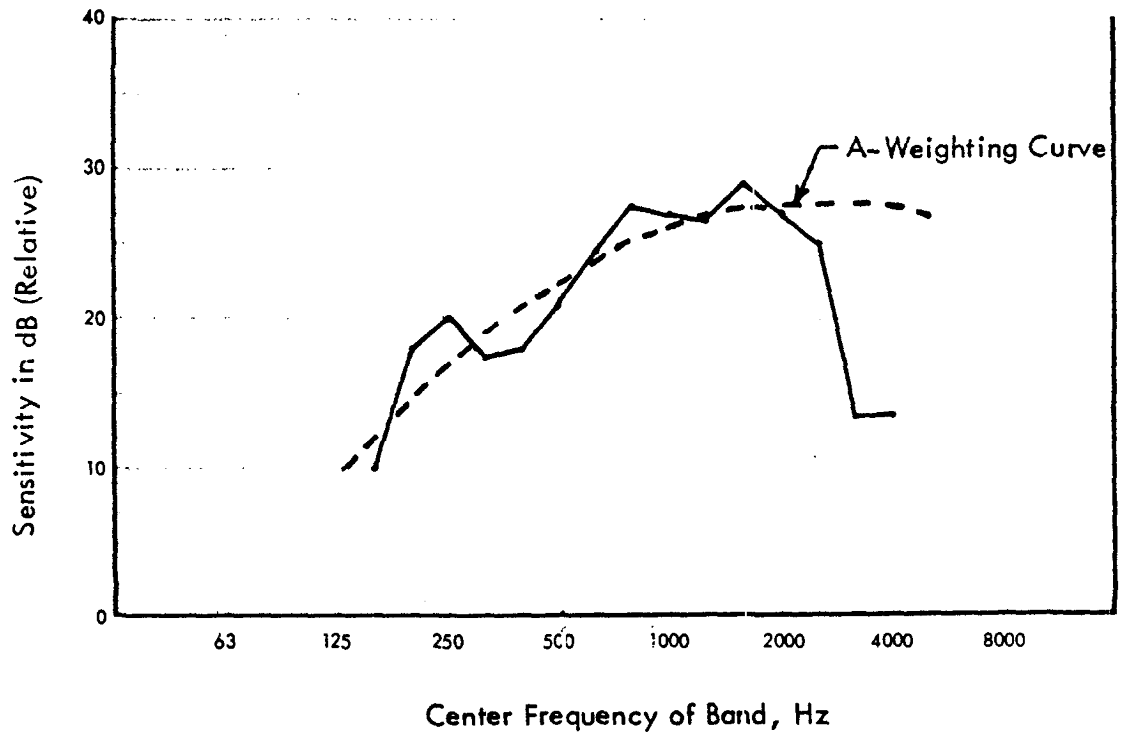


Figure 6-4. Frequency Response of the Acoustic Sensor. Measured with 1/3 octave bands of pink noise.

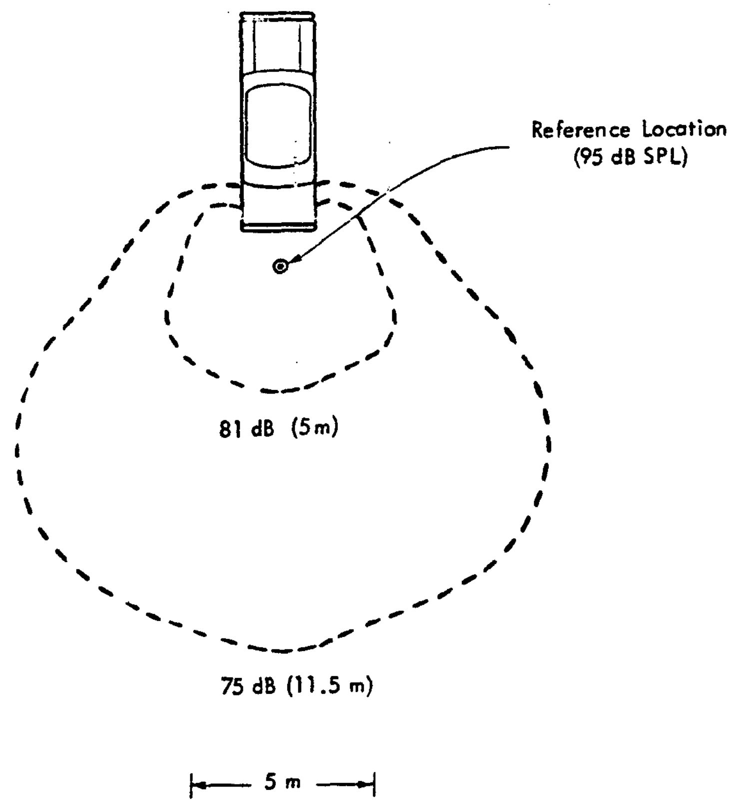


Figure 6-5. Directivity of the Warning Signal System. Dashed Lines are Contours of Equal Sound Pressure Level.

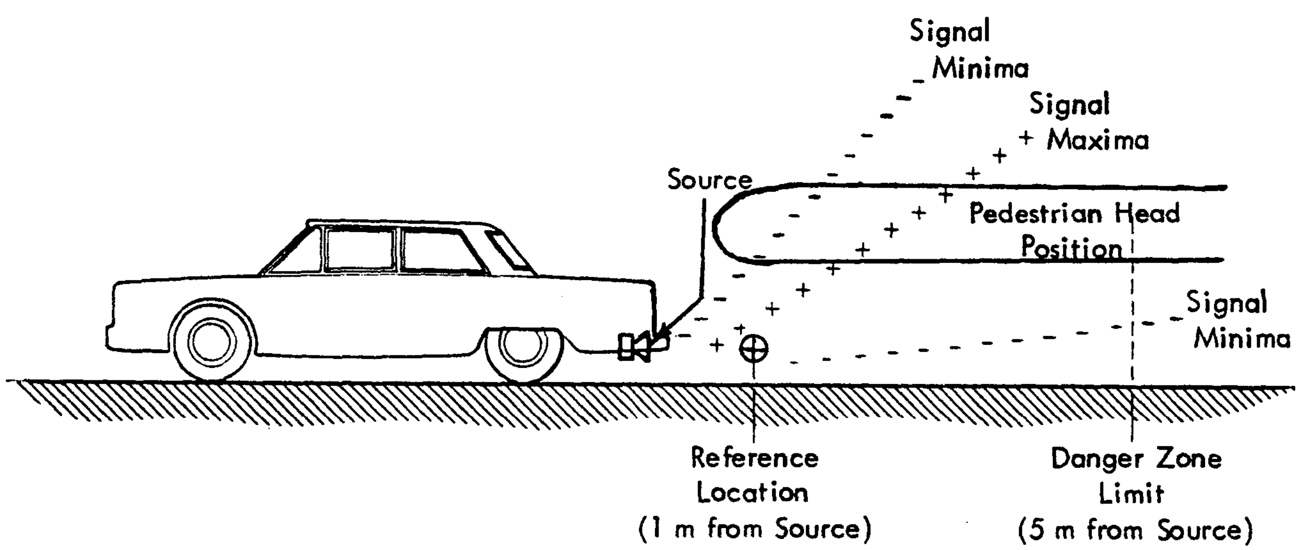


Figure 6-6. Illustration of the Signal Level Variations in the Vertical Plane Behind the Vehicle.

Input power requirements for the system are nominal: during receiving only 23 ma at 12 volts are required. When driving the loudspeaker at maximum output levels, input current pulses are approximately 2 amps peak to peak.

6.3 System Installation and Operation

The warning signal system is completely self-contained requiring only a 12V DC supply which is normally available in most vehicles. It contains an internal loudspeaker which may be used for demonstration purposes and a phone jack allows connection of an external speaker, which disconnects the internal unit. Two rotary switches control the on and off time of the pulsed tone over a range of 10 to 1.

Installation of the system in a vehicle is accomplished by connecting the +12 Volt battery lead to the barrier strip, connecting ground to the vehicle body, and connecting a lead to the back-up light circuit. The external loudspeaker should be mounted at the rear of the vehicle facing backward. On some vehicles it may be mounted just below the bumper to make it least conspicuous. If a permanent installation is being made, the +12 Volt power should be tapped following the ignition switch. When the system is connected as described here, it will operate using the three toggle switches or by leaving the main power switch and the warning signal switch on and operating the vehicle normally.

On and off times of the warning signal are controlled by setting the positions of the two rotary switches. Table 6-1 lists the duration times for each switch position. Any combination of on and off times are available by selecting the appropriate positions. Evaluation of the system was performed with S1 set to position 3 and S2 set to position 2.

Once the system is installed, it should be calibrated. The best method is to choose a quiet location where the idling vehicle will control the ambient at the speaker. With a sound level meter measure the A-weighted noise level at the speaker location. Activate the warning signal and measure the signal level at 1

Table 6-1

Warning Signal Tone - On and Off Time for Each Switch Position

Switch S1 or S2 Position	Tone Off Period (S1)	Tone On Period (S2)
1	0.065 sec	0.042 sec
2	0.131	0.095
3	0.200	0.142
4	0.267	0.190
5	0.336	0.236
6	0.402	0.283
7	0.468	0.327
8	0.526	0.368
9	0.595	0.420
10	0.662	0.463

meter directly in line with the speaker. The sound level meter will indicate a level approximately 5 dB below the desired peak signal level which can be read off the curve of Figure 6-2. For example; if the ambient level is 65 dBA, the measured signal level at the reference location should be approximately 76 dBA. Sensitivity changes may be made by adjusting the 50K, 10 turn potentiometer on the system circuit board, accessible through a hole in the case.

6.4 System Design Comments

The first breadboard of the system utilized an electret microphone as the acoustic sensor. Electret microphones, of the type used, have become quite common, being used extensively in hearing aids and inexpensive tape recorders. If a microphone of this type were used, good environmental protection would be required. It was felt this would severely limit the acceptability of the design.

Using a microphone in the circuit did allow a valuable design concept to be used. An electronic switch was used to deactivate the microphone circuit during bursts of the loudspeaker, a period of 100 milliseconds. The microphone would thus "listen" between each burst of the warning signal and continuously readjust the signal level to track the ambient. This design feature would be extremely beneficial; the signal would obviously be less annoying because it would not exceed the preset ambient-to-signal level, and it would also be less likely to result in the signal being unheard in a suddenly increased ambient behind the vehicle.

The second generation breadboard eliminated the microphone but maintained the continuous level adjustment. A single loudspeaker, functioning as a microphone between output signal bursts, was used. Again, an electronic switch was required to deactivate the microphone circuit during output signal bursts. The circuit was never completely operational, as the timing control of the preamplifier was critical due to the loudspeaker ringing after being driven with each tone burst. After each burst, the loudspeaker would continue to oscillate or ring for up to 50 milliseconds, depending on the drive amplitude. If the microphone circuit was activated immediately after the output burst, it would receive a large signal not due to the acoustic ambient. Eliminating this transient required additional complexity in the timing circuitry.

This circuit also utilized a variable transconductance amplifier, a relatively new development in integrated circuits. It was used for amplifier switching and gain control functions but it was not easily adaptable to this single supply amplifier design.

Because of its complexity, the continuously adjustable output level feature was finally abandoned. A system design of this type would be ideal, as it could be powered from the back-up light circuit alone and would continuously adjust itself to the ambient level.

The final system design described earlier was the best choice, considering the many options available at this time. Trade offs between system complexity, circuit element costs and potential environmental protection problems, were the guiding criteria of the design.

6.5 Propagation of the Warning Signal

There are two conflicting aspects to the use of an audible back-up warning signal on automobiles. First, we wish to produce a signal level which will adequately warn a pedestrian who is in danger from the backing vehicle.

And in conflict with this requirement, we must minimize the annoyance to the remainder of the population.

Of course, there is some educational benefit to be derived in having a signal which is audible to much of the populace; they would then become familiar with the device and its intent. The educational process may be brief, evidence the publics' rapid familiarity with seat belt warning signals. For this reason, the signal should be optimized to warn the target population and simultaneously not annoy the general population.

The peak warning signal output level has been selected to be approximately equal to or slightly above the ambient level in the region 5 meters from the rear of the vehicle. Exact values for this difference are impossible to assign due to the following:

- In quiet ambient areas, the automobile self-noise controls the signal level. This would result in an elevated signal level relative to the pedestrians ambient.
- A loud, short term noise, possibly from a passing vehicle could result in an artifically high signal level.
- If the ambient level was minimum when the signal was activated, the signal could be unheard when the ambient increases.

6.5.1 Signal Propagation Near the Vehicle

A warning signal frequency of 1250 Hz has been selected with the intensity controlled by a microphone monitoring the ambient level up to the instant the car is placed in reverse. Propagation of the warning signal in the near vicinity of an automobile (out to the danger zone limit of 5 meters) will be highly variable due to reflections and shadow effects from close-by structures and vehicles. Based upon the relationship between the ambient level and the warning signal level (illustrated earlier in Figure 6-2) there will be a condition where the signal will be only about 12 dB above the threshold of audibility. Of course these conditions exist straight back from the vehicle at the extent of the warning zone. The source directivity (shown in Figure 6-5) cause signal levels at right angles from the vehicle rear to be approximately 6 dB lower than straight back.

If it is assumed the ambient level in the vicinity of the vehicle is constant, the warning signal level will seldom exceed this ambient noise level out to the limit of the danger zone. Thus the signal from one vehicle would seldom affect the level control of a system on a second vehicle. This influence of other vehicles upon the level control mechanism was studied in a large parking lot. This observation to be described in the next section indicated that seldom does more than one car back at a time, and when they do they are separated by several rows of parked cars.

6.5.2 Propagation Within the Community

We have reported the noise level extant at various types of community locations and the level variations to be expected were portrayed in Figure 4-3.[20] To exactly determine the signal level in the near region of the test vehicle during the system evaluation was not a feasible task.

Audibility tests were performed at different parking locations to determine the distance of signal perception. The results were highly variable, dependent on the fluctuations of the ambient at both the vehicle and the receiving location. Generally the signal was only barely audible at distances of 150 feet. Variability of this distance was also due to obstacles in the near vicinity of the vehicle.

The factor of multiple vehicles backing simultaneously was also examined. A large parking lot in a commercial shopping area was carefully watched for a period of about 10 minutes. The lot could hold almost 600 cars and during the observations, approximately 300 cars were present.

During each minute of this period a maximum of 2 vehicles at a time were backing, with several rows of parked cars separating them. In the 10 minute period a total of 9 vehicles backed. This data sample, taken at midday should represent the average activity. Store closing times, and sale days would likely result in more backing activity but the observations indicated the annoyance factor in this area would be minimal.

To estimate the impact of the warning signal on the community A-weighted energy average noise level (L_{eq}) we must consider, in addition to its amplitude, the duty cycle of the signal and the activation period of the warning.

The warning signal duty cycle has been defined: a burst of 0.1 second duration followed by 0.2 second of silence. This implies that only one-third of the acoustic energy is emitted as compared to the case when the signal is on 100 percent of the time. A reduction of one-third in acoustic energy corresponds to a level reduction of about 5 dB below the signal peak level. Thus, this correction must be applied to the energy average estimation.

Based upon observations made of drivers preparing to back, described in Section 4.4, it is estimated that an average duration for backing a vehicle would be approximately 7 seconds. An estimate of the number of vehicles backed within any given hour would be difficult to assess. At some locations, such as following a sporting event, several hundred could be backed within a short period. However, at an average parking site, during a busy period of the day, a conservative estimate may be that between 20 to 50 vehicles per hour would be backed. This would then result in 140 to 350 seconds of warning signals being generated within the parking area, corresponding to 3.9 percent to 9.7 percent of exposure time, respectively. Thus, in order to affect the L_{eq} during this average hour, the noise level produced by the warning signals must approach within:

For 3.9 percent exposure time -

$$14 - 6 = 8 \underline{\text{ dB}}$$

and for 9.7 percent exposure time -

$$10 - 6 = 4 \underline{\text{ dB}}$$

above the existing L_{eq} in the parking area. The 6 dB correction in the above calculation allows for the difference in levels required to produce an increase of 1 dB in the existing level. When the signal duty cycle correction is applied, the final values are between 13 dB and 9 dB as the range of differences required for the peak warning signal level to exceed the L_{eq} and thus affect it.

It was shown in Figure 6-2 that the warning signal does not exceed the ambient A-weighted noise level except for a small distance from the vehicle.[20] It would therefore appear to be a minimal problem of the warning signal annoying an appreciable segment of the population except under rare special conditions.

6.6 Specification of the Warning Signal

This specification establishes the characteristics of an audible automobile back-up warning device. The device will incorporate a transducer to measure the ambient background noise level and establish the signal output at a predetermined level above the ambient. It is intended for use on private automobiles and other vehicles which normally operate on public streets and thoroughfares.

6.6.1 Mounting

The device shall be mounted at the rear of the vehicle and be protected to withstand normal wear and tear, and adverse environmental conditions. It shall be mounted with the sound source projecting the signal rearward and unless the source also acts as the microphone, this sensor will be incorporated as an integral part of the assembly.

6.6.2 Power

When ignition power is available, the microphone section of the system shall be activated and monitor the acoustic noise level. When the gearshift is placed in reverse, the warning signal shall be activated and remain on until the gearshift is disengaged from reverse or until ignition power is removed.

6.6.3 Device Characteristics

6.6.3.1 Microphone Circuit

The frequency response of the microphone section of the device shall approximate the characteristics of a Type 3 sound level meter as described in

ANSI S1.4 - 1971. The A-weighted relative response from 100 Hz to 2 kHz shall be met for sound arriving at perpendicular incidence. The tolerance for the response shall be ±5 dB.

The electronic noise level of the microphone circuit, when measured in a quiet environment, shall be equivalent to less than 55 dB SPL.

6.6.3.2 Control Voltage

The microphone section shall produce a control voltage proportional to the measured input SPL. The input SPL will range from 65 dB SPL (10 dB above the internal noise floor) to a maximum level of 85 dB. As an example, control voltages for these two SPLs would be 100 mv and 1 volt respectively.

6.6.3.3 Warning Signal Format

The warning signal shall be a pulsed sinusoid (or square wave) at a frequency of 1250 Hz (±200 Hz). The signal on-time shall be 100 m sec (±20 m sec) and the signal off-time shall be 200 m sec (±40 m sec). Rise and fall times of the signal shall be less than 5 m sec. The first pulse of the warning signal shall occur within 100 m sec of the time the auto is placed in reverse and the system shall continue pulsing until the gearshift is disengaged from reverse or until ignition power is removed.

6.6.3.4 Warning Signal Output

Output of the warning device shall be measured at a horizontal distance of 1 meter behind the rearmost point of the vehicle at the same height as the device. At this reference location the peak SPL shall be as indicated in Table 6-2 when measured according to paragraph 6.4. The values of the control voltage shown in this table are not required; it is only necessary to maintain the relationship between the input SPL and warning signal SPL.

Table 6-2

Warning Signal System Parameters

Input SPL, dB	Control Voltage* Volts	Peak Warning Signal SPL at Reference Location dB re 20μPa
65 and less	0.1	80
70	0.18	85
75	0.32	90
80	0.56	95
85 and greater	1.0	100

*These values are shown for illustration purposes only.

6.6.4 Acoustic Measurement Procedures

Sound pressure level output of the device shall be measured according to the procedures described in paragraph 2 of ANSI S1.2-1971, "Method for the Physical Measurement of Sound." Measurements shall be made with a microphone system or sound level meter conforming to the specifications of a Type 2 General Purpose Sound Level Meter set forth in ANSI S1.4-1971, "Specification for Sound Level Meters." If necessary, appropriate corrections will be applied to account for the warning signal duty cycle.

7.0 EVALUATION OF THE WARNING SIGNAL SYSTEM

The effectiveness of the warning signal was measured by performing a series of evaluation tests at locations where pedestrians are typically in danger from backing vehicles. Four levels of effectiveness were measured. Two of these levels are defined in terms of the subject's verbal report, and two in terms of the subject's non-verbal behavior. The criterion of effectiveness becomes more stringent from the lowest level (1) to the highest level (4). The four levels of effectiveness were:

Verbal Reports

(1) Subject reports having heard the signal (signal detectability).

(2) Subject attributes the signal to the appropriate source (signal discrimination).

Non-Verbal Behavior

(3) Subject emits an observational response, e.g., glances at the appropriate automobile.

(4) Subject executes an avoidance response, i.e., stops walking, changes course, speeds up, etc.

The criteria for success of the system was that the subject either reports having heard the signal or that the subject was observed to notice the signal. This process of alerting was judged successful if 95 percent of the target population responded favorably.

One problem in interpreting the evaluation of the back-up warning device is that pedestrians do not presently know the meaning of its signal; i.e., they would not attribute the sound of the device to a backing automobile without additional information or other cues. The effectiveness of the device would therefore be significantly under-estimated if one considered only the percentage of cases in which the subject executes an avoidance response.

In addition to determining whether the device was successful according to the criteria discussed above, the field experiment determined its effectiveness relative to a control condition. The percentage of cases in which the device satisfies each of the four criteria mentioned above were compared for an experimental and a control treatment. In the experimental treatment, the subject was exposed to the warning device plus all the customary cues of a backing automobile (except movement of the automobile). The control condition exposed the subject to the same conditions as the experimental treatment, except that the warning signal was omitted.

7.1 Evaluation Method

During each test sequence of the evaluation tests the driver of the test vehicle would sit, apparently unaware of the pedestrian activity. In some cases the rear view or side mirror was used to determine when the subject was entering the test area. In others, the interviewer or observer signalled the driver to start the sequence. The driver used care to avoid looking at or making eye contact with the subject. Even with these precautions, some subjects reported in the interview that the driver was aware of their presence and thus they felt no threat from the vehicle.

Tests were performed both with the device and without it:

- With the device -- The test vehicle engine was started and allowed to idle. When the subject reached the danger zone boundary, usually 5 to 10 feet before the accident zone, the warning signal and back-up lights were activated and left on until the subject passed the vehicle.
- Without the device -- The sequence timing was identical, engine started, and then back-up lights only were activated.

For both sequences, brake lights were also activated with the back-up lights, but the gearshift was never placed in reverse. A microphone was mounted above the rear bumper and recordings of the acoustic levels, ambient and signal, were made during each test sequence.

The observer and interviewer took positions on opposite sides of the test zone to allow them to best observe each subjects reaction to the tests. They intentionally tried to be inconspicuous to minimize the subjects being distracted. They also avoided obviously watching the subject before each test. When the subject passed the vehicle, at the end of the test sequence, the interviewer would approach the subject and conduct the interview. Reactions to the interview were varied.

7.2 Subject Selection

At the request of the National Highway Traffic Safety Administration, Wyle studied 160 back-up accidents and extracted data relevant to the potential effectiveness of a back-up warning device. These data, presented in Section 2.0 of this report, provide a logical basis for the design of experiments to evaluate the effectiveness of such a device. Many factors bear on the accident cause and its prevention. A large percentage of the pertinent factors were incorporated into the experimental design but some were difficult to guarantee as controlling elements of the experiment. The previous research has shown that both age and sex are determiners of risk in the back-up situation and can influence one's capability to respond to a warning device. Table 7-1 shows a breakdown of the actual accident victims by age and sex; percentages shown were used as a guideline for subject selection.

Table 7-1
Accident Victims' Age and Sex
(percent of total)

	Young (0-24)	Middle (25-44)	Older (45+)
Male (58%)	22	14	23
Female (42%)	15	10	16
TOTAL	37 %	24 %	39 %

During the evaluation tests subjects were selected from available pedestrians at each site. Although some percentages varied from those desired, the values obtained, illustrated in Table 7-2, were not unreasonably distributed.

Table 7-2

Evaluation Test Subjects' Age and Sex

(percent of total)

	Young (0-24)	Middle (25-44)	Older (45+)
Male (38%)	4	19	11
Female (62%)	15	17	31
TOTAL	19%	36%	45%

Details of the data shown in Table 7-2 are derived from the data in Appendix B. Ages shown are estimates based on observations of the testing personnel.

7.3 Site Selection

A major factor in the cause of a back-up accident is the type of location. Table 7-3 shows the back-up accident distribution by type of location derived from Section 2.0. These data show that nearly two-thirds of all accidents occur in parallel parking situations or when backing out of an alley or driveway.

Table 7-3

Accident Locations

Location	Percent of Accidents Accounted For
Mid-block, near curb	36
Alley or driveway	29
Off-street parking areas	13
Crosswalk	19
Other	3
TOTAL	100%

During the evaluation tests observations were made at locations as illustrated by the distribution shown in Table 7-4.

Table 7-4

Distribution of Test Subjects by Age and Site Locations (74 Subjects)

Percent of Subjects Observed

Type of Site	Age			
	0-24	25-44	45+	Total
Mid-Block	7%	8%	5%	20%
Alley or Driveway	0	11%	11%	22%
Parking Lot	0	4%	3%	7%
Crosswalk	12%	13%	26%	51%
TOTAL	19%	36%	45%	100%

The distribution shown in Table 7-4 does not exactly match the desired balance between types of sites but time did not allow sufficient observations at some of the more sparsely active sites.

The accident data, from Section 2.0, were also analyzed to determine the time of day most back-up accidents occur. The results indicated the peak incidence rates occur near lunchtime and in the late afternoon, but with some accidents occurring during all hours. The evaluation tests were mostly performed during the late morning to mid afternoon period, when pedestrian subjects were most plentiful at the sites.

Table 7-5 lists the test sites, their classification, and the number of subjects observed at each. Complete descriptions of each site are contained in Appendix C.

Table 7-5

Test Sites and Number of Subjects Observed During Evaluation Tests

Site Number	Site Location	Type of Site	Number of Subjects Observed
1	Sepulveda (North), Westchester	Crosswalk	25
2	Sepulveda (South), Westchester	Crosswalk	13
3	Karls Stationers, Westchester	Mid-Block	4
4	F. W. Woolworth, Westchester	Mid-Block	11
5	Boys Market, Hawthorne	Parking Lot	3
6	9th Street, Los Angeles	Alley	0
7	6th Street, Los Angeles	Alley	16
8	Sav-On, Westchester	Parking Lot	2
		TOTAL	74

7.4 Evaluation Test Data

This section presents data and data analyses from the field evaluation tests of the back-up warning device for automobiles. The effectiveness of the device was evaluated in terms of data gathered from behavioral observations and subject interviews in the field. The device would be considered successful if it were shown to have elicited a noticeable response and/or the subject indicated that he noticed the device in 95 percent of the tests.

The data were gathered on log sheets and later coded as shown in Appendix B. In the analyses that follow, the data for 74 subjects were tabulated to indicate the comparison of interest and the appropriate statistical test(s) follow. A total of 94 subjects were observed. The signal level was inadequate for the first six subjects tested with the device. For subsequent subjects, the signal level was higher in amplitude than for these first six. For 14 other subjects, the observational and interview data were inadequate.

Several types of data were gathered, but critical among these for testing the effectiveness of the device were the behavioral observations and interview data. Two observers carefully watched each subject as he passed behind the test vehicle. The observers were positioned so that they had different viewing angles. Thus, one observer may have seen an avoidance behavior while the other did not. After the test and interview, the observers discussed what each saw and agreed upon a pooled rating. The pooled ratings were used for the analysis that follows. The interview obtained data directly from the subjects as to whether they noticed the test vehicle or not. A subject was considered to have "noticed" if he exhibited a visual or physical response to the test vehicle, or stated during the interview that he noticed. Thus, if the subject was aware of the vehicle, but no response was observed, this subject was effectively warned and it was discovered during the interview. Not all subjects consented to an interview, and some subjects were not adequately observed because of traffic patterns (both pedestrian and automobile). Thus, there were 14 unknowns on both pooled rating and interview data in the 88 subjects. These subjects were excluded from the data analyses.

In Table 7-6 below, "Subject Noticed" were all of those who were given a pooled rating of 2 (visual response only) or higher (physical response) and/or gave a positive response on the interview when asked if they noticed the test vehicle or the warning device (when used). The data in Table 7-6 indicate: 1) that approximately 95% of the observed subjects noticed the test vehicle when the device was used, and 2) the tests with the device resulted in significantly more subjects noticing than the tests without the device ($\chi^2 = 20.15$, df = 1, $p < 0.001$). The χ^2 value was calculated using the Yates correction for continuity as shown in equation (7-1), where a = 51, b = 3, c = 9, d = 11, and N = 74 from the table.[40]

$$\chi^2 = \frac{N\left([\, ad - bc \,] - N/2 \right)^2}{(a+b)\,(c+d)\,(a+c)\,(b+d)} \qquad (7\text{-}1)$$

where:

χ^2 is a value calculated to test a hypothesis that the changes in a situation had no affect on the variable measured.

a, b, c, d are table values.

N is the number of subjects.

df is the degrees of freedom.

p is the probability.

Thus, the back-up warning device satisfies the basic criteria of being 95% effective, and more effective than starting the car (back-up lights, engine noise, etc.) without the device.

Test	Subject Noticed	Subject Did Not Notice	Total
With Device	51	3	54
Without Device	9	11	20
Total	60	14	74

Note: Entries are frequencies (# of subjects).

Table 7-6. Overall Effectiveness

The population that was analyzed was distributed as shown earlier in Table 7-2. It was shown that most of the subjects were 25 years old or older, and that most of the subjects over 45 years old were women. The three subjects who did not notice the car when the device was used were one 25-44 year old and two 45+ year olds, all males, and all in the crosswalk location.

The two independent sets of observations (one from each observer) were matched by subject and a Kendall rank correlation coefficient was computed, where all physical responses were scored as 3, visual response only = 2, no response = 1.[41] Data from both observers were obtained for 70 test subjects. A correlation of $\tau = 0.75$ was found between the two observers. Using the fact that τ is approximately normally distributed for $N > 10$ (here $N = 70$), the observed $\tau = 0.75$ was found to be very significant ($p < .001$). Thus, there was a high degree of agreement between the observers.

Although the categories of slow, medium, and fast walking speeds were not defined precisely, the subjects were rated on their speed as they passed the test vehicle. Of the 74 subjects whose responses were known, 10 were classified as walking slowly, 54 were walking medium speed, and 10 were walking relatively fast. Table 7-7 shows the breakdown of walking speeds by the subject's noticing the test vehicle. All three subjects who did not notice the test vehicle when the back-up warning device was used were walking at medium speed. The rate of noticing across speeds is 80%, 81%, and 80% for slow, medium, and fast speeds - so walking speed (within this limited sample of data) does not appear to play a significant role.

Subject Reaction	Speed			Total
	Slow	Medium	Fast	
Noticed Test Vehicle	11%	60%	11%	82%
Did Not Notice	2%	14%	2%	18%
Total	13%	74%	13%	100%

Table 7-7. Noticing the Test Vehicle Versus Walking Speed

Table 7-8 presents the test data by location type.

The data show that all three subjects who failed to notice the test vehicle when the back-up device was used were in the crosswalk situation.

Test Location	With Device		Without Device	
	Noticed	Didn't Notice	Noticed	Didn't Notice
Mid Block	15%	0	1%	4%
Alley/Driveway	18%	0	4%	0
Parking Lot	5.5%	0	1%	0
Crosswalk	31%	4%	5.5%	11%
Total	69.5%	4%	11.5%	15%

Table 7-8. Test Data Versus Test Location

Of the 40 subjects with exposure to the device who responded to the interview question concerning hearing the device, 36 stated that they did hear it. For the three subjects who did not respond, two said they did not hear the device and no response to the question was obtained from the third. Thus, there were two subjects who responded behaviorally and yet stated that they did not hear the device. This raises the issue that some of the behaviors involved in crossing the street or similar activities may be so well practiced that the subject can respond to stimuli without fully realizing that he has done so.

Finally, 34 of the subjects who were exposed to the device expressed their reactions to the unusual sound. The results of this interview question are tabulated in Table 7-9. Over one quarter of the subjects who responded to the interview question concerning their reaction to the device thought it was a warning of some kind. Several of these thought it was a warning that the test vehicle was backing up. These reactions were with no prior exposure to the device or its intent and purpose.

The question of exactly where the pedestrian was alerted by the warning signal was critically examined. Based upon the observations during the system evaluation, only a few subjects noticed the signal before they were behind the vehicle. This does not necessarily mean they did not hear the signal before this, only that their visual response was late. A few subjective tests with willing subjects indicated the signal was easily audible at the warning zone limit. The results of the analysis of the system evaluation data was predicated on the thesis that any warning qualified as a positive response.

Reaction	Frequency	% of Total Reactions
Curious	18	53
Startled	0	0
Unaffected	7	21
Thought it was a warning	9	26
Total	34	100

Table 7-9. Subject Reactions to Back-up Warning Device

Behavioral Observation Analysis Conclusions

The device was shown to be significantly more effective in getting people to notice a backing vehicle than the combination of normal cues (backing lights, the starting of the motor, etc.). It should be noted that the cue of changing gears (slight movement of the car) was missing in all tests. Also, the device contributed to the test vehicle being noticed in almost 95% of the tests when the device was used. The subjects stated that their attention was usually drawn to the test vehicle by the device, out of curiousity or because they thought the sound was a warning.

A large percentage of the subjects were very cooperative, mildly curious, and attempted to be helpful. Many subjects would continue walking if the interviewer walked with them. Some subjects were not cooperative - too busy or in a hurry and would not respond to questions - felt their privacy invaded - objected to the tests - one completely ignored the interviewer. These subjects did not comprise more than about 10% of all the subjects, most were quite helpful.

Identification of the signal as a back-up warning was mixed. Some subjects knew exactly its purpose; others thought it was a seat belt signal, a doctor's paging system, one even thought it was a signal for the driver indicating the presence of a pedestrian behind the car (an interesting alternative).

7.5 Noise Data Analysis

Noise data was collected at each test site. The ambient noise level was recorded at the rear of the test vehicle and the noise level of the device was also measured at the same location. Laboratory analysis of these recordings produced ambient descriptors, test vehicle noise levels, and warning signal levels for each successful test sequence.

To illustrate the variations in noise level recorded at the rear of the test vehicle during the evaluation tests, Figure 7-1 shows four typical test sequences. In the time histories, the pulse before the signal is the vehicle engine starting after which the ambient may be controlled by the engine noise. These recordings were made with a microphone above the bumper while the system loudspeaker was mounted below the bumper.

The ambient levels existing during each test sequence are illustrated in Figure 7-2. Actual levels for each individual test are listed with the subject coded data in Appendix B. These levels, in general, represent a reasonable range of levels experienced at the types of sites used.

During the evaluation tests, recordings were made of the ambient levels. Table 7-10 lists the test sites and the computed energy-average of the noise level. These levels were obtained from data recorded between each test sequence. The data at these sites may be compared to the preliminary data obtained at 8 other test sites early in the program, shown in Table 4-3 earlier.

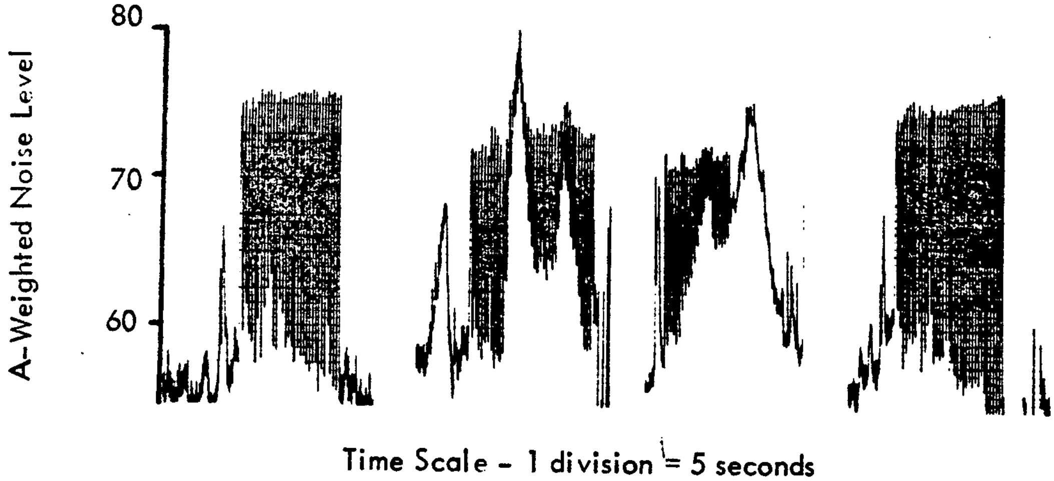


Figure 7-1. Time History Examples of the Warning Signal Test Sequence. Recorded at the test vehicle rear bumper.

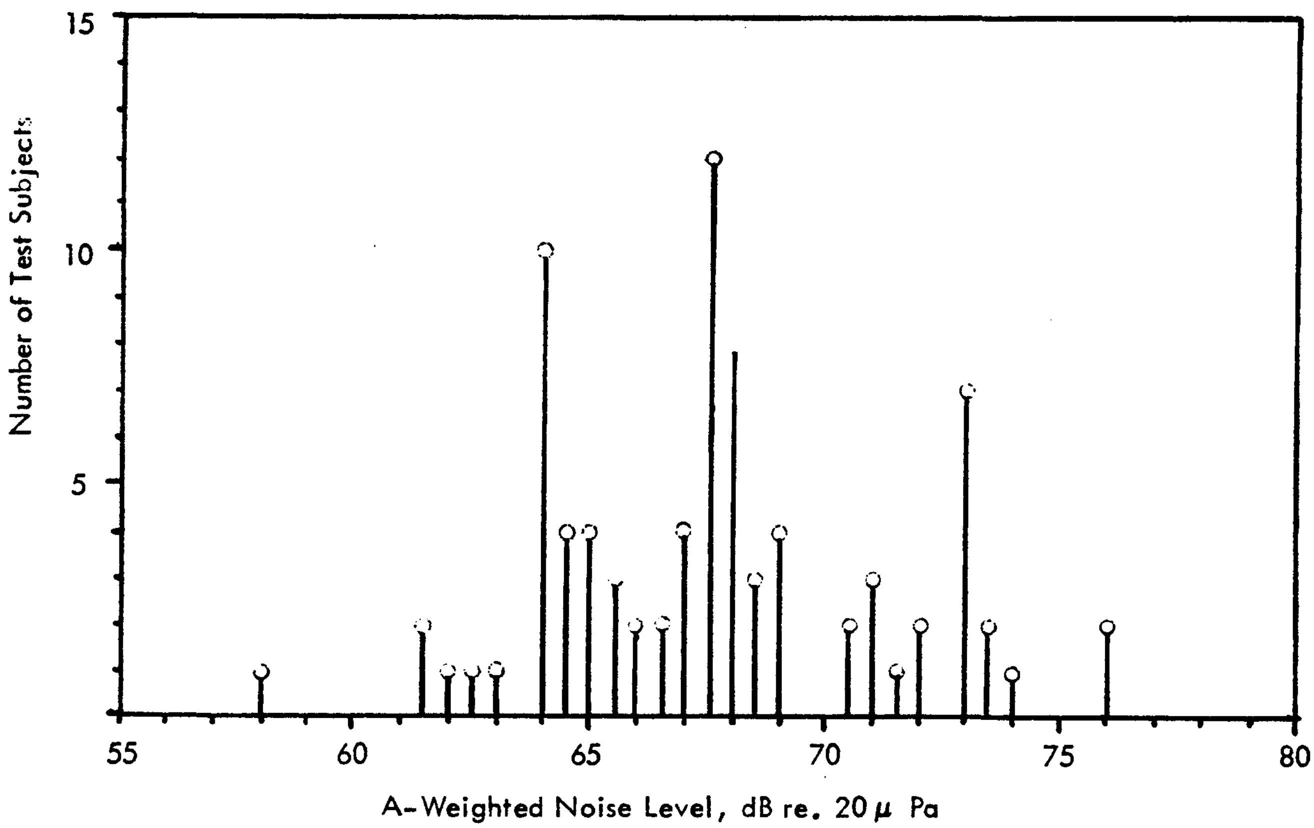


Figure 7-2. Recorded Ambient Level for the Field Evaluation Tests. Noise levels present before the vehicle engine was started.

Table 7-10

Summary of Ambient Levels Measured at the Evaluation Test Sites

Site Number	Site Location	Type of Site	L_{eq} (1)	Approximate L_5
1	Sepulveda (North)	Crosswalk	72.1	80
2	Sepulveda (South)	Crosswalk	67.6	69
3	Karls Stationers	Mid-Block	63.4	66
4	F. W. Woolworth	Mid-Block	67.4	72
5	Boys Market	Parking Lot	58.7	63
6	9th Street Alley	Alley	73.4	76
7	6th Street Alley	Alley	73.5	79
8	Sav-On	Parking Lot	68.9	73

(1) Energy-average noise level during intervals between test periods.

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APPENDIX A

SUMMARY OF BACK-UP ACCIDENT DATA

This appendix contains detailed data derived from a sampling of accident data from three different pedestrian accident studies. Analyses of the data listed is contained in Sections 2.0, 3.0, and 4.0 of the report. Code letters used to identify the accident cause, used for the analysis in Section 2.0, refer to the following definitions:

Pedestrians Who Would Not Benefit From an Audible Warning

a. Pedestrian saw vehicle, unable to avoid

b. Pedestrian saw vehicle, did not avoid

c. Young child (less than 5 years old)

f. Unoccupied vehicle

Pedestrians Who Would Likely Benefit From an Audible Warning

d. Pedestrian was not aware the vehicle was backing

e. Pedestrian saw vehicle too late to avoid

Table A-1

Summary of Pertinent Data from 34 Cases of Pedestrian Back-up Accidents
(The original data extracted from cases comprising the study of Reference 9)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
D 2001	F	63	Commercial Intersection	12/30/69	1715	1966	Slight Injury	Car parallel-parked, backed into pedestrian zone; pedestrian did not see car.	d
D 2007	M	41	Gas Station Lot	1/12/70	1725	1964	No injury	Car backing in station lot; attendant crossing behind did not see car move.	e
D 2055	M	5	Residential Intersection	4/23/70	1545	--	Serious	Car backed through intersection, struck child inroadway near corner.	d
D 2127	F	7	Near Intersection	2/16/70	1130	1959-61	Serious	Car backed over curb and struck child on sidewalk.	d
D 2086	F	4	Residential Driveway	6/9/70	1900	1966	Unknown	Car backing from driveway, child walking in same direction as car motion.	c
D 2043	F	22	Commercial Intersection	4/8/70	0135	--	Slight Injury	Car backing near intersection struck pedestrian in crosswalk.	d
A 7040	M	47	Residential Shopping Area Street	6/27/70	1940	1966	Slight Injury	Car backing to parallel park; pedestrian in crosswalk saw car but failed to take action.	b
A 6005	M	6	Residential Multi-Family	3/24/70	1150	1970	No injury	Car backing in mid-block; pedestrian darted out and did not see.	d
D 2162	M	76	Commercial Intersection	8/11/70	1810	1968 (truck)	Slight Injury	Car backing in street, backed into pedestrian zone.	d
D 2053	F	39	Commercial Intersection	4/17/70	1230	1964	Slight Injury	Car backing in street, backed near pedestrian zone.	d
9 2073	M	48	Commercial Mid-block	5/22/70	1630	1967 (truck)	No injury	Tow-truck backing, hit pedestrian jaywalking.	d
D 2153	F	23	Mid-block	8/5/70	0010	1964	Slight Injury	Car backed intentionally into pedestrian.	a
D 2124	M	25	Residential Intersection	7/14/70	1800	1964	Slight Injury	Car backing near intersection; pedestrian in crosswalk.	d
6 2073	M	58	Parking Garage Driveway	8/5/70	1750	--	Slight Injury	Car backed from parking garage; pedestrian on sidewalk.	d

Table A-1 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
6 1150	M	69	Commercial Intersection	8/12/70	1830	1960	Slight Injury	Car backing from alley struck pedestrian crossing alley.	d
A 5007	M	33	Commercial Loading Dock	4/10/70	1130	1969	Moderate Injury	Truck backed into scaffold injuring 3 men.	a
2 2170	F	72	Residential Multi-Family Mid-block	4/26/70	1335	1965	Serious Injury	Vehicle backing in street; pedestrian stepped from sidewalk.	d
B 2010	M		Commercial Alley	12/16/69	1100	1968 (truck)	Fatal	Vehicle backing in alley; pedestrian visibility obscured.	d
B 1058	F	2	Residential Multi-Family Mid-block	6/4/70	1800	1966	Moderate Injury	Vehicle backing in driveway; pedestrian playing.	c
1 1045	M	53	Residential Multi-Family Driveway	3/9/70	1800	1966	No injury	Vehicle backing near corner; pedestrian saw but failed to take action.	b
1 1042	F	54	Residential Multi-Family Mid-block	3/28/70	1420	1959 (truck)	Slight Injury	Vehicle backing near curb; pedestrian between parked cars saw too late.	e
1 1031	M	58	Commercial Mid-block	2/10/70	0540	1962 (truck)	Moderate Injury	Vehicle backing into parking space; pedestrian working on vehicle did not see.	d
1 1025	F	17	Commercial Mid-block	2/2/70	1945	1965	No injury	Vehicle backing into parking space; pedestrian crossing between cars, saw vehicle too late.	e
1 4024	F	51	Commercial Mid-block	8/18/70	1500	1968 (van)	Moderate to none	Vehicle backing into alley; pedestrian crossing alley.	d
6 1086	M	74	Residential Multi-Family Intersection	4/27/70	0740	1966	Slight Injury	Vehicle backing from parking space; pedestrian in crosswalk did not see.	d
B 3053	M	29	Commercial Gas Station Lot	6/2/70	1330		Moderate Injury	Vehicle backing in gas station; pedestrian working on car saw vehicle too late.	e

Table A-1 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
A 8054	M	30 35	Commercial Intersection	6/22/70	2340	1970	Slight Injury	Vehicle backing out of intersection; pedestrians crossing at corner.	d
A 8050	F	66	Commercial Intersection	6/17/70	1010	1966 (truck)	Moderate Injury	Vehicle backing; pedestrian crossing between cars near intersection.	d
A 8029	M	51	Industrial Mid-block	5/4/70	1605	1969	Moderate Injury	Vehicle backing from loading dock; pedestrian on sidewalk.	d
A 8044	M	20	Commercial Driveway	5/17/70	1040		No injury	Vehicle backing into lot; pedestrian crossing parking lot.	d
B 2036	M	50	Residential Single-Family Intersection	4/9/70	1415	1969	Slight Injury	Vehicle backing near corner; pedestrian just exited from vehicle.	e
B 4023	M	25	Residential Single-Family Intersection	4/22/70	1010	1954 (van)	Slight Injury	Vehicle backing from parking space; pedestrian crossing at corner.	d
3 3003	M	6	Apartments Mid-block	3/8/70	1620	1961	Moderate Injury	Vehicle backing into street from "driveway", pedestrian on sidewalk saw vehicle too late.	e
A 1019	F	54	Commercial Intersection	12/29/69	0925	1969	Fatal	Vehicle backing into street; pedestrian crossing saw vehicle but too shocked to move.	a

Table A-2

Summary of Pertinent Data from 99 Cases of Pedestrian Back-up Accidents
(original data extracted from Bio-Technology Study – Urban Accidents, Reference 17)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
7049	M	19	Parking Lot	4/30/74	1338	1968	No Injury	Car backed out of parking space into pedestrian.	e
5226	F	20	Near Intersection	4/14/74	1024	1966	Slight Injury	Car backed through crosswalk after passing intersection.	d
10127	F	85	Near Intersection	5/25/74	2015	1973	Slight Injury	Car stopped in intersection and backed up through crosswalk.	d
14303	M	60	Residential Mid-block	9/10/74	1204	1967	Slight Injury	Car parallel-parked, backed into pedestrian crossing street.	d
1625	M	28	Residential Open Lot	9/27/74	1550	1972	Slight Injury	Car in open lot backed into pedestrian on sidewalk.	d
1591	M	60	Gas Station Lot	9/20/74	0030	1964	Slight Injury	Car backing from pump struck pedestrian	d
1599	M	3	Residential Driveway	9/22/74	1700	1973	Slight Injury	Car backed into child playing in driveway.	c
14365	F	70	Residential Driveway	9/11/74	1500		Slight Injury	Car backing out of driveway struck pedestrian on sidewalk.	e
1791	M	18	Intersection	2/3/73	1200		Slight Injury	Car backed through crosswalk from intersection striking pedestrian in crosswalk.	d
3280	M	28	Residential Mid-block	2/28/73	1910		Moderate Injury	Car parallel-parked struck pedestrian while backing out of space.	e
663	M	25	Gas Station Lot	4/10/73	0740		Slight Injury	Car backing in lot struck pedestrian standing by another car.	d
7074	M	36	Gas Station Lot	5/5/73	1010	1973	Moderate	Car backed over pedestrian; pedestrian was working under another car.	d
934	F	77	Parking Lot	5/12/73	1025	1959	Slight Injury	Car backing struck pedestrian leaning over another car.	d
8199	F	76	Driveway	5/25/73	1600	1969	Slight Injury	Car backing into street struck shopping cart; pedestrian was walking behind cart.	e
1027	F	57	School Parking Lot	5/26/73	2013	1969	Serious		d
1149	M	52	Commercial Mid-Block	6/13/73	1630	1967	Slight Injury	Car parallel-parked struck pedestrian while backing out of space.	d
2264	M	38	Commercial Parking Lot	11/2/73	2330	1962	Moderate	Drunk driver backed into drunk pedestrian.	b

Table A-2 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
16892	F	5	Residential Driveway	7/3/74	1800	1964	Moderate	Car started in gear, backing into pedestrian.	d
18804	F	30	Commercial Intersection	7/26/74	1700	1967 (truck)	Slight Injury	Mail truck parallel-parked; struck pedestrian while backing out.	d
20228	F	79	Residential Alley	8/12/74	1510		Moderate	Unoccupied car rolled into pedestrian.	f
24036	M	1	Residential Driveway	9/19/74	1905	1974	Moderate	Child in driveway; fell under wheel of backing car.	c
597867	F	52	Hospital Parking Lot	11/7/74	1215		Slight Injury	Car backing in open area; struck pedestrian.	d
73948	M	29	Residential Mid-block	2/11/73	0315	1972	Fatal	Pedestrian unloading van from behind; driver's foot slipped hitting gas pedal.	a
096-038	F	5	Residential	2/24/73	1225		Moderate	Child sitting on curb; car backed over feet.	a
115301	M	83	Commercial Mid-block	3/5/73	0945	1967	Moderate	Car backing; pedestrian walked out from between parked cars.	e
150120	M	36	Residential Mid-block	3/24/73	0625	1970 (truck)	Moderate	Firetruck backing; struck fireman.	d
162740	F	32	Commercial Intersection	3/30/73	2210	1973	Slight Injury	Car backed through intersection; struck pedestrian in crosswalk.	d
196516	F	65	Commercial Mid-block	4/16/73	0900	1970	Slight injury	Car backing; pedestrian walked out from between parked cars.	e
242089	M	70	Commercial Mid-block	5/8/73	1005	1966	Moderate	Car backing to parallel park; pedestrian stepped off curb.	d
15	F	31	Residential Mid-block	5/1/74	1300	1974	Slight Injury	Car backing to park; pedestrian stepped behind car.	d
4	F	53	Commercial Driveway	5/4/74	1050		Slight Injury	Car backing from driveway; pedestrian crossing driveway.	d
17	F	30	Commercial Bus Stop	5/30/74	1033	1970 (truck)	Slight Injury	Truck, stopped in bus zone; backed into pedestrian boarding bus.	d
1	M	30	Residential Driveway	6/4/74	0820		Serious	Car backing out of driveway struck pedestrian on sidewalk.	d
00	F	38	Commercial Mid-block	7/13/74	0100		Moderate	Truck backing; knocked pedestrian down; truck moved forward, knocking pedestrian down again with front bumper.	d

Table A-2 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
0122	F	70	Gas Station Lot	8/10/74	1200		Slight Injury	Car backing out of station too fast; struck grocery cart and pedestrian.	a
24	M	27	Commercial Mid-block	11/6/74	1600	1964 (truck)	Slight Injury	Truck backing; struck pedestrian jaywalking.	d
91	M	13	Residential Mid-block	12/9/74	1630	1972	Moderate	Car parallel-parked; backed into pedestrian crossing street. Pedestrian was not looking.	d
64	M	30	Commercial Driveway	12/5/74	1220	1968	Moderate	Car backed into police officer. (Officer had originally stopped traffic to permit this car to back up.)	d
0722	M	5	Near Intersection	12/30/74	1200	1971	Slight Injury	Car, accidentally in reverse gear, backed into crosswalk.	d
6	M	66	Commercial Parking Lot	10/12/74	0955	1966	Slight Injury	Car backed into pedestrian; pedestrian was standing by cars in the parking lot.	d
A	M	5	School Driveway	1/19/73	1530	1964	Moderate	Car backing into street; struck pedestrian on sidewalk.	d
B	M	34	Residential Mid-block	6/11/73	0830	1970 (truck)	Slight Injury	Garbage truck backing; struck garbage man.	a
C	M	1	Residential Driveway	6/16/73	1705	1964	Fatal	Car backing; knocked pedestrian over with rear bumper and backed over him with front tire.	c
D	F	45	Residential Mid-block	7/7/73	2215	1970	Severe	Vehicle backing; struck pedestrian who had just exited from car.	a
E	M	17	Undeveloped Roadway	7/19/73	1410		Moderate	Tractor backed over pedestrian working on road.	d
02505	F	80	Residential Driveway	2/19/74	0804	1973	Moderate	Car backing out of driveway; struck pedestrian on sidewalk.	e
21	F	58	Commercial Mid-block	1/2/73	1020	1969 (truck)	Slight Injury	Truck backing at curb; struck pedestrian crossing street.	d
3	F	48	Commercial Parking Lot	6/15/73	2105	1972	Serious	Pedestrian sitting on hood of car behind. Car in front backed up, hitting pedestrian's leg.	a
F	M	41	Residential Intersection	9/21/73	0150	1964	Slight Injury	Car backing; struck pedestrian in middle of intersection.	d
23	M	23	Road Construction Area	10/3/73	1335		Serious	Truck backing; struck flagman, who was facing opposite direction, and ran over his leg.	d

Table A-2 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
34	F	35	Commercial Mid-block	11/30/73	1849		Slight Injury	Car backing out of parking lot struck pedestrian crossing street.	d
C0875	M	20	Residential Mid-block	1/20/74	0125		Slight Injury	Car struck pedestrian while backing up to flee pursuers.	e
C2746	M	25	Residential Mid-block	2/28/74	2305	1965	Moderate	Unoccupied vehicle rolled back, pinning pedestrian against another car.	a
C2040	F	6	Residential Driveway	2/13/74	1445	1969	Slight Injury	Car backing out of driveway; struck pedestrian standing in the street.	d
C1739	M	72	Commercial Crosswalk	2/7/74	1010	1972	Serious	Car backing from parking space; pedestrian in crosswalk.	d
C4028	M	5	Residential Driveway	3/28/74	1555	1964	Serious	Car backing out of driveway struck child.	d
C 5382	M	7	Residential Driveway	4/24/74	1710	1970	Moderate	Car backed out of driveway; pedestrian on skateboard darted across.	d
C5295	M	28	Commercial Driveway	4/23/74	1040		Moderate	Van backing out of driveway struck pedestrian crossing street toward the van.	e
C6753	M	3	Residential Driveway	5/23/74	1500		Moderate	Car backing out of driveway; struck child behind.	c
C5851	M	29	Residential Mid-block	5/4/74	0130	1966	Slight Injury	Driver of car released hand-brake on slope; in neutral gear, car backed into pedestrian.	a
C8579	M	83	Residential Driveway	6/8/74	0655	1951	Serious	Unoccupied car rolled backward out of driveway striking owner.	f
C7842	F	80	Commercial Driveway	6/14/74	1645	1972	Slight Injury	Car backing out of driveway; struck pedestrian on sidewalk.	d
C9064	M	53	Residential Dead-End Street	7/8/74	1105	1969	Serious	Car backing; struck pedestrian standing by second car, went over curb and hit a wall.	d
C8956	F	32	Commercial Bus Stop	7/5/74	1530	1974	Moderate	Car backed up near bus stop; struck pedestrian on sidewalk.	d
C8886	M	34	Recreation Park Road	7/4/74	1410	1973 (jeep)	Serious	Jeep, accidentally in reverse gear, backed into second car crushing pedestrian between.	e
C11904	F	5	Residential Driveway	9/1/74	1600	1971	Moderate	Car backing out of driveway; struck child sitting by driveway.	d

Table A-2 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
C11989	M	60	Commercial Alley	9/3/74	2005	1959	Serious	Car backing down alley struck pedestrian crossing alley.	d
C13014	F	1	Residential Driveway	9/26/74	1530	1973 (van)	Fatal	Van backed out of driveway; struck and ran over child.	c
B13310	F	68	Residential Intersection	9/8/73	1010	1969 (van)	Serious	Van backing into intersection; struck deaf pedestrian crossing intersection diagonally.	a
B13589	M	73	Commercial Alley	9/14/73	1040	1973	Moderate	Car backing up; pedestrian stepped behind car.	a
C14106	F		Commercial Alley	1/19/74	0915	1970 (van)	Serious	Van backed out of alley into street; struck pedestrian crossing intersection.	e
C13307	F	25	Commercial	10/2/74	1210		Moderate		d
C15618	M	25	Undeveloped Area	11/17/74	0030	1969	Slight Injury	Car, backing into street, struck two pedestrians crossing street.	e
C14776	M	68	Industrial Alley	11/1/74	1230	1966	Moderate	Pickup backing; struck man who walked out from behind trash bin.	d
C16957	F	55	Residential Mid-block	12/13/74	1430	1964	Moderate	Car parked; struck pedestrian crossing street while backing.	e
B00649	F	23	Residential Mid-block	1/14/73	2330	1965	Slight Injury	Car backing; struck pedestrian on sidewalk.	e
B02610	F	30	Residential Mid-block	2/21/73	2015		Moderate	Car backing; struck pedestrian crossing street.	e
B03827	F	25	Residential Mid-block	3/16/73	1815	1972	Slight Injury	Car backing down street; pedestrian stepped behind car.	e
B04812	M	7	Residential Mid-block	4/3/73	1750	1967	Slight Injury	Car backing up; ran over foot of child on curb.	b
B06239	M	3	Residential Driveway	4/29/73	1400	1971	Moderate	Car backing out of driveway; struck child on toy behind.	c
B06982	F	39	Residential Driveway	5/13/73	1030	1971	Serious	Car in reverse gear; driver's foot slipped off clutch, ran over pedestrian's foot.	a
B07960	F F	45 48	Commercial Intersection	6/1/73 6/1/73	1345 1345	1972 1972	Moderate Moderate	Van backed around corner, hitting two pedestrians crossing street.	d

Table A-2 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
B08077	M	52	Undeveloped Dirt Road	6/3/73	0810	1972	Moderate	Vehicle backed into pedestrian, while pedestrian was giving directions to the driver.	e
B08168	F	23	Residential Driveway	6/5/73	0400	1965	Slight Injury	Car backing out of driveway struck pedestrian on sidewalk.	e
B08293	M	15	Residential Mid-block	6/7/73	1730	1971	Slight Injury	Vehicle backing; pedestrian ran behind.	d
B08430	F	2	Residential Driveway	6/9/73	1845	1973	Serious	Car backing out of driveway; struck child playing in driveway.	c
B08772	M	2	Residential Mid-block	6/15/73	1800	1972 (van)	Slight Injury	Van backing up; child drove toy behind vehicle.	c
B12109	F F	21 20	Residential Residential	8/16/73 8/16/73	0600 0600	1973 1973	Slight Slight	Car backing with door open; struck two pedestrians.	e
14685	F	1	Residential Dead End Street	10/5/73	1510	1970	Moderate	Child walked behind backing car.	c
B15369	M	17	School Parking Lot	10/18/73	0845	1965	Slight Injury	Car backing; pedestrian stepped off curb behind vehicle.	e
B15502	F	54	Commercial Mid-block	10/20/73	1250	1967	Moderate	Truck parallel-parked; struck pedestrian crossing street while backing out.	d
B16453	F	3	Residential Driveway	11/7/73	1605	1962	Moderate	Car backing out of driveway; struck child walking in gutter.	c
B17628	M	57	Commercial Intersection	11/28/73	0955	1969	Moderate	Car backed over curb; struck pedestrian on bus bench.	a
B18010	M	81	Residential Driveway	12/5/73	1600	1964	Serious	Car backing out of driveway; struck pedestrian on sidewalk.	e
B18006	M	4	Residential Driveway	12/5/73	1510	1964	Serious	Child walked toward backing vehicle.	c
B18284	M	23	Mid-block	12/10/73	2230	1970	Serious	Van backed down street; struck pedestrian crossing street.	d
573-5	F	80	Industrial Mid-block	1/12/73	0830	1962	Moderate	Pedestrian stepped off curb; backing truck ran over her foot.	d

Table A-2 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
673-16	M	55	Commercial Asphalt Yard	1/18/73	0715	---	Fatal	Truck backed into pedestrian while unloading; ran over pedestrian's legs.	d
673-92	F M	33 4	Residential Angle Parking	4/7/73 4/7/73	1645 1645	1968 1968	Moderate Serious	Car backed out of parking space; lost control, struck pedestrians on sidewalk.	a

Table A-3

Summary of Pertinent Data from 27 Cases of Pedestrian Back-up Accidents
(original data extracted from a current study by Bio-Technology - Rural Accidents, Reference 17)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
070	M	80	Commercial Parking Lot	8/13/74	1245	1974	Moderate	Car parked diagonally; struck pedestrian while backing out.	d
095	M	--	Residential Mid-block	12/15/74	0035	1964	Slight Injury	Car backing struck pedestrian and another car; driver was attempting to avoid drunk pedestrians molesting him.	a
006	F	37	Rural Near Intersection	7/9/74	1750	1967	Moderate	Pickup backing away from intersection struck pedestrian crossing road.	d
11066	M	1	Residential Driveway	6/5/74	1155	1968	Moderate	Car backing out of driveway struck pedestrian crossing driveway.	c
050	M	64	Commercial Suburban Mid-block	7/1/74	0910	1967	Moderate	Car, accidentally in reverse gear, backed into officer in CHP inspection lot.	d
029	M	7	Residential Mid-block	5/14/74	1515	1968	Slight Injury	Car backing out of driveway, struck pedestrian walking bicycle across street.	e
042	M	24	Gas Station Lot	8/19/74	0250	1967	Slight Injury	Car backing at gas pump; backed into car pinning pedestrian in between.	a
050	M	2	Residential Mid-block	10/28/74	1405	1968	Serious	Child ran toward backing car.	c
030	F F	54 52	Rural Shoulder Near Intersection	6/10/74 6/10/74	1009 1009	1973 1973	Serious Fatal	Vehicle stopped on shoulder. Unaware that vehicle was in reverse gear, backed into two pedestrians.	e
061	F	6	Residential Driveway	1/2/74	1200	1971	Serious	Car backing out of driveway; struck child playing in driveway.	d
016	M	4	Residential Driveway	4/12/74	1615	1965	Serious	Car backing out of driveway; backed over child playing in driveway.	c
010	F	8	Rural Road Shoulder	4/11/74	1545	1973	Moderate	After passing pedestrian, car stopped then backed into pedestrian who was facing the other direction.	d
078	M	36	Rural Parking Lot	6/9/74	1615	1965	Slight Injury	Drunk driver backed into pedestrian.	d
068	M	3	Residential Driveway	7/10/74	1630	1967	Serious	Car backing out of driveway struck child playing in driveway.	c

Table A-3 (continued)

Case #	Sex	Age	Location	Date	Time	Car Year	Accident Severity	Remarks	Accident Cause
014	F	3	Rural Store Parking Lot	3/22/74	1620	1965	Moderate	Car backing; struck child sitting behind.	c
43008	F	52	Commercial Parking Lot	3/27/74	1503	1974	Slight Injury	Car, accidentally in reverse gear, backed into pedestrian.	e
70008	M	62	Rural Residential Mid-block	9/29/74	1130	1965	Serious	After talking with driver, pedestrian walked behind car; car backed into him.	e
001	M	86	Residential Dead End Street	10/26/74	1245	1973	Moderate	Pedestrian walked into ambulance backing up.	d
62018	M	16	Residential Driveway	2/14/74	2000	1969	--	Car backed out of driveway; struck pedestrian on parked motorcycle on opposite side of road.	e
046	M	1	Residential Gravel Road Mid-block	2/19/74	1810	1965	--	Car backing along road; child ran out behind moving vehicle.	c
024	F	10	Sand Along Beach	5/30/74	1310	1969	Slight Injury	Vehicle backing out of loose sand; pedestrian not watching where she was going.	e
169	M	86	Residential Driveway	7/15/74	1120	1951	Slight Injury	Car backed out of driveway; pedestrian on sidewalk.	e
165	F	22	Residential Mid-block	12/12/74	1225	1966	Slight Injury	Car backing with door open; pinned pedestrian against telephone pole.	e
164	M	84	Residential Mid-block	12/15/74	2015	1975	Moderate	Car backing in street; pedestrian crossing street walked behind car.	e
10066	M	3	Residential Driveway	7/6/74	1820	1963	Slight Injury	Car backing out of driveway; child riding tricycle on sidewalk.	c
10018	F	11	Residential Mid-block	2/7/74	2030	1965	Slight Injury	Car backing to park along curb; pedestrian stepped behind car.	d
049	M	10	Residential Driveway	6/10/74	2015	1965	Moderate	Car backed into driveway; pedestrian struck while playing in driveway.	d

APPENDIX B

FIELD EVALUATION - SUBJECT DATA ANALYSIS

Evaluation Procedure

Observations and interview data was recorded on data acquisition forms. These forms were laid out to correspond to the general objectives of the experiment. Figure B-1 illustrates the form used by the observer who controlled the experiment and logged the subject's reaction. After the test sequence, the interviewer contributed to the site diagram description and, with the observer, generated a pooled subject response rating, incorporating both observations.

Figure B-2 is an example of the interviewer's log form to produce observational and interview data. An independent rating for each subject from each observer was recorded along with the subject's distance from the rear of the test car when the behavior was noted. Additional relevant information was also recorded such as the behavior of people, not targeted subjects, who reacted to the device when passing by.

A notable change to the interviewers log was made during the early stages of the evaluation tests. It was originally intended that the interviewer would first identify himself and briefly explain the test. Most subjects appeared confused by the explanation so it was abandoned. After the key questions were answered, if the subject was still curious, the test objective was explained to the subject. At the conclusion, many subjects expressed a favorable judgement toward the test goals.

Analysis Procedure

The most important data results in the evaluation of the back-up warning device were derived from the ratings by the observers. These ratings of the subject's behavior were determined as the subject approached the test vehicle and reacted to the warning cues. The interview occurred after the ratings were generated. Thus, the ratings were not biased by the subject's responses in the interview, or his refusal to be interviewed. Since the two raters generated data independently, a measure of the reliability of their ratings was obtained by generating a contingency coefficient of correlation using the two sets of data.[40] The ratings of the observer and interviewer

Audible Warning Signal Field Evaluation

Observer's Log

Test No. ________

Test Site ____________________ Date __________ Time __________

Test Sequence: With Device ________ Without ________

Subject: Male ________ Female ________

Age: 0-24 ____ 25-44 ____ 45+ ____

Subject Response:	Observer Rating	Pooled Rating
1. No noticeable response	____	____
2. Visual response only	____	____
3. a. Avoidance response - stopping or retreating	____	____
b. Avoidance response - change course (forward)	____	____
c. Avoidance response - speeding up	____	____

Site Diagram

Indicate North Direction

Indicate Curb or adjacent vehicles

Indicate Subject Path, mark T at test start location and X at subject response location

Subject Speed:

Slow ________ Medium ________ Fast ________

Comments ____

____

Figure B-1. Observer's Data Log

Audible Warning Signal Field Evaluation

Interviewer's Log

Test No. ________

Test Site ____________________ Date __________ Time ____________

Test Sequence: With Device ______ Without ________

Subject: Male ______ Female ______

Age: 0-24 ____ 25-44 ____ 45+ ____

Subject Response:

1. No noticeable response ____
2. Visual response only ____
3. a. Avoidance response - stopping or retreating ____
   b. Avoidance response - change course (forward) ____
   c. Avoidance response - speeding up ____

Interview:

"As you walked past that car, did you notice or did you not notice if the engine started up?" Noticed ________

Didn't notice ________

Interviewer instructions: if device used, ask:

"As you walked past that car, did you or did you not hear an unusual sound?" Heard ________

Didn't hear ________

Interviewer instructions: if they did hear, ask this question:

"Was your reaction to the unusual sound Curious ________

Startled ________

Unaffected ________

(select one)

"Do you have any known hearing problems at this time?" ________

"Thank you for your help."

Comments ______________________________

____

Figure B-2. Interviewer's Data Log

were compared on-site to generate a pooled score for each subject. If the observers agreed, then the pooled score was the one agreed upon. If they did not agree, they resolved the conflict at the test site and agreed upon a joint rating to be recorded. It was not uncommon for one observer to see some behavior that the other observer could not see. The original independent ratings were used to measure the reliability of the rating scale, while the pooled or joint rating were used to analyze the effectiveness of the device.

All pertinent data derived from the observer and interviewer logs were coded according to the key shown in Figure B-3. These data are listed in Figure B-4. The coding block numbers were then sorted and analyzed using a standard computer analysis program.

Following analysis, all subject scores were categorized in a table similar to the following:

	Type of Response (Scale Value)	
	No Response (1)	Some Response (2 or 3)
Car With Device		
Car Without Device		

Within the scope of this program it was not feasible to sample a sufficient number of responses to perform a classical statistical analysis. Practical "small sample" analyses were made to assure the overall effectiveness of the device.[4]

The observers' descriptions of the responses and the breakdown of responses into scale values 2 and 3 allowed a description of the ways in which people responded to the device. The descriptions of the responses were categorized to indicate which responses were the most prevalent.

The acoustic data, recorded at the rear of the test vehicle, were analyzed to determine:

- The ambient level prior to the test initiation, including the statistical levels and L_{eq}.
- The maximum level of the test vehicle's self noise.
- The warning signal level for each test sequence.

1	2	3	4	5	6	7	8	9	10	11	12	13

<u>Block</u>

1 & 2	-	Subject Number	
3	-	Test Site Code	0 = mid-block/ 1 = alley, driveway 2 = parking lot/ 3 = crosswalk
4	-	0 = with device/ 1 = without	
5	-	0 = male/ 1 = female	
6	-	0 = 0-24/ 1 = 25-44/ 2 = 45 +	
7	-	Observer Rating	1 = 1/ 2 = 2/ 3 = 3a/ 4 = 3b/ 5 = 3c 9 = none given by observer
8	-	Interviewer Rating - Same as 7	
9	-	Pooled Rating - Same as 7	
10	-	Speed	0 = slow/ 1 = medium/ 2 = fast
11	-	Engine question	0 = noticed/ 1 = didn't/ 9 = no interview
12	-	Beeper question	0 = noticed/ 1 = didn't/ 9 = not applicable
13	-	Reaction	0 = curious/ 1 = startled/ 2 = unaffected 3 = thought it was warning/ 9 = not applicable, unknown

Figure B-3. Back-Up Warning Device Field Evaluation Subject Coding Key

Site	Coding Blocks 1	2	3	4	5	6	7	8	9	10	11	12	13	Test Ambient	
1	~~0~~	~~1~~	~~3~~	~~0~~	~~1~~	~~2~~	~~1~~	~~1~~	~~1~~	~~1~~	~~0~~	~~1~~	~~9~~	67	*
1	~~0~~	~~2~~	~~3~~	~~0~~	~~0~~	~~0~~	~~2~~	~~2~~	~~2~~	~~1~~	~~9~~	~~0~~	~~9~~	67	*
1	~~0~~	~~3~~	~~3~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~1~~	~~9~~	~~9~~	~~9~~	67	*
1	~~0~~	~~4~~	~~3~~	~~0~~	~~0~~	~~2~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~9~~	63	*
1	~~0~~	~~5~~	~~3~~	~~0~~	~~0~~	~~2~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~9~~	64	*
1	0	6	3	1	1	2	1	1	1	0	9	9	9	65	
1	~~0~~	~~7~~	~~3~~	~~0~~	~~0~~	~~2~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~9~~	60	*
3	0	8	0	0	0	1	1	2	2	0	0	0	0	61.5	
3	0	9	0	0	1	1	2	1	2	1	0	0	0	61.5	
3	1	0	0	0	1	2	3	3	3	0	9	9	9	68.5	
3	1	1	0	0	1	1	9	3	9	1	0	0	2	68.5	
2	1	2	3	0	1	1	1	1	1	1	1	1	9	68	
2	1	3	3	0	1	2	1	1	1	0	1	0	2	68	
2	1	4	3	0	1	2	3	9	2	1	9	9	9	-	
2	1	5	3	0	0	1	2	2	2	2	0	0	2	-	
5	1	6	2	0	0	1	2	2	2	1	0	0	3	64.5	
5	1	7	2	0	1	2	4	5	4	1	0	0	3	58	
5	1	8	2	0	0	2	4	4	4	1	1	0	3	67.5	
6	1	9	1	1	0	0	1	9	9	1	9	9	9	73.5	**
6	2	0	1	0	0	1	1	9	9	1	9	9	9	74	**
7	2	1	1	0	0	2	4	4	4	1	0	0	3	-	
7	2	2	1	0	0	2	2	2	2	1	1	1	9	69	
7	2	3	1	0	0	2	3	4	3	2	0	0	0	70.5	
7	2	4	1	0	1	2	2	2	2	1	0	0	3	67.5	
7	2	5	1	0	0	1	2	9	9	1	9	9	9	↓	**
7	2	6	1	0	0	1	2	9	9	1	9	9	9	↓	**
7	2	7	1	0	0	2	2	9	9	1	9	9	9	↓	**
7	2	8	1	0	0	2	2	9	9	1	9	9	9	↓	**
7	2	9	1	0	0	2	2	9	9	1	9	9	9	67.5	**
7	3	0	1	0	0	2	2	2	2	2	0	0	0	67	
7	3	1	1	1	0	1	4	4	4	1	1	9	9	76	
7	3	2	1	1	0	1	2	2	2	0	0	9	9	69	
4	3	3	0	0	1	1	3	3	3	1	0	0	0	66	
4	3	4	0	0	1	1	1	1	1	1	0	0	2	65	
4	3	5	0	0	1	0	2	2	2	1	0	0	0	66	
4	3	6	0	0	1	2	2	2	2	0	1	0	0	69	
1	3	7	3	1	1	2	1	1	1	2	1	9	9	71	
1	3	8	3	1	1	0	9	1	9	1	1	9	9	65.5	
1	3	9	3	1	1	1	2	2	2	2	9	9	9	68.5	

Figure B-4. Coded Subject Data

Site	Coding Blocks													Test Ambient	
	1	2	3	4	5	6	7	8	9	10	11	12	13		
1	4	0	3	1	1	2	1	1	1	1	1	9	9	68	
1	4	1	3	1	0	1	4	1	1	2	1	9	9	68	
1	4	2	3	1	1	2	2	1	2	0	1	9	9	66.5	
1	4	3	3	0	0	1	2	2	2	2	1	0	0	71.5	
1	4	4	3	0	1	2	2	2	2	1	1	1	9	66.5	
1	4	5	3	0	1	2	2	2	2	1	9	9	9	73	
1	4	6	3	0	1	0	2	2	2	1	9	9	9	↓	
1	4	7	3	0	1	0	2	2	2	1	9	9	9	↓	
1	4	8	3	0	1	1	2	2	2	1	9	9	9	↓	
1	4	9	3	0	1	1	2	2	2	1	9	9	9	↓	
1	5	0	3	0	0	0	2	2	2	1	9	9	9	↓	
1	5	1	3	0	0	0	2	2	2	1	9	9	9	73	
4	5	2	0	1	0	1	1	9	9	1	9	9	9	64.5	**
4	5	3	0	1	0	2	1	1	1	1	1	9	9	64	
4	5	4	0	1	1	2	1	9	9	1	9	9	9	↓	**
4	5	5	0	1	1	0	1	9	9	1	9	9	9	↓	**
4	5	6	0	1	1	0	1	9	9	1	9	9	9	↓	**
4	5	7	0	1	1	0	1	9	9	1	9	9	9	64	**
4	5	8	0	1	1	1	1	1	1	1	1	9	9	-	
4	5	9	0	1	1	0	1	1	1	1	9	9	9	-	
4	6	0	0	0	1	0	9	3	9	1	0	0	3	64	
4	6	1	0	0	1	0	1	2	2	1	0	0	2	64.5	
8	6	2	2	1	1	1	1	2	2	1	0	9	9	64	
8	6	3	2	0	0	1	2	2	2	2	1	0	3	76	
7	6	4	1	1	0	1	1	1	1	1	0	9	9	67	
7	6	5	1	0	0	1	2	2	2	1	0	9	9	72	
7	6	6	1	0	1	1	2	2	2	1	0	0	9	72	
7	6	7	1	0	1	2	2	2	2	0	1	9	9	70.5	
7	6	8	1	0	0	1	2	2	2	1	9	9	9	71	
7	6	9	1	0	0	2	2	2	2	2	1	0	0	68	
7	7	0	1	0	1	2	2	2	2	1	1	0	0	71	
7	7	1	1	0	0	1	4	2	4	1	0	0	0	67.5	
7	7	2	1	0	1	1	4	2	4	1	0	0	0	67.5	
2	7	3	3	0	1	0	1	2	2	1	1	0	0	65	
2	7	4	3	0	1	0	1	2	2	1	1	0	0	65	
2	7	5	3	0	0	1	2	2	2	1	0	0	2	65.5	
2	7	6	3	0	1	1	2	2	2	1	9	9	9	65.5	
2	7	7	3	1	0	0	1	1	1	1	1	9	9	64.5	
2	7	8	3	0	1	2	2	2	2	1	1	0	0	63	
2	7	9	3	1	1	2	1	2	1	1	0	9	9	68	
2	8	0	3	0	1	2	1	2	1	1	1	1	9	62	
2	8	1	3	0	1	0	2	2	2	2	1	0	9	62.5	
1	8	2	3	0	1	2	1	1	1	1	9	9	9	64	
1	8	3	3	1	0	2	1	1	1	1	1	9	9	-	

Figure B-4. Continued.

Site	Coding Blocks 1	2	3	4	5	6	7	8	9	10	11	12	13	Test Ambient	
1	8	4	3	0	1	2	1	2	2	1	0	0	0	69	
1	8	5	3	0	1	2	2	2	2	1	0	0	3	64	
1	8	6	3	1	1	2	1	2	2	0	0	9	9	67.5	
1	8	7	3	0	0	1	1	2	2	1	1	0	0	64	
1	8	8	3	1	0	1	1	2	9	1	9	9	9	67.5	**
1	8	9	3	1	1	2	1	2	9	1	9	9	9	67.5	**
1	9	0	3	0	1	2	2	2	2	1	1	0	2	67	
1	9	1	3	1	1	2	2	2	2	1	1	9	9	68	
1	9	2	3	0	1	2	2	2	2	1	1	0	3	73.5	
4	9	3	0	0	1	0	2	2	2	1	1	0	0	68	
4	9	4	0	1	1	2	3	1	3	0	0	9	9	67	

Figure B-4. Concluded.

Note: The test ambient level was the A-weighted noise level just before the engine was started, recorded at the vehicle rear bumper.

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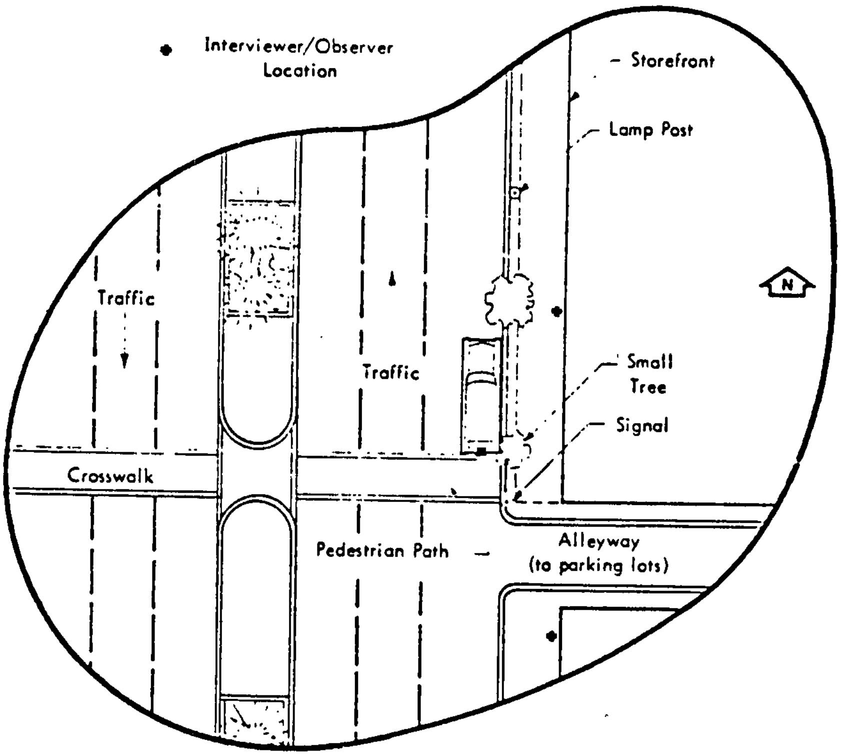
*Data from these subjects was not analyzed due to insufficient signal levels. The signal level was increased following subject 7.

**Data from these subjects were excluded from the analyses because their responses were unknown, or the observations that were made were not adequate due to traffic conditions, obstructions, etc.

APPENDIX C

EVALUATION TEST SITE DIAGRAM AND DESCRIPTIONS

SITE 1 – Sepulveda Blvd. (facing north), Westchester
(on Sepulveda between Manchester Blvd. and 88th St.)



Site Description

A divided highway passing through a downtown shopping district. Very little pedestrian activity before 10:00 a.m. Approximately 20 to 50 pedestrians use the crosswalk during a 1-hour period with possibly 20 percent crossing without using a "walk" signal. When the crossing signal button was depressed, a 30 second delay was not uncommon, and a flashing yellow light changed to flashing red, creating a boulevard stop for traffic.

Pedestrian Behavior

Pedestrians crossing against the light were distracted by approaching traffic, whereas others appeared more secure in the crosswalk. Many pedestrians were at the far boundary of the crosswalk during the test, as they were walking toward the alley way between the shops. Their reaction to the vehicle starting and activating the warning signal was seldom more than a slight turn of the head or a glance in the direction of the vehicle.

Test Sequence

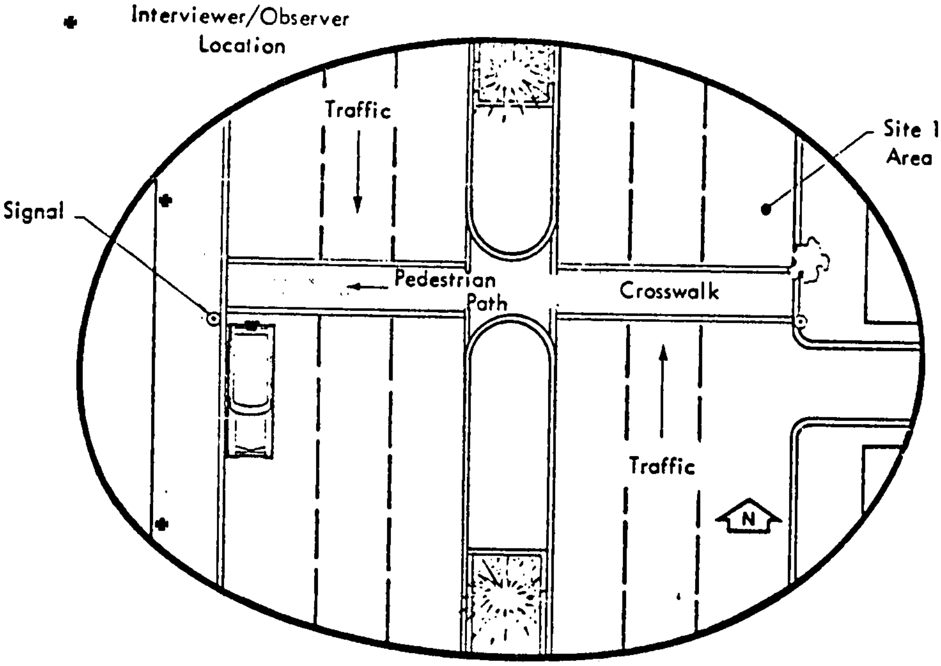
At this location, all subjects approached the vehicle from the street (west to east). Pedestrians going in the other direction (east to west) would wait close to the vehicle;

consequently, there was insufficient warning time to activate the test sequence. The test sequence began when the pedestrian started to cross the street; the driver, waiting near the front of the vehicle, walked around and entered the vehicle. As the pedestrian left the center divider, the vehicle was started, and as the pedestrian entered the danger zone the warning signal and back-up lights were activated.

Classification

Crosswalk

SITE 2 – Sepulveda Blvd. (facing south), Westchester
(on Sepulveda Blvd. between Manchester Blvd. and 88th St.)



Site Description

Same as Site 1.

Pedestrian Behavior

This area is predominantly occupied by shoppers; the majority waited for the crossing light but at least 20 percent walked across without waiting for the signal. After crossing the street, pedestrians turned north, passing at the far side of the crosswalk or turned south, passing close to the vehicle. Reactions to the vehicle or the warning signal were slight; most people barely turned their heads despite the fact they were usually behind the vehicle.

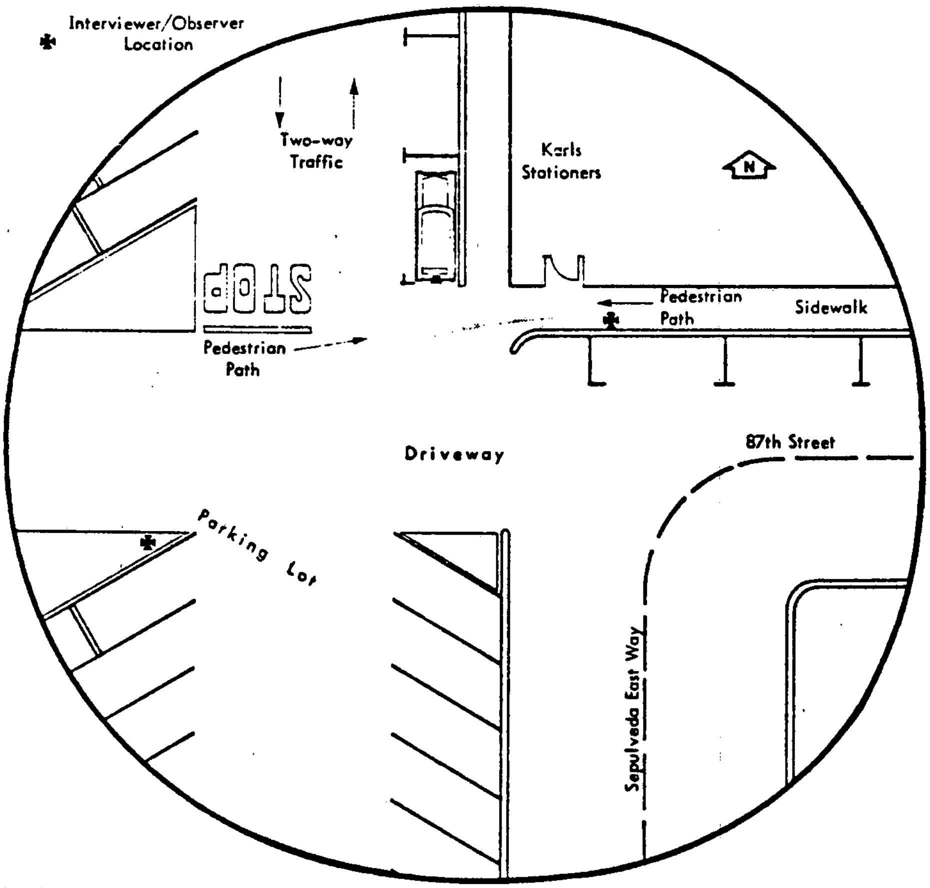
Test Sequence

Similar to the tests at Site 1. The vehicle was started when the pedestrian left the center divider and the warning signal was activated when the pedestrian was approximately 15 feet from the vehicle, the boundary of the danger zone.

Classification

Crosswalk

SITE 3 — Karls Stationers, Westchester
(at the intersection of 87th St. and Sepulveda East Way)



Site Description

A parking lot bounding a right angle street. Sepulveda Blvd. is the next street to the west where Sites 1 and 2 were located. Pedestrian traffic volume was very low with only five to 10 per hour crossing behind the vehicle. Vehicular traffic in this area was also light.

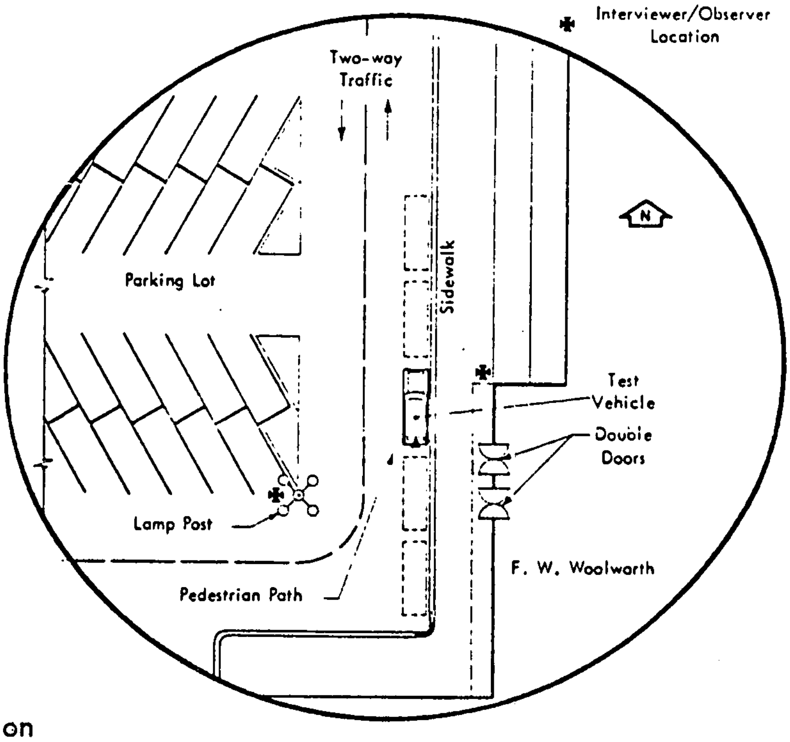
Pedestrian Behavior

Subjects were selected approaching from both directions. This complex intersection provided many distractions for pedestrians; however, they did not demonstrate any excessive reactions, only looking at the vehicle.

Classification

Mid-Block

SITE 4 – F.W. Woolworth, Westchester
(between Sepulveda Blvd. and Sepulveda West Way, south of Manchester Blvd.)



Site Description

A commercial shopping area where stores face Sepulveda Blvd. on the east with a large parking lot behind the stores. Two-way traffic along the parking lot edge and parallel parking along a sidewalk create an ideal mid-block situation. Pedestrian traffic was light in this area but many customers exiting from Woolworth passed behind the test vehicle to reach the parking lot.

Pedestrian Behavior

Subjects were observed entering and leaving Woolworth, most of them exiting the store and passing behind the vehicle. Most of the subjects simply glanced at the vehicle but several paused at the curb upon hearing the signal.

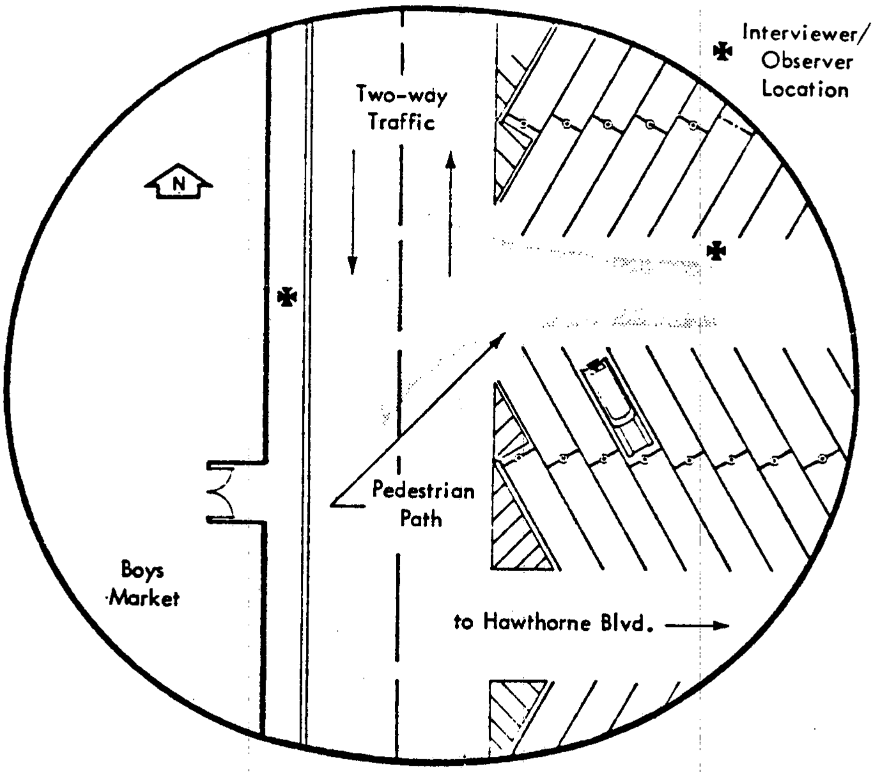
Test Sequence

The vehicle was started when the subjects passed the exit door and the warning signal was activated when they were a few feet from the vehicle.

Classification

Mid-Block

SITE 5 — Boys Market, Hawthorne
(at 11873 S. Hawthorne Blvd.)



Site Description

A small commercial shopping area. All spaces around the test vehicle were occupied by parked cars during the tests. Subjects were selected from pedestrians coming from the store to the parking lot.

Pedestrian Behavior

Subjects in parking lots seemed more aware of the test vehicle and usually responded by either slowing or changing course. Mid-block and crosswalk subjects seldom responded in this manner.

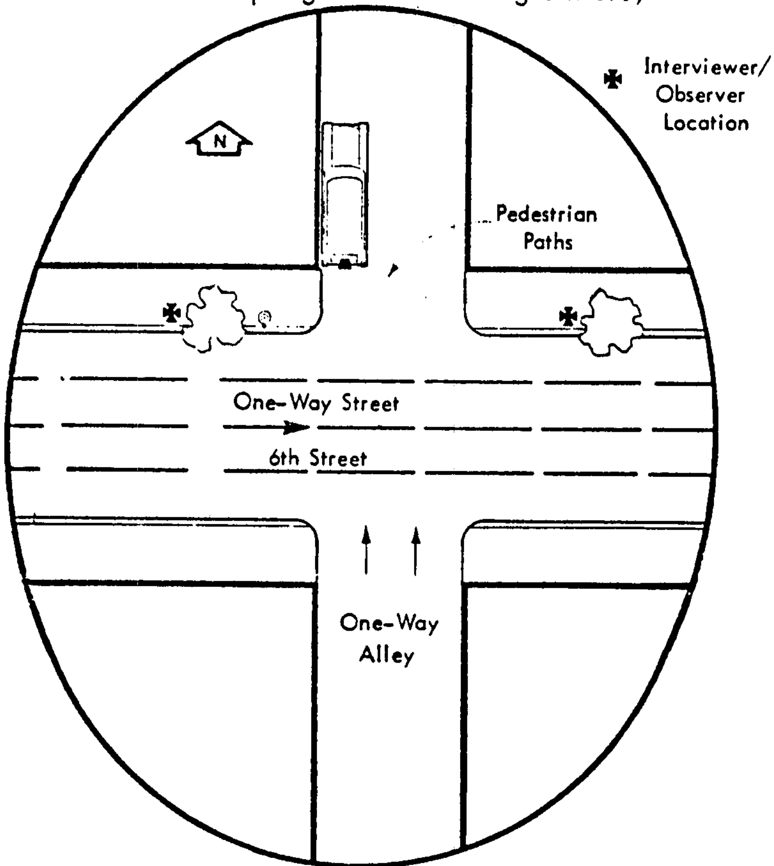
Test Sequence

When the subject was approximately two cars away, the engine was started and when one car away, the warning signal was activated.

Classification

Parking Lot

SITE 7 – 6th Street, Los Angeles
(alley between Main and Spring Streets crossing 6th St.)



Site Description

Alley in a busy downtown commercial district. Heavy vehicle and pedestrian traffic. In general, pedestrians were not as cooperative during questioning; most were in a hurry.

Pedestrian Behavior

At this location, pedestrians seemed most threatened by the vehicle; one subject even warned interviewer about backing vehicle. Most subjects responded by looking at the vehicle and some slowed or changed their course.

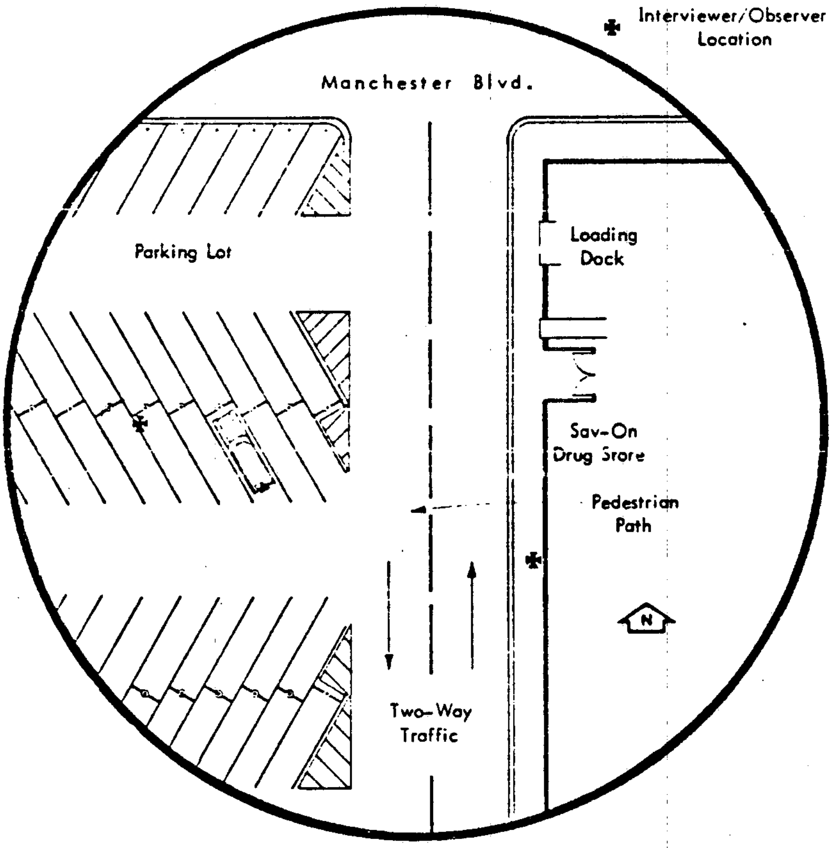
Test Sequence

Subjects were selected from pedestrians walking from east to west, since they could see the vehicle as they approached. The vehicle was started before they entered the alley and the warning signal activated just before reaching the vehicle.

Classification

Alley or Driveway

SITE 8 – Sav-On Drug Store
(between Sepulveda Blvd. and Sepulveda West Way south of Manchester Blvd.)



Site Description

A commercial shopping area adjacent to a large parking lot. Pedestrian traffic volume was light. Subjects were observed exiting from stores and returning to their cars in the parking lot.

Pedestrian Behavior

Pedestrian traffic was leisurely with most subjects watchful of vehicles in the area. Some subjects slowed or changed their path of travel.

Test Sequence

The engine was started when the subject was about two cars distant and the warning signal activated when subject was 6 to 8 feet away.

Classification

Parking Lot