USER GUIDELINES FOR LIGHTS AND SIRENS

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CONTENTS

Abstract

The subject of visual and auditory warning devices (lights and sirens) for emergency and service vehicles is surveyed from a broad perspective. It is intended that these Guidelines should provide directly useful information at all levels from the selection of hardware to an understanding of the psychophysical factors determining the effectiveness of these devices. Topics covered include: the theory of warning signals; the present uncontrolled situation and the need for uniform national standards; a summary of the NILECJ-NBS standard for warning-light systems, including an explanation of the reasons for the principle requirements imposed; a similar explanatory summary of the NILECJ-NBS standard for sirens; a set of recommendations for actions that can be taken immediately to improve the signal effectiveness of emergency vehicles; an illustrated classification of the many types of emergency-vehicle warning lights; and brief summaries of some of the physical measurements that were made on a selection of lights and sirens.

KEY WORDS: Conspicuity; emergency vehicle; flashing light; level, sound; lights; signal light; siren; sound level; standards; vehicle, emergency; warning light; warning signal.

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1. SCOPE OF THE PROBLEM

1.1. The Need for Prompt Response

A major requirement of law enforcement activities is the need to respond quickly to emergency situations. This rapid reaction capability is required both for operations which are relatively routine and those which constitute serious emergencies. The need for timeliness becomes apparent when we explore situations where there is an unusual delay between a call for assistance and the arrival of squad-car officers responding to the emergency.

Let us consider two examples, one relatively routine (traffic accident) and the other, the commission of a serious crime (armed robbery). The common feature of these two instances is that the delay in arrival results in greater disruption to the general public and makes it more difficult for police officers to perform their function.

A. A traffic accident is reported with a disabled vehicle on a major roadway.

<u>Consequences of Delay</u>:

- A serious disruption of traffic.
- A greater likelihood of secondary accidents resulting from drivers dividing their attention between driving and viewing the accident scene.
- Injuries associated with the accident are likely to become more severe in the absence of medical attention.

B. An armed robbery is reported to be in progress.

<u>Consequences of Delay</u>:

- Criminals have more time to complete their work and escape.
- Witnesses to the crime are more likely to disperse.
- Injured victims of crime are likely to receive delayed attention.

1.2. Some Sources of the Problem

The difficulty experienced by an officer trying to move quickly through traffic during emergencies is affected by traffic volume, automobile design, lack of uniformity of regulations, environmental constraints and limitations of available warning signals.

The fact that there are more vehicles on the road with each passing year is evident to every motorist. In addition to the automobiles and trucks, there is the increasing presence of motorcycles and bicycles on many of the roadways. In dense traffic, constant attention must be paid to the maneuvers of nearby vehicles. Under these conditions it is difficult for a warning signal to capture the attention of an already preoccupied motorist.

Because the rear-view mirror is so far from the driver's forward line of sight, it is particularly difficult for a light signal coming from an overtaking vehicle to be noticed. Vision in the outer portions of the visual field (the periphery) has characteristics different from direct central vision, so in analyzing the visual aspects of warning lights, it is important to concentrate on what is seen in the periphery. Moreover, most people pay much less attention to things seen in perhipheral vision than to what is being viewed directly.

Automobile design today makes it easy for the occupants of a car to isolate themselves, intentionally or unintentionally, from most of the sounds in their external environment. If advertising claims are to be believed, many manufacturers are making increasing efforts to make their cars quiet. Such automobiles provide an effective barrier against not only unwanted outside sounds, but also those that should be heard -- such as sirens. Other factors which make it difficult for the sounds of warning sirens to reach the driver are the accessories often present in vehicles such as tape recorders, radios and air conditioners. All of these devices are capable of producing sounds which will effectively mask out all but the loudest sounds produced outside the vehicle.

Simply stepping up the intensity of siren sounds is not the answer to the problem of designing more effective auditory warning systems. The heightened concern among the general public for an improved environment makes this possible solution unacceptable. Even the sirens in present use are the cause of many complaints in the community because of the disturbance that they produce. Any increase in volume of sound is almost certain to produce more complaints because of the larger number of people affected and because of the increased severity of the effect on those people near the sound source. A substantial increase over present sound levels might even produce actual hearing damage to pedestrians and nearby motorists driving with open windows.

The present intensity situation is less critical with respect to warning lights, but here, too, intensity increases must be limited to avoid excessive glare at night (which may temporarily blind or disorient nearby drivers). If pushed to sufficiently high intensities, light flashes can do physical damage to the eyes of viewers.

One of the factors contributing strongly to the present chaotic condition concerning warning signals is the absence of sufficiently restrictive regulations. In many communities it is relatively easy for a variety of people and organizations to justify the need for having an emergency signal on a vehicle. As of 1968, the National Committee on Uniform Traffic Laws and Ordinances of Washington, D.C. reported 25 categories of vehicle authorized by at least one state to display a warning light. A partial listing of these vehicle types includes: (1) school buses; (2) snow-removal vehicles; (3) other highway-maintenance vehicles; (4) tow trucks; (5) mail vehicles; (6) volunteer firemen's vehicles; (7) public-utility emergency or repair vehicles; (8) public service vehicles; (9) funeral-home vehicles; (10) vehicles towing buildings; (11) pilot cars for oversized loads; (12) the oversized loads themselves; (13) mobile units of news media; (14) sanitation vehicles; (15) forest wardens' vehicles.

1.3. Variability in Warning Systems

The variety of types of vehicles authorized to use emergency warning systems constitutes only one aspect of the problem. The other major difficulty is the lack of uniformity of warning systems within individual communities and from place to place. Tables 1.3-1 and 1.3-2 provide some idea of the variety of systems in current use today.

TABLE 1.3-1: SIRENS

Location in Which Siren Mounted, By Department Type

ELECTRONIC SIRENS*

	LOCATED ON ROOF			LOCATED UNDER HOOD		
	On Utility Bar % Depts.	Directly On Roof % Depts.	Total % Depts.	Behind Grille % Depts.	In Engine Compartment % Depts.	Total % Depts.
50 Largest Cities	61	30	91[b]	25	5	30[b]
City 50+[a]	74	16	90	24	4	28
City 10-49	71	4	75	28	4	32
City 1-9	52	12	64	39	4	43
Townships	54	4	58	33	17	50
State	37	16	53	45	18	63
County	38	11	49	58	11	69
All Depts. N=360	58	13	71	35	8	43

[a]No. of vehicles in department.

[b]Sums of % depts. using sirens on roof and under hood may total more than 100%, because many depts. use both locations (not necessarily on the same vehicles).

*Information summarized from Klaus and Bunten (1973).

TABLE 1.3-1: SIRENS (cont.)

ELECTRO-MECHANICAL SIRENS*

	LOCATED UNDER HOOD			LOCATED ON ROOF		
	Behind Grille	In Engine Compartment	Total	On Utility Bar	Directly on Roof	Total
State	48	59	107[b]	0	7	7[b]
Townships	43	57	100	14	0	14
County	39	58	97	11	6	17
City 10-49[a]	46	46	92	29	4	33
City 1-9	57	29	86	18	0	18
Fifty Largest Cities	42	42	84	16	5	21
City 50+	54	23	77	14	11	25
All Depts. N=180	48	43	91	14	6	20

[a]No. of vehicles in department.

[b]Sums of % depts. using sirens on roof and under hood may total more than 100%, because many depts. use both locations (not necessarily on the same vehicles). The same overlap may exist within the separate under-hood or on-roof categories, and clearly does for under-hood usage by state police depts.

*Information summarized from Klaus and Bunten (1973).

TABLE 1.3-2: LIGHTS*

Color Combination Used, By Department Type

	City 10-49[a]	County	50 Largest Cities	Town ship	City 50+	City 1-9	State	All Dept. Types
	% of Depts. Using This Color/Colors							
RED								
Red Only	54	56	52	45	54	64	57	56
Red and Clear	12	11	13	21	10	8	4	11
Red and Blue	11	8	9	7	8	8	2	8
Total of Depts. Using Red Lights In Any Combination	77	75	74	73	72	70	63	75
BLUE								
Blue Only	21	24	28	21	23	23	34	24
Red and Blue	11	8	9	7	8	8	2	8
Blue and Clear	2	0	2	0	2	4	0	2
Total of Depts. Using Blue Lights In Any Combination	34	32	39	28	33	35	36	34
YELLOW								
Yellow Only	7	11	11	7	12	9	19	11
CLEAR								
Clear Only	6	3	4	7	5	1	2	4
Red and Clear	12	11	13	21	10	8	4	11
Blue and Clear	2	0	2	0	2	4	0	2
Total of Depts. Using Clear Lights In Any Combination	20	14	19	28	17	13	6	17

No. of Respondents = 437

[a]No. of vehicles in department.

*Information summarized from Klaus and Bunten (1973).

The lack of uniformity of warning signals makes it difficult for travelers, truck drivers and others making long-distance trips to know how to respond to a warning signal. They find that they are often unfamiliar with the customs and regulations of the communities through which they travel and that their usual method of responding to emergency signals at home is frequently inappropriate in other jurisdictions. Under the best circumstances, drivers are somewhat confused by unfamiliar signals and are likely to drive less smoothly and decisively than usual. In the worst instances, there may be an increase in the probability of either causing or being directly involved in an accident as a result of confusion when confronted by an unfamiliar signal.

Historically, most of the organizations employing emergency vehicles were local in character and the signaling systems employed were developed in response to specific requirements. The vehicles typically serviced a relatively small area with the drivers having only a limited need to move from one jurisdiction to another. The local drivers could therefore be expected to be familiar with the warning systems in use and respond appropriately in the presence of these emergency signals. As the suburbs grew and the lines between adjacent communities became blurred, there were more occasions for vehicles to cross jurisdictional boundaries. The signals familiar to one community were then used in places where they were less recognizable because different signals had been employed. Another factor which further added to the complexity of the situation, and still generates considerable confusion, is the variety of jurisdictions overlapping in most localities. City, County, State, and Federal organizations have responsibilities which overlap each other, and in many instances each one has control over the warning systems it employs. As a result, a local community is likely to have emergency vehicles representing a broad spectrum of activities and governmental responsibilities, with each jurisdiction making independent decisions about how best to design an emergency warning system for vehicles. Because there is tremendous variation even among police vehicles, it is evident that there would be many problems for both the emergency vehicle operators, and for civilian drivers, even if no one but police used warning signals. Unfortunately, however, the problems are multiplied by the number and types of organizations permitted to use emergency warning devices.

In addition to the considerable variety in the basic light and siren configurations discussed above, there is a great profusion of different types of specific hardware units available on the market. Chapter 5 of this Guideline is an appendix that lists and illustrates many of the types of warning-light units currently available. In many of these categories, several different manufacturers offer lights of the same basic type, and some of the manufacturers may produce a number of different models of the same type. Our collection of manufacturers' and distributors' catalogs -- which is by no means exhaustive -- includes 400 distinct models of emergency-vehicle warning lights, but all of them fall into one of the categories listed in Chapter 5.

2. WARNING SYSTEMS

Before evaluating the existing warning systems and making recommendations for improving them, it might be useful to take a closer look at these systems. Among the factors to be examined are:

What is a warning system? .... What is it designed to accomplish?

What are the characteristics of a good system?

How are warning devices purchased today?

One of the first things that comes to mind in considering warning systems is the combination of lights and sirens used on police vehicles. However, a warning system is best thought of not as a collection of hardware, or even as group of visual and auditory warning signals, but rather, in functional terms, as a means of communicating a particular message (or series of messages) to the drivers of other vehicles. In other words, the signaling devices are merely the means of transmitting information. This distinction is an important one because the problem of devising adequate warning systems requires an understanding of not only the capabilities of various hardware configurations (lights and sirens) but of the traffic situation, the environment and most importantly how people respond to signals. Unless all of these factors are considered, it will be difficult to improve the present unsatisfactory situation.

2.1. Factors Contributing to a Good Warning System

After determining that warning signals are basically communication systems, we can identify several characteristics associated with "good" systems.

1. Optimum conspicuity - The warning should be readily noticeable (conspicuous) to drivers of other vehicles during all situations and conditions normally expected while driving. The intensity of any signal therefore must not fall off below the level where it is just barely detectable by other drivers, except at very long ranges. The system should be effective regardless of: time of day, traffic, weather, road characteristics, locale (urban, suburban, rural, etc.)

The conspicuity of a flashing warning light depends on a number of factors. Among these are: (1) the effective intensity; (2) the flash rate; (3) the ratio of the time that the light is on to the time that it is off, during a complete flash cycle ("duty cycle" or "on-off ratio"); (4) the detailed variation of the intensity of the light flash ("pulse shape" or "waveform") during the time the light is on ("flash duration"); (5) the color of the light; (6) the angular sweep of the beam if the light is rotating; (7) the area of the light-emitting surface; (8) the motion of the light source (up and down or side to side); (9) the number and spatial arrangement of the lights if the configuration includes more than one light; and (10) the pattern in time ("phase relations") of the flashes from the various lights in a multi-light configuration.

Unfortunately, because being conspicuous requires being as different as possible from the background, the conspicuity of a signal light depends not only on the above 10 aspects of the light itself, but also on the same aspects of each light appearing in the background at the time the signal light is being used. Nobody knows how to combine all these factors quantitatively into a numerical prediction of the conspicuity of a specified signal light against a specified background, but the role of the factors listed above has been discussed in detail in another report (Howett, Kelly, and Pierce, 1974) issued as part of the same project that produced this Guideline.

2. Environmentally acceptable - The system should not unduly disturb those people who are "innocent bystanders". The type of signals and intensities employed must not consitute a public nuisance, disrupting the normal life of community residents and pedestrians. To the extent possible, the signal should be directed only at those individuals for whom the signal message is intended.

3. Be clearly understandable - Getting the attention of the driver of a civilian vehicle is only the first task of a warning system. He must be able to readily interpret the message -- to know what he is expected to do. Unfortunately, this cannot be accomplished completely by the physical design of the system, but rather depends on other things such as standardization of signals, control of use of signals, and public education.

4. Be easy to use - The system should minimize the amount of time and effort required to put it into operation. It should have only those modes of operation actually required by the users and should be designed to minimize possible selection errors when a choice of signals is possible.

5. Be reliable - The system "hardware" should be relatively simple, durable, difficult to steal or vandalize, trouble free, and easily maintained.

6. Low cost - The system should be relatively inexpensive in terms of dollar cost and should not consume an undue amount of power.

These factors deal with a variety of problem areas - economics, maintenance, reliability and the response of people to the signals. However, the critical area of concern is the reaction of other drivers on the road to the signals. Warning system effectiveness is largely determined by the responses of people to the signals (assuming no "hardware" problems).

2.2. Reaction of Drivers to Warning Signals

In order for a driver to react properly to the appearance of an emergency signal, a number of conditions are required. Some of them are based on the characteristics of people and how they respond, while others are concerned with environmental and hardware considerations. The driver, who is the "target" for the signal transmitted by the warning system, is the most important factor in determining the success or failure of the system. For this reason, we will focus our attention on him.

In order to understand the situation faced by an automobile driver who is the "target" of an emergency signal it is necessary to examine all phases of the activities involved -- from the sensing of the signal to the completion of his actions as well as all of the major steps in between. When this sequence of events and processes is carefully studied it becomes evident that the requirements placed on the driver are very complex. Any number of things can go wrong, and frequently do.

There are no fewer than five different things that a driver is called upon to do when in the presence of a warning signal. Moreover, they must be performed in the correct sequence for the activities to be timely and appropriate.

1. The signal must first be sensed. People are aware of only a portion of the total amount of energy present in the environment. (Among the waves normally present but not sensed by humans are infrared, ultra-violet, electromagnetic, ultra-sonic, radio and x-rays.) In order to perceive, or sense, energy, two conditions are necessary. (1) We must have a sense organ which is capable of detecting the form of energy transmitted, including the frequency of the energy if it is in the form of a wave. (2) The energy must be of sufficient intensity that our sense organs are sensitive enough to perceive that it is present. For example, in order for a sound to be audible, it must not only transmit an adequate amount of acoustic energy, but must also contain frequencies roughly between 20 and 20,000 Hz (cycles per second) because the ear does not respond to sounds outside of this range.

Similarly, a visible light must not only transmit an adequate level of radiant energy, but must also contain wavelengths roughly between 350 and 850 nanometers (billionths* of a meter) because the average human eye does not respond to lights outside of this range. In frequency terms directly comparable to the limits given above for sounds, the range of the eye's response is from about 350 trillion* to 850 trillion* Hz. (Since response at the extremes of the above wavelength range is quite

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* These numbers are used in the sense accepted in the U.S.A.: 1 billion = 1,000,000,000 and 1 trillion = 1,000,000,000,000.

feeble, a narrower range of wavelengths is often specified as covering the "visible spectrum"; for example 380-760 or even 400-700 nanometers.)

These sensitivity ranges for sounds and lights are maximum limits for young, healthy humans. Unfortunately, a significant percentage of licensed drivers have hearing or vision defects. The ability to respond to high frequencies of both sound and light is progressively lost as part of the normal aging process. Thus, very high-pitched tones (above 15,000 Hz, for example) cannot be heard at all by typical older people, and their sensitivity to blue and violet light (short wavelength, high frequency) may be seriously impaired. Some people of all ages have congenital or acquired hearing losses for low or middle sound frequencies, sometimes in addition to high-frequency losses. With respect to light, about 8 percent of male Americans have defects of color vision (largely inherited), usually known as "color blindness". (The inherited disabilities are sex-linked and much rarer in women.) The principal problem with color-defective drivers is a reduced or totally absent ability to distinguish certain shades of red, yellow, and green from each other. Since these three colors are so commonly used in traffic signals and (except for green) in emergency-warning lights, it clearly behooves us to choose shades of red, yellow, and green that minimize the confusions of the color-defective. In the case of traffic lights, the strategy that has been adopted is to use somewhat orangish reds and somewhat bluish greens, since for the common types of color defectives, a color containing some blue is clearly distinguishable from yellow or colors confused with yellow.

In order to determine how much intensity a signal must provide in order to be detected, it is necessary not only to take account of the preceding considerations, but also to examine the conditions under which the signal is normally used. For example, in a very quiet environment a siren can be heard for very long distances in flat terrain. If the same siren were employed in the middle of a downtown city street, it probably could not be detected more than a block away. Engineers sometimes use the concept of signal-to-noise ratio in explaining this type of problem. That is, the strength of the "signal" provides only part of the information necessary to predict effectiveness -- it is also necessary to account for the level of "noise" where the signal is going to be used. "Noise" in this sense can mean sound or it can refer to so-called "visual noise" -- the color, intensity and other characteristics of lights which in a midcity area make it difficult to detect the signal lights on an emergency vehicle.

In the instances of both lights and sound, <u>when the intensity of the "noise" (background) is much greater than that of the signal, it is very difficult to detect the signal</u>. The other critical factor in detection is the degree of similarity between the signal and the background. <u>The more alike the signal and background are, the more difficult it is to detect the signal</u>.

2. <u>The signal must be noticed</u>. Even if a signal is designed so that it <u>can be</u> detected by drivers, there is no assurance that it <u>will be</u> noticed. It is important to realize that in any large, relatively unselected group of people such as drivers, all abilities extend over a considerable range. There are at least some people with permanently impaired senses due to age, eye or ear disorders, or brain damages. In addition, there are other drivers who cannot be expected to respond appropriately because of temporary circumstances due to such factors as sleepiness, inattention, emotional state, intoxication and influence of drugs. In the case of both the permanent and temporary conditions, drivers sometimes fail to see even the most obvious objects in front of them. We must therefore expect that <u>any</u> warning system that can be designed will fall short of 100% effectiveness -- the latter is an unattainable goal.

Anyone in the process of learning how to drive, quickly finds that it is no simple task to master. A driver must be able to manipulate the controls of a car while paying attention to many things in the environment such as the behavior of other vehicles, traffic lights, signs, and roadway conditions. By the time a driver has mastered the basic skills of being able to maneuver the car adequately in traffic and has learned the meaning of many signals encountered while driving (traffic lights, brake lights, horns), much of his driving behavior is almost automatic -- a well trained habit. The scanning of attention is one of the strong habits developed with experience. This procedure is necessary because of the impossibility of simultaneously keeping track of the many things that occur on and near the road which might be of interest to a driver.

The function of a warning signal is to interrupt the normal routine of driving an automobile by attracting the attention of the driver despite the possibility that his attention might be focused elsewhere. It takes a signal of unusual impact to be successful under these circumstances.

3. Interpretation of the signal. Even after a driver has noticed the presence of a warning signal, his job has just begun. He has to determine the meaning of the signal. Based on his training, past experience and reasoning he will judge the purpose of the signal and try to anticipate what he is expected to do, as a driver. The ability to interpret a signal correctly is based upon several factors, but perhaps the most important ones are the "message set" (the number of possible messages and their meaning) and the number of possible interpretations (degree of ambiguity). The more messages and interpretations that are possible, the longer it takes to react to a signal and the greater the likelihood that an error will be made. As an illustration, a driver has a rather simple task when he sees a basic traffic light and must respond appropriately. ("Basic" here means not flashing and not masked into an arrow shape.) For the most part, the same signals are used throughout the country and they always have the same meaning. A driver does not have to spend any time determining the meaning of a basic red or green light. (The message set is usually limited to three at most -- red, yellow and green -- and the signals are free from ambiguity.)

Contrast the traffic light example with the warning signal situation that currently prevails. As noted previously, there are no nationally "standardized" lights or sirens and consequently a signal is subject to any number of interpretations, depending largely on the personal experience of a particular driver. There has been very little systematic work performed concerned specifically with the design of warning systems for land-based vehicles, and consequently each law enforcement agency, fire department, and ambulance corps is relatively free to design its own system. Automobile drivers are expected to react appropriately to all of them although they differ considerably from one another. Drivers operating in their local communities can be expected to become fairly familiar with the variety of messages to be seen there, but once "away from home", these associations are often no longer appropriate and may even get them into difficulty on occasion, since the same signals may be used elsewhere with quite different meanings.

4. Deciding what to do and when. Once a driver correctly interprets the message (clear a path for an oncoming emergency vehicle) he must decide how he best can accomplish this goal. A number of alternative actions are open to him which might be disastrous under some circumstances and appropriate under other conditions. In the many jurisdictions in which the proper response is legally prescribed, the driver must recall what the required action is. He must also be aware of the movement of other vehicles sharing the road, terrain features,

availability of a road shoulder and countless other factors which could spell the difference between causing or being involved in an accident and responding correctly. The speed of his reaction as well as its nature is an important determinant of the effectiveness of his driving behavior.

5. <u>Performing the action</u>. Finally, the driver has to maneuver his car in the way that he decided to. Reacting to an emergency situation is an emotional experience very different from the normal driving routine and can therefore result in inappropriate driving behavior. A driver who is easily "rattled" may respond too hastily or without making certain that no other automobiles are nearby, and create a dangerous situation not only for himself but for other road users, including the emergency vehicle.

This summary of the requirements placed on the driver during an emergency situation indicates that although many of the answers are not known, there is a considerable amount of information available concerning the factors that should affect the design of efficient warning systems. Unfortunately, this know-how has not had much practical effect because it has not been readily accessible to those responsible for designing and purchasing warning systems.

2.3. Messages Transmitted by Current Warning Systems

It has already been noted that the design of a warning system depends largely on two factors: (1) the identification of the message (or messages) which are to be transmitted and (2) the determination of the best way to communicate that information. Both of these factors are closely associated with the ability of civilian drivers to receive and then interpret the messages appropriately. A "successful" warning system must therefore be designed to take advantage of the capabilities of motorists while taking account of their limitations in receiving and processing signals.

Because so many automobile trips today cross jurisdictional boundaries, and because the signal systems of even neighboring jurisdictions may be quite different, the effect has been to discourage drivers from even trying to remember what combination of lights denotes what type of vehicle in which of the jurisdictions they pass through. The argument can be made therefore, that warning systems in use today, even when effective in reaching the target drivers, transmit primarily a single message -- "driver, be on the alert because something unusual is happening on the road." When this message is received and understood, the driver of a vehicle is prepared to respond in some manner different from his usual driving behavior. Data identifying the specific type of vehicle transmitting the signal isn't really of value to the driver -- beyond differentiating emergency vehicles from slow-moving service vehicles -- because it is likely that this information would have little if any effect on his driving behavior. He is likely to react the same way whether the vehicle is an ambulance, a police car, or a fire truck. He may have to slow down, stop, pull to the side of the road or perform one of several maneuvers, but he will probably not continue to pursue his usual driving habits. Information concerning the location and direction of the emergency vehicle may provide a clue as to what particular course of action should then be followed by the "civilian" driver.

2.4. Purchase of Warning Systems

A recent national survey of police departments of various sizes and jurisdictions (Klaus and Bunten, 1973) confirms the need for better information. The survey results indicate that most departments do not have the resources or expertise to do any systematic testing of their own. As might be expected, warning lights and sirens are purchased in the same manner as other, less critical equipment. This routine purchase procedure is a partial explanation for many of the problems associated with warning systems.

In order to make an informed recommendation concerning an equipment purchase, some basic information must be available. First, it is essential to specify in some detail the function(s) to be performed by the equipment. It is then highly desirable to be able to assess the equipment in an objective and quantitative manner. This evaluation is usually accomplished by indicating a series of tests to be conducted, with minimum acceptable requirements specified. Competing products can then be evaluated based on their performance on these standardized tests and other factors such as cost and proven reliability. There is nothing novel about this procedure but when we try to apply it to the purchase of warning systems, there are special problems.

In the case of most "hardware" purchases, there is little or no difficulty specifying what function is to be accomplished by the equipment -- it is almost self-evident. For example, if a desk were purchased, size, height, number and type of drawers might be specified and the test might be accomplished largely by means of a visual inspection (plus, perhaps, a bit of knocking and shaking to establish a minimal degree of sturdiness). The most important factor in making a selection would probably be the price. Specifying requirements for a radio receiver would be more complex. Factors such as the ability to operate under adverse weather conditions, permissible noise levels, degree of sensitivity, could all be subject to evaluation by objective tests. As in the previous instance of a desk, specifying the purpose of a radio receiver is not difficult and it has been done countless times by many organizations. Since radio transmission systems are frequently used for speech communications, considerable time and effort has been spent in developing sets of words and messages as standardized tests used in evaluating such systems. The assessment is primarily based on the percentage of words or messages correctly received over the system under conditions simulating real-use situations. The development of the tests themselves, and the experimental procedures under which they are conducted (signal-to-noise ratio being of critical importance) was a difficult and time consuming process which took many years to perfect.

Now, consider the purchase of a warning system. As noted previously, the most important function to be performed by the system is to help clear a path through traffic for a police emergency vehicle. This is easily understandable, but how can this be effectively accomplished?

For a variety of reasons, this is not an easy question to answer with any certainty.

One way to learn more about the problem is for researchers to conduct laboratory and field investigations as they did for radio transmission systems. This approach has been used only to a limited extent in the design of police warning systems. Many of the problems normally encountered in traffic conditions have never been examined and therefore the results of laboratory studies have not been properly tested under realistic driving situations. A great deal is known about many of the individual factors that are important in driving (such as eyesight, hearing, understanding messages). However, a very complicated situation arises when a driver must respond to a warning signal in addition to carrying out the many tasks arising under normal driving conditions. The information that is available concerning the way people hear, see, and understand messages was obtained under very different circumstances and therefore has only limited application to emergency traffic situations.

Laboratory studies are certainly not the only way to solve a problem. We might hope to rely on the experience and judgment of those who actually use the equipment. Since warning systems have been used for many years by a large number of departments, a considerable amount of this type of experience has been accumulated. Does this information help us in our task of specifying how warning signals should be designed? Unfortunately, it really cannot help us very much.

The typical police department uses a warning system which has been designed or selected based on their own experiences and preferences. Systems to accomplish this general purpose have been in use for a long period of time, so there have been many opportunities to make changes over the years. The department has usually also found it possible to obtain information formally and informally from other police departments and from publications directed toward police officers. Under these circumstances, if a variety of police agencies developed warning systems with similar characteristics based on their individual experiences, we would have some information that could be used in writing purchase specifications. Regrettably, an examination of the variety of warning systems now in use demonstrates more of the opposite effect -- almost every department has its own solution to the problem. Even though the warning devices are designed to accomplish the same functions, and the experiences of the police with particular designs could be expected to be similar, there is only limited agreement about many of the characteristics of a "good" system.

There is a relationship between the size of a police department and the type and value of the information they can obtain to help them make intelligent equipment purchases. Information costs money and larger departments have more money and manpower to devote to this task. Naturally, small departments are likely to have a very limited amount of data because of the small number of devices that are purchased. Even large departments often have experience with a limited number of systems because of the economics involving price reductions for large quantities. Other factors which would favor the purchase of a limited variety of systems are the uniformity of maintenance requirements for a particular system and the need to modify vehicles to accommodate particular systems. Although additional information is available when police departments contact one another and exchange experiences, the departments rely on manufacturers' data for a considerable amount of their information.

The lights and sirens available for purchase at any time consist primarily of refinements of techniques which have been used for many years. Unfortunately, the most important information required for the intelligent purchase of warning devices has not been available -- namely, the demonstrated effectiveness of a system in performing the function for which it was designed.

We therefore find that neither scientific information nor experience provide a clearcut answer concerning <u>how</u> to design a warning system.

Why the difficulty?

The reasons stem from four primary issues which have been discussed earlier in this report.

1. The messages transmitted by warning systems.

2. The need to understand "conspicuity"

3. The operating environment for warning systems - (lack of standardization, control of use).

4. The wide variety of systems in current use.

These difficulties do not change the need for information to be used as guidance in warning system purchases. But we also should realize the real limitations of the information available which forms the basis of our evaluation.

3. THE NEW STANDARDS

3.1. What Was the Basis for Evaluating Warning Systems? How Were the Standards Developed?

As a result of the early studies that were conducted before preparing the standards, it became evident that no simple test could now be devised which could evaluate total warning systems in terms of their effectiveness as used in the real-life situation. The problem was far too complicated and much of the needed information was not available. Instead, it became necessary to gather, from whatever relevant sources existed, as much information as possible that could be used to define reasonable criteria for warning systems.

A number of tests were conducted using some of the warning lights -- but they were limited in scope. A thorough test program of physical measurements and judgments of "conspicuity" under realistic conditions could not be conducted under the scope of the program -- although this information is needed for the development of an improved standard. The studies that were completed provided information that was helpful in better understanding the many problems associated with warning light measurements and in devising an interim standard. However, there is no way of knowing how typical our data were because of the limitations in size and scope of the investigations.

Two types of warning lights for which we were able to obtain physical measures by readily available methods were rotating incandescents and gaseous-discharge flashers. Table 6.1-1 in the appendix designated Chapter 6 gives the results, the important quantities being the effective intensities of the lights. The concept of "effective" intensity will be explained in the following section (3.2).

In the case of the sirens, rather extensive physical measurements were made (Jones, Quindry, and Rinkinen, 1974), but no psychophysical testing was attempted. The perceptual problems connected with sirens are in certain respects less complex than those associated with lights.

The sense of sight is highly directional and selective: (1) one can see clearly only over a narrow central portion of the visual field; (2) the response characteristics of the outer (peripheral) parts of the eyes are quite different from those of the central parts; and (3) there is usually a strong concentration of attention on the objects imaged in the center of the visual field. With sounds, on the other hand, there is no such elaborate spatial organization: sounds originating anywhere are collected in the same two ears, and although there are some differences in our ability to localize sounds reaching us from different directions, in general the loudness with which a sound is heard does not vary importantly with the position of the normal listener's head. Moreover, in contrast with the easy confusion of signal lights with other lights in the environment, the sound of a siren is highly distinctive and is usually recognized for what it is as soon as it can be steadily heard over the background sounds. With sirens, then, the essence of the warning-signal problem is to determine what level of sound is needed to achieve definite audibility inside a sound-attenuating automobile, in the presence of substantial levels of background noise; and to calculate at what range any particular siren will deliver the necessary sound level into the passenger compartment of the automobile. The first part of the problem is perceptual in nature, and Jones, Quindry, and Rinkinen (1974) strongly recommend perceptual tests in the future to provide factual backing (or a basis for revision) for a theoretical model they applied to calculate some answers. On the basis of their current theoretical model, sirens of the kind now available should usually not be audible at the long ranges needed to facilitate emergency-vehicle maneuvering. Specifically, on the basis of their model, plus measurements they made on the sound-attenuating characteristics of automobiles and the level of background noise in typical road environments, they calculated that no electromechanical siren tested would be audible to a driver even at a distance of 16 meters (52 ft), and one or possibly two out of four electronic sirens tested would be audible at a range of 64 meters (210 ft).

Other sources of information on both lights and sirens were the experiences of police departments and an examination of the actual systems in current use. This information was obtained in meetings, reviews of publications, and survey results.

3.2. Summary of the NILECJ-NBS Standard on Warning-Light Systems for Emergency and Service Vehicles

As explained earlier in this guideline, one of the most serious problems in the present emergency-vehicle warning-light situation is the lack of nationwide standardization. A valuable improvement in driver responsiveness could therefore be expected upon the universal adoption of any reasonable signal system for emergency vehicles. It would not help very much to standardize the signals carried by only a single type of emergency vehicle, such as police vehicles, as long as all the other types of signal-bearing vehicles in each of the thousands of different jurisdictions across the country are left free to use similar displays that could be confused with whatever the police might adopt. Therefore, the National Bureau of Standards, under contract to NILECJ, set itself the task of drafting a total standard for warning-light systems carried by all emergency and semi-emergency vehicles (National Institute for Law Enforcement and Criminal Justice, 1974b). NBS attempted to go beyond the arbitrary selection of a single system, to the rational selection of the best possible system based on all existing knowledge about warning lights.

A. Meanings of the Signals

First, a basic decision was made that the meanings of the emergency signals should relate to the actions expected of the target drivers, and not to the class of emergency vehicle (police, fire, ambulance) issuing the signal. Second, it was decided that there were basically only three different situations faced by a driver in connection with the appearance of an emergency vehicle:

(1) The emergency vehicle is approaching the target vehicle at high speed. The required action, regardless of emergency-vehicle category, is for the target driver to get (or remain) out of the way.

(2) The special (semi-emergency) vehicle is moving slowly or otherwise presenting a hazard (e.g. frequent stops or wide load) to normal-speed traffic. The required action is for the target driver to slow down to the point where the nature of the hazard can be assessed, and then to pass cautiously or remain behind at low speed, as traffic conditions and the nature of the hazard require.

(3) The emergency vehicle is not operating in the emergency mode, but is on routine patrol or is parked off the road (e.g., giving a traffic ticket). The required action is for the target driver to proceed prudently. He should obviously, on the one hand, slow his vehicle down to the speed limit if he is moving too fast; and, on the other hand, should not slow down excessively (to "sightsee") but should do his part to keep the traffic flow moving at a near-normal pace.

B. The Three Signal Configurations

Corresponding to the three signaling situations listed above, the light configurations chosen were:

(1) A 360° alternating red and white light, plus two red fore-and-aft flashers (covering at least 20° on either side of the forward direction and at least 20° on either side of the rearward direction, one fore-and-aft set mounted toward each side of the vehicle); or, alternatively, two of the 360° alternating red and white lights.

(2) One or two 360° yellow ("amber") lights.

(3) One 360° blue light.

These configurations are illustrated in Figs. 3.2B-1 and 3.2B-2.

Note that the standard is a performance standard that specifies what signals are to be produced, without spelling out the means used to produce them. Thus, in terms of present technology, all the types of lights except for the blue lights of the third configuration can be generated by either incandescent or gaseous-discharge ("strobe") sources (the exception to be explained shortly). Moreover, the performance emphasis of the standard allows for the future development and use of new types of light sources, as long as they can produce the specified signals.

The standard further restricts the red and white alternating light of the first configuration and the yellow light of the second to concentrating their light energy into relatively brief flashes, having a duration less than 20% of the total on-off cycle. (A short flash gets more visual effect from the same amount of energy than a long flash.) However, the blue light of configuration (3) is restricted to being on longer than it is off (on 50% to 70% of the cycle). Such occulting lights are sensed as flashing off rather than on, connoting a lesser sense of urgency. Present-day xenon flashlamps cannot remain on for such prolonged periods, but manufacturers of steady-burning gaseous-discharge sources could very well develop in the future lamps and circuits that meet the requirements.

INSTALLATION OPTIONS FOR EMERGENCY VEHICLE WARNING LIGHTS

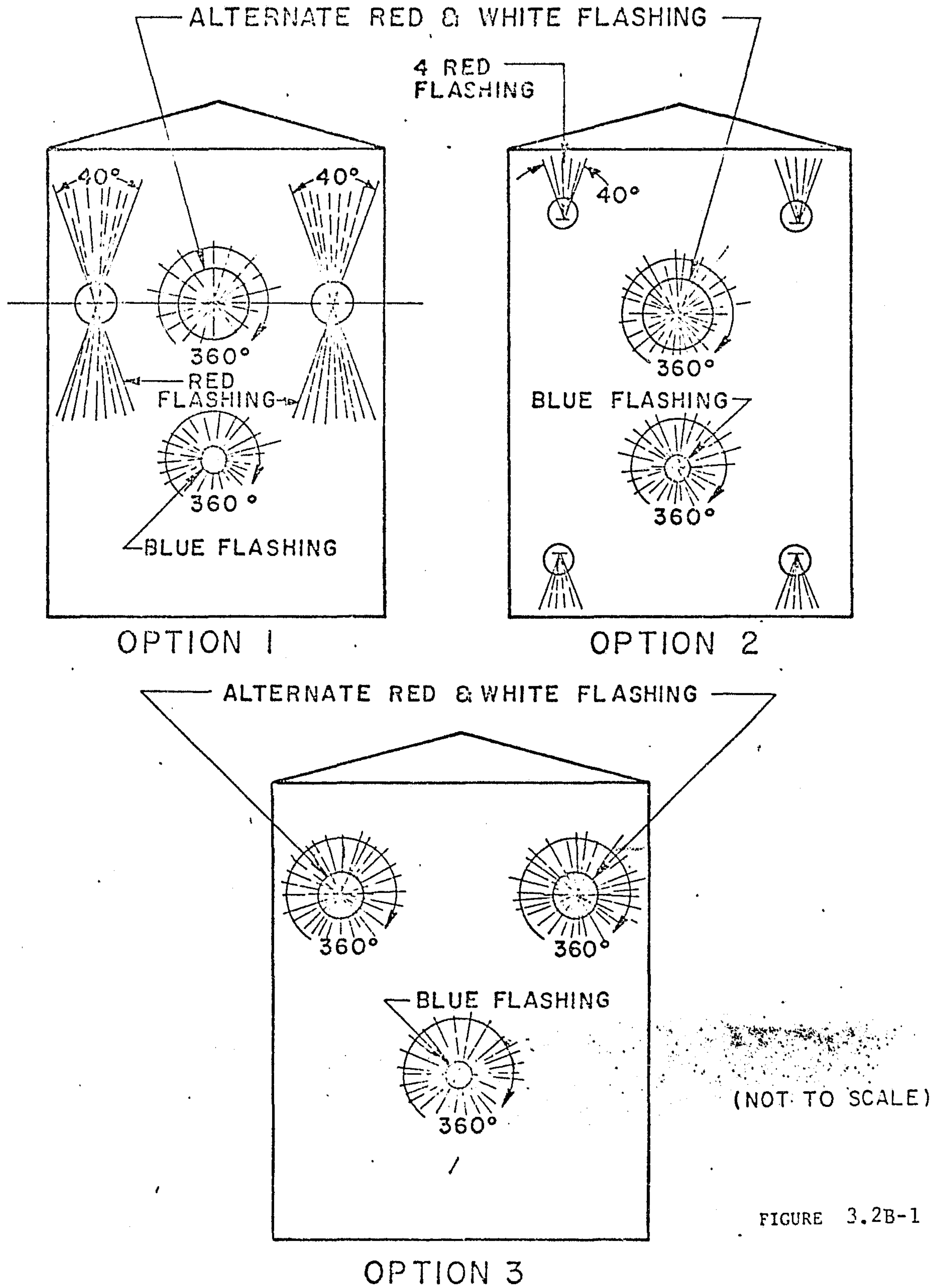
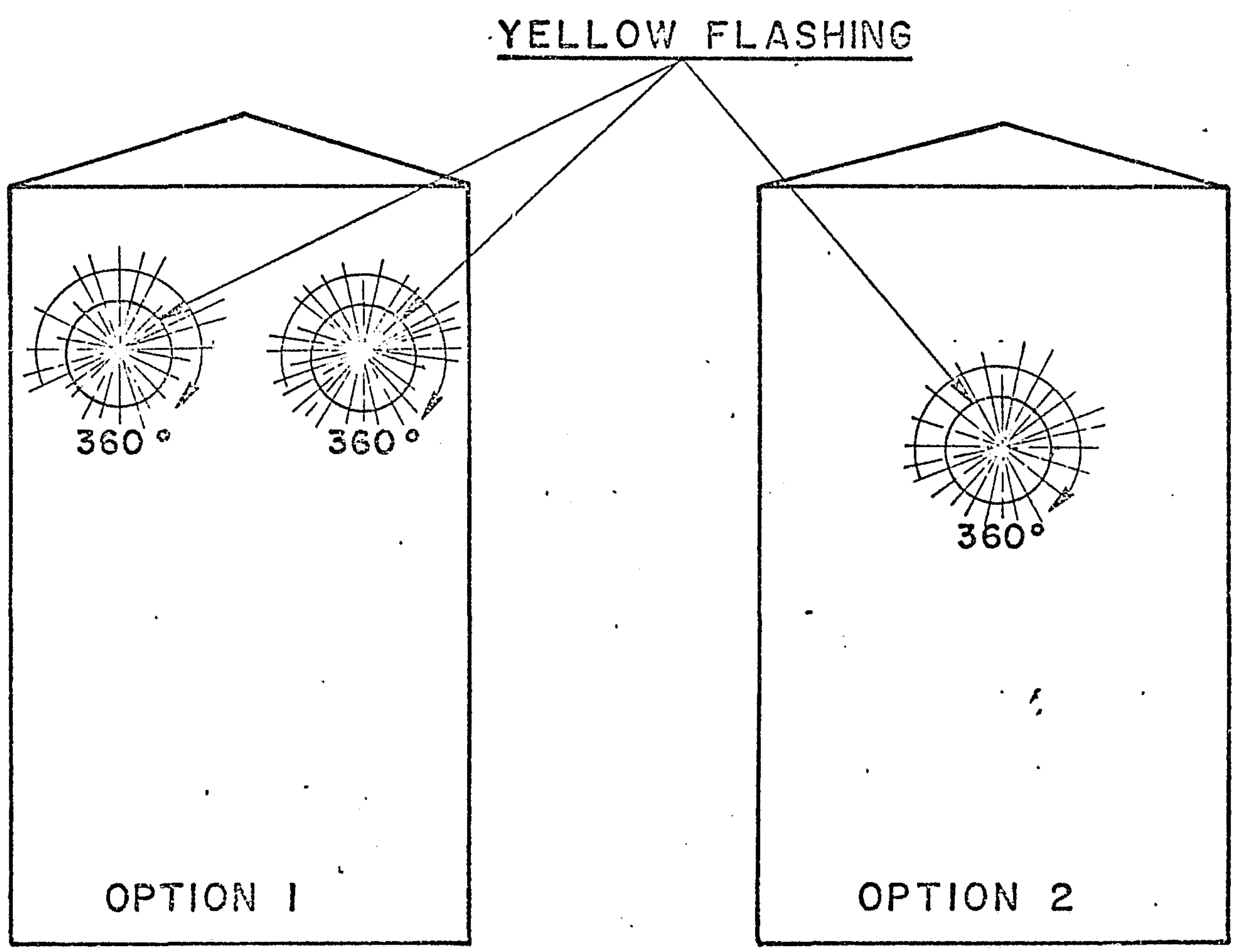


FIGURE 3.2B-1

INSTALLATION OPTIONS
FOR
SERVICE VEHICLE FLASHING LIGHTS



(NOT TO SCALE)

FIGURE 3.2B-2

The supplementary red flashers of configuration (1) are restricted only to an upper limit of 70% "on" time, so that brief flashes are acceptable for this type of light.

Ordinarily, any emergency vehicle (that makes high-speed runs) would be expected to be equipped with both configurations (1) and (3), as shown in any of the three optional arrangements of Fig. 3.2B-1. Semi-emergency vehicles (not making high-speed runs) would be expected to be equipped only with the yellow light(s) of configuration (2), as shown in Fig. 3.2B-2. The current version of the standard makes no explicit allowance for the case of an emergency vehicle standing still <u>on</u> the road, as frequently occurs following a traffic accident. In that situation, the target drivers are rapidly overtaking the emergency vehicle, and will see the red/white and the red lights far ahead of them. The code of driver behavior that would go with the proposed signal system should require a driver who notices he is closing on a vehicle displaying the emergency signal configuration to slow drastically to the point where he can come to a full stop, if necessary, in the vicinity of the emergency vehicle. It might be helpful in alerting the oncoming drivers to the on-road hazard at the earliest possible moment for a distinctive signal display to be prescribed for this special situation. One configuration that would be available for this purpose with no additional hardware would be the simultaneous use of the red/white and red emergency signal <u>plus</u> the blue "presence" light. Since the blue light alone will frequently be associated with a parked emergency vehicle, and the red/white and red display identifies an active emergency, simultaneous use of the two configurations would be interpreted quite naturally as a stationary emergency situation. Unfortunately, it would be necessary to make the blue light much brighter than the present standard requires it to be, if it is not to be hidden in the glare of the emergency lights and the headlights of oncoming traffic.

C. Flash Rates

A desirable and currently typical rate of flashing for a light meant as an emergency signal is 90 flashes per minute (fpm). The range allowed by the standard for the red/white, red, and yellow lights is 90 ± 10 fpm. The blue lights are used in non-emergency situations (except as suggested in the preceding paragraph) to indicate mere presence, so a slower, less urgent flash rate of 60 ± 5 fpm was prescribed.

The standard requires that when the dual red flashers of configuration (1) are used, they must be synchronized. The main purpose of these supplementary lights, located near the edges of the vehicle roof, is to provide a signal that will be visible to drivers whose view of most of the emergency vehicle's roof -- including the center -- is blocked by other vehicles. (The third option of two alternating red and white lights, out near the roof edges, accomplishes the same purpose.) Since it will not be rare for only one of the red flashers to be visible by itself, it was considered desirable to have the standard emergency flash rate of 90±10 fpm apply to these lights as well as to the red/white alternating light. At present, dual roof-edge lights that are hooked together at all are sometimes arranged to flash synchronously, and sometimes alternately. If two lights with individual flash rates of 90 ± 10 fpm are operated alternately, the combination produces 180 ± 20 fpm, and at long range, where the separate lights may not be visually separable, the appearance would be of a very rapid series of flashes. The requirement of synchronous operation thus guarantees that the perceived flash rate associated with the supplementary red lights will always appear as 90 ± 10 fpm, regardless of whether one or both lights are seen, and regardless of the distance.

D. Minimum Intensities

The one factor more important than any other in determining the attention-attracting power of a light is its intensity. When the light is not seen as steady but is producing discrete flashes, a measure called <u>effective intensity</u> is used, which specifies a steady-light intensity that is visually equivalent in a specific sense. The effective intensity value assigned to a flashing light is intended to represent the actual intensity of a steady light that disappears from view, in the dark, at the same distance as the flashing light. It should be noted that effective intensity is the only widely accepted intensity rating for any time-varying light, but the measure originated in the specific, relatively simplified context of looking for isolated signal lights at night in approximately known directions. Fortunately, recent experimental work at NBS carried out as part of the present project has established that the effective intensity of flashing lights correlates well with observers' impressions of the attention-attracting power (conspicuity) of the lights in the daytime.

In the current version of the standard, the effective intensity levels required are:

(1) 4000 cd for the white and 800 for the red component of the alternating light; and 500 cd for the fore-and-aft red lights.

(2) 2000 cd for the yellow light.

(3) 10 cd for the blue light.

The blue intensity of 10 cd is virtually useless in the daytime, and not visible from great distances at night. Since no emergency reaction to the blue light is desired, there is no minimum safe range of detection to worry about, and power was conserved by setting a low intensity requirement.

On the other hand, the 4000 cd required for the white light is relatively high. Very few units now on the market emit flashes of such intensity, but such units can be produced with existing technology. (In the restricted sample of lights that we measured, three units were in the 3200-3500 cd range; see Table 6.1-1 in Chapter 6.) The purpose of the high-intensity white component of the red-and-white light is to attract attention at the maximum feasible range. (The red component of the alternating light and the red flashers serve principally to make the total signal stand out against a background that is frequently spotted with many other white lights.) If some improvement in the range of effectiveness of emergency-vehicle warning lights is to be made -- and such improvement seems badly needed -- then going to higher intensities cannot be avoided.

However, the 4000-cd requirement was based on providing an adequate effectiveness range in the daytime, when lights are hardest to see. There is some evidence that such lights may be disturbingly bright at night, for observers at short distances from the emergency vehicle. On the basis of experimental work carried out at the Highway Safety Research Institute of the University of Michigan, Rudolf G. Mortimer (1971) recommended that lights used on automobiles as stop (brake) or turn signals should have intensities (when steadily lit) of about 2000 cd in the daytime, and no more than about 150 cd at night. The proposed daytime level was based on judgments by the observers of "adequate brightness for visibility as a signal", and the nighttime maximum was based on judgments of sufficient brightness "as to cause discomfort". Requiring that the effective intensity of emergency-signal flashes be at least twice the intensity of brake lights or turn signals seems entirely reasonable if the emergency-signal flashes are to be highly conspicuous in traffic (particularly since doubling intensity does not increase the subjective impression of brightness by the same 100%, but only by about 25 to 30%).

Hence, the 4000-cd white-light effective-intensity minimum required in the present standard seems quite defensible as a daytime standard. However, on the basis of Mortimer's discomfort results, it would appear that it might be better to require a lower level for night signal flashes. Further experimental work seems called for to determine a suitable night intensity level for purposes of emergency signaling. Such work must take account of the fact that some degree of annoyance is a reasonable price to pay for having a signal effective at the longest feasible range. The upper limit should be set on the basis of avoiding blinding drivers with afterimages for excessively long periods of time following viewing of a flash, rather than on the basis of subjective disturbance. It should also be kept in mind that ordinary automobile low-beam headlights typically have on-axis intensities of 20,000 cd, and even several degrees off axis may still put out a few thousand candelas. Nighttime emergency signals on crowded roads are competing with a sea of these headlights.

If future experiments do establish that a wide disparity between desirable daytime and nighttime levels exists, the solution might be to maintain a capability for both levels, as recommended by Mortimer for stop and turn signals. His suggestions is that the switch for selection between the dual intensity levels be linked to the headlight switch of the vehicle, so that the lower nighttime intensity is automatically activated whenever the headlights are lit (i.e., when it is dark). If the same principle is applied to warning lights, only a single on-off switch for the emergency lighting system is necessary, and the officer responding to a sudden emergency call does not have to take time -- and possibly commit an error -- by choosing between a daytime switch and a nighttime switch. Mortimer also suggests that an out-of-the-way manual override switch can be provided, which permits the driver to make a deliberate choice of the high intensity level at night in special situations of reduced visibility. An unfortunate defect in this system, as applied to emergency vehicles, is that the latter often have their headlights turned on during emergency runs in full daylight, thus increasing their overall conspicuity. With Mortimer's proposed circuitry, the lower nighttime level for the emergency lights would then be in effect. Perhaps the solution would be to link the level of the emergency-light intensities not to the headlights, but to a photocell that measures the ambient light and automatically switches to the lower level if it is dark enough outside (but again with a manual override provided).

The 4000-cd minimum for white light flashes amounts to a requirement imposed on the bare light source (although, more precisely, the requirement applies to the light source covered by the usual clear dome). At present, colored signals are produced either by covering the bare source with a colored dome or by coating the bulb face with colored material and using a clear dome. The reduced intensity requirements for the red and yellow lights of the system are based on the fractions of light transmitted by typical glass or plastic filters of the respective colors. That is, most yellow filters transmit about half the light striking them, so that a 4000-cd white light covered by a yellow filter would put out an intensity of 2000 cd, and this level has been required in the standard. Red filters typically transmit about 20% of the incident light, so a 4000-cd (effective intensity) white source would emit about 800 cd through a red filter, and this is the level required for the red component of the alternating emergency light. The red flashers, since they generate supplementary rather than primary signals, are required to have only 500 cd of effective intensity. Finally, a strong blue that is neither excessively pale (whitish) nor greenish -- and the standard requires such blues -- can only be obtained at the cost of a great deal of intensity. Blue filters that meet the color specifications of the standard transmit only about 3% of the light from a white incandescent source (and perhaps 6% of the bluer white light produced by a xenon discharge lamp). An incandescent lamp producing 4000-cd flashes could thus produce about 120 cd of good blue light. However, because of the non-urgent function of the blue lights in the proposed system, the standard saves battery drain by asking for only 10 cd of blue light, corresponding to an incandescent source flashing with an effective intensity of about 330 cd or to a 165-cd xenon-discharge source, approximately.

E. Choice of Colors

The use of yellow for semi-emergency vehicles seemed an obvious choice because of the existing widespread familiarity with yellow as a caution signal in traffic lights and highway construction flashers. Yellow is already the most common color used on slow-moving vehicles, on a nationwide basis (although its use is far from universal). Finally, it was desirable to use yellow lights as some part of the signal system because higher intensities can be obtained for yellow than for any other strong color, for a fixed energy input to the white light source. [This was explained in the preceding section (Minimum Intensities).]

The very highest intensities, for fixed electrical input, can be obtained from the bare white lamp (or the lamp in a clear dome). The use of white as part of the primary emergency signal therefore seemed essential, from a practical standpoint. A pure white emergency signal is not acceptable, because there are too many other white lights on and near roadways (headlights, street or roadway lights, etc.) to allow the white signal to be adequately conspicuous. A signal alternating white with some strong chromatic color to provide distinctiveness seemed the evident solution, so the remaining problem was to choose the chromatic color.

The choice came down to red or blue, because at present green has an almost universal connotation of "go", the opposite of a caution or emergency signal. As explained in the preceding section, a heavy price must be paid in loss of intensity when blue lights are used (a factor of as much as 6 or 7 relative to red). If there were some extremely compelling reason to prefer blue to red, perhaps the great intensity loss -- or the compensatory 6- or 7-fold increase in power drain to provide comparable intensity -- might be acceptable. On the contrary, however, the arguments for red over blue, even apart from the critically important intensity consideration, seemed to us, on balance, to be stronger. Red's advantages are: (1) red already has an almost universal connotation of danger or emergency; (2) red light penetrates fine-particle hazes better than equal-intensity light of any other color; and (3) red is still seen as red even near the borderline of visibility, whereas all other colors tend to fade into white near the threshold of visibility. The arguments for blue are: (1) blue is highly distinctive because there are no blue traffic lights and few other blue lights in the street and road environment; (2) blue is (allegedly) a "soothing" color (as opposed to the "exciting" red) and might engender less hostility in anti-authority neighborhoods (we know of no controlled experimental evidence for this claim); and (3) blue is the standard police-car signal in much of Europe, and international standardization is desirable. With respect to seeing and responding to signals at the earliest possible moment, the arguments for red seem stronger.

With red having been chosen as the chromatic component of the basic emergency signal, blue then became the only reasonable choice for the non-emergency "presence" lights. Unlike green, the recent use in the United States of blue as a signal on emergency and semi-emergency vehicles has made most people aware of its status as a special-vehicle indicator.

The standard defines precisely which colors are to be considered as being white, red, yellow, and blue. Without such restrictions, confusion in color identification can occur at long range. For example, an excessively pale blue can be seen as being white, or a very orangish yellow can be taken to be red. The color limits in the standard agree with the signal-color definitions being considered for adoption by the International Commission on Illumination (CIE), and differ somewhat from the color limits presently specified by the Society of Automotive Engineers (SAE) (which currently has no blue definition at all). One example of why the CIE boundaries were preferred is the blue limit of the color white. The present SAE definition of white is based on the formerly universal use of incandescent lamps, and excludes as unacceptable the bluish white light produced by xenon flash lamps, whereas the CIE boundaries are extended to include the xenon-discharge white color.

F. Other Requirements of the Standard

The essential requirements for the signals have now been described, and these specifications form the heart of the standard. Any type of device capable of producing the required configurations of signals is perfectly acceptable, so the standard in no way discourages the development of new lighting technology. However, regardless of the kind of device that may be employed, certain physical limitations should reasonably be imposed on its functioning. For example, it should not wear out after brief service, and it should be able to perform properly in the more difficult kinds of environments which exist around the United States (for example, in the extremes of temperature ordinarily encountered, in high humidity, in a dusty atmosphere, etc.) In terms of number of pages, therefore, a large part of the standard is devoted to spelling out specific requirements of this type, and the methods to be used to measure the various kinds of performance involved. The requirements and test methods are based partly on existing standards of the SAE for automotive lighting devices, and partly on standards in use in the field of aviation for types of flashing lights very similar to those now used on automotive emergency vehicles. In short, much previous experience has established the practicality of the specific levels of hardware performance demanded by the standard.

The present version of the standard imposes requirements in each of the following categories: (1) general; (2) design; (3) ruggedness; (4) material; (5) power; (6) radio noise interference; (7) wiring; (8) installation; (9) performance; (10) signal characteristics; (11) effective intensity; (12) signal color; (13) signal maintenance; (14) life; (15) control switches; (16) flashers; (17) auxiliary power units; and (18) workmanship.

Among the "performance" requirements [item (9) above], specific tests are prescribed for the following variables: (a) operation at room temperature; (b) flash rate; (c) minimum effective intensity; (d) radio interference; (e) life; (f) low temperature; (g) high temperature; (h) humidity; (i) vibration; (j) moisture; (k) dust; (l) corrosion resistance; and (m) signal color.

3.3. Summary of the NILECJ-NBS Standard for Emergency-Vehicle Sirens

Although many emergency and service organizations at all jurisdictional levels have attempted to create distinctive warning-light configurations to set them apart, there seems to have been considerably less elaboration of the sonic warning signals. There is some degree of specialization: loud horns are rarely used as emergency signals by police patrol cars (Klaus and Bunten, 1973), and are probably used mostly by fire engines and perhaps by some ambulances. In general, however, the attitude seems to have been that a siren is a siren, and identification functions have been left to the warning lights and vehicle paint patterns. The technology of sonic warning devices may become more varied at some time in the future, but at present there is no need to set a chaotic multiplicity of signal systems in order, as there was with lights. The standard for sirens

(National Institute for Law Enforcement and Criminal Justice, 1974a) is therefore a good deal simpler than that for lights, with only a few restrictions on the signal, and most of the material deals with hardware and test procedures.

A. Classification of Sirens

Reflecting current technology, the standard distinguishes three classes of sirens, according to the method by which the sound is generated. There is a basic dichotomy between (1) electronic sirens, which feature one or more speakers driven to produce sounds by electrical impulses coming from an electronic signal generator; and (2) other sirens which produce sounds as a result of a repetitive mechanical action. Present sirens generating sounds by mechanical means are rotary in nature, and involve the spinning of an element, the rotor, within or around a stationary element, the stator. This type of siren is currently subdivided into two classes: the (strictly) mechanical siren, in which the rotor is driven by a mechanical linkage to some rotating part of the vehicle or engine; and the electromechanical siren, in which the rotor is driven by an electric motor.

B. Siren Control Functions (Modes)

Originally, all sirens operated under the "manual" siren function, in which someone throws a switch (or mechanical clutch), causing the sound level to increase to the maximum value of which the siren is capable, and to then remain at the maximum level until the switch is released or opened. Later, automatic cycling of the siren was introduced, and with some electronic sirens, several different modes of automatic cycling are available. There are three quite distinct automatic siren modes that are widely used and are relatively familiar to many people in the U.S.A. The "wail" function -- the one most commonly used in this country -- produces a continuous automatic cycling of increasing and decreasing sound level at a rate of 8 to 30 oscillations per minute (0.13 to 0.50 Hz). The "yelp" function produces sounds perceived as quite different from the "wail" mode, but the "yelp" is actually only a "wail" speeded up to a rate of 60 to 75 oscillations per minute (1.00 to 1.25 Hz). Finally, the "hi-lo" function -- common in Europe -- produces a repetitive alternation of two fixed tones of different pitch.

C. Frequency Composition

The standard requires the frequency spectrum of the siren to include a strong concentration of power within the frequency range to which the normal human ear is most sensitive. Specifically, it is stated that the spectrum shall include one or more frequencies within the octave bands centered at 500 or 1000 Hz (that is, in the approximate range of 353 to 1414 Hz), at a sound pressure level of at least 128 dB, measured at a distance of 2 meters.

D. Sound Level

Because the ear is not equally sensitive to sounds of all frequencies, determining the overall auditory effect (loudness) of a complex sound requires weighting the physical sound-pressure-level spectrum by the sensitivity function of the ear and totalling the weighted pressures over all frequency bands. Several different sensitivity functions, applying under different conditions, have been standardized, and the most common of these is known as the A-weighting function. Most sound level meters have the A-weighting function built in electronically, in very close analogy to the built-in luminous-efficiency weighting function in photometers (the latter function being built in optically, through the use of a transmitting filter).

For a siren (or pair of sirens operating as a unit), the standard requires the A-weighted sound level to be at least 132 dB on the forward (longitudinal) axis and at least 128 dB in the directions at ± 45° from the axis. These levels must be reached at a distance of two meters (6.6 feet) between the sound level meter and the acoustic center (apparent point of sound radiation) of the unit. The sound level requirement refers to measurements made under free field conditions; that is, within a space such that there is no appreciable back reflection from the boundary surfaces of the space. An adequate approximation to free field conditions is considered to exist either in an anechoic chamber, the walls of which are nearly completely sound-absorbing, or out in an actual open, flat field, with the unit mounted high enough above the grass-covered ground to minimize reflection of sound from the ground.

In the limited siren test program carried out in connection with the project that led to the standards and these Guidelines, NBS found that of the four electronic sirens tested (see Table 6.2-1 in Chapter 6), one put out less than 132 dB(A) in all modes, on axis at 2 meters (the weakest level of all being 126 dB in the yelp mode for that siren). Two of the four sirens met the standard in all modes, the maximum level attained being 151 dB in the wail mode of one siren. For each of these four sirens, the sound levels in corresponding directions for all three automatic modes (yelp, wail, and hi-lo) are within 4 dB of each other, with the wail consistently being the loudest mode. The fourth electronic siren met the standard on axis only in the wail mode, at 133 dB(A), but failed in the yelp mode at 129 dB(A). However, even the wail mode of this siren did not pass the standard overall, since on one side the level was only 125 dB(A) at 45°, less than the required 128 dB.

NBS tested nine electromechanical sirens (see Table 6.2-2 in Chapter 6) and found sound levels that tended to be lower than those measured for the electronic sirens. In fact, all of the nine electromechanical units, ranging in on-axis level from 115 to just under 132 dB(A), failed to meet the standard's requirement for 132 dB(A).

E. Electronic Sirens With Dual Speakers

When an electronic siren system has a sufficiently powerful amplifier, it is feasible to distribute the amplified electrical signal to more than one speaker. A common configuration is two roof-mounted, forward-facing speakers, one on each side of the vehicle. Because the same sounds are generated in the two speakers at the same time, sound interference patterns occur, the significant variables affecting the strength or weakness of the resultant signal at each point in space being the wavelength of the sound and the distances from the point to the acoustic centers of the speakers. In certain directions, the dominant frequency of the siren tone may suffer some destructive interference, and hence the signal can be inaudible to listeners in those directions, even though it can be clearly heard by listeners located further away from the vehicle in other, more favorable directions. Test data (Jones, Quindry, and Rinkinen, 1974) on dual-speaker systems indicates that the destructive interference effects are somewhat more severe when the two speakers are connected in antiphase (vibrating in opposite directions in response to a given electrical input) than when the speakers are connected in phase (vibrating in the same direction at the same time). Consequently, the standard requires that dual speakers must be connected in phase.

The forward direction is the most important for emergency-vehicle warning signals, and the destructive interference between signals from out-of-phase speakers is particularly bad precisely in the forward direction. For in-phase speakers, there is some constructive interference (enhancement) in the forward direction, and it is helpful if the two speakers are oriented very nearly in the forward direction. The standard therefore requires that the acoustic axis of each speaker be within 10° of the forward direction.

F. Other Requirements of the Standard

As with the standard for lights, a large part of the siren standard concerns itself with provisions meant to assure that the hardware will continue to perform adequately in the face of harsh environmental conditions. The standard also spells out in considerable detail the procedures to be used for making the critical tests of acoustic output. The various required tests are based on practices already established by widely recognized standardizing organizations. The siren standard makes reference to American National Standards (ANSI, formerly ASA), U.S. Military Specifications (MILSPECS), International Standards Organization (ISO) Recommendations, and Society of Automotive Engineers (SAE) Standards.

The present version of the siren standard imposes requirements in each of the following categories: (1) general; (2) ruggedness; (3) materials; (4) wiring; (5) radio noise interference; (6) performance; (7) power supply; (8) installation instructions; (9) identification markings; and (10) test samples.

Among the "performance" requirements [item (6) above], specific tests are prescribed for the following variables: (a) high temperature; (b) low temperature; (c) humidity; (d) moisture; (e) vibration; (f) dust; (g) corrosion resistance; (h) radio noise interference; (i) sound pressure level.

4. HELPFUL ACTIONS THAT CAN BE TAKEN NOW

It will no doubt be some time before the voluntary NILECJ standards are finally promulgated and publicized, and it is not known at this time whether departments will be encouraged to conform only for new warning-unit installations, or will also be expected to discard all older units that do not meet the standard. However, there are three steps toward improvement that can be taken now by all users of emergency-vehicle warning lights. These steps are meant to apply to police and fire vehicles and ambulances, and not to service vehicles, who are encouraged to switch to all yellow lights. Also described below is an important check that should be made by all users of multiple-speaker electronic sirens.

4.1. Alternate Color with White

Because of the extreme importance of the effective intensity of the light flashes, all-colored signals such as all red or all blue should be abandoned. If a colored dome is in use on a rotating light, discard it for a clear dome, and obtain the color by using colored bulbs. Replace half of the bulbs by clear (white) bulbs, so that every other flash is white. In rotating units containing three bulbs, replace one bulb by white, so that the pattern appears as pairs of colored flashes separated by single white flashes.

Where non-rotating, flashed units are employed -- whether gaseous-discharge ("strobe") or incandescent -- one of two alternating lights can be made white. If only a single flasher is in use, consider installing a second, white unit to alternate with the first.

4.2. Use the Biggest Bulbs You Can

Since intensity is so important, check with the manufacturer of your unit to find out the maximum bulb wattage he considers practical to use in his unit. If over-large bulbs are installed, plastic domes can melt and other damage may be done to the electrical or mechanical components. Using higher-wattage bulbs will increase the power drain on the vehicle's electrical system, so consider upgrading the latter, if necessary, by using special heavy-duty alternators and batteries.

4.3. Paint Your Vehicles to be Conspicuous

Everything else being equal, the larger the area covered by the source of a signal the better (but with diminishing returns beyond some large area). It appears impractical to expect the warning lights carried by emergency vehicles to be made much more than a foot in diameter. However, the surface of the emergency vehicle itself can be regarded as an auxiliary visual signal, and in bright sunlight the surface signal could under some circumstances prove more potent than any light signal used. Esthetic considerations presumably have had a strong influence in the past on the colors and patterns used in the painting of emergency vehicles. Another factor has been the desire for distinctiveness among different categories of emergency vehicles (fire engines red, ambulances white, etc.) In any event, visibility and conspicuity have not been the exclusive concerns of those responsible for the decoration of emergency vehicles.

At night, and against dark backgrounds such as earth or foliage in the daytime, light colors such as white or yellow are more visible, and some fire departments now paint their engines yellow or white for that reason. (Night visibility of emergency vehicles is of some concern, because the vehicles sometimes do not use their warning signals, as when returning from emergency runs.) Unfortunately, with snow on the ground a white vehicle is all but invisible, and the noticeability of a yellow vehicle seen at a distance is not much better. Only dark colors show up really well against snow, or, for that matter, bright sky. A vehicle of intermediate reflectance, such as medium gray or tan, is not strikingly visible against either light or dark backgrounds, and is poorly visible against backgrounds of intermediate lightness, such as the road suface itself, on many occasions.

The solution appears to be to make the vehicle both very light and very dark simultaneously. Obviously, there is no way of arranging this for the vehicle as a whole, but it is certainly possible to make half the vehicle light and half dark. It would be wrong to paint the left half light and the right half dark, or the front half light and the rear half dark. It is important that large areas of both light and dark be visible regardless of the direction from which the vehicle is viewed. A fine checkerboard pattern would not serve well; although certainly conspicuous at close range, a checkerboard vehicle would appear to have a uniform, medium lightness at distances beyond which the individual squares could be resolved. The optimum arrangement would appear to be a "harlequin" pattern in which each major surface of the car (sides, rear, hood, roof) is divided into two to four rectangles painted alternately light and dark; in other words, an extremely coarse checkerboard.

<u>A harlequin-painted vehicle, regardless of the angle of view, contains a large area that contrasts maximally in lightness with any background whatever</u>. If the background is dark, the light area of the vehicle has maximum contrast with it; if the background is light, the dark area of the vehicle has maximum contrast with it; and if the background is medium, both the light and dark areas of the vehicle contrast with it about as much as anything can.

Sketches of several harlequin-type patterns were produced, and in Figs. 4.3-1 to 4.3-3, there are presented six views of an automobile painted according to the one best pattern discovered. The pattern is simple, follows the natural divisions of the vehicle, and exhibits substantial areas and edges of both black and white regardless of the angle of view. Since the pages are white, the view simulates the appearance of the harlequin-painted car in snow. Note that the pattern shown in Figs. 4.3-1 to 4.3-3 may be slightly preferable to the inverse (negative) pattern, in that the black area of the hood may somewhat reduce glare in the driver's eyes during driving in sunny weather.

An extremely important fact about color contrast, to which designers of all kinds should pay much more attention, is that for many practical purposes, only lightness contrast counts. When one or both of the contrasting areas subtends a small angle at the observer's eye, differences in hue and saturation do not add as much to the overall impression of difference between colors, as does a substantial lightness difference. At very long viewing distances, the contribution of the hue and saturation differences fades toward zero. As a result of this rule, it is possible to retain color coding for close-up identification in harlequin-painted vehicles. For example, ambulances could be painted black and white, fire engines dark red and reddish white, and police cars navy blue and very pale blue. In each case, the presence of the basic hue (or its absence, in the black-white combination) will permit the same kind of identifiability of function that we have now, but the chromatic content of the colors will not significantly affect the ability of any of these vehicles to stand out against any background.

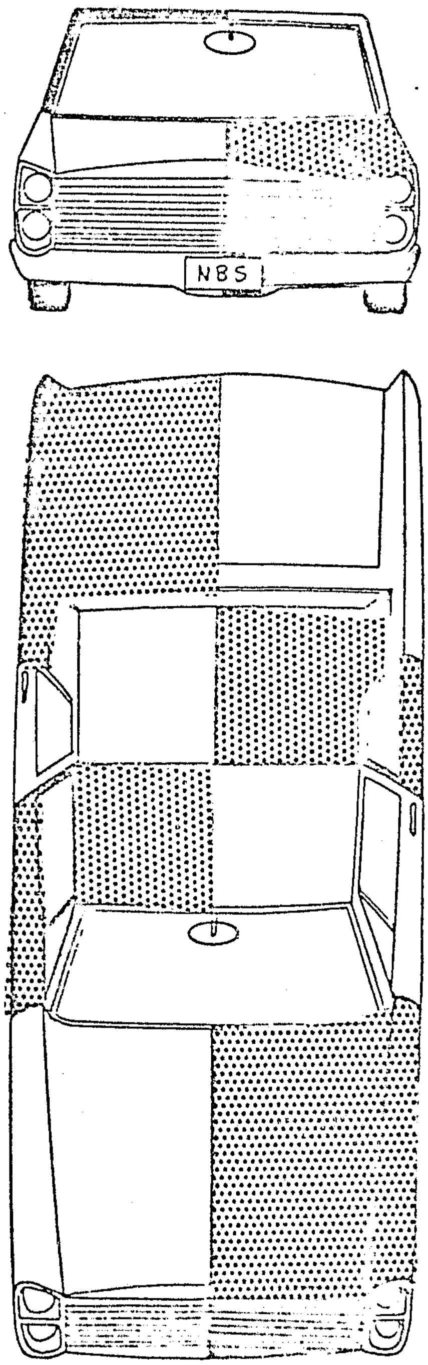


Fig. 4.3-1. Front views of a super-conspicuous harlequin-painted automobile, showing contrast with a white background. Upper view, from below the roof line; lower view, from above the roof line.

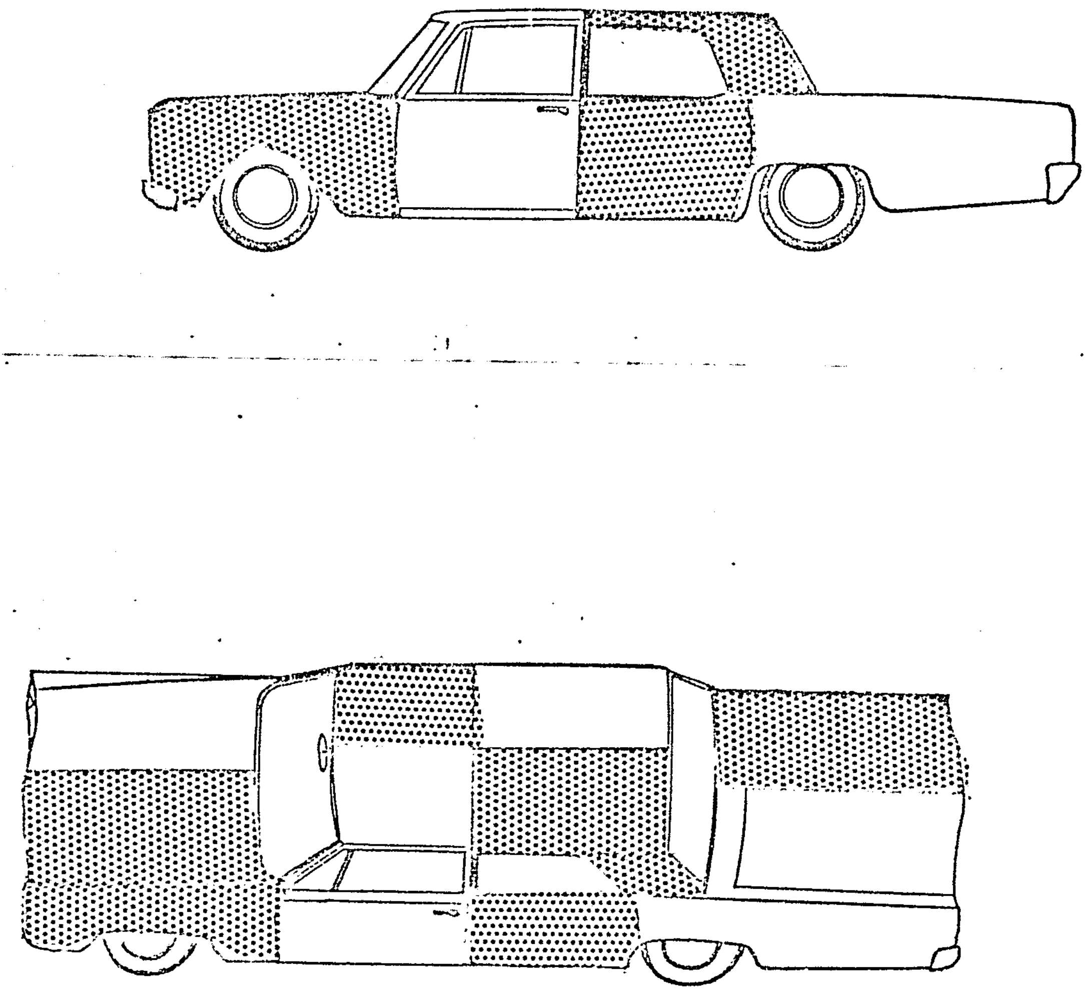


Fig. 4.3-2. Side views of a super-conspicuous harlequin-painted automobile, showing contrast with a white background. Upper view, from below the roof line; lower view, from above the roof line.

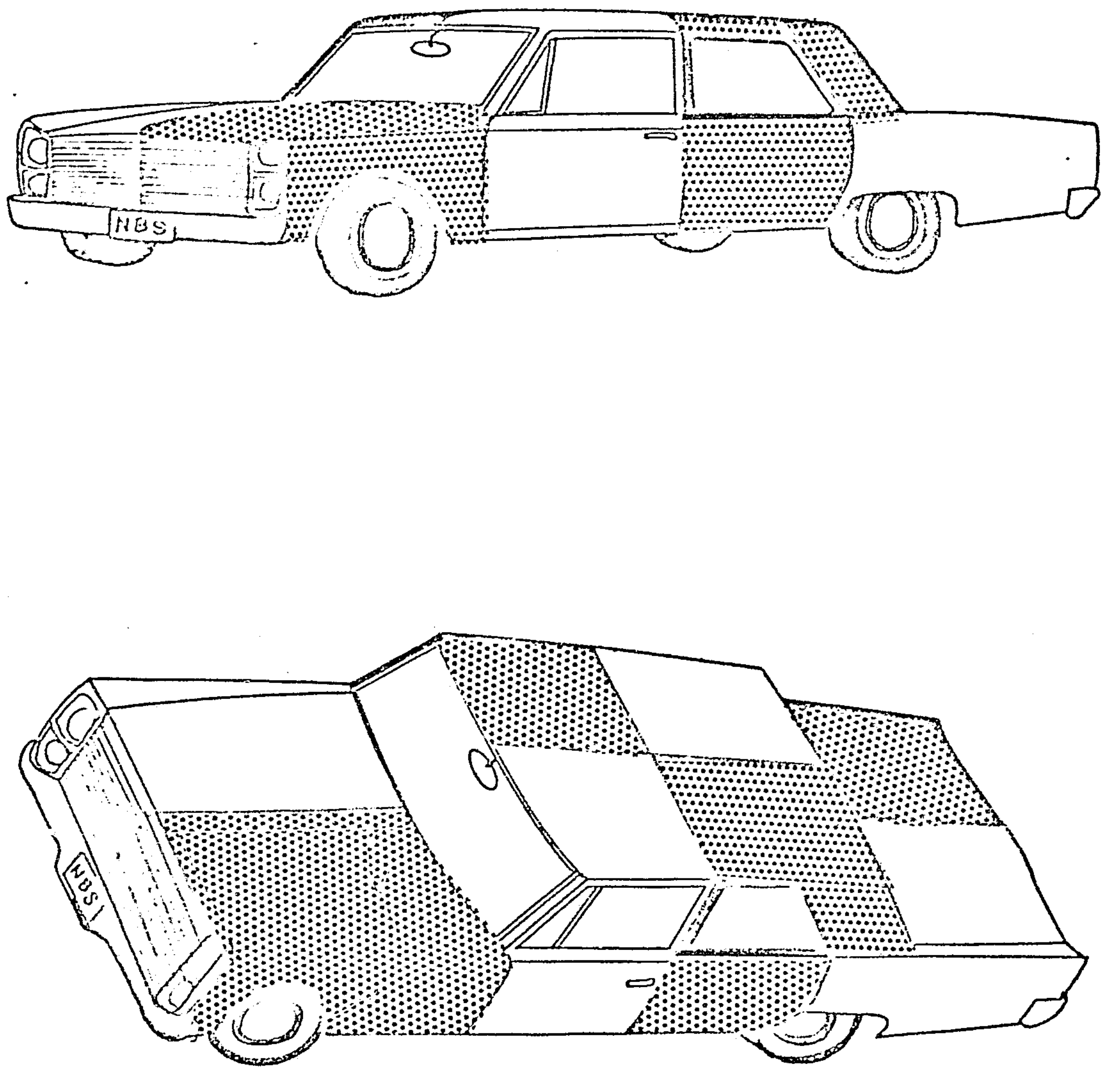


Fig. 4.3-3. Diagonal views of a super-conspicuous harlequin-painted automobile, showing contrast with a white background. Upper view, from below the roof line; lower view, from above the roof line.

One other step that can be taken to improve the night visibility of vehicles is the application of retroreflective paint or tape on all sides of the vehicle. Some police departments have spelled out the word POLICE on the trunk and fenders in lettering of this type (which shines back in a driver's eyes when his headlights strike it). It is important for daytime identification purposes that the retroreflective patches contrast strongly in lightness with the painted areas on which they are placed (either very light patches on a very dark background or vice versa). The police department of an important Eastern city, apparently not familiar with the dominant role of lightness contrast, has made the serious error of using tan (dark yellow) retroflective letters on a medium blue background, the two colors being of nearly equal reflectance in daylight. Despite the fact that the hues yellow and blue are about as different as possible, the overall contrast between the letters and background is not very great, and the message (POLICE) is not easy to see at any distance when the level of light is reduced (dawn, dusk, or heavy overcast). The solution would be a switch to bright yellow or white (light) retroreflective letters on a navy blue (dark) background.

4.4. Make Sure Multiple Sirens Are in Phase

As explained in Section 3.3E, considerable losses in the sound levels produced by a battery of two electronic sirens can occur in certain directions -- particularly the critical forward direction -- if the two speakers are connected to the electrical input with opposite polarity (in antiphase) rather than with the same polarity (in phase). Therefore, any vehicle on which two or more side-by-side electronic sirens are run from the same signal generator should be checked carefully by a knowledgeable technician or engineer to be sure that all the speakers move in the same direction in response to electrical signals of a given polarity.

Occasional vehicles use a pair of electronic sirens with the speakers in line along the vehicle's longitudinal axis, one behind the other, rather than in the more common side-by-side arrangement. In order to obtain the loudest signal in the forward direction, such speakers should be connected with the same polarity, but the electrical signal to the front speaker should be electronically delayed so that the sound emitted from the front speaker is in exact phase with the sound passing over it from the rear speaker. Since the speed of sound is approximately 1100 feet per second, sound waves cover a distance of one foot in 1/1100 of a second, or about 0.91 milliseconds (ms). The delay required on the signal to the front speaker is therefore equal to 0.91 ms multiplied by the separation of the acoustic centers of the speakers in feet.

As an alternative to calculating the required delay, the delay can be varied electronically until the measured sound level at a distant point directly in front of the vehicle (along the longitudinal axis) is greatest. While wasteful of effort when only two speakers are involved, this empirical procedure can be applied to any geometrical arrangement of multiple speakers driven from the same signal generator. Each speaker except the rearmost can be equipped with a variable time-delay circuit set by trial at that value which gives the maximum forward signal. Because the goal is to make the signal as loud as possible at locations very far ahead of the vehicle along the longitudinal axis, the point at which it is desirable to bring into phase the sound outputs from all the speakers can be regarded as essentially "at infinity". The lines joining this distant point to the acoustic centers of the speakers are therefore all virtually parallel to the longitudinal axis. It thus follows that the delay required for each speaker can be calculated (as above) on the basis of the separation along only the longitudinal direction -- regardless of lateral location -- of that speaker from the transverse line on which the rearmost speaker or speakers lie.

APPENDICES

5. WARNING-LIGHT UNITS: CLASSIFICATION AND ILLUSTRATIONS

What follows is an illustrated outline of the various types of lamps used in warning-light units, and of the kinds of light units that we have knowledge of.

I. Types of Lamps

Only two basic types of light sources are in current use in emergency-vehicle warning lights: incandescent lamps, and gaseous-discharge flash tubes.

A. Incandescent lamps

1. With attached reflector. These lamps are used with their axes at least approximately horizontal.

a. Reflector is metal coating on inside of bulb. These lamps are known as PAR lamps, because the coated rear surface of the bulb usually has a parabolic cross-section. (PAR is an acronym for "parabolic aluminized reflector.") Parabolic mirrors can concentrate the light into a tight beam, when desired.

b. Reflector is metal coating on outside of bulb. Such bulbs frequently are not parabolic in shape.

c. Reflector is an external concave mirror, usually metal, attached to the lamp base.

2. Without attached reflector. These lamps are used with their axes vertical. The light is concentrated by external mirrors or lenses not attached to the lamp.

B. Gaseous-discharge flash lamps

These lamps consist of a tube, frequently bent into a coil, containing a suitable gas such as xenon. A high-voltage surge of electricity is discharged from a condenser (capacitor) through the length of the tube, making the gas glow momentarily. The discharge glow is very bright while it is on, but it is only on for a very short time, usually well under a thousandth of a second (millisecond) and often under 100 millionths of a second (microseconds). Hence the total luminous energy of the flash may or may not exceed the energy delivered by a rotating incandescent lamp, which delivers a less intense but more prolonged flash.

1. Inside a PAR bulb. The incandescent filament in an internally reflectorized parabolic (PAR) bulb is replaced by a flash tube. The output is a directional beam.

2. Bare tube, or tube inside non-reflectorized bulb. The light is emitted over 360°, but may be concentrated in various patterns by external mirrors or lenses (usually fresnel lenses).

II. Types of Lights

A. Rotating

1. Rotating lamps; one to four reflectorized lamps, facing radially outward on rotating horizontal base.

a. All lamp axes horizontal.

Fig. 5-Ala. Rotating base carries three sealed beam (PAR) incandescent lamps with colored faces, under a clear dome.

b. One or more lamp axes tilted above or below horizontal.

2. Fixed lamp, non-reflectorized, axis vertical.

a. Lens(es) rotating around lamp.

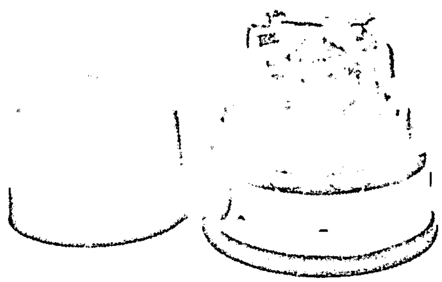
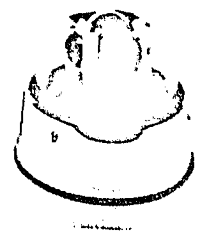


Fig. 5-A2a.
Left: three clear lenses rotate around a fixed incandescent lamp suspended downward from above, under a colored dome.
Right: four colored lenses rotate around an upright incandescent lamp, under a clear dome.



b. Concave reflector(s) rotating around lamp.

B. Oscillating

1. Horizontal oscillation

a. Reflectorized lamps, axes horizontal, on oscillating horizontal base; three or four lamps facing radially outward.

b. Array of separate reflectorized lamps, axes horizontal, lamps oscillating synchronously.

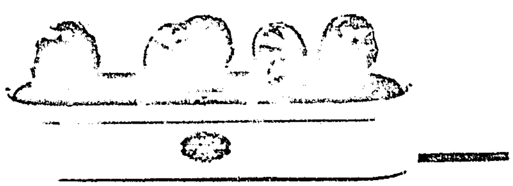


Fig. 5-B1b. Roof bar includes five sealed beam incandescent lamps oscillating synchronously under a clear dome. Pattern: two clear lamps at front oscillate around forward direction with mirror image relationship with respect to midline; single red lamp oscillates around rearward direction; one of the two side-facing red lamps oscillates around to rear, the other around to front.

2. Combined vertical and horizontal oscillation, around horizontal axis; single reflectorized lamp, results in "figure 8" motion.

3. Vertical oscillation combined with horizontal rotation; one lamp in a rotating group (A1a) also oscillates vertically above and below horizontal.

C. Flashing

1. Incandescent lamps, current interrupted. Beam concentrated by:

a. Reflectors

.i. Built-in (sealed beam lamp).

.ii. External parabolic reflector.

b. Fresnel lenses: front, front and rear, or 360°.

2. Gaseous-discharge flash lamps (e.g. xenon).

a. Covering 360°.

.i. Uniform over 360°, cylindrical fresnel lens.

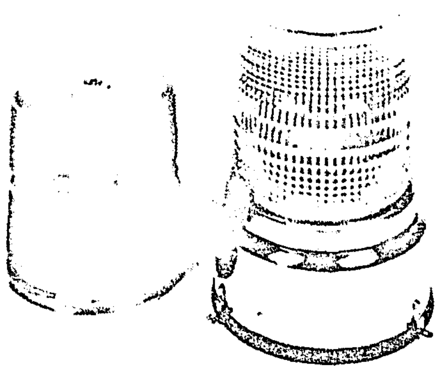


Fig. 5-C2a.i. Xenon flash lamp under clear dome, with substitutable colored dome also shown. Horizontal ridges on dome constitute a cylindrical fresnel lens that concentrates the light around the horizontal plane. Vertical ridges break up (diffuse) the light to make the entire dome seem to glow.

.ii. Extra concentration in fore and aft directions ("bullseye" fresnel lens).

Fig. 5-C2a.ii. Xenon flash lamp inside a "bullseye" fresnel lens-dome, under a smooth clear dome. Substitutable colored outer dome is also shown. The circular ridges in the inner dome constitute a spherical fresnel lens that concentrates the light around the forward direction. There is another bullseye to the rear, and cyclindrical fresnel lenses on the sides. The light is concentrated around the horizontal plane with peak intensity to the front and rear, but some intensity all the way around.

.iii. Mirror, paraboloid of rotation, ring flash tube along focal circle.

b. Restricted beam; flash-tube source inside sealed beam bulb.

D.. Combination Units

These units are often mounted on a roof bar, or sometimes the components are directly mounted on the roof. Complex assemblages can be put together, but the basic units involve two end lights and a center position that may or may not contain a light.

1. End units: rotating sealed-beam incandescents (Ala).

a. Nothing in center.

b. Siren in center; may also have mirrors to produce extra fore-and-aft flashes.

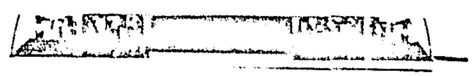


Fig. 5-D1b. Roof bar with two 2-bulb A1a units, one at each end, rotating in opposite directions synchronously. Siren is in the middle. Three mirrors mounted inboard of lights on each side produce a supplementary triple flash forward on each side as lights turn in toward siren. Newer model than that shown uses four mirrors on each side to provide supplementary double flashes both forwards and rearwards. Clear domes are shown on both sides, but substitutable colored domes are available.

2. <u>End units: fixed</u> sealed beam flashers.

a. Ends: electrically <u>flashed incandescents</u> (C1a.i).

<u>Center: rotating</u> sealed beam incandescents (A1a).

b. Ends: sealed beam <u>gaseous-discharge flash tubes</u> (C2b).

<u>Center: 360° gaseous-discharge</u> flasher (C2a.i).

Fig. 5-D2b. Roof bar with 360° xenon flasher (C2a.i) in center and forward-directed sealed-beam xenon flashers (C2b) at ends. The center lamp is covered with a clear fresnel lens-dome inside a smooth, colored outer dome. Controls permit flashing of: (1) center unit only; (2) end units only, flashing alternately; or (3) all three lights, with simultaneously flashing end units alternating with center unit.

3. <u>Special features</u>.

a. <u>Oscillating array</u> (see B1b). Four or more lights oscillate horizontally around forward, rearward, and sideward directions.

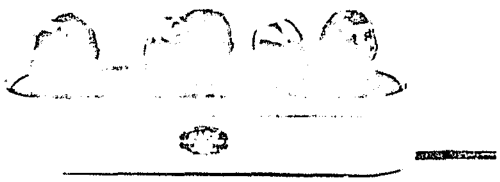


Fig. 5-D3a. [Same unit as shown in Fig. 5-B1b.] Roof bar includes five sealed beam incandescent lamps oscillating synchronously under a clear dome. Pattern: two clear lamps at front oscillate around forward direction with mirror image relationship with respect to midline; single red lamp oscillates around rearward direction; one of the two side-facing red lamps oscillates around to rear, the other around to front.

b. Electrically extendible mounting bar; array of lights can be raised several feet vertically.

E. Steady lights (spotlights, floodlights, and searchlights). Lamp may be plain incandescent, tungsten quartz halogen, or continuously operated gaseous-discharge.

1. Remotely positioned

   a. Electrically controlled

   b. Mechanically controlled.

2. Hand adjusted; on universal mount.

3. Hand held.

Table 6.1-1. Physical Specifications on a Selection of 360° Warning Lights

Unit	Lamp Type[a]	No. of Bulbs	Watts per Bulb	Rotating Elements	Flash Rate (fpm)[b]	Effective Intensity (cd) at Indicated Elevation					
						Below Horizontal -5°		Above Horizontal +5°		Horizontal 0°	
						Min.[c]	Max.	Min.[c]	Max.	Min.[c]	Max.
1	Ir	2	35	2 lamps	98		1200		140		1580
2	Ir	2	30	2 lamps	94		150		350		840
3	Ir	2	30	2 lamps	91.8		40		640		940
4	Ir	3	30	3 lamps	103.7		990		40		780
5	Ir	4	35	4 lamps	100		1390		400		3210
6	Ir	4	30	4 lamps	107.5		200		1980		2170
7	Ir	4	30	4 lamps	228		1330		480		1430
8	In	1		3 lenses	108		110		60		120
9	In	1		3 lenses	106.6		160		--		50
10	In	1		3 lenses	140		80		90		100
11	In	1	60	4 lenses	95		120		520		590
12	In	1	36	1 reflector	107.3		80		100		500
13	In	1	36	1 reflector	120.5		90		320		320
14	In	1	50	1 reflector	73		220		380		410
15	Ix	2	36	2 lamps	121.4		410		100		600
16	Ixp	2	40	2 lamps	87.4		40		240		160
17	CDi	1		--	80	270	3470	200	2600	200	2600
18	CD	1		--	66	70	3270	70	2000	70	3400
19	CD	1		--	95	250	560	220	480	380	840
20	CD	1		--	120	290	350	250	290	290	350
21	CD	2[d]		--	120	210	450	230	500	240	510

[a] Lamp-Type Code: Ir = internally reflectorized (PAR) incandescent lamp; In = non-reflectorized incandescent lamp; Ix = incandescent lamp with attached external reflector; Ixp = incandescent lamp with reflective coating painted on outside of bulb; CD = condenser-discharge (gaseous-discharge) lamp (xenon); CDi = condenser-discharge lamp (xenon) plus steady incandescent lamp.

[b] fpm = flashes per minute

[c] Rotating lights have the same maximum intensity in all directions. Because of the construction of the flash tube, stationary xenon flashers are more intense in some directions than in others, and the maximum and minimum intensities are given. The great discrepancies between maximum and minimum for units 17 and 18 are deliberately induced by using a lens-dome that concentrates the light in the fore and aft directions, as shown in Fig. 5-C2a.ii.

[d] This light consists of two complete optical units, with separate sources, bases, and domes, operated alternately from a single power supply.

6.2 Sirens

Table 6.2-1. Sound Level Measurements on Electronic Sirens

Unit	Mode	Direction Relative to Axis[a]	Sound Level, dB(A)[b]	Relation to Standard[c]	Overall Pass-Fail[d]
1	Yelp	0°	126.4	-	F
		45°L	119.9	-	
		45°R	123.4	-	
	Wail	0°	130.8	-	F
		45°L	124.3	-	
		45°R	127.8	-	
	Hi-Lo	0°	126.8	-	F
		45°L	120.3	-	
		45°R	123.8	-	
2	Yelp	0°	128.6	-	F
		45°L	127.1	-	
		45°R	120.6	-	
	Wail	0°	132.8	+	F
		45°L	131.3	+	
		45°R	124.8	-	
3	Yelp	0°	147.2	+	P
		45°L	142.2	+	
		45°R	140.7	+	
	Wail	0°	150.9	+	P
		45°L	145.9	+	
		45°R	144.4	+	
4	Yelp	0°	134.9	+	P
		45°L	128.4	+	
		45°R	132.9	+	
	Wail	0°	139.3	+	P
		45°L	132.8	+	
		45°R	137.3	+	
	Hi-Lo	0°	135.3	+	P
		45°L	128.8	+	
		45°R	133.3	+	

[a] The forward direction is 0°. L and R denote left and right, as viewed by an observer behind the siren looking out in the forward direction.

[b] A-weighted sound level at 2 meters, in free-field conditions.

[c] Standard requires at least 132 dB(A) at 0°, and 128 dB(A) at ±45°. Minus sign means level less than standard, plus sign greater.

[d] Mode of unit fails if any of the three requirements listed in Footnote c is not met. "Pass" here refers only to the sound-level requirement of the standard.

Table 6.2-2. Sound Level Measurements on Electromechanical Sirens

Unit	Direction Relative to Axis[a]	Sound Level, dB(A)[b]	Relation to Standard[c]	Overall Pass-Fail[d]
	0°	124.8	-	
1	45°L	119.3	-	F
	45°R	118.3	-	
	0°	127.1	-	
2	45°L	121.1	-	F
	45°R	121.6	-	
	0°	131.8	-	
3	45°L	126.8	-	F
	45°R	125.3	-	
	0°	115.1	-	
4	45°L	111.1	-	F
	45°R	112.6	-	
	0°	123.9	-	
5	45°L	119.4	-	F
	45°R	117.4	-	
	0°	122.2	-	
6	45°L	119.2	-	F
	45°R	117.7	-	
	0°	123.9	-	
7	45°L	119.4	-	F
	45°R	119.4	-	
	0°	121.7	-	
8	45°L	119.7	-	F
	45°R	117.2	-	
	0°	126.2	-	
9	45°L	120.7	-	F
	45°R	121.2	-	

[a]The forward direction is 0°. L and R denote left and right, as viewed by an observer behind the siren looking out in the forward direction.

[b]A-weighted sound level at 2 meters, in free-field conditions.

[c]Standard requires at least 132 dB(A) at 0°, and 128 dB(A) at ±45°. Minus sign means level less than standard, plus sign greater.

[d]Mode of unit fails if any of the three requirements listed in Footnote c is not met. "Pass" here refers only to the sound-level requirement of the standard.

7. REFERENCES

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