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Emergency Vehicle Warning Systems

Law Enforcement Technology

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

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Emergency Vehicle Warning Systems

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FOREWORD

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This document is a law enforcement equipment report developed by LESL under the sponsorship of NIJ. Additional reports as well as other documents are being issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles, and clothing.

Technical comments and suggestions concerning this report are invited from all interested parties. They may be addressed to the Law Enforcement Standards Laboratory, National Bureau of Standards, Washington, DC 20234.

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EMERGENCY VEHICLE WARNING SYSTEMS

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The subject of visual and auditory warning devices (lights and sirens) for emergency and service vehicles is surveyed from a broad perspective. The report should provide directly useful information at all levels from the selection of hardware to a general understanding of the psychophysical factors determining the effectiveness of these devices. Topics covered include: an analysis of warning signals; the present situation and the need for uniform national standards; suggested performance standards for warning light systems and for sirens, including the reasons for the principal requirements; recommendations for actions that can be taken to improve the signal effectiveness of emergency vehicles; and brief summaries of some of the physical measurements that are made on a selection of lights and sirens.

Key words: Conspicuity; effective intensity; emergency warning lights; flashing lights; lights, warning; sirens; sound level; warning lights; warning signals.

INTRODUCTION

The typical emergency vehicle warning system consists of lights and sirens, which are used to clear a path through traffic for a police or other emergency vehicle. A 1972 national survey of police departments [1][1] pointed out their need for relevant, objective technical information when purchasing warning systems. In response to this need, the National Bureau of Standards Law Enforcement Standards Laboratory initiated a project to develop performance standards for lights and sirens used as emergency vehicle warning systems.

The identification of performance attributes of warning lights and sirens, the establishment of the methods of testing and measuring each attribute and the evaluation of the minimum performance levels for each one are essential steps in the development of meaningful performance standards. These procedures are usually straightforward and clearly understood. Attempts, however, to apply these procedures to technology which involves the visual and auditory senses is especially difficult, not only due to human variables, but also because of the large number of combinations and configurations of warning lights and sirens on the market.

Warning systems have been used for many years by a large number of departments and considerable operational experience has been accumulated. Although there have been interdepartmental exchanges of information, no single system has been evolved as the "best" warning system. In fact, the plethora of systems would seem to indicate that each department has reached its own solution independently.

This report discusses the problems associated with the functional use of emergency vehicle warning systems and a recommended national standard system of warning light signals. It also describes in general terms the types of lights and sirens that are commercially available, and presents the results of laboratory tests on a small sample of such units. In addition, it recommends steps that the user can take to increase the effectiveness of emergency vehicle warning systems. The report is intended to supplement NBS Special Publication 480-16 [2], "Emergency Vehicle Warning Lights: State of the Art."

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[1] Numbers in brackets refer to references in appendix A.

Signal Effectiveness

A number of factors make it difficult to gain the attention of motorists by means of warning lights. The increased number of vehicles on the road with each passing year is evident to every motorist. Motorcycles and bicycles add to roadway congestion. Under these conditions, warning signals often fail to capture the attention of motorists, who are fully occupied maneuvering their vehicles through traffic.

Compounding the driver's problem of identifying a warning light, is its location in his or her field of view. The sense of sight is highly directive and selective. A warning light may not always be in the driver's forward line of sight. Vision in the outer portions of the visual field (the periphery) has characteristics different from direct central vision. In analyzing the visual aspects of warning lights, it is therefore important to concentrate on what is seen in the periphery. Moreover, most people pay much less attention to things seen in peripheral vision than to what is being viewed directly. Because the rearview 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.

Not only is it often difficult for visual signals to be seen, but many modern automobiles provide an effective barrier against audible signals, as well. Automotive accessories, such as tape decks, radios, and air-conditioners produce sounds which can effectively mask many emergency vehicle sirens. Simply stepping up the intensity of siren sound is not the answer to the problem. Even the sirens now in use cause complaints, and any increase in loudness is almost certain to produce more complaints. A substantial increase over present sound levels might even produce hearing impairment to the operators of the emergency vehicles themselves, since they may be exposed to the loud noise over prolonged periods.

The signal intensity situation is less critical with respect to warning lights, but here, too, intensity increases must be limited to avoid the temporary blinding or disorientation of nearby drivers. The momentary blinding of drivers by bright lights, most commonly by headlights, is well known [3]. Thus, with respect to both warning lights and sirens, the selection of a proper intensity involves a careful balance between the opposing demands of signal effectiveness and environmental acceptability.

Signal Variability

In addition to the problem of making warning signals perceptible to drivers, the signals must be easy to identify. According to the National Committee on Uniform Traffic Laws and Ordinances, at least 25 categories of vehicles are authorized by various State or local governments to display warning lights. A partial listing of these categories includes: civil defense vehicles, school buses, snow removal vehicles, highway maintenance vehicles, tow trucks, mail trucks, volunteer firefighters' vehicles, public utility vehicles, public health vehicles, hearses, vehicles carrying oversized loads, pilot cars for oversized loads, news media mobile units, sanitation vehicles, and forestry service vehicles, in addition to the usual fire department vehicles, police cars, and ambulances.

Only police, fire vehicles, and ambulances are considered true emergency vehicles by most jurisdictions. Most of the other vehicles authorized to display warning lights are service or semi-emergency vehicles. The essential distinction between the two categories reflects the purpose of the warning light. An emergency vehicle makes high-speed runs and needs to signal other vehicles to clear a path for it. On the other hand, service vehicle warning lights are intended to indicate potential danger due to causes such as low speed operation, frequent stops, hazardous materials, or unusual size.

The variety of vehicles authorized to use warning systems is only one aspect of the problem. Another is the lack of uniformity among warning systems within and between communities. Table 1 shows the pattern of usage of the two major types of sirens among seven categories of police

TABLE 1. *Siren mounting locations by department type*[a]

	50 Largest cities (%)	City 50+[b] (%)	City 10-49[b] (%)	City 1-9[b] (%)	Township (%)	County (%)	State (%)	All department types (%)
ELECTRONIC SIRENS								
Of 437 responding depts., used by:	96[c]	92	83	73	83	75	81	82
Located on roof								
On utility bar	61	74	71	52	54	38	37	58
Directly on roof	30	16	4	12	4	11	16	13
Located under hood								
Behind grille	25	24	28	39	33	58	45	35
In engine compartment	5	4	4	4	17	11	18	8
ELECTROMECHANICAL SIRENS[d]								
Of 437 responding depts., used by:	41[c]	42	33	36	24	51	57	41
Located on roof								
On utility bar	16	14	29	18	14	11	0	14
Directly on roof	5	11	4	0	0	6	7	6
Located under hood								
Behind grille	42	54	46	57	43	39	48	48
In engine compartment	42	23	46	29	57	58	59	43

[a] Information summarized from Klaus and Bunten [1]

[b] Number of officers in city police department. The category "City 50+" excludes the 50 largest cities (in 1970 population).

[c] Percentages of departments of a given type using electronic and electromechanical sirens total more than 100 percent, because some departments use both types of sirens. Similarly, some departments use more than one location for their sirens.

[d] The "Electromechanical" category includes purely mechanical sirens as well, but these are now rare.

departments, and the location of the sirens on the vehicles. There are four common locations for mounting sirens; the favored location varies with the type of siren; and departments of different size and jurisdictional level follow somewhat different practices with respect to both siren type and location.

The variation in user practice is even greater with respect to warning lights. Table 2 illustrates the very confused picture with respect to color. This lack of warning signal uniformity between communities makes it difficult for travelers to know how to respond to a warning signal. They may be unfamiliar with the customs and regulations of the communities through which they are traveling and their usual response at home may be inappropriate. Even under the best of circumstances, drivers may be confused by unfamiliar signals, which can increase the probability of their causing or being involved in an accident.

Both tables 1 and 2 are summaries of information from the LEAA Police Equipment Survey of 1972 [1], which may be consulted for further details.

Table 2. *Color of emergency flashing lights by police department type*[a]

	50 Largest cities (%)	City 50+[b] (%)	City 10-49[b] (%)	City 1-9[b] (%)	Township (%)	County (%)	State (%)	All department types (%)
RED								
Red only	52	54	54	64	45	56	57	56
Red and white	13	10	12	8	21	11	4	11
Red and blue	9	8	11	8	7	8	2	8
Total of departments using red lights in any combination	74	72	77	80	73	75	63	75
BLUE								
Blue only	28	23	21	23	21	24	34	24
Red and blue	9	8	11	8	7	8	2	8
Blue and clear	2	2	2	4	0	0	0	2
Total of departments using blue lights in any combination	39	33	34	35	28	32	36	34
YELLOW								
Yellow only	11	12	7	9	7	11	19	11
WHITE								
White only	4	5	6	1	7	3	2	4
Red and white	13	10	12	8	21	11	4	11
Blue and white	2	2	2	4	0	0	0	2
Total of departments using white lights in any combination	19	17	20	13	28	14	6	17

Number of responding departments=437.

[a] Information summarized from Klaus and Bunten [1].

[b] Number of officers in city police department. The category "City 50+" excludes the 50 largest cities (in 1970 population).

AN ANALYSIS OF WARNING SYSTEMS

Before discussing particular warning systems, it might be useful to take a closer look at warning systems in general. Among the factors to be examined are:

- What is a warning system?
- What is it designed to accomplish? and,
- What are the characteristics of a good system?

The usual way people think about an emergency warning system is as a combination of lights and sirens. However, for fundamental understanding, it is best not to think of it as a collection of hardware, or even as a group of visual and auditory signals. Rather, it should be considered in functional terms—as a means of communicating a particular message. This point of view is important because the problem of devising adequate warning systems requires an understanding not only of the hardware, but also of the traffic situation, the environment and, most importantly, how people respond to signals.

Factors Contributing to a Good Warning System

There are several characteristics associated with "good" systems. Such systems should:

Have optimum conspicuity—The warning should be readily noticeable by drivers of other vehicles during all normal situations. The intensity of any signal, therefore, must not fall below the level where it is detectable by all drivers who must be warned. The system should be effective regardless of time of day, traffic, weather, road characteristics, locale (urban, suburban, rural), etc.

The degree of conspicuousness of a flashing light depends on a number of factors. Among these are: (1) The effective intensity; (2) the flash rate; (3) the duty cycle—the ratio of the time that the light is on to the length of the complete flash cycle; (4) the 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 dimensions of the beam; (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; and (10) the pattern in time ("phase relations") of the flashes from the various lights in a multilight configuration.

However, the conspicuity of a signal light depends not only on these 10 aspects of the light itself, but also on the same aspects of each of the other lights present in the background. There is no known way to combine all these factors into a quantitative prediction of the conspicuity of a specified signal light against a specified background. This problem is discussed in detail by Howett, Kelly, and Pierce [2].

Be environmentally acceptable—The system should not unduly disturb bystanders; the types of signals and intensities employed must not constitute a public nuisance. To the maximum extent possible, the signal should be directed only at those for whom the signal message is intended.

Be clearly understandable—Getting the attention of the driver is only the first task of a warning system. In addition, the driver must be able to readily interpret the message and know what he or she is expected to do. This cannot be accomplished solely by the design of the system, but rather depends on other things such as signal standardization and public education.

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

Be reliable —The system hardware should be relatively simple, durable, difficult to steal or vandalize, trouble-free, and easy to repair.

Be economical—The system should have a relatively low life-cycle cost of acquisition and maintenance.

Be compatible with the vehicle—The system should be designed for easy installation, removal and reinstallation and should not consume an undue amount of power or space.

These factors deal with a variety of problem areas. However, the most critical area is driver reaction to the signals.

Reactions of Drivers to Warning Signals

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. When this is done, it becomes evident that the requirements placed on the driver are complex: any number of things can go wrong. Five different responses are expected of a driver when exposed to a warning signal.

The signal must first be sensed. For a sound to be audible, it must transmit an adequate amount of acoustic energy at frequencies approximately between 20 and 20,000 Hz. Similarly, for a light to be visible, it must transmit an adequate level of radiant energy at wavelengths approximately between 400 and 700 nm. These sensitivity ranges are the nominal limits for young, healthy humans.

However, a significant percentage of licensed drivers have hearing and or vision deficiencies. For example, very high-pitched tones (above 15,000 Hz) cannot be heard by many older persons, and their sensitivity to blue and violet light may be impaired. Some people of all ages have hearing losses in low or middle frequencies, as well as in the the high-frequency band.

Approximately 8 percent of male Americans have some degree of defect in their color vision (color blindness), a condition that is much rarer in women. Such individuals have a reduced or totally absent ability to distinguish certain shades of red, yellow, and green from each other. Since these three colors are commonly used in traffic signals and emergency warning lights, it is clearly desirable to use shades of color that minimize the problems of the colorblind. In response to the needs of those with color vision deficiencies, traffic lights are a somewhat orangish red and a somewhat bluish green, since for the common types of color blindness, a color containing some blue is clearly distinguishable from yellow, or colors confused with yellow.

To determine the intensity a signal must have in order to be detected, it is necessary not only to take the preceding considerations into account, but also the conditions under which the signal is used. For example, in a quiet environment a siren can be heard for a very long distance. The same siren employed in the daytime in a downtown city street may not be heard more than a block or two away. Engineers use the term "signal-to-noise ratio" in explaining this concept. That is, the strength of the "signal" is only part of the information necessary to predict a siren's effectiveness; the amount of background "noise" present is also important. "Noise" in this sense can mean either sound or visual interference.

When the intensity of the background noise approaches that of the signal, it is very difficult and sometimes impossible to detect the signal. For this reason, both warning lights and sirens are often used simultaneously. The other critical factor in detection is the degree of similarity between the signal and the background noise. The more alike they are, the more difficult it is to detect the signal.

The signal must be noticed. Even if a signal can be detected, there is no assurance that it will be noticed. There are some drivers with permanently impaired senses. Others cannot respond appropriately because of temporary factors such as sleepiness, inattention, emotional state, intoxication, or the 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.

A driver must be able to manipulate the controls of a car while paying attention to many things, including the behavior of other vehicles, traffic lights, signs, and roadway conditions. By the time a driver has mastered the basic skills, much of his or her driving behavior is almost automatic. The ability to continually shift attention is one of the strong habits developed with experience. This procedure is necessary because of the difficulty in keeping track of the many things that may occur simultaneously on or near the road which might be of concern to a driver. The primary function of a warning signal, therefore, is to interrupt the normal routine of driving by attracting the attention of the driver, despite the likelihood that his or her attention may be focused elsewhere.

The signal must be interpreted. After a driver has noticed a warning signal, he or she has to determine its meaning. 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 or signals) and the number of possible interpretations (degree of ambiguity). The greater the number of messages and interpretations, the longer it takes to react to a signal and the greater the probability of error. As an illustration, a driver has a rather simple task upon seeing a basic traffic light. The message set is usually limited to three—red, yellow and green—and the signals are relatively free from ambiguity (stop, proceed with caution, go). Contrast the traffic light example with the warning signal situation (table 2), where each law enforcement agency, fire department, and ambulance corps is relatively free to design its own system. An automobile driver is expected to react appropriately to all of them, although they differ considerably from one another. A driver operating in his or her own local community is expected to become familiar with the variety of messages used there, but once "away from home," these associations may no longer be correct and could cause difficulty since the familiar signals may have quite different meanings elsewhere.

The decision, what to do and when, must be made. Once a driver correctly interprets the message, e.g., to get out of the way of the oncoming emergency vehicle, he or she must decide how to accomplish this goal. A number of alternative actions 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 know and remember the required action, be aware of the movement of other vehicles sharing the road, the terrain features, the availability of a road shoulder, and many other factors which could spell the difference between responding correctly and causing or being involved in an accident. The speed of the driver's reaction, as well as its nature, is an important determinant of the effectiveness of his or her driving behavior.

The action must be performed. Finally, the driver has to maneuver the car properly. Reacting to an emergency situation is an emotional experience different from the normal driving routine and can result in incorrect 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 him or her self, but for others as well.

Messages Transmitted by Warning Systems

The diversity of emergency signals is such that most drivers do not try to learn what the combinations of lights and/or sounds mean in the jurisdictions they pass through. The warning systems in use today primarily transmit a single message: "Be on the alert because something unusual is happening on the road." Identification of the type of emergency vehicle is of little value to the driver—beyond the differentiation of emergency vehicles from slow-moving service vehicles, and the driver is likely to react the same way whether the vehicle is an ambulance, a police car, or a fire truck. The driver may slow down, stop, pull to the side of the road, or perform some other maneuver, but will probably not continue to drive as usual. Information concerning the location and direction of movement of the emergency vehicle would help determine the particular course of action that should be followed.

Emergency Vehicle Warning Lights

The National Bureau of Standards conducted a limited number of tests on warning lights during the course of this project. Table 3 presents the results obtained. The important parameter is the effective intensity, which is defined as the intensity of a steadily burning lamp that disappears from view at the same distance as the flashing light in question.

Only two basic types of light sources are in current use in emergency vehicle warning lights: incandescent lamps and gaseous-discharge flash tubes (strobes). There is disagreement over the relative merits of these two types of warning lights. An important advantage of strobe lights is that they are more efficient at converting electricity into light. It is widely believed that in order to produce flashes of the same effective intensity as a strobe unit, an incandescent-lamp unit may draw as much as twice the electrical power. (We have, however, seen an unpublished analysis that claims that this belief is mistaken, and that because of higher optical efficiency, principally due to the smaller size of the light-emitting element, rotating-incandescent units produce at least as much effective intensity as strobes, for a given level of power consumption.)

Some users believe that strobes are unsatisfactory in some applications because it is difficult to judge their distance. This is ascribed to the extremely brief duration of strobe flashes, which are completed long before human eyes can shift their positions. However, the means to solve this quick-flash problem seems to be available. In some current non-automotive applications, strobe lights are operated in a so-called "flick" mode. The lights are flashed repetitively in a burst of light pulses. Each pulse is a typical strobe flash (of lower intensity), and the time between flashes is very short, but the train of pulses continues for a time comparable to the duration of a rotating-incandescent flash. The observer sees the train as a single longer-duration flash. The total light energy in the train of flashes is also comparable to that which would have been produced by the same quantity of electrical energy used to produce a single traditional strobe flash.

TABLE 3. *Physical characteristics of some 360° warning lights*

Warning light ID number	Lamp type[a]	Lamp designation	No. of lamps	Watts per lamp	Rotating elements	Flash rate (fpm)[b]	Effective intensity (cd) at indicated elevation: Below horizontal -5° Min.[c]	Below horizontal -5° Max.	Above horizontal +5° Min.	Above horizontal +5° Max.	Horizontal 0° Min.	Horizontal 0° Max.
24	PAR	4436 PAR 46	2	35	2 lamps	98	---	1200	---	140	---	1580
46	PAR	4416 PAR 36	2	30	2 lamps	94	---	150	---	350	---	840
11	PAR	4416 PAR 36	2	30	2 lamps	91.8	---	40	---	640	---	940
01	PAR	4416 PAR 36	3	30	3 lamps	103.7	---	990	---	40	---	780
09	PAR	4436 PAR 46	4	35	4 lamps	100	---	1390	---	400	---	3210
26	PAR	4416 PAR 36	4	30	4 lamps	107.5	---	200	---	1980	---	2170
45	PAR	4416 PAR 36	4	30	4 lamps	228	---	1330	---	480	---	1430
10	IN	WRM 44	1	--	3 lenses	108	---	110	---	60	---	120
14	IN	WRM 44 (100 cp)	1	--	3 lenses	106.6	---	160	---	----	---	50
30	IN	WHE 44K (100 cp)	1	--	3 lenses	140	---	80	---	90	---	100
25	IN	1019 (100 cp)	1	60	4 lenses	95	---	120	---	520	---	590
32	IN	1507 (50 cp)	1	36	1 reflector	107.3	---	80	---	100	---	500
20	IN	1195 (50 cp)	1	36	1 reflector	120.5	---	90	---	320	---	320
29	IN	1940	1	50	1 reflector	73	---	220	---	380	---	410
16	IX	1195	2	36	2 lamps	121.4	---	410	---	100	---	600
22	CDI	---------------	1+2I[d]	--	----------	80	270	3470	200	2600	200	2600
07	CDI	---------------	1+2I	--	----------	66	70	3270	70	2000	70	3400
18	CDI	---------------	1+I	--	----------	95	250	560	220	480	380	840
33	CD	---------------	1	--	----------	120	290	350	250	290	290	350
15	CD	---------------	2[e]	--	----------	120	210	450	230	500	240	510

[a] Lamp types: PAR=parabolic aluminized reflector incandescent lamp; IN=non-reflectorized incandescent lamp; IX=incandescent lamp with attached external reflector; CD=condenser-discharge (gaseous-discharge) lamp (xenon); CDI=condenser-discharge lamp (xenon) plus one or more steady incandescent lamps.

[b] fpm=flashes per minute.

[c] Rotating incandescent lights have the same or nearly the same maximum intensity in all directions. However, because of the construction of the flash tube, stationary xenon flashers are usually significantly more intense in some directions than in others, and the maximum and minimum intensities are given. The great discrepancies between maximum and minimum for lights 22 and 07 are deliberately induced by using Fresnel lenses that concentrate the light more in the fore and aft directions than in other directions.

[d] "1+2I" means one xenon flash lamp plus two small, steady incandescent lamps. "1+I" means one xenon flash lamp plus one small, steady incandescent lamp.

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

At least one manufacturer of emergency vehicle warning lights has made a start in adapting this principle to automotive applications. That company produces a unit that emits, in each cycle, two strobe flashes which are separately visible but are seen as overlapping in time. The overall visual signal—the double flash—appears to last approximately as long as a rotating incandescent flash.

In making inquiries of manufacturers or distributors, the key information is the effective intensity of the light flashes produced by the unit. However, some manufacturers may not be able to supply this information, at this time. It is hoped that the use of the effective intensity measure in catalogs and promotional literature will become more common in the future and replace the use of the peak intensity (candlepower) of the flash. The NBS study revealed that the effective intensity of the flashes produced by rotating incandescent units nearly always ranged between 3 and 25% of the peak intensity of the flash, and was usually in the 5 to 10 percent range.

The effective intensity of strobe units, however, is approximately in the range of 0.01 to 0.1 percent of the peak intensity (that is, between 0.0001 and 0.001 of the peak). Thus, a strobe light with a peak intensity of 1 million candelas will probably have an effective flash intensity of about 100 to 1000 cd. Since 100-cd flashes are relatively weak and 1000-cd flashes relatively strong, a rule-of-thumb estimate of the effectiveness of these lights is clearly not very useful. If the total energy in the flash of a strobe light is given in candela-seconds, then the effective intensity in candelas is approximately equal to the energy multiplied by five. These estimates are discussed in NBS Special Publication 480-16 [2], which also contains descriptions and photographs of many different warning light systems and a comprehensive glossary of warning light terms and definitions. Copies may be obtained by writing to the Chief, Law Enforcement Standards Laboratory, National Bureau of Standards, Washington, DC 20234.

Emergency Vehicle Sirens

Although many emergency and service organizations have attempted to create distinctive warning light configurations to set them apart, there has been considerably less elaboration of sonic warning signals. While there are some differences in the ability of an individual to localize sounds from different directions, the loudness with which a sound is heard does not in general vary importantly with the position of the listener's head. Moreover, in contrast with the easy confusion of a signal light with other lights in the environment, the sound of a siren is highly distinctive and is usually recognized as soon as it can be steadily heard.

There is some degree of specialization in the use of sound signals; for example, air horns are used by many fire departments when a vehicle is approaching an intersection. Air horns are used less frequently by ambulances and rescue vehicles, and rarely by police vehicles. Similarly, the wail/yelp/high-low sound patterns are not used for specific identification purposes, other than to attract attention and to indicate the passage of an emergency vehicle of some type. The specific identification of the type of emergency vehicle is determined by the configuration of the vehicle, the paint colors and pattern, and the warning light array.

Two basic types of sirens are in current use. There are electronic sirens, with one or more speakers driven by electrical impulses coming from an electronic signal generator; mechanical sirens, which produce sound by spinning an element (the rotor) within or around a stationary element (the stator). There are two subcategories of mechanical sirens, the strictly mechanical siren (now rare), 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.

Originally, all sirens operated in the "manual" mode; i.e., a switch (or mechanical clutch) was closed, causing the sound level to increase to the maximum value that the siren was capable of producing, and to remain at the maximum level until the switch was opened. There are now, in addition, three quite distinct and widely used automatic siren modes. The "wail" function produces a continuous cycling of increasing and decreasing sound level at a rate of about 15 to 30 oscillations per minute (0.25 to 0.5 Hz). The "yelp" function produces sounds that are perceptually different from the "wail," but the "yelp" is actually only a "wail" speeded up to about 160 to 240 oscillations per minute (2.7 to 4.0 Hz). Finally, the "high-low" function produces a repetitive alternation of two fixed tones of different pitch at a nominal cycling rate of about 40 to 60 oscillations per minute (0.7 to 1.0 Hz). There is some evidence, however, that the high-low mode is less effective as an audible warning signal than the wail or yelp [4].

Since sirens are not normally operated in the manual mode, the resulting signal is complex in nature, varying in both frequency and sound pressure at any instant in time throughout a single wail, yelp, or high-low cycle. Further, the ear is not equally sensitive to sounds of all frequencies. Consequently, determining the auditory effect (loudness) of a complex sound requires weighting the sound pressure at each frequency by the sensitivity of the ear at that frequency, and totalling the weighted pressures over all frequencies. Several different ear sensitivity functions, applying under different conditions, have been standardized. The most common weighting, which is appropriate for the measurement of the sound pressure of sirens is the A-weighting function and is built in electronically in most sound level meters. The sensitivity of the human ear is near its peak over a broad frequency range from about 2000 to 5000 Hz, as reflected in the A-weighting function.

The research to date concerning the effectiveness of sirens has been limited. In addition, in those cases when sound measurements have been made, the individual researchers have used different test procedures. There is, however, reasonable agreement with respect to the effective range at which a driver within a vehicle can hear a siren. Potter et al. [4], conducted a series of perceptual tests and calculated "warning effectiveness distances" for several different driving situations, with respect to urban/suburban/rural, windows open or closed, and approaches of emergency vehicles from directly behind or at a crossroads. The calculated warning effectiveness distances varied over a range of less than 3 m (12 ft) to 135 m (445 ft). The authors state that "most typically" the warning effectiveness distances are 38 m (125 ft) or less. Based upon the model developed in earlier NBS research [6], which used the criterion of audibility developed by Corliss et al. [5], a siren would require an A-weighted sound pressure output of at least 132 dB on the forward axis at a distance of 2 m (6.6 ft) from the acoustic center (apparent point of sound radiation) of the unit, to assure that the siren could be heard within a closed, air-conditioned car at a distance of 32 m (105 ft).[2] Also, it was determined that a siren system should have a pattern of sound emission that does not drop off in level by more than 7 dB at 50° on either side of the forward axis.

Table 4 shows the results obtained by NBS during recent sound pressure measurements of three electronic sirens, in combination with four speakers (7 out of the 12 possible combinations). The entries in the table are A-weighted sound levels measured at a distance of 3 m from the geometric center of the front plane of the speaker. The values on axis range from 115 to just under 120 dB. Only one combination failed to be within 7 dB of the on-axis level at ±50°. One of the sirens produced higher sound levels in the wail mode than the yelp mode, and with one exception, the two modes for all siren and speaker combinations differed by less than 1 dB.

These recent NBS tests included only a single electro-mechanical siren, the measurements on which are displayed in table 5. This siren has an output on axis of just under 109 dB, and thus is from 6 to 9 dB lower in level than the electronic sirens tested (table 4). However, it had less off-axis level drop-off than any electronic siren-speaker combination listed in table 4, its level at ±50° being only 3.1 dB less than the on-axis output.

It should be noted that the siren sound level measurements summarized in tables 4 and 5 are not directly comparable to the measurements made either by Jones et al. [6] or Potter et al. [4]. The new NBS measurements were made at a distance of 3 m (10 ft) as opposed to distances of 2 m (7 ft) for Jones et al. and 3.6 m (12 ft) for Potter et al. On the basis of an assumption of

[2] These sound level recommendations refer 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. In practice, an adequate approximation to free field conditions is considered to exist in an anechoic chamber, the walls of which are nearly completely sound-absorbing.

Table 4. *Electronic sirens*[a]

Siren identification number	Mode[b]	Direction[c]	Speaker identification number NBS-1S	NBS-2S	NBS-3S	NBS-4S
NBS-1E	Yelp	0°	117.3	116.0	115.0	
		±50°	110.6	108.4[d]	108.8	
	Wail	0°	117.2	115.6	115.0	
		±50°	110.5	108.2[d]	108.9	
NBS-2E	Yelp	0°		117.4	116.9	
		±50°		110.9	111.4	
	Wail	0°		117.2	116.8	
		±50°		110.8	111.4	
NBS-3E	Yelp	0°			115.6	119.6
		±50°			111.0	114.3
	Wail	0°			116.7	119.8
		±50°			111.3	114.0

[a] Table entries are A-weighted sound levels in decibels relative to a reference sound pressure of 20 micropascals, at a distance of 3 m in free-field conditions (an anechoic chamber). Without exception, the maximum sound pressure level for all of these electronic siren-speaker combinations occurred within the octave band centered at 1000 Hz.
[b] Yelp measurements were made with the slow setting on the sound-level meter. Wail measurements were made with the setting for a 30-s averaging time.
[c] Levels given for ±50° are averages of the levels measured at +50° and –50°. The difference was less than 1 dB in every case.
[d] Only this siren-speaker combination, for both yelp and wail modes, is down more than 7 dB at ±50°.

Table 5. *Electromechanical siren*

Siren identification number	Mode	Direction	Sound level
NBS-1M	Manual	0°	108.8
		±50°	105.7

Notes:

1. Table entries are A-weighted sound levels in decibels relative to a reference sound pressure of 20 micropascals, at a distance of 3 m (10 ft) in free-field conditions (an anechoic chamber). The maximum sound pressure level for this electromechanical siren occurred within the octave band centered at 2000 Hz.
2. Measurements were made with the slow setting on the sound-level meter.
3. Level given for ±50° is an average of the levels measured at +50° and –50°. The difference for this siren was only 0.1 dB.

hemispherical spreading (inverse square law for power), sound level measurements on a particular siren would drop 3.5 dB when the distance is increased from 2 to 3 m (7 to 10 ft); 5.1 dB when the increase is from 2 to 3.6 m (7 to 12 ft); and 1.6 dB when the increase is from 3 to 3.6 m (10 to 12 ft).

In addition, Jones et al. made measurements integrated over a period of 0.1 s and reported the highest such measurement over the full wail cycle, which lasts several seconds. The new NBS measurements (tables 4 and 5) and those reported by Potter et al. [4, p. 22] are root-mean-square averages over the full cycle. According to figure 3 (p. 17) of [4], the maximum level attained during the wail cycle by one electronic siren they tested is about 15 dB above the mean level. If this difference can be taken as typical, it can be concluded that, on the basis of differences only in measuring distance and integration time, Jones et al. would have reported levels about 18.5 dB higher than those in table 4, if they had measured the same sirens; thus, according to their model, the siren in table 4 would be audible at a distance of 32 m (105 ft), but not much beyond. It should be noted that Jones et al. strongly recommend perceptual tests to verify, or provide a basis for revision, of the model that they applied. Similarly, further investigation of the peak frequency of sound emission may be warranted. Potter et al. [4] conclude that the effectiveness of sirens could be improved if the frequency of peak emission (typically around 1000 Hz) were raised to 3000 Hz; in contrast Jones et al. [6], on the basis of a similar analysis concluded that an increase in the peak frequency to even 2000 Hz would provide only a marginal increase in effectiveness.

Electronic Sirens with Dual Speakers

When an electronic siren system is sufficiently powerful, it may use more than one speaker. A common configuration is two roof-mounted, forward-facing speakers. Because the same sounds are generated in the two speakers at the same time, sound interference patterns occur. The strength of the resultant signal at each point in space depends on 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 less capable of being heard in those directions, even though it can be clearly heard further away from the vehicle in other, more favorable directions.

Test data [6] on dual-speaker systems indicate that the interference effects have a more desirable pattern when the two speakers are connected in phase (vibrating in the same direction at the same time) than when they are connected in anti-phase. The forward direction is the most important, and the destructive interference between signals from out-of-phase speakers is particularly bad in that direction. For in-phase speakers, there is even some constructive interference (enhancement) in the forward direction [7].

In general, then, it is best to point side-by-side dual speakers directly forward, and to connect the speakers in phase. However, it is possible that special electronic siren systems with unusual characteristics might perform best with some other arrangement. Any such system should, of course, be installed in accordance with the manufacturer's recommendations.

NATIONAL STANDARDIZATION OF WARNING LIGHT SIGNALS

A major problem with emergency vehicle warning lights is the lack of nationwide standardization [2]. A valuable improvement in driver responsiveness could be expected upon the adoption of any reasonable national system. It would obviously not help very much to standardize the signals carried by only a single type of emergency vehicle, such as police vehicles, if the other types of signal-bearing vehicles were free to use displays of their own choosing.

A voluntary performance standard for emergency vehicle warning lights is currently in preparation at the National Bureau of Standards [8]. The intent of this standard is to specify performance levels and test methods for warning light systems, irrespective of the color coding embodied in the system. Thus, the standard would be suitable for adoption in virtually any jurisdiction, regardless of current laws and regulations governing the characteristics (particularly the colors) of the light signals.

What follows is a suggested system for warning light signals, originally proposed by C. A. Douglas, and includes recommendations for a single, nationally uniform set of colors. Explanations for the choices made are integrated into the text. As previously stated, a system of this type cannot have its full effect on improving highway safety unless it is the only system in use. Accordingly, State highway commissions should give consideration to the advantages of adhering to such a uniform system for all emergency and service vehicles under their jurisdiction.

Meanings of the Signals

Emergency signals should relate to the actions expected of the target drivers, and not to the class of emergency vehicle (police, fire, or ambulance) issuing the signal. Basically there are only two different actions required of a driver in connection with the appearance of an emergency/service vehicle:

(1) Yield the right-of-way! A police, ambulance or fire vehicle is responding to an emergency. The required action, regardless of emergency vehicle category, is for other drivers to yield the right-of-way, to clear the left lane by bearing to the right, or taking such other action as the situation requires.

(2) Slow down—proceed with caution! A service vehicle is stopped, moving slowly, or otherwise presenting a hazard to normal-speed traffic. The required action is for drivers to slow down to the point where the nature of the hazard can be assessed, and to pass cautiously, or stop, as traffic conditions and the nature of the hazard require. Each driver should slow his or her vehicle to a safe speed, keep the traffic flow moving, and not "sightsee."

Color Selection

The use of a warning light system consisting of several colors depends on the ability of the observer to recognize each color; to recognize the signal system a particular color belongs to; and, finally, to remember the meaning of that color in that signal system. Since the number of colors that can be reliably recognized in isolation, under viewing conditions that are at all difficult, is quite small, most lighting signal systems are chosen from among the same colors: red, yellow, green, blue, and white. The use of the same colors with similar meanings in different signal systems has the advantage of reducing the total number of color associations to be remembered, and the disadvantage of requiring dependence on cues other than color (often location or size) to determine to which signal system the observed light belongs. Thus, both red automobile brake lights and red traffic lights suggest the need for stopping or preparing to stop, and they are told apart primarily by where they appear relative to the vehicles and the road. Experience suggests that the advantage cited, which leads to quicker reaction times, outweighs the disadvantage.

The use of yellow for semi-emergency or service vehicles is an obvious choice because of its widespread use as a caution signal in traffic lights and highway construction flashers. Yellow is already the most common color used on slow-moving vehicles, although its use is far from universal. Finally, it is desirable to use yellow lights as some part of a signal system because higher intensities can be obtained for yellow than for any other color, for a fixed energy output of the white light source.

The very highest intensities, for a fixed electrical input, can be obtained from an unfiltered white lamp. The use of white as part of the primary emergency signal therefore seems essential, from a practical standpoint, in order to achieve the objective of alerting motorists at the longest feasible range. A pure white emergency signal is not acceptable, because there are too many other white lights on and near roadways (headlights, street lights, etc.) which prevent the white signal from being adequately conspicuous. A signal alternating white with some strong chromatic color to provide distinctiveness seems to be the solution; the remaining problem is to choose the best chromatic color. White and yellow flashes are hard to distinguish, so yellow is not a suitable choice. This was the final consideration in settling on the assignment of yellow to service vehicles.

The choice for emergency vehicles, therefore, comes down to red or blue, since green has an almost universal connotation of "go," the opposite of a caution or emergency signal. Blue has some advantages: (1) there are relatively few blue lights in the nighttime environment, so blue is a more distinctive color; (2) blue is often associated with the police image as "the men in blue"; and (3) blue is currently the standard police car signal in many other countries, and international standardization may be desirable. However, as explained later in this report, a heavy price must be paid in loss of intensity when blue lights are used.

It is also true that, except for a very small number of people who are either totally color blind (monochromatic) or who are tritanopes and have difficulty in recognizing blue and yellow, a saturated blue can be distinguished readily by nearly everyone, under good viewing conditions. As pointed out earlier, approximately 8 percent of the male population is color blind and has varying degrees of difficulty in distinguishing certain shades of red, yellow, and green. Unfortunately, under the conditions important for detecting long-range light flashes—namely, a small spot of light delivering little energy during a brief flash—everyone's vision tends toward tritanopia, so blue becomes difficult to identify.

Aside from improved intensity, which is discussed later, the advantages of red are: (1) it is readily identified as meaning "danger" or "emergency"; (2) it penetrates fine-particle haze better than other colored lights of equal effective intensity; and (3) it is still seen as red even near the borderline of visibility, whereas all other colors tend to fade into white.

On the whole, the arguments seem to favor red over blue, and with the extremely important intensity consideration also taken into account, red is the clear choice as the color to be alternated with white in the primary emergency signal.

A standard for emergency vehicle warning lights that is in preparation at the National Bureau of Standards [8] defines precisely which colors are to be considered as being white, red, yellow, and blue to avoid the confusion in color identification which can occur at long range. For example, an excessively pale blue may appear as white, and a yellow that is very orangish may appear to be red. With the exception of the blue, the color limits in this proposed standard agree with corresponding unrestricted or restricted limits adopted by the International Commission on Illumination (CIE).

The topic of chromaticity is discussed in detail in the IES Lighting Handbook [9], which includes a color plate of the CIE 1931 chromaticity diagram. Figure 1 shows a plot of the chromaticity boundaries for emergency vehicle signal light colors, as specified in the proposed standard, superimposed on the CIE chromaticity diagram.

Recommended Colors, Configurations, and Duty (On-Off) Cycles

Corresponding to the two signaling situations cited in the previous paragraph, "Meanings of the Signals," the light signals suggested are:

(1) For emergency vehicles requiring the right-of-way over other traffic: either, (a) one 360° flashing or rotating red-and-white warning light mounted along the centerline of the vehicle's roof, plus one red warning light mounted on each side of the roof and flashing in both the forward and rearward directions; or, (b) two 360° rotating or flashing red-and-white warning lights, one mounted on each side of the roof. These side lights alert oncoming traffic to the presence of an emergency vehicle when that vehicle may be partially concealed by a larger vehicle or other obstruction (see fig. 2). When fore-and-aft flashing lights are used, they should cover at least 20° on either side of the forward and rearward directions; all lights should cover at least 20° above and below the horizontal.

NBS research indicates that because of its relatively low intensity (for a given wattage) and poor visibility against a blue sky, an all-blue light is not as effective as a red-and-white light during daytime hours. At night, however, the blue light appears to gain considerably in effectiveness. Departments that wish to use a blue light to distinguish police cars from other emergency vehicles might consider using a low-powered blue light, steady or flashing, in conjunction with the universal red-and-white warning light system. In the form of a spotlight, the blue light could be used at close range to signal a particular driver to pull over. As a roof light, it

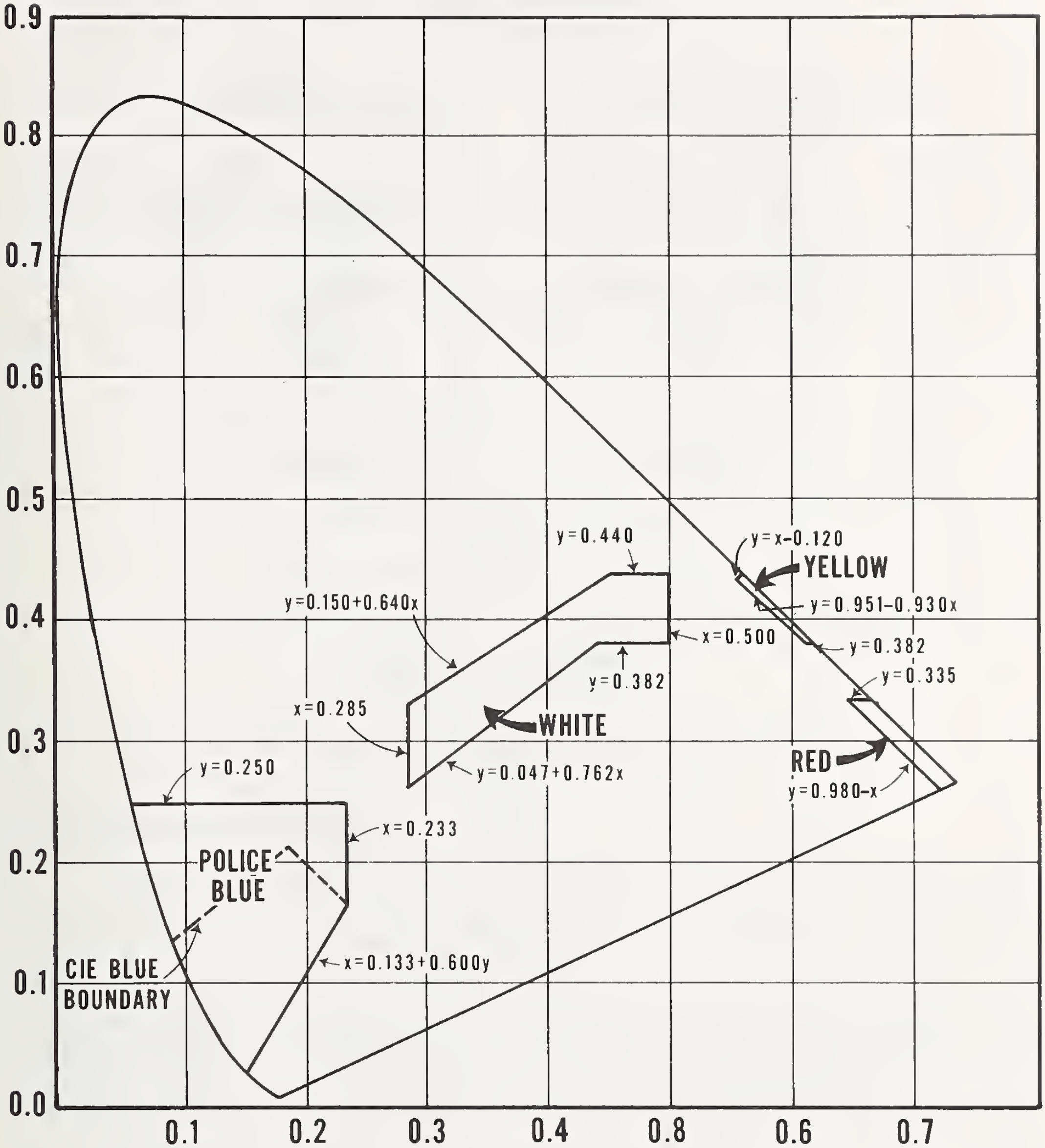

FIGURE 1. *CIE chromaticity diagram (1931) showing boundaries for red, yellow, white, and police blue.* Reprinted with permission of Hoffman Engineering Corp., Old Greenwich, CT (June 1978).

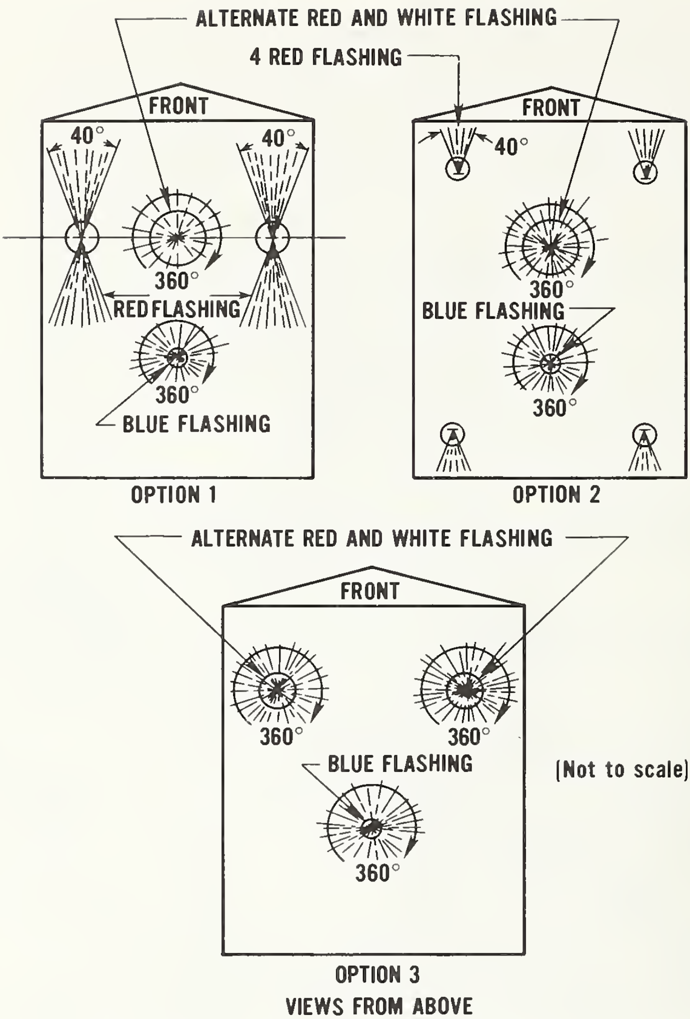

FIGURE 2. *Rooftop installation configurations for emergency vehicle warning lights.* Option 2 is recommended for fire engines and other long emergency vehicles to mark the rear corners of such vehicles. Options 1 and 3 are alternate, but less preferred configurations for long vehicles. Options 1, 2, and 3 are all equally acceptable for sedan-based vehicles. Blue flashing lights are for use on emergency vehicles during non-emergency situations.

could be used by itself to mark a police car pacing traffic at night, a function for which the red-and-white emergency lights would be inappropriate.

(2) For service vehicles warning motorists to proceed with caution: either, (a) one 360° flashing or rotating yellow ("amber") warning light mounted along the centerline of the vehicle's roof; or, (b) two 360° flashing or rotating yellow lights, one mounted on each side of the roof (see fig. 3) should be used.

Thus, all true emergency vehicles (fire, ambulance, and police) would be equipped with red-and-white alternating signals, and possibly additional red signals, while service vehicles would be equipped only with yellow signals. Blue signals would be optional for use only for short-range identification of police vehicles.

For maximum effectiveness, emergency warning lights should concentrate their light energy into relatively brief flashes having a duration less than 20 percent of the total on-off cycle; a short flash gets more visual effect from the same amount of energy than a long flash [2]. Supplementary, non-emergency warning lights could be on longer than they are off (on 50 to 70% of the cycle). Such lights are perceived as flashing off rather than on, connoting a lesser sense of urgency.

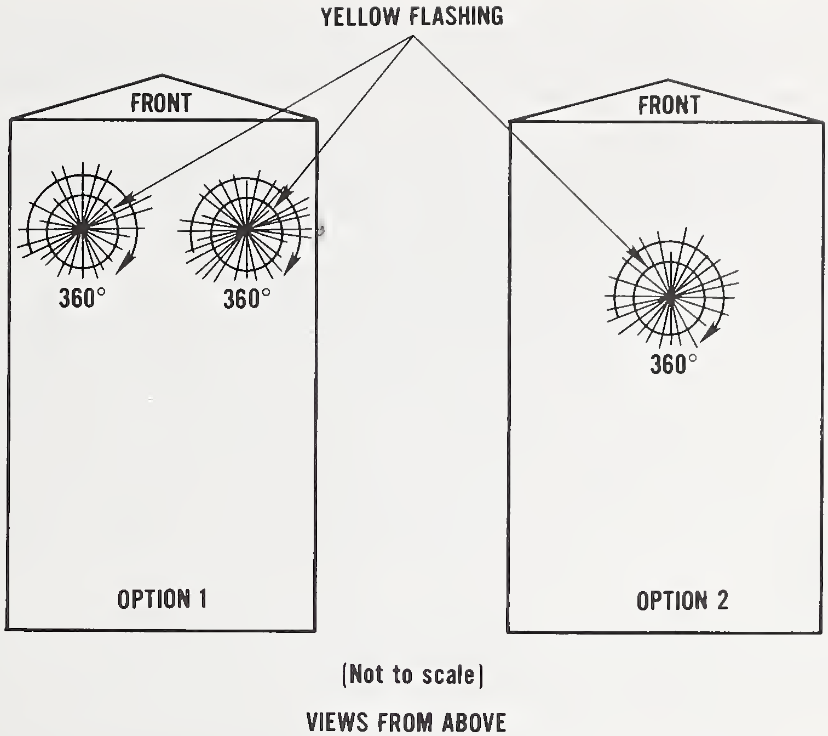

FIGURE 3. *Rooftop installation configurations for service vehicle warning lights.* Option 1 is preferred over option 2.

Recommended Flash Rates

A desirable and currently typical rate of flashing for a light meant as an emergency/service signal is 90 flashes per minute (fpm), ±15 fpm. This would be suitable for red-and-white, red, and yellow warning lights. For blue identification lights, a slower, less urgent flash rate of 60±10 fpm is suggested.

When dual red flashers are used, they should be synchronized to flash simultaneously. At present, if the lights are synchronized, they are sometimes arranged to flash simultaneously, and sometimes alternately. If two lights with individual flash rates of 90±15 fpm are operated alternately, the combination produces 180±30 fpm. When both lights are in view at long range, where the individual lights are not visually separable, the appearance is of very rapid flashes. Simultaneous operation at 90±15 fpm would assure that the perceived flash rate is always 90±15 fpm, and the merged flash from the two sources would contain more energy than a flash from one of the sources operating alone. There is some reason to believe that synchronization of the two red edge-lights with the central red-and-white alternator would also be desirable.

Recommended Minimum Intensities

The most important factor in determining the conspicuity of a light is its intensity. When the light is flashing, rather than burning steadily, the important measure is its effective intensity; that is, the visually equivalent steady intensity. This is the actual intensity of a steady light that disappears from view, in the dark, at the same distance as the flashing light. The measure originated in the specific context of looking for isolated signal lights at night in approximately known directions. Experimental work at NBS established that the traditionally calculated effective intensity of flashing lights correlates well with the conspicuity of the lights as seen peripherally in the daytime [10]. Based upon that research, the effective intensity levels of the components of an emergency vehicle's principal flashing light, particularly for daytime use, should be at least 2000 cd for white, 1000 cd for yellow, 400 cd for red, and 200 cd for blue.

The 200 cd minimum for blue does not apply to the system proposed previously in this report, which did not recommend an all-blue light as an emergency signal. Any departments currently using all-blue lights should try to upgrade to the 200 cd level. If a blue light is used for police identification purposes, within the system previously proposed, an effective intensity of 20 cd could be sufficient. This level of intensity is of little use in the daytime, and not visible from great distances at night. However, since no emergency reaction to the blue light is desired, there is no minimum safe range of detection to worry about and power can be conserved by using this low intensity. In bright daylight, the painted markings on the vehicle body, if sufficiently conspicuous, would serve as a more effective presence signal than the blue light.

The 2000 cd proposed for white lights is relatively high, but available in current commercial production (see table 3, last column). The purpose of the high intensity white component of a 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 cluttered 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 to be needed—then going to higher intensities cannot be avoided. Thus, the 2000 cd proposal is based on providing an adequate effectiveness range in the daytime, when lights are the most difficult to perceive. There is some evidence, however, that such lights may be disturbingly bright at night.

On the basis of experimental work performed at the Highway Safety Research Institute of the University of Michigan, Rudolf G. Mortimer [11] recommended that automobile stop (brake) or turn-signal lights should have intensities of approximately 2000 cd in the daytime, and no more than about 150 cd at night. His 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." Suggesting that the effective intensity of emergency signal flashes be at least equal to the intensity of brake lights or turn signals seems reasonable if the emergency signal flashes are to be highly conspicuous in traffic. Thus, 2000 cd white lights seem quite reasonable for daytime use.

However, since Mortimer's discomfort research indicates that it might be advisable to have a lower level for night signal flashes, further experimental work is necessary to determine a suitable night intensity level. Such work should take into account 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 a driver with after-images for excessively long periods of time, 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 they may still emit several thousand candelas.

If future experiments do establish a need for varying daytime and nighttime effective intensity levels, the solution might be to maintain a capability for both levels, as recommended by Mortimer [11] for stop and turn signals. He suggested that the switch for selection between the two intensity levels be linked to the headlight switch of the vehicle, so that the lower nighttime intensity is automatically activated whenever the headlights are on. Mortimer also suggested that an out-of-the-way manual override switch be provided. A problem in this system, is that emergency vehicles often have their headlights turned on during daylight emergency runs in order to increase their overall conspicuity. Perhaps the solution would be to link the level of the emergency light intensities to a photocell that measures the ambient light and automatically switches to the lower level when it is dark enough, but again with a manual override provided.

The 2000 cd figure for white light flashes applies to the bare light source covered by a clear dome. At present, colored signals are produced either by covering the bare light source with a colored dome or by coating the bulb face with colored material and using a clear dome. The reduced intensities suggested 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 approximately half the incandescent lamp light striking them, so that a 2000 cd white light covered by a yellow filter would put out an intensity of approximately 1000 cd. Red filters typically transmit approximately 20 percent of the incident light, so a 2000 cd white source would emit around 400 cd through a red filter. The red fore-and-aft flashers of this proposed system can be cut back to only 300 cd, since they generate supplementary rather than primary signals.

A strong blue that is neither excessively pale (whitish), nor greenish can only be obtained at great cost in intensity. Suitable blue glass filters transmit only approximately 3 percent of the light from a white incandescent source and perhaps 6 percent of the bluer white light produced by a xenon discharge lamp. Plastic filters of the proper blue color can transmit up to about twice these percentages. Thus, a xenon lamp producing 2000 cd flashes could produce about 240 cd of truly blue light through a plastic filter. Blue filters that are whitish or greenish transmit a higher fraction of the light, and most of the blue domes and bulb coatings used in commercial emergency vehicle warning lights are made with less pure colorations.

IMPROVING VISUAL AND AUDIBLE EFFECTIVENESS

It is recognized that not every police department will be in a position, in the immediate future, to adopt the warning light system proposed in this report. However, in the interim there are three steps that can be taken by all users of emergency vehicles to improve their visual signal effectiveness, where applicable laws and regulations permit. These steps are meant to apply to all emergency vehicles (police, fire, and ambulance), and not to service vehicles, which are encouraged to standardize on all-yellow lights to distinguish them from emergency vehicles. Also described below is an important check that should be made by all users of multiple-speaker electronic sirens.

Alternate color with white. Because of the extreme importance of the effective intensity of the light flashes in attracting attention at maximum distance, single-color signals, such as all-red or all-blue, should not be used. If a colored dome is in use on a rotating light, replace it with a clear dome, and replace every other clear (white) bulb with a colored bulb, so that every other flash is white. In a rotating unit containing three bulbs, convert it to one white bulb and two colored bulbs under a clear dome, so that the pattern appears as a pair of colored flashes alternating with one white flash. In any bulb replacement, use bulbs of the same general type and beamspread characteristics as the original. Usually, only the color should be changed, but if the electrical system permits, colored bulbs of higher wattage can be used to make the intensity of the colored flashes more comparable to the intensity of the white flashes.

Where non-rotating, flashing units are employed, whether strobe or incandescent, one of two alternating lights should be made white. If only a single colored flasher is in use, consider installing a second, white unit to alternate with it.

Use the largest bulbs possible. Since intensity is so important, check with the manufacturer or distributor of the light unit to learn the maximum bulb wattage considered suitable for use in it. If bulbs too high in wattage are installed, plastic domes can melt and damage can be done to the electrical or mechanical components. Higher-wattage bulbs will increase the power drain on the vehicle's electrical system, so the system should be upgraded by installing heavy-duty alternators, batteries, and wiring.

Paint vehicles to be more conspicuous. The surface of the emergency vehicle itself gives a visual signal, and this surface signal can be more potent than a light signal, under some circumstances. At night, or against dark backgrounds such as earth or foliage in the daytime, light colors such as white or yellow are most visible. Some fire departments paint their vehicles yellow or white for that reason. With snow on the ground, however, 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 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 many road surfaces.

The suggested solution is to have half of the vehicle painted light and the other 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 small-square 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 distinguished.

The recommended arrangement [2] is 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 resembling an extremely large square checkerboard. A harlequin-painted vehicle, regardless of the angle of view, would contain a large area that contrasts maximally in lightness with any background. Figure 4 shows such a harlequin-painted automobile. Since the page is white, the view simulates the appearance of the car against snow. Note also that, regardless of the background, the large boundaries between the light and dark areas on the vehicle itself provide highly visible edges. As a rule of thumb, the white or light-colored paint should have a luminous reflectance over 70 percent, and the dark-colored paint a reflectance below 10 percent.

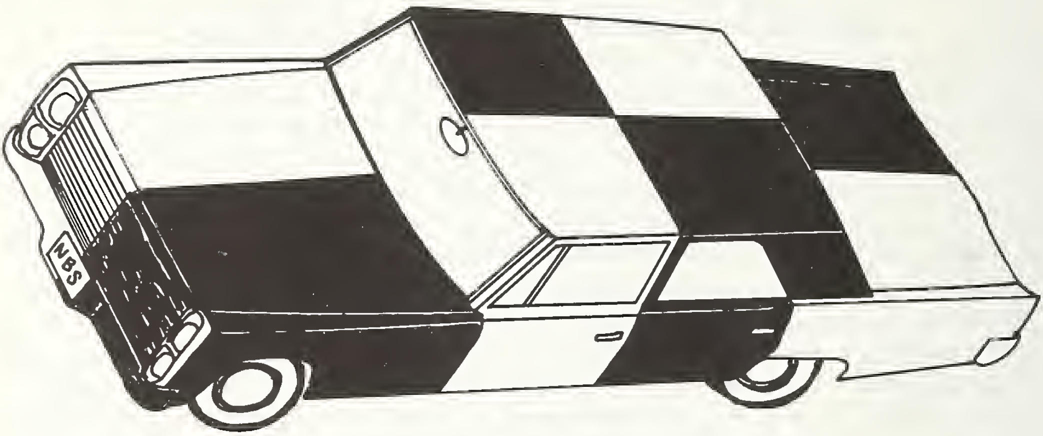

FIGURE 4. *A harlequin-painted automobile, showing contrast with a white background.*

An important fact about color contrast is that, for many practical purposes, only lightness contrast counts. When one or both of the contrasting areas appear small to the observer, differences in hue and saturation do not add as much to the overall impression of difference as does difference in lightness. At very long viewing distances, the contributions of the hue and saturation differences approach zero. As a result of this fact, it would be possible to retain color coding for close-up identification of harlequin-painted vehicles, if desired. For example, ambulances could be painted black and white, fire engines dark red and white, and police cars navy blue and white. It is important that any jurisdiction that mandates the adoption of harlequin painting for emergency vehicles should simultaneously prohibit the use of such a painting pattern by any private vehicle.

Retroreflective paint or tape can also effectively improve the visibility of a vehicle. However, it is important for daytime identification purposes that the retroreflective patches contrast strongly in lightness with the painted area on which they are placed. One large city department has used dark yellow ("gold") retroreflective 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 daylight contrast between the letters and background is not very great, and the message (POLICE) is not easy to read at a distance when the level of light is low (dawn, dusk, or heavy overcast). One solution would be a switch to bright yellow or white (light) retroreflective letters on a navy blue (dark) background.

Make certain that multiple sirens are in phase. Considerable losses in the sound levels produced by electronic sirens can occur in certain directions—particularly the critical forward direction—if two speakers side by side are connected with opposite polarity (in anti-phase), 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 carefully checked by a knowledgeable technician or engineer.

A few vehicles now use a pair of electronic sirens with one speaker behind the other, rather than side by side. 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 it from the rear speaker.

The speed of sound at sea level is approximately 335 m (1100 ft) per second, and sound waves travel 0.3 m (1 ft) in about 0.91 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 (in metric units, 3.0 ms multiplied by the speaker separation in meters). Instead of calculating the required acoustic delay, a variable time-delay circuit connected to the front speaker can be set so that the measured sound level at a distant point directly in front of the vehicle is at a maximum. This procedure can be used with any arrangement of multiple speakers, if every speaker but the rearmost is equipped with an adjustable delay circuit.

APPENDIX A—REFERENCES

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