# SIGNAL LIGHTING SYSTEM REQUIREMENTS FOR EMERGENCY, SCHOOL BUS, AND SERVICE VEHICLES

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16. Abstract

This report reviews the inconsistency between various state laws and the Uniform Vehicle Code regarding lighting systems for special vehicles and school buses. Accident data are cited that may have pertinent implications to the problem of lighting system design for these vehicles. Driver behavior problems that may be associated with the ambiguity of current signal messages are discussed. Subsequently, an analysis of the signal messages that are necessary to conduct particular vehicular missions is presented. A review of lighting devices available disclosed that there is a diverse array of lighting devices available. Psychophysical visual and applied research was reviewed for information on the advantages and disadvantages of various coding parameters. An analysis of color, intensity, and flash rate summarized the information available that is applicable to special vehicle signaling systems. From this information was developed a set of recommended signals to transmit the messages deemed necessary for the efficient and safe conduct of various vehicular missions. These recommendations took into account current legal, stereotype, and changeover constraints. School bus signaling procedures were also reviewed and specific recommendations are made for new signals, usage procedures, legal language, and research.

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# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

### LENGTH

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |

### AREA

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
|  | acres | 0.4 | hectares | ha |

### MASS (weight)

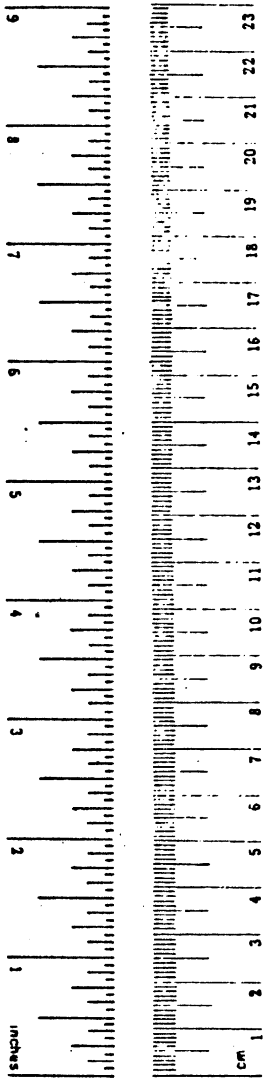
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
|  | short tons (2000 lb) | 0.9 | tonnes | t |

### VOLUME

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |

### TEMPERATURE (exact)

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |



## Approximate Conversions from Metric Measures

### LENGTH

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |

### AREA

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres |  |

### MASS (weight)

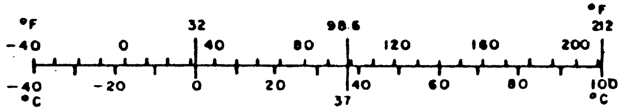
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons |  |

### VOLUME

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |

### TEMPERATURE (exact)

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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

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DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

# TECHNICAL SUMMARY

| | |
|---|---|
| CONTRACTOR<br>The Regents of the University of Michigan<br>Highway Safety Research Institute | CONTRACT NUMBER<br>DOT-HS-6-01468 |
| REPORT TITLE<br>Signal Lighting System Requirements for Emergency, School Bus, and Service Vehicles | REPORT DATE<br>November 15, 1978 |
| REPORT AUTHOR(S)<br>David V. Post | |

The impetus for this project grew out of the publication of "Warning Lights for Special Purpose Vehicles" in Traffic Laws Commentary, Vol. 4, No. 3 (December 1975) and "Laws Requiring Drivers to Stop for School Buses" in Traffic Laws Commentary, Vol. 2, No. 5 (August 1972). These two documents were prepared by the National Committee on Uniform Traffic Laws and Ordinances for the National Highway Traffic Safety Administration of the Department of Transportation. These documents show that there is little uniformity among state laws as to the use of signal lighting systems on various classes of special purpose vehicles that are equipped with auxiliary signal lights in addition to the signal lights required on all vehicles by FMVSS 108. Furthermore, many states do not even have laws pertaining to certain classes of vehicles. The laws that do exist tend to be very general, perhaps specifying color only, and usually do not detail the type of signal light, mode of operation, location, configuration, intensity, or flash rate required. Little recognition is evident of a need for particular vehicles to communicate specific information to other drivers. Additionally, state laws concerning school buses were found to be inconsistent in terms of specification of the "4 lamp" or "8 lamp" system as per FMVSS 108, lighting and stop arm equipment specified, operational requirements for the signaling system, and laws covering driver response to the signaling system.

Because of increasing interstate mobility and increased busing of school children, there may be no valid safety alternative to providing a high degree of uniformity in signaling systems for emergency, school bus, and service vehicles. Adequate and clear vehicle-to-driver communication can only be obtained if there is some consistency to the driver behavior elicited by various signal lighting systems.

The purpose of this project was to analyze vehicle-to-driver communication requirements for emergency, school bus, and service vehicles so that effective signaling systems for these vehicles can be specified to provide a nationwide uniform signaling system.

To address the problem of non-standardization of signaling system on special purpose vehicles, such as police, fire, ambulance, school bus, and service vehicles, the following actions were taken. A review of state laws and applicable sections of the Uniform Vehicle

(Continue on additional pages)

Code sought to point out the lack of adequate and consistent legal requirements for lighting systems. Accident data were also reviewed to determine the nature of current signaling system inadequacies. Also, the interaction between light signal and driver behavior was examined. Subsequently, information that could lead to a classification of signal messages as a function of the operations engaged in by typical special purpose vehicles was sought from the literature, various agencies, and officials. A schema was developed which related the following factors: agency, vehicle, operation, vehicular mission, signal message, accompanying situational conditions, redundant systems frequently used, and the level of signal commonality desirable. Seven messages were indicated as being sufficient for the signaling needs of all special purpose vehicles.

To determine the coding to be employed for particular signals it was first necessary to survey the parameters currently in use as indicated by catalogs of numerous manufacturers, an equipment guide used by police chiefs, and advertisements occurring in law enforcement, medical service and transportation magazines. This compilation indicated that a large number of coding parameters were in use in the multitude of lighting systems available. Thus, user/marketplace interaction has not produced a consensus to delineate potentially desirable coding parameters. Therefore, a large body of literature relevant to determining the perceptual advantages and disadvantages associated with various parameters was collected and reviewed. This review concluded that little data regarding the conspicuity of various lighting parameters exist that is relevant to auxiliary vehicular light signals.

An analysis of color, intensity, flash rates and additional conspicuity considerations attempted to derive, from the available body of basic and applied visual information, data pertinent to design of auxiliary vehicular light signals. One method utilized was to combine the perceptual aspects of a given color with the physical limitations of producing such a color. Thus, the problem addressed here was not to determine the most visible color, but the lighting parameters that can produce the most easily seen signal. This analysis also sought to point out the shortcomings of basing conclusions on a particular finding which may be unsupported by other research efforts. In addition, current SAE specifications were critically reviewed and suggestions are made for color, intensity, flash rate, and contrast requirements for adequate signal lights.

Changeover considerations of both, state legal requirements and hardware in use, were reviewed to determine the extent that current practices should influence design of a standardized and/or improved auxiliary light signaling system. Little data was found to be available on the physical specification of signal units in use on ambulance and fire vehicles and the information on police vehicles may be out-of-date. Proliferation of lamps on specific vehicles and in situations where multiple vehicles are present was discussed in the context of limiting signals to the minimum necessary to ensure that an approaching driver receives the appropriate message.

A special analysis lead to recommendations for new legal and hardware requirements for school buses which are described in terms of changes that would be necessary in the Uniform Vehicle Code. This analysis took into account the use of school buses on different types of highways, and considered the importance of stop arms, and proper usage of signals by bus drivers.

The following recommendations and procedures for implementing them were produced by this project.

A "Clear the Right-of-Way" signal should be required on police, fire, and ambulance vehicles. It is recommended that this signal be composed of dual red beacons of 600 effective candlepower, synchronized to flash at 150 flashes per minute (fpm).

A "Hazard-Vehicle on Right-of-Way" signal should be required on police, fire, and ambulance vehicles. It is recommended that this signal be composed of an upper pair of rear facing red lamps of 600 candlepower flashing alternately at 90 fpm, plus flashing of the lower turn signal lamps alternately, but out of phase with the upper lamps.

A "Caution-Slow Moving Vehicle" signal should be required on wreckers and maintenance vehicles. It is recommended that this signal be composed of a pair of rear mounted yellow beacons of 1500 effective candlepower flashed at 90 fpm plus a similar rooftop beacon, if necessary to project the signal 360° around the vehicle. Postal vehicles should continue to use a simultaneously flashing pair of rear mounted yellow automotive signal lamps for this signal. In urban traffic a yellow rooftop lamp capable of projecting 600 effective candlepower to the rear, while pulsed at 90 fpm, should operate when postal vehicles are stopped on the right-of-way.

A "Vehicle Present in Hazardous Location" signal composed of simultaneously flashing yellow-rear signals should be required on all vehicles. Signal enhancement may be necessary for special vehicles.

A "Stop-Immediately" signal composed of a blue spotlamp with a unique flash pattern should be required and restricted to usage on all police vehicles.

The forward facing school bus loading lamps should not be operated on a divided highway where no passenger crossing is to take place. The upper rear red lamps, required on school buses by FMVSS 108 for conveying a "Stop-Do Not Pass" signal when school buses are stopped in the right-of-way for loading of passengers, should probably be supplemented by other devices. Flashing of the brake lamps alternately, but out of phase with the upper lamps is recommended. Additionally, use of the "Stop-Do Not Pass" signal may be warranted while the bus is stopping since an unambiguous pre-stop signal is desirable.

Research should be conducted to determine whether an octangular stop arm configuration, with or without lights attached, offers an improvement over the recommended system, and whether lower alternately flashing lamps would increase the effectiveness of the "Stop-Do Not Pass" signal message. The use of flashing high beams should be evaluated as part of the "Clear the Right-of-Way" signal. Development of a distinctive flashing blue spotlamp for the "Stop-Immediately" signal should also be undertaken.

Research should be conducted, using both subjective and objective measures of conspicuity, so that the comparative effectiveness of lamp types can be more fully understood. This research should lead to evolutionary signal improvements, especially for the "Clear the Right-of Way" message.

# PREFACE

This project was conducted under the direction of David V. Post, who also served as the Principal Investigator and thus was responsible for production of this report. Mr. Post is a Senior Research Associate in the Human Factors Group, Highway Safety Research Institute, University of Michigan and has been employed as a full-time researcher in the human factors area at HSRI since 1968. Mr. Post graduated from the University of Michigan in 1966 with an A.B. degree in Psychology and obtained a M.S. degree in Psychology from Eastern Michigan University in 1972. Mr. Post has conducted and published research dealing with the psychometric identification of problem drinkers, evaluation of automobile rear signaling systems, multiple headlamp beam systems, reflectorized license plates, and turn and hazard warning signals. Much of his work involving vehicle lighting has been under contract to the National Highway Traffic Safety Administration or the Motor Vehicle Manufacturers Association.

Dr. Michael Sivak prepared the Review of Research on Color and Intensity Perception. Dr. Sivak received his Ph.D. in Experimental Psychology from the University of Michigan in 1976. He has worked at the Highway Safety Research Institute since 1976, primarily in the areas of visual perception and information processing.

Grateful acknowledgement is hereby given Dr. Sivak for cooperation in tabulating the information in Tables 6-11, his assistance in clarifying various issues, and preparing the above mentioned section of this report.

Grateful acknowledgement is hereby given Dr. Paul Olson for his comments and suggestions resulting from discussion of project direction and review of draft materials.

Flora Simon was responsible for typing of the final report and for secretarial services throughout the project. Her services and patience were greatly appreciated.

Mike Perel served as the Contract Technical Manager, relieving Rube Chernikoff of this duty upon Mr. Chernikoff's retirement. My appreciation goes out to Mr. Chernikoff for seeing the problems inherent in the special vehicle lighting system in the United States and the need to address these problems. Mr. Perel did an admirable job in attempting to understand the complexity of the current situation, as did Mr. Chernikoff, and the nature of the difficulties involved in proposing solutions to the problem of standardization.

Acknowledgement should also go to Corwin Moore of the Highway Safety Research Institute for recognizing the problems associated with the lack of emergency signal uniformity and suggesting use of signal messages to reduce driver confusion. His ideas which were contained in a HSRI proposal to the Motor Vehicle Manufacturers Association in 1975 were of considerable benefit to this project.

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# BACKGROUND

The inconsistency in signaling standards is shown in great detail in the Traffic Law Commentaries entitled Laws Requiring Drivers to Stop for School Buses (Yaw, August 1972) and Warning Lights for Special Purpose Vehicles (English, Young and Friedland, December 1975).

The pattern of inconsistency in emergency vehicle signaling systems is similar to that involving school buses except that there is a greater array of signaling coding dimensions contributing to the inconsistency in the case of special purpose vehicles. Uniform Vehicle Code provision 12-227 prohibits use of alternately flashing high mounted front and rear pairs of red signal lights, except on school buses and authorized emergency vehicles where they are required, and/or police vehicles where they are permitted. While 35 states have laws governing the usage envisioned in UVC 12-227, they vary enormously in respect to color and operational specification. The states are also at variance with the code and each other in respect to use of special privileges exempting authorized emergency vehicles from various traffic ordinances (parking speed limits, stop signs and lights, and direction of traffic flow). The Uniform Vehicle Code section 12-218 specifies the types of lamps to be required on authorized emergency vehicles by section 12-227 and allows use of red, or red and white rotating beams. Only 17 states require fire vehicles to be equipped with specified warning lights, while 9 states refer to UVC 12-227. However, most of the state laws require or authorize flashing red lamps for fire vehicles, and, in addition, some other states require or permit use of steady red lights. Only 6 states require police vehicles to be equipped with specified signal lights while 8 more refer to UVC 12-218. While most jurisdictions treat ambulances the same as fire vehicles regarding warning lights, 17 states require specified signal lights for ambulances and 9 more states refer to UVC 12-218.

Of the 27 states that specify special warning lamps for highway maintenance vehicles, 15 require amber. Four states specify red, 1 state specifies some red and some amber, 1 state specifies blue, and 6 don't specify color. California goes so far as to specify the use of the amber warning light only when an unusual traffic hazard exists. Thus, for these California vehicles a message is defined. However, 24 other states do not even have laws relating to use of warning lights on highway maintenance vehicles. The same problem exists for wreckers, public utility vehicles, and highway maintenance vehicles.

Obviously, safe interstate travel could be promoted by development of standardization of the signal units and their usage that is permitted or required by the various states. Developing nationally uniform special vehicle signaling laws and standards would reduce driver confusion and thus enhance driver safety.

Looking at the accident data involving emergency vehicles, a State of New York report written by Newcomb and Carpenter (1972) indicates that emergency vehicles (police, fire, and ambulance) were nearly 2-1/2 times more vulnerable to vehicles entering from a cross street than non-emergency vehicles. Most accidents to such vehicles involved two vehicles striking at an angle under emergency conditions. These accidents represent 40 percent of the total sample which was stratified by accident severity. However, if the "Unknowns" are removed from the directional analysis the percentage jumps to 52 percent. Among the multi-vehicle collisions (exempting the single-vehicle collisions), the relevant percentage is 56 percent, indicating that well over half of the sample were involved in such collisions. These data would indicate that a major concern is short distance transmission of the message "yield right-of-way" to drivers who may only be able to perceive it peripherally. The three next most common accidents in order were rear-enders which occurred with one vehicle parked not at an intersection, one vehicle stopped at an intersection, and one vehicle stopped in traffic not at an intersection. Police vehicles and other emergency type vehicles (excepting fire and ambulance) were found to be about equally involved in intersection and non-intersection accidents. Nearly 1/2 of the intersection accidents occurred at an angle while the most prevalent non-intersection accident occurred with one vehicle parked.

The New York study (1972) also states that the emergency vehicle driver is at fault only about 33 percent of the time, while the general population is at fault nearly 50 percent of the time. From this, one can conclude that the emergency vehicles are being struck considerably more often than they are striking another vehicle. Data also indicated that non-operation of warning devices was not a problem since in most cases both lights and siren were in operation. The estimated cost of ambulance and fire truck accidents in New York in 1970 while these vehicles were in an emergency situation was estimated to be two million dollars based on the National Safety Council formula contained in the Traffic Safety Memo #113.

Data from the California Highway Patrol (1974) show that "Rear-end collisions (including side-swipes), involving parked patrol vehicles, accounted for a large portion of injuries received by CHP personnel involved in patrol vehicle accidents." About 30% of the total patrol vehicle injuries in 1970-1972 were attributed to rear-end collisions. During this period approximately 1/3 of the visible injuries, 1/2 of the severe injuries and the one fatality, resulted from rear-end collisions. In the majority of these collisions, approximately 60%, no emergency equipment was in use at the time of the impact. However, in about 30% of these rear-end accidents a single amber light was illuminated and in another 9% a red light or red and amber lights were being used. The vast majority of these accidents took place on dry roads in clear weather with the largest proportion (48%) of them occurring during daylight. Apparently, police patrol vehicles need increased protection to the rear, especially when parked, and thus, a policy of using lights to mark the presence of such vehicles should be encouraged. An improvement over the single amber light marking system also seems warranted.

The New York and California accident data show that improved operational performance of signal lights is indicated as having potential for reducing accidents with emergency vehicles.

School buses, similarly, have signal light systems which vary in description and usage from state to state (see Yaw, 1972). Fifteen states substantially conform to FMVSS 108 which is consistent with provision 12-228 of the uniform commercial code which requires red alternately flashing school bus loading lamps visible at 500 feet in normal sunlight front and rear, and permits additional use of similar, but inboard yellow lamps. Nineteen other states generally use similar coding systems, but do not specifically require such equipment or do not specify the type of equipment precisely enough to define the equipment. However, 10 states were found to have <u>no</u> legal specification that all school buses be equipped with a particular type of warning signal and 7 other states require certain types of warning signals with 2 of these requiring stop arms.

Eighteen states require the use of visual signals only when the school bus has stopped to receive or discharge pupils and another 3 permit such use at the bus driver's discretion. Fifteen states require usage of red or special signals prior to stopping, in addition to when the school bus is stopped, and another 3 states require amber alternately flashing lamps prior to use of red lamps which meet the FMVSS 108 provision.

Further confusing drivers, 8 states have provisions that prohibit use of the visual signals in certain areas. For example, in Baltimore, use of visual signals is prohibited in that urban area as their use is thought to reduce pedestrian safety (School Bus Fleet, Feb./Mar., 1976). Other states similarly draw distinctions between urban and rural use by restricting visual signal usage at intersections, and/or in business, or residential sections. Thus, the interstate driver may be as ignorant of signal usage in certain locales as the interstate driver. In addition, 35 states are in substantial agreement with the UVC 11-706 provision which states that drivers need not stop when encountering a bus on a different roadway of a divided highway and eight more states permit passing of buses traveling in opposite directions on such roadways. Three more states while permitting passing of buses in opposite directions do not require the highway to be divided. Although in many particular situations a driver need not stop for buses on divided highways or in loading zones, the school bus drivers may, in fact, use the warning lamp systems, thus requiring the car driver to know the law and analyze the situation before he can determine whether he is required to stop or not. The signal usage itself should be encoded so that a following or approaching driver can determine the action that he is required to take from the mode of operation, color and location of the signal. Since 46 states do not require the driver to stop for oncoming school buses on three or more lane highways or different roadways or divided highways, the school bus should not be flashing alternating red to the front in these situations, as this will tend to confuse drivers and also children who might assume that they have the right-of-way.

A paper by Marsden (1975) found that in most San Diego school pedestrian collisions, the pedestrian was at fault. However, in pedestrians collisions involving school buses, all the pedestrians were hit by oncoming vehicles. Siegel, Nahum and Runge (1971) present casualty data which show that twice as many students were killed as pedestrians than as bus occupants in 1969. Data provided by D. Soule of a NHTSA survey for 1968 and 1969 also show that more fatalities occur to pedestrians than bus occupants. Additionally, accident data from Hull and Knebel (1968) also indicates that in terms of fatalities it is the pupil pedestrian that is in danger with about 2/3 being struck by another vehicle and about 1/3 by the school bus. In pedestrian injuries, also, the pupil was most often struck (74%) by another vehicle, but 26% were struck by the bus itself. All of these data indicate the need to protect the student while he is a pedestrian.

Accident data may be helpful in design of a school bus lighting system and operational procedures. The Garrett et al. (1974) study of Western New York school bus accidents indicates that most multi-vehicle school bus accidents involving injury were rear-end impacts. The rear-end injury and property damage accidents occurred most frequently when one vehicle was stopped. This vehicle was usually the school bus which was stopped between intersections in traffic presumably to load or unload children. Thus, these data along with other data in the same report indicate that while ice, snow and rain are contributing factors to many of the injury-producing rear-end accidents involving school buses, similar accidents occurred when the roads were dry. These data indicate that there are problems in car driver detection of signals, knowledge of required action, early transmission of a "prepare to stop" message, and/or engagement of signal systems by bus drivers.

# INTRODUCTION

No national standards currently exist concerning the required, permitted, or restricted use of emergency vehicle signal lamps. Most states' Vehicle Codes establish certain standards, but the variation between states is considerable, as was shown in Traffic Laws Commentary, December, 1975. As shown in this document, the primary distinction between use of the different signaling modes (color, alternating versus simultaneous flashing, $360^0$ beacon use, etc.) is the agency or authority on whose vehicles such devices are mounted. The importance attributed by the public to signal lights used on the vehicles of specific agencies is probably correlated with the conspicuity of the lighting systems employed because of past experience. Past experience has probably conditioned the public to expect relatively intense signals with complex flash characteristics to appear on police vehicles which often conduct "important" missions. The public is aware that many police vehicles conduct "important" missions as they are frequently observed disregarding speed limits and other traffic control devices such as stop signs and traffic signals. Conversely, relatively dim slowly flashing signals are probably considered to be indicative of public service or utility vehicles which seldom are observed conducting missions which are important enough to justify special driving priviledges. In fact, such vehicles are often observed parked with their signals operating. Thus, popular consensus would probably attribute the following "priority" to agencies based on the relative importance of the most often observed vehicular missions of that agency.

(a) Highest Priority: police vehicles

(b) Second Priority: fire and ambulance vehicles

(c) Third Priority: (wreckers, auto-service vehicles, and road maintenance vehicles [snowplows, graders, etc.])

(d) Lowest Priority: public services and utilities vehicles; and vehicles of other local government agencies not normally responding to emergencies or parked in the right-of-way.

The agency "priority" may or may not coincide with the relative importance of the message that a vehicle needs to convey in any given situation. For example, a snowplow in the median of a divided highway that is changing direction and thus will merge on the left side lane, while slowly moving, needs to be very conspicuous to insure that the message "slow moving vehicle - danger" is conveyed. Thus, in this instance a vehicle that is considered to be of third priority needs to convey a high priority message. On the other hand, a police vehicle may be stopped on the shoulder of the road to check out a vehicle that may be abandoned, stolen, and/or disabled. In such an instance, since the police vehicle is encroaching on a shoulder not intended or normally used for parking, its presence needs to be conveyed. The presence of parked vehicles near a highway is generally considered a hazard and thus, a "hazard warning signal" would seem to be appropriate for the police vehicle. Thus, in this case the police vehicle is not creating a hazard that is any greater than that created by a regular motor vehicle and use of high intensity, fast flash rate, red or blue lamps commonly found on police cars may elicit inappropriate driving behavior such as slowing down or changing lanes unnecessarily. In addition, use of highly conspicuous signals in the "parked hazard" situation described would tend to weaken the associations between various real emergencies and use of the highly conspicuous signal previously associated with them.

Driver behavior needs to be a function of the mission of special vehicles, but currently upon signal detection there is no way of readily determining whether a signaling vehicle is, 1) stopping him for a traffic violation, 2) engaged in pursuit, 3) rushing to an accident, 4) involved in accident scene activities, or 5) moving slowly or parked. About all drivers can ascertain upon detecting a signal, at this point in time, is that they should monitor the source of the signal so that they might eventually learn via other cues its relative importance and any action required of them. Even if he has waited to make a vehicle identification subsequent to signal detection, a driver could not be immediately sure as to what course of action he should take. Knowledge of the vehicle type does not necessarily determine the action that a driver should take since emergency vehicles engage in different operations which may require different driver response.

Now, in the case of a moving ambulance with a signal operating, it could be argued that knowledge of the vehicle type determines the required driver action since a moving ambulance with signal lights operating is engaged in a medical mercy mission which will be facilitated if all drivers clear the right-of-way. However, why force the driver to be able to identify the moving ambulance? It would be much more direct to provide a light signal which could be identified as being specific to the message "Clear the Right-of-Way" which could be ascertained at a relatively long distance.

Current ambulance signal lights may not elicit proper behavior. One reason is that, many vehicles which are engaged in low priority missions are, nevertheless, often using signal lights which are similar or identical to those frequently used by ambulances. Unfortunately, it may be that drivers have come to wait for vehicle identification after signal detection before altering their driving behavior. During this waiting period the driver can ascertain whether the signaling vehicle is engaged in an operation which requires that he get out of the way or whether it's just another instance of a wrecker or garbage truck mimicking the signals of an ambulance or rescue vehicle. Since the ambulance may be coming from behind and/or obscured by other vehicles, the vehicle may have to be relatively close for identification to take place. This time period from signal detection to vehicle identification represents avoidable delay time during which an ambulance may be hindered in getting to its destination and delivering life sustaining services.

The problems of recognition and driver response to signal lights of police and fire vehicles are similar to those just mentioned in regard to ambulances. Police and fire vehicles have a need to get to an emergency destination as soon as possible in order to protect life and property. When engaged in such important missions, an unambiguous "Clear the Right-of-Way" signal could be of enormous benefit in distinguishing emergency vehicular missions from less important missions conducted by other vehicles.

There appears to be a need for more standardization between the signals used by different vehicle types which engage in similar operations, such as high speed travel with special driving priviledges. This could lead to reduced driver confusion and thus, reduce driver hesitancy which may be caused by the current ambivalent meanings associated with special vehicular signals. Similarly, there needs to be more differentiation between signals on vehicles which undertake radically different missions. Some vehicular operations depend on other drivers immediately clearing the right-of-way while other vehicular operations do not require signals to convey messages of such high importance. Signal usage should be restricted to the extent that signal meaning is not compromised via association of the same signal with different needs for vehicular communication.

What is needed is an analytical look at special vehicles to determine their typical operating characteristics and their needs to convey unambiguous messages in order to improve driver response. Such an analysis could be used as the basis for determining sets of messages that various vehicles need to convey and for determining what degree of similarity or differentiation is needed between the signaling systems allowed on various vehicles.

# ANALYSIS OF SIGNAL REQUIREMENTS

As shown in the introductory section, it needs to be determined what agencies and vehicles require special lighting systems. The types of operations that they engage in that require use of special lighting signals is also relevant to design of vehicular signaling systems.

A classification methodology should be developed to determine a logical set of message signals that can be specified for various vehicle types engaged in various missions and to determine the extent that the lighting systems must accommodate typical usage conditions.

The first necessary step to develop a system of messages is to determine:

1. The agencies that employ vehicles for special purposes.
2. The different classes of vehicle that each agency employs to carry out its function.
3. The operations that each class of vehicle is involved in.
4. The specific messages that may be required for each type of mission.
5. The typical usage circumstances which may affect message transmission on various types of missions.

It was decided that the agencies that most frequently must convey signals, such as law enforcement (police), fire and rescue, emergency medical and ambulance service, and school transportation departments should have their vehicular signaling needs analyzed and coded first due to the importance of signaling systems on these vehicles, as evidenced by their commonly frequent usage. Next, it was decided to include agencies whose usage of auxiliary and colored lights is similar to or mimics lighting system usage on the vehicles used by the agencies just mentioned. Thus, the post office, highway and roadway maintenance departments, public and private utilities and public and private towing services were included, so that, the required coding scheme could be designed to distinguish between messages used by these vehicles and messages requiring greater urgency that are more frequently used in situations of great importance by the previously mentioned primary vehicles.

Among the vehicles that were included as special vehicles in the analysis of signaling requirements for special vehicles were the following:

VEHICLES

Police Car
Police Motorcycle

Fire Truck
Rescue Unit

Ambulance

Maintenance Truck
Snowplow
Parked Highway Equipment

Mail Delivery Vehicle

Wrecker

Public Utility Truck

Type I Bus
Type II Bus (Mini)

From a consideration of the situations that these vehicles may be involved in, was derived the following set of potentially desirable messages.

POTENTIALLY DESIRABLE MESSAGES

Clear the Lane

Clear the Roadway

Pull Over and Stop

Vehicle in Hazardous Location

Slow Down - Traffic Hazard Ahead

Traffic Change Lane or Direction

Traffic Stop

Vehicle is Present

Be Prepared to Stop

Caution - Slow Moving Vehicles

Stop - Do Not Pass

In order to determine what vehicles should be equipped to transmit which messages an attempt was made to tabulate the operations that are characteristic of various special vehicles. This information was obtained from a light usage table provided by the Washington State Patrol (Appendix A), the Police Traffic Services Handbook (1973), discussions with police, school bus, and state highway department officials and observations of vehicles in use. From this information was derived Table 1 which categorizes various types of special vehicles by the types of operations they engage in. It enumerates the agency/vehicle/operation combinations for which messages need to be developed. For each operation a distinct mission name was chosen that was broad enough to cover various operational situations that could adequately use the same message. For each mission name

TABLE 1. LISTING OF SPECIAL VEHICLE OPERATIONS

| AGENCY | VEHICLE | OPERATION |
|---|---|---|
| Police | Car/Motorcycle | Emergency/pursuit driving |
| | | Emergency scene activities - on roadway |
| | | Ticketing of motorist |
| | | Roadside vehicle investigation |
| | | Apprehension of motorist |
| Fire/ E.M.S. | Truck/rescue | Emergency driving |
| | E.M.S. Unit/ ambulance | Emergency scene activities - on roadway |
| | | Roadside care/patient loading/fire fighting |
| Post Office | Cars/jeeps | Vehicle moving slowly to deliver mail |
| | | Vehicle stopped to deliver mail |
| Highway/ Roadway Commission | Trucks | Maintenance off right-of-way |
| | | Maintenance on right-of-way |
| | | Merging from median |
| Public/ Private Utility | Trucks | Vehicle moving slowly with traffic to plow/grade/repair |
| Public/ Private Towing | Wrecker | Assisting disabled vehicle |
| | | Towing disabled vehicle |
| | | Accident removal activity |
| | | Travel to accident |
| | | Travel to disabled vehicle |
| Public/ Private School Transportation | Type I Bus | Stopping in right-of-way for loading |
| | Type II Bus (mini-bus) | Stopped in right-of-way for loading |
| | | Stopped off right-of-way for loading |
| | | Stopped off right-of-way |

a mission description was also derived (Table 2) which included an operational definition of the mission and examples of the typical situations which fall under the operational definition for each mission. Each of the mission descriptions cover a multitude of driver and/or vehicle actions that may be similarly defined under a common heading. Thus, the minimum vehicular message set must provide a clear message for each of the following missions in order to adequately signal the course of action required by any of the sumsumed driver/vehicle actions or operations.

### MISSION SET

A. Emergency or Pursuit
B. On Roadway Emergency Scene Activities
C. Roadside Operations
D. Slow Vehicle Operation
E. Citizen Control
F. Stopping for Loading
G. Stopped for Loading

The messages in the following message set were delimited from the potentially desirable messages to respectively match, in as clear and succinct a manner as possible, the mission set as indicated by the alphabetic letter codes.

### MESSAGE SET

A. Clear the Right-of-Way
B. Hazard--Vehicle on Right-of-Way
C. Vehicle Present in Hazardous Location
D. Caution--Slow Moving Vehicle
E. Stop - Immediately
F. Be Prepared to Stop
G. Stop - Do Not Pass

Thus, all of the potentially desirable messages are included functionally in the listing of messages above, except for potentially desirable message number 6, "Traffic Change Lane or Direction." This

## TABLE 2. SPECIAL VEHICLE MISSIONS - DEFINITIONS AND EXAMPLES

### A. Emergency or Pursuit

Engagement of an authorized emergency vehicle in driving activity which requires maximum right-of-way special driving privileges will be given to such vehicles only when engaged in an activity generally considered to be an emergency call or pursuit.

Examples - High speed pursuit by a police vehicle in an attempt to apprehend a law violator, disregard of traffic control devices including speed limits by police, fire, and ambulance vehicles that are responding to an emergency.

### B. Roadway Emergency Scene Activities

Engagement of an authorized emergency vehicle in non-driving (parking) activity which requires maximum right-of-way.

Special parking privileges will be given to such vehicles only when engaged in an activity generally considered to be an emergency necessity.

Examples - parking a police car in the middle of the roadway in an attempt to apprehend a law violator or direct traffic during an emergency situation, parking a fire, ambulance or rescue vehicle in the middle of the roadway in order to conduct fire fighting, medical treatment or rescue activities in conjunction with an emergency.

### C. Roadside Operations

Operation of a motor vehicle in a slow moving or stopped manner off the roadway. Such operation shall generally take place on the shoulder of the roadway but may take place in the property right-of-way.

Examples - A police car stopped on the roadway shoulder engaged in the process of ticketing a motorist or vehicle investigation, a fire vehicle that has pulled off the roadway engaged in fire fighting or maneuvering for such activity, an ambulance or rescue unit on the shoulder loading passengers or assisting injured persons or moving along the shoulder between locations of injured persons, a wrecker parked or moving off the roadway assisting a disabled vehicle or being used to assist in repairs, a vehicle stopped to deliver mail or moving between mailboxes in a setting which permits off roadway travel.

## D. Slow Vehicle Operation

Operation of a motor vehicle in a slow moving manner on a roadway at speeds minimally 10 mph/15 km lower than the mean traffic speed. Such operation shall generally take place in the right most traffic lane.

Examples - Towing a disabled vehicle appreciably slower (10 mph/15 km or more) than the traffic speed, operating a grader or other maintenance vehicle wholly or partially on the roadway at 10 mph/15 km or more below the mean traffic speed, delivering mail in such a manner to travel on the roadway at speeds 10 mph/15 km or greater below the mean expected traffic speed.

## E. Citizen Control

An activity engaged in by law enforcement officers whereby a citizen must stop as required by law when ordered to do so by a police officer.

Only a law enforcement officer has to be able to transmit the message "Stop Immediately" to communicate to a citizen that the citizen is required by law to stop. Special equipment must be provided an officer assigned to a vehicle to enable him to transmit this message while the vehicle is in motion or stationary.

Examples - A law enforcement officer stopping a citizen for any legitimate purpose including ticketing a motorist for a moving, vehicular, or license violation; apprehending a suspected law violator who may or may not be a vehicle occupant; ordering a vehicle or traffic to stop in situations where a police officer must exercise control of vehicles due to extenuating circumstances where operation of traffic control devices is inadequate.

## F. Stopping for Loading

An activity engaged in by bus operators that allows a bus to decelerate as it approaches a passenger loading area.

Example - A school bus decelerating as it prepares to stop at a loading area.

## G. Stopped for Loading

An activity engaged in by bus operators that allows persons access to the bus while protected by law from passing vehicles.

Example - A school bus loading pupils while displaying a legally recognized signal that requires drivers to take special precautions which include stopping in some circumstances.

message is probably inherent in message B - Hazard--Vehicle on Right-of-Way which implies that a driver will have to modify his speed and/or direction.

It must now be determined whether the message set was adequately assigned to the mission set and can adequately represent the operations listed in Table 1. An attempt was made to assign the messages to specific vehicle missions such that all vehicular operations could be adequately represented. In Table 3 it can be seen that all of the operations listed in Table 1 are described by a more global mission definition and that the message set was assigned to the mission set in such a way as to provide a distinct message for all the operations listed, regardless of the vehicle or agency involved in the operation.

A summary of code letters in Table 4 is designed to give a handy reference to persons interpreting Table 3 and it is recommended that Table 2 be consulted until readers have associated the restrictive mission definition with the mission name.

The listing of accompanying conditions in Table 3 contains only the most directly pertinent situational circumstances that have a bearing on the need for particular coding requirements for a particular operation. Thus, the fact that both plows and dump trucks frequently make turns in the median with heading angles of $90^0$ to the high speed traffic flow is a typical usage circumstance that would be listed here since it involves a particular type of oeration, i.e., merging from median, and would thus apply to all vehicle types engaging in this operation. Other circumstances of usage that transcend operations, but that may be associated with particular vehicle types are not enumerated for the sake of brevity since a specific vehicle type may be engaged in numerous operations each of which may entail different circumstances. Additionally, factors such as the frequent use of snowplows during snowstorms which degrade visibility will be considered later during the development of signal systems since a circumstance such as "frequent usage in snow storms" is

# TABLE 3

(see overview)

# TABLE 3. SPECIAL VEHICLE MESSAGE ANALYSIS

| AGENCY | VEHICLE | OPERATION |
|---|---|---|
| Police | Car/Motorcycle | Emergency/pursuit driving |
| | | Emergency scene activities - on roadway |
| | | Ticketing of motorist |
| | | Roadside vehicle investigation |
| | | Apprehension of motorist |
| Fire/ E.M.S. | Truck/rescue | Emergency driving |
| | E.M.S. Unit/ ambulance | Emergency scene activities - on roadway |
| | | Roadside care/patient loading/fire fighting |
| Post Office | Cars/jeeps | Vehicle moving slowly to deliver mail |
| | | Vehicle stopped to deliver mail |
| Highway/ Roadway Commission | Trucks | Maintenance off right-of-way |
| | | Maintenance on right-of-way |
| | | Merging from median |
| Public/ Private Utility | Trucks | Vehicle moving slowly with traffic to plow/grade/repair |
| Public/ Private Towing | Wrecker | Assisting disabled vehicle |
| | | Towing disabled vehicle |
| | | Accident removal activity |
| | | Travel to accident |
| | | Travel to disabled vehicle |
| Public/ Private School Transportation | Type I Bus | Stopping in right-of-way for loading |
| | Type II Bus (mini-bus) | Stopped in right-of-way for loading |
| | | Stopped off right-of-way for loading |
| | | Stopped off right-of-way |

## TABLE 3. (cont.)

| MISSION | MESSAGE | ACCOMPANYING CONDITIONS | REDUNDANT[1] SYSTEMS | COMMONALITY |
|---|---|---|---|---|
| A | A | 1. High relative velocity of police vehicle | B/C | B |
| B | B | 2. High relative velocity of motorist's veh. | A | B |
| C | C | 3. Frequent heavy traffic hazard. | A | A |
| C | C | 4. Hazard to personnel outside vehicle | A | A |
| E | E | 5. Imitation of law enforcement | D | C |
| A | A | Same as 1 above, limited EMS electrical current | A/B/C | B |
| B | B | Same as 2 above, police vehicle may be present | A | A |
| C | C | Same as 4 above | A | B |
| D | D | 6. Slow moving on/off roadway behavior | A | B |
| C | C | Same as 3 above | A/E | A |
| C | C | 7. No immediate hazard | None | A |
| B | C[2] | Same as 4 above, but personnel on roadway | A | A |
| D | D | 8. High relative velocity of vehicles at 90° | None | B |
| D | D | Same as 6 above | A | B |
| C | C | Same as 3 above | A | A |
| D | D | None | A | A |
| B | C[2] | Police vehicle present | A | A |
| None/A | None/A | Need for extraction apparatus requires message A | None | B |
| None | None | None | None | None |
| F | F | ----- | E | B |
| G (E) | G (E) | Traffic direction/use of other traffic controls | G/E | B |
| G | F/G | Pedestrians Crossing requires message G | G/E | B |
| None | None | Breakdown | A | A |

[1] Not including auxiliary lights near or on the vehicle roof top.

[2] Other mobile lighting shall indicate that a change in direction is required, otherwise a B message would be required. This provision shall protect the uniqueness of message B--Hazard--Vehicle on Right-of-Way for police, fire and ambulance vehicles at emergency scenes that are on a roadway.

## TABLE 4. SUMMARY OF CODE LETTERS:

### MISSIONS

A. EMERGENCY OR PURSUIT
B. ON ROADWAY EMERGENCY SCENE ACTIVITIES
C. ROADSIDE OPERATIONS
D. SLOW VEHICLE OPERATION
E. CITIZEN CONTROL
F. STOPPING FOR LOADING
G. STOPPED FOR LOADING

### MESSAGES

A. CLEAR THE RIGHT-OF-WAY
B. HAZARD--VEHICLE ON RIGHT-OF-WAY
C. VEHICLE PRESENT IN HAZARDOUS LOCATION
D. CAUTION--SLOW MOVING VEHICLE
E. STOP - IMMEDIATELY
F. BE PREPARED TO STOP
G. STOP - DO NOT PASS

### COMMONALITY (UNIQUENESS)

A. MAY BE NORMAL VEHICLE SIGNAL
B. MUST BE A SPECIAL VEHICLE AUXILIARY SIGNAL
C. MUST BE A UNIQUE SPECIAL VEHICLE AUXILIARY SIGNAL

### REDUNDANT CODING SYSTEMS

A. FLASHING WARNING LAMPS
B. FLASHING HIGH BEAMS
C. SIREN
D. SPOTLIGHT
E. BRAKE LAMPS
F. TRIANGULAR SMV EMBLEM (SMV-SLOW MOVING VEHICLE)
G. STOP ARM

obviously not as pertinent to dump trucks as to snow plows, even though both are trucks that are involved in plowing operations.

A listing of redundant systems currently in use is provided in Table 3 along with a commonality rating for each operation. The redundant systems column lists some prevelant redundant signaling systems, which are not high mounted, that influence overall system effectiveness. Also, in cases where this interaction is advantageous or may be designed to be advantageous, it may be wise to specify operation of the redundant system in conjunction with the primary signaling system.

The commonality ratings in Table 3 attempt to determine the level of uniqueness that is considered pertinent to the mission/message combinations. While some messages can possibly be conveyed by a normal vehicle signal alone or in combination with other signals (A), other messages require a special vehicle auxiliary signal which may be shared with other special vehicles and which may be supplemented by a normal vehicle signal (B), and other messages absoulutely require a special vehicle auxiliary signal that is not used in a shared capacity with other special vehicles due to a necessity for unique coding (C). These ratings attempt to determine the general need for signal type, but the specific combination of signals permitted shall reflect various circumstances particular to operation of specific vehicle types.

As discussed in the introduction, the desirable driver response is a function of the vehicular mission. Using different signals to convey messages A-G should allow the driver responses below to be associated with vehicular missions A-G, respectively.

## DRIVER RESPONSES

A. Move out of the path of an approaching vehicle.
B. Proceed slowly and prepare to stop.
C. Observe and avoid vehicle.
D. Pass vehicle with caution.
E. Pull over and stop.
F. Slow down and prepare to stop soon.
G. Stop - do not Pass

# A LOGICAL ANALYSIS OF AMBULANCE SIGNALING NEEDS

Table 1 (page 14) indicated that ambulances undertake three basic operations and that these operations are not only different from those undertaken by other special vehicles, but also involve higher priority missions than some of the other vehicular operations enumerated. The listing of general operations indicated that ambulances engage in high speed, roadway and roadside acitivites. Table 2 (page 16) more clearly defined in broader terms the missions that are essential to operation of emergency medical service ambulances (missions - A, B, C) and also defines the missions that would be required of other special vehicles in order to conduct all the operations listed in Table 1. Ambulances are defined here as having different needs from postal, maintenance, towing, and transportation vehicles. However, it is recognized that their needs to get to the scene of an emergency quickly and to park in the right-of-way in order to obtain the best location from which to load patients or dispense medical treatment are similar in some respects to the needs of fire and police vehicles. Although fire and police vehicles may be engaged in somewhat different operations, they also have needs to get through traffic quickly and to be able to operate from roadway and roadside locations in order to conduct various operations.

Thus, in brief, ambulances do engage in high priority missions and have needs above and beyond those of many other special vehicles. For these reasons, ambulances need signals which are clearly detectable and which communicate their purpose quickly. Just as it seems reasonable to equip an ambulance with lighting systems capable of higher priority messages than vehicles that do not engage in missions of such high importance, it seems reasonable to equip ambulances and other special vehicles with similar signals, if in fact the same driver response is desired in a particular situation, i.e., high speed travel through traffic. The action that other drivers must take for an emergency vehicle to carry out its mission unhindered is considered to be of primary importance.

It is considered desirable to develop a distinct message for "Clear the Right-of-Way" that can be transmitted via light signaling systems. Color and intensity coding have been shown to be capable of allowing signal identification for up to ten signals under laboratory conditions (Halsey and Chapanis, 1951), however, the discriminability of various signals under real world conditions is unknown. Currently, red, white, blue, yellow, and green are used as traffic or special vehicle signaling colors either singly or in combination. Intensity is used at two or more levels to distinguish normal from special vehicles. Combining these parameters and/or using color combinations should allow for development of several signals which can be identified and recognized after detection has taken place. Additionally, considerations such as steady vs. flash and flash pattern can be used to distinguish emergency vehicle signals from traffic signals, normal vehicle signals, school bus signals, etc.

Table 5 shows how the primary missions that ambulances engage in can be associated with particular messages which could be used to communicate specific meanings to drivers and pedestrians. The Clear the Right-of-Way, Hazard--Vehicle on Right-of-Way, and Vehicle Present in Hazardous Location messages assigned to the ambulance missions could offer improved communication if use of these messages was restricted, such that public exposure to the signals conveying these messages was consistent with the need to influence driver behavior. This would entail that only ambulances and other emergency vehicles which actually engage in missions which require similar driver and pedestrian response would be allowed to give signals such as "Clear the Right-of-Way." The redundant signaling systems available for use have been indicated in Table 5 along with mention of some other considerations and requirements which might influence signal design. Because of variances in practices from one locale to

TABLE 5. Summary of Ambulance and Emergency Medical Services Signaling Considerations.

| Specific Operation | General Mission | Signal Messages | Redundant Systems | Other Considerations | Signal Requirements |
|---|---|---|---|---|---|
| Emergency driving to or from accident scene. | A - Emergency | Clear the right-of-way. | Hazard warning lamps/siren, flashing headlights or low mounted front beacons. | High relative velocity of ambulance, limited electrical current because of use of medical equipment. | High effective intensity with high day and night conspicutiy to ensure maximal detection. |
| Emergency scene activities on a roadway involving diagnosis, treatment, and loading of patients. | B - On roadway emergency scene activities. | Hazard-vehicle on right-of-way. | Hazard warning lamps/flashing headlights. | High relative velocity of motorist's vehicle - police vehicle may be present. | Need for a highly effective long distance transmission signal may be superseded by availability of such a signal on other nearby emergency vehicles. |
| Roadside care/ patient loading activities where the emergency vehicle itself is not impeding traffic flow. | C - Roadside operations. | Vehicle present in hazardous location. | Hazard warning lamps/flashing headlights. | Hazard to personnel outside vehicle - other special vehicles may be present. | Vehicles should be adequately marked without use of a signal which conveys a high priority message and which might lead to inappropriate "gawking" or "slowing" behavior. |

another, it cannot be ascertained what redundant systems are actually being used until a survey is conducted that is similar to the Law Enforcement Assistance Administration Police Equipment Survey of 1972 (Klaus and Bunten, 1973).

## CODING PARAMETERS AVAILABLE

Now that the set of appropriate messages has been delimited and the messages determined that are necessary for particular classes of vehicles, the appropriate coding dimensions need to be determined.

The second essential step in developing a message signaling system is to obtain a knowledge of devices in use or available from manufacturers and be familiar with the coding parameter combinations available and the ranges of flash rate, intensity, etc. that are available. Failure to develop equipment familiarity could lead to scientifically accurate, but unrealistic recommendations. To this end, information was sought from major manufacturers and suppliers. A comprehensive listing of equipment manufacturers and suppliers is contained in "The IACP Police Buyer's Guide" which was compiled by the International Association of Chiefs of Police for publication in the October, 1976 issue of the Police Chief magazine. The IACP guide was used in conjunction with articles and advertisements appearing in the Police Chief, and School Bus Fleet magazines[1] to determine and locate sources of lighting equipment. Information on current products, coding parameters, and product superiority was requested from over two dozen pertinent sources; information was assembled from those manufacturers listed in Appendix B. The large number of manufacturers enumerated is indicative of the scope of the signaling specification problem. Each manufacturer has a large number of configurations of various devices available, which with the purchasing options available makes a seemingly infinite array of lighting systems available. These systems are used in various regional jurisdictions because of cost, local and/or regional political considerations, salesmanship persuasion, and confusion regarding device utility. The array of configurations available is too voluminous to present in a compact format, thus an attempt has been made to distill the coding parameters and their values that are available. Thus, Tables 6-11 report the range of values available for various parameters that are used in describing lighting devices; it should be noted that many devices are available which do not specify many parameter values. Note, however, that this

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[1] Emergency Medical Service magazine was also consulted.

compilation is not necessarily exhaustive and was compiled in 1976, thus, it does not include recently developed quartz-halogen sealed beams.

TABLE 6

(see overview)

## TABLE 6

## PARAMETERS IN USE FOR ROTATING LIGHT UNITS

| | |
|---|---|
| Flashes per Minute | 60-90; 70; 80; 90; 100; 115; 120; 135; 150 |
| Number of Bulbs | 1; 2; 3; 4 |
| Type of Bulbs | Tungsten Filaments; Tungsten Sealed Beam |
| Bulb Size | 6" (PAR 46); 5" (PAR 36) |
| Bulb Position | Horizontal; Horizontal/Angled |
| Bulb Voltage | DC: 6; 12; 12.8; 24; 32; 36; 48; 64; 75; 120; 250<br>AC: 24; 110; 120; 240 |
| Amperage | 1.5; 3; 3.25; 3.5; 4; 4.5; 5; 6.2; 6.5; 7; 10; 11; 11.7; 15 |
| Bulb Candlepower | 30; 50; 75; 100 |
| Beam Candlepower[1,2] | 1,350; 3,500; 6,022; 7,500; 8,250; 10,000; 16,750; 33,000; 35,000; 40,000; 50,000; 60,000; 200,000 |
| Dome | Acrylic; Lexan; Polycarbonate |
| Color | Clear; clear white; red; amber; blue; green; split colors |

| Voltage (D.C.) | 6 | 12 | 12 | 12 | 24 | 12 | 12 | 12 |
|---|---|---|---|---|---|---|---|---|
| Amperage No. of bulbs | 6.5/1 | 3.25/1 | 4/2 | 3.5/1 | 1.5/1 | 3.25/1 | 3.5/1 | 4.5/1 |
| Bulb Candlepower | 50 | 50 | 30(w) | 75 | 50 | 50 | 50 | 50 |
| Beam Candlepower[1,2] | 1,350 | 1,350 | 3,500 | 6,022 | 7,500 | 7,500 | 8,250 | 8,250 |

[1] With Clear Dome

[2] Effective Intensity is Usually 5-10% of Peak Intensity.

## TABLE 6 (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Voltage (D.C.) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 24 |
| Amperage No. of bulbs | 7/2 | 11/3 | 15/4 | 6.2/2 | 11.7/4 | 5/2 | 10/4 | 3/2 |
| Bulb Candlepower | -- | -- | -- | -- | -- | -- | -- | -- |
| Beam Candlepower[1,2] | 16,750 | 16,750 | 16,750 | 33,000 | 33,000 | 35,000 | 35,000 | 35,000 |

[1] With Clear Dome

[2] Effective Intensity is Usually 5-10% of Peak Intensity as shown by Howett, Kelly and Pierce's (1978) calculations involving 2 and 4 lamp units.

## TABLE 7

## PARAMETERS IN USE FOR FLASHING INCANDESCENT LIGHT UNITS

| | |
|---|---|
| Flashes per Minute | 60; 65; 75; 80; 90; 60-120 |
| Number of Bulbs | 1; 2; 3; 4 |
| Type of Bulbs | Tungsten Filament; Sealed Beam |
| Bulb Size | 6" (PAR 46) |
| Visibility | $180^0$, $360^0$ |
| Bulb Voltage | DC: 6; 12; 24; 36; 48; 115 |
| Amperage | 1.5; 3; 3.25 |
| Bulb Candlepower | 32; 50 |
| Beam Candlepower[1] | 1,000; 4,000; 10,000; 50,000; 60,000; 75,000 |
| Dome | Fresnel Glass; Fresnel Acrylic; Lexan; Stratolite; Heat Resistant Polymer |
| Color | Clear; Red; Amber; Yellow; Blue; Green |

| | | | |
|---|---|---|---|
| Voltage | 12 | 12 | 24 |
| Amperage No. of bulbs | 3/1 | 3.25/1 | 1.5/1 |
| Bulb Candlepower | 50 | 50 | 50 |
| Beam Camdlepower[1] | 10,000 | 10,000 | 10,000 |

---

[1] With Clear Dome

# TABLE 8

## PARAMETERS IN USE FOR FLASHING STROBE LIGHT UNITS

| | |
|---|---|
| Flashing per Minute | 60-80; 65-75; 75; 80; 90; 100; 120 |
| Type of Bulbs | Sealed Beam; Xenon |
| Bulb Size | PAR 46; PAR 64 |
| Visibility | 180°, 360° |
| Bulb Voltage | DC: 6; 12; 14; 24; 36; 48; 64; 72; 75; 250<br>AC: 110; 115; 120; 220; 240 |
| Amperage | .31; .375; 1.5; 1½-3½; 2; 2.25; 2.5; 3; 4; 4.5; 5.4; 9 |
| Beam Candlepower[1] | 440,000; 500,000; 834,000; 1,000,000; 1,179,000; 1,700,000; 1,760,000; 2,000,000; 2,000,000/4,000,000; 4,000,000; 4,429,000; 6,435,000; 6,604,000; 8,981,000 |
| Dome | Acrylic; Lexan Fresnel; Pyrex Glass |
| Color | Clear; amber; yellow; red; blue; green; split colors |

| | | | | | | |
|---|---|---|---|---|---|---|
| Voltage (D.C.) | 12 | 12 | 120 | 12 | 14 | 14 |
| Amperage (No. of Bulbs) | 2/1 | 4/1 | .375/1 | 4.5/1 | 5.4/2[2] | 9/4[3] |
| Beam Candlepower[1,4] | 500,000 | 834,000 | 834,000 | 834,000 | 834,000 | 834,000 |

| | | | | | |
|---|---|---|---|---|---|
| Voltage (D.C.) | 12 | 13 | 12 | 12 | 12 |
| Amperage (No. of Bulbs) | 2.5/1 | 2.25/1 | 3/1 | 2/1 | 4.5/1 |
| Beam Candlepower[1,4] | 1,000,000 | 1,000,000 | 1,000,000 | 1,000,000 | 1,760,000 |

TABLE 8. (cont.)

| | | | | | |
|---|---|---|---|---|---|
| Voltage (D.C.) | 12 | 14 | 12 | 12.8 | 12.8 |
| Amperage (No. of Bulbs) | 4.5/1 | 5.4/1 | 4/4 | 1½/1 | 3.5/1 |
| Beam Candlepower[1,4] | 1,179,000 | 1,179,000 | 2,000,000 | 2,000,000 | 4,000,000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Voltage (D.C.) | 14 | 14 | 14 | 14 | 14 | 14 |
| Amperage (No. of Bulbs) | 5.4/2[2] | 9/4[3] | 9/4[2] | 9/2[3] | 5.4/1 | 5.4/1 |
| Beam Candlepower[1,4] | 4,429,999 | 4,429,000 | 6,604,000 | 6,604,000 | 6,435,000 | 8,981,000 |

[1] Peak C.P. with Clear Dome

[2] Alternating Flashes

[3] Alternating pair of flashes

[4] Effective Intensity of 1,000,000 candelas peak intensity is approximately 100-1000 candelas, roughly peak intensity times .0003 according to Howett, Kelly and Pierce, 1978.

## TABLE 9

## PARAMETERS IN USE FOR STEADY LIGHT UNITS

| | |
|---|---|
| Number of Bulbs | 1 |
| Type of Bulbs | Sealed Beam; Super Crystal; Dual Filament Spot/Flood, Spot Light; Quartz Flood Light |
| Bulb Size | 5" (PAR 36); 6" (PAR 46), 7" (PAR 56) |
| Sweep | Horizontal: 400°; 450°; Vertical: 70°; 80° |
| Bulb Voltage | DC: 12; 24<br>AC: 120; 125; 130; 208; 240; 277 |
| Beam Candlepower[1] | 1,000; 4,000; 28,000/72,500; 50,000; 75,000; 100,000; 110,000; 200,000; 240,000; 330,000; 10,500 lumens; 33,000 lumens |
| Color | Clear; Red; Blue; Amber |

| | | | |
|---|---|---|---|
| Voltage | 12 | 12 | 24 |
| W | 100/1 | 100 | 330 |
| Beam Candlepower[1] | 100,000 | 240,000 | 330,000 |

[1] With Clear Dome

### TABLE 10

### PARAMETERS IN USE FOR OSCILLATING LIGHT UNITS

| | |
|---|---|
| Bulb Voltage | 6; 12; 14 |
| Range of Horizontal Oscillation | 95° |
| Color | Clear White; Red; Blue; Amber; Green |

### TABLE 11

### PARAMETERS IN USE FOR COMBINATION LIGHT UNITS[1]

| | |
|---|---|
| Bulb Voltage | DC: 6; 12; 24 |
| Amperage | 4; 4½; 6; 10; 12; 17; 18; 22.5 |
| Dome | Polycarbonate; Heat Resistant Polymer |
| Color | Clear; Amber; Blue; Green; Red |

[1] The specifications of the components are included in Tables 6 through 10.

# REVIEW OF PSYCHO-PHYSICAL RESEARCH ON SIGNALING PARAMETER CHARACTERISTICS

Several coding parameters are available and useful. Currently, the primary coding parameters are color and intensity, with color being decidedly the predominant coding dimension. Intensity is used in a secondary role primarily to distinguish normal vehicle signals from those of special vehicles. Thus, development of a coding scheme should concentrate on using color to convey the necessary information. Intensity should be used as a redundant parameter designed to ensure message transmission. Flash rate, flash sequence, light output shape, duty cycle and contrast are other factors affecting perception which should be used as factors in specification of lighting systems to ensure that recommended signals have the level of detectability and conspicuity commensurate with message importance.

To determine the operating characteristics of signals to convey the messages delineated in the previous chapters, it is necessary to consider pertinent literature which might bear upon the visual conspicuity of vehicular lighting signals. Thus, an extensive literature review was undertaken to determine what evidence is at hand that would be useful in determining the advantages and disadvantages of use of various colors in different situations. Little applied research has been done on coding parameters using real world conditions, thus, this review necessarily includes a great deal of basic perceptual research.

Because purported facts from the basic visual perception literature are often used to support various notions about conspicuity, it was felt that a summary of that research was indispensable to a discussion of conspicuity. Therefore, a literature review section entitled "Review of Research on Color and Intensity Perception" was prepared by Dr. Michael Sivak. This section is followed by one entitled "Review of Methodological and Conceptual Problems in Applied Conspicuity Research." The latter section seeks to examine various problems in applied research and review-research involving measures of effectiveness and conspicuity. These sections were prepared to provide a common ground of visual and conspicuity literature. They are followed by a section entitled "Overview of Literature Review" which attempts to put these reviews into perspective.

# REVIEW OF RESEARCH ON COLOR AND INTENSITY PERCEPTION

MICHAEL SIVAK

## Color Perception

Hue (color) is one of the subjective dimensions of a colored light, the others being brightness and saturation. To the first approximation the hue of an object depends on the wavelength distribution of the light emitted or reflected by the object, brightness on the intensity, and saturation on the excitation purity, where wavelength, intensity (luminance) and excitation purity are physical dimensions of light. In terms of wavelength of the light, the visible spectrum corresponds approximately to wavelengths from 400-700 nm (Marriott, 1976b). The color names of the spectrum are approximately as follows (Marriott, 1976b):

Violet: 400-440 nm
Blue: 440-500 nm
Green: 500-570 nm
Yellow: 570-590 nm
Orange: 590-610 nm
Red: 610-700 nm

The human visual system does not respond to all wavelengths in the same manner. There is substantial evidence that the absolute visual threshold as well as threshold for perception of color vary depending on the wavelength of the light. There is some evidence indicating that the consistency of suprathreshold color identification, localization, conspicuity, and reaction time to colored lights changes according to the dominant wavelength of the light. Furthermore, it is well established that color-defective and older people have problems with certain wavelengths. These and other aspects of spectral sensitivity of human visual system have substantial bearing on the effectiveness of emergency and warning lights and will now be discussed in more detail.

### Detection Thresholds

The lowest luminance (intensity) thresholds are for peripheral as opposed to foveal stimuli (Pirenne, 1967) since the rods, abundant in the periphery, are more light sensitive than cones, which are the receptors in the fovea (Oesterberg, 1935).

For peripheral stimuli the luminance threshold (dark adapted, rod threshold) is lowest for bluish-green wavelengths around 505 nm (Kinney, 1955, 1958; Wald, 1945; Walters and Wright, 1943). The sensitivity declines as the wavelengths either increase or decrease away from 505 nm (blue-green) as shown in Figure 1.1. At 400 nm (violet) the sensitivity declines by about 2 1/4 log units from the maximum value; at 700 nm (deep red) by approximately 5 log units. That means that 700 nm light has to be approximately 100,000 times more intense to be seen than 505 nm light.

For foveal stimuli the luminance threshold (light adapted, cone threshold) is lowest for green wavelengths around 555 nm (Kinney, 1958; Sperling & Hsia, 1957; Wald, 1945) as shown in Figure 1.1. This shift of peak sensitivity by about 50 nm (from the peak of the dark-adapted sensitivity) into the green region of the spectrum is called the Purkinje effect. As could be seen from Figure 1.1., the foveal sensitivity declines with either an increase or a decrease of the stimulus wavelength away from the peak sensitivity at 555 nm.

From Figure 1.1 it can be seen that if the wavelength of the stimulus flash is approximately 650 nm or longer, the dark adapted sensitivity is not better than the light adapted sensitivity. However, if the wavelength of the stimulus flash is less than 650 nm, the dark adapted rod (peripheral) sensitivity is higher than the light adapted cone (foveal) sensitivity (i.e., the dark adapted threshold is lower).

The practical implications of the threshold measurements for the driving situations are, however, limited. First, the peripheral (rod) threshold data is rather irrelevant, since it is obtained under dark-adapted, scotopic conditions. Most of the driving, however, is done under photopic or mesopic conditions (Cole, 1972; Schmidt, 1966; Projector & Cook, 1972). Second, the foveal (cone) threshold data are of limited value because of the small size of the fovea in comparison to the size of the periphery. The fovea occupies only about 1-2$^{o}$ of

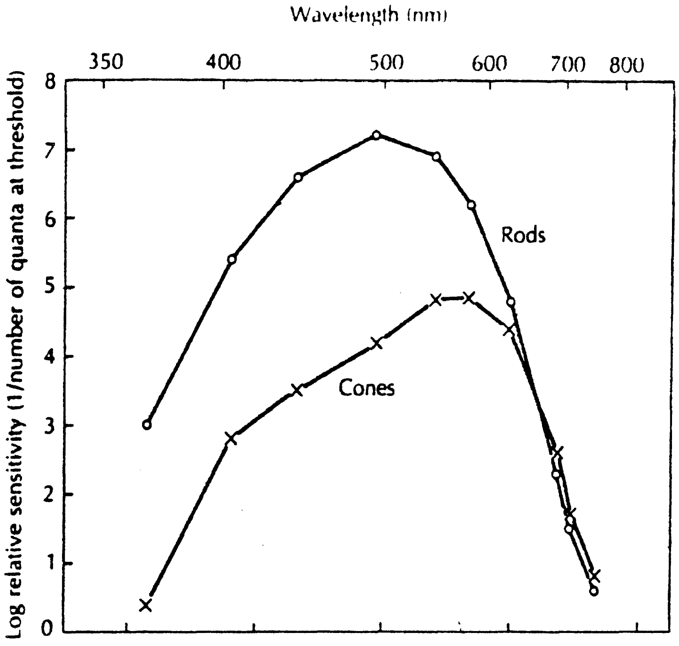

Figure 1.1. Photopic (day/cone) and scotopic (night/rod) spectral sensitivity curves. [After Cornsweet (1970), based on data from Wald (1945)].

the visual field (Polyak, 1941) while the periphery occupies the remainder of the visual field which extends to about 175-180° in the horizontal meridian and 100-120° in the vertical meridian (Burg, 1968; Connolly, 1966; Schmidt, 1966). The relatively small size of the fovea makes it thus unlikely that a randomly located target will fall on the fovea.

Suprathreshold Effectiveness

Suprathreshold determinations of the "effectiveness" of various wavelength is more valuable for practical purposes than threshold measurements. The effectiveness of a given color, however, can be defined in various ways. Several possible measures of suprathreshold effectiveness, namely brightness, reaction time, localization, color perception thresholds and consistency, and conspicuity will now be briefly discussed.

A. Brightness. Chapanis and Halsey (1955) have investigated the luminance of various equally bright colored lights.[1] The results indicate that for the small stimuli tested (18' of visual angle) red lights (610-670 nm) need the least amount of luminance to achieve a given low level of brightness, while saturated yellow lights (570-585 nm) need the most luminance. (The degree of dark-adaptation was not specified in this report.) Middleton and Gottfried (1957) tested a series of colors for the brightness as point sources (.5' of visual angle) at levels about 20 times the foveal threshold against a dark background (the intensity of the various colors was approximately the same). Middleton and Gottfried found deep red to be perceived as being the most bright color, while they found some greens and some blues to be perceived as the least bright colors. This finding is not necessarily contradictory with Figure 1.1 which shows that the eye is less sensitive to red than to green at threshold since the perceived brightness in Middleton and Gottfried study was measured at suprathreshold levels.

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[1] Luminance and intensity are objective measures of the quantity of light emitted or reflected by an object, while brightness is a subjective impression of the light emitted or reflected.

Several attempts were made to quantify the differences in the brightness of various colors. The Committee on Motor Vehicle (Exterior) Lighting (CMVL, 1964) reports the ratio of the effectiveness of red, yellow, and white signals to be 1:3:5 in terms of candlepower. However, it is not clear whether the brightness was indeed the measure of effectiveness, nor whether the ratio applies to daytime and/or nighttime.

Kilgour (1960) evaluated the signal effectiveness "under the more or less average sunshine conditions of Michigan and under high-intensity sunlight and high-contrast conditions of Arizona (p. 95)." On the basis of these tests Kilgour recommends candlepower ratios of 1:3:5 for red, amber, and white colors of vehicle lamps and signals. However, Kilgour does not specify how he defined the measured effectiveness.

A University of California at Berkely report (UCB, 1968) provides effectiveness ratios of 1:2:2.5:4 for red, green, amber, and white signals (p. 52). Fisher (1969) reviewed the data of Adrian (1963), Jainski and Schmidt-Clausen (1967), and Rutley et al. (1965), covering a range of day, night, and laboratory conditions and recommends the intensities of red, green, yellow light signals to be 1:1.6:3.

Mortimer (1970) provides luminance ratios for equivalent brightness of signals presented against a light background in a simulation of the visual aspects of the driving task. For the daytime, the ratio of greenish-blue, red, amber, and white is .85:1:2.58:5.28; for nighttime .53:1.00:1.22:1.86. Mortimer's daytime data is in good agreement with those of the CMVL (1964), the UCB (1968) and Kilgour (1960). Fisher's extrapolation agrees with Mortimer's daytime data except for the color green which Mortimer's extensive study found to be more effective than red.

B. Reaction Time. Reaction time to the onset of lights is another measure used to evaluate the effectiveness of colored lights. Allen, Strickland, and Adams (1967) investigated the reaction time to lights projected onto a movie of 50-65 mph highway traffic. The subject saw the scene as if he were driving the camera car. The subject was instructed to count the number of approaching cars and to push a button if a test light appeared superimposed in the right roadway area of the picture. Allen et al. (1967) have shown that for lights of equal luminance, the reaction time was fastest for red targets. Reaction times to amber and green targets were second and third fastest, respectively, while white targets produced longest reaction times. However, these differences disappeared, when the lights were matched for subjective brightness (as opposed to physical luminance). Connors (1975a) investigated reaction times to lights of various colors in a search paradigm, in which dark adapted subjects searched for targets amidst a simulated star background. The apparent brightness of the differently colored lights was equated. The results indicate that the reaction time was shortest for blue targets. Green targets were second most "effective," followed by white and yellow targets. The red targets resulted in the longest reaction times.

Post (1975) investigated reaction time to red and amber automobile signals of typical automotive design which incorporated a 1:2.5 daytime luminance ratio via selected intensities of 110 candlepower for red and 275 candlepower for yellow (for a 12.56 sq. inch lamp). Post found that shorter response times were elicited for turn and hazard signals when the flashing lamps were amber, rather than red. This effect was caused primarily by large significant RT differences to the different colors in the nighttime hazard mode which were probably determined by the brightness difference between the colors at night. The number of undetected signals was not significantly different for red and amber signals in the daytime but fewer amber signals went undetected at night, probably due to their higher brightness.

C. Spatial Localization. Veridical spatial localization is another important parameter of effectiveness of colored lights, since several studies indicate that the perceived distance of targets varies with their color (Allen, 1964; Kishto, 1968; Mount et al., 1955; Zajac, 1953). Allen (1964) reports a tendency to overestimate the distance of red lights, to underestimate the distance of blue lights, and to estimate correctly the distance of green lights. Contradictory results were obtained by Zajac (1953) who argues that "objects are seen as nearer with longer-wave-lengths and as farther away with shorter wave-lengths of light (p. 144)." Mount et al. found that in comparison to grey paper stimuli, the colored ones were perceived in front of their nearest brightness-matched grays. The comparisons between the various colors on perception of distance is not very informative, since the colors varied in their reflectance. However, it isn't clear from Allen (1964) nor Zajac (1953) either, whether they equated for luminance or brightness of their stimuli.

### D. Color - Perception Thresholds and Consistency of Color Naming.

For a given color to be an efficient carrier of meaning, its color perception threshold should be low and the reliability of the color perception should be high. Connors (1968) addressed the question of the minimum luminance necessary for the foveal perception of red, green, and blue when the dark-adapted observer knew in advance the hue of interest. The results indicate that red is generally perceived at lower luminances than blue or green. In a subsequent experiment (Connors, 1969) dark-adapted subjects were required to identify the color of the fovealy presented stimuli. The red color (642 nm) required the least amount of luminance, followed by yellow (584 nm), green (521 nm) and blue (468 nm). Furthermore, the red color gave most reliable responses and fewest confusions in the hue identification. Hill (1947) investigated the color recognition threshold for a range of colors. Dark-adapted subjects viewed point-source targets against a dark background. The results indicate that the red light needed the least amount of luminance for correct color identification, while yellow light required the highest level of luminance. Walraven (1962)[2] investigated the consistency of giving a certain flash a certain color name, as a function of the wavelength of the flash. Walraven found that for both the color-threshold intensities and 4x the color-threshold intensities the reliability of color naming was highest for red color (approximately 700 nm). The green color (500-520 nm) was the second best, followed by blue (470 nm) and yellow (570-590 nm). At low light intensities color identification becomes poor. With very low intensities a light might be detected but there is no color sensation. Thus, the intensity of the light has to be increased above absolute threshold level to obtain veridical color perception. The intensity interval between the absolute threshold of light and the level at which the color can be recognized is known as the photochromatic interval (Marriott, 1972c) or achromatic zone (Bouman and Walraven, 1972). This interval is narrowest for deep red and widest for yellow (Walraven, 1962). Furthermore, for the red color (700 nm) incorrect color names were never given even if the light intensity was from the photochromatic interval--observers reported either red or no hue. On the other hand, yellow was often mistaken for red, green, or white (Walraven, 1962).

E. Conspicuity. Conspicuity or attention-getting quality is another important measure of the effectiveness of a colored light. Allen (1966) argues that the (peripheral) conspicuity of lights depends on the apparent brightness and not on the color of the light. However, as Connors (1975a) has shown, even when the apparent (foveal) brightness of the differently colored lights is equated, there are still residual differences in the conspicuity of colors. In this study, dark adapted subjects searched for a point source targets seen against a star background (luminance 0.034 ml) simulating a cockpit task. While searching for target lights, the subject was simultaneously engaged in an auxiliary mental task. The results of the search task indicate that for equally bright lights, red lights

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[2] Walraven (1962) cited by Bouman and Walraven (1972).

were missed more frequently than targets of other hues. Detection rates for the yellow, white, green, and blue targets were not statistically different from each other. (The brightness level of the targets was not specified.)

F. Glare Resistance. Rutley et al. (1965), cited by Fisher (1969), investigated the threshold levels of discomfort glare from traffic signals. The results indicate that the threshold glare level is about 1.5-3 times higher for a yellow than for green or red lights, which is useful since it has been pointed out above that the intensity requirements for yellow lights are greater than for green or red lights. However, the increase in the threshold of discomfort glare for yellow vs. red light is in the same range as the necessary increase in the intensity of a yellow light to be perceived as bright as a red light, negating the glare-resistant advantage of a yellow light.

### Peripheral Color Vision

Since the number of color-sensitive cones decreases with increase in the retinal eccentricity (Oesterberg, 1935), it is not surprising that color perception deteriorates with increase in the peripheral eccentricity (Boynton et al., 1964; Gilbert, 1950; Moreland, 1972; Moreland and Cruz, 1958; Weale, 1951, 1953a, 1953b, 1956; Weissman, 1955; Weitzman and Kinney, 1969). According to Boynton et al. (1964), "color-naming at 0 degrees differs little from that at 20 degrees, but a marked deterioration of performance occurs between 20 and 40 degrees (p. 666)." All stimuli subtended $3^o$ and were presented at 1000 trolands. The dark adapted subject viewed the targets against a dark visual field. The decrement in performance was manifested by a reduction in red and especially large decrement in green responses. Also, reliability of the responses decreased with increasing eccentricity--remaining quite high for red and blue response categories but dropping substantially for the green response category. Boynton et al. (1964) used relatively large stimuli ($3^o$) with relatively long exposure durations (300 msec). As Weitzman and

Kinney (1969) have shown, with smaller-sized targets and/or shorter durations there is a substantial decrement in color vision already at $5^{0}$ of retinal eccentricity. The decrement is evident primarily by the reduced number of green and yellow responses, while blue and red responses are least affected.

## Abnormal Color Vision

Approximately 8% of the male population (Cole, 1972; Marriott, 1976a; Projector and Cook, 1972; Shirley and Gauthier, 1966) and .4% of the female population (Marriott, 1976a) have defective color vision. As Projector and Cook (1972) have pointed out, "human vision has innumerable defects, ... some of consequence in driving, and some irrelevant or negligibly small in effect (p. 140)." Two types of color defectives are of particular interest to traffic engineers: protanopes and deuteranopes, representing 1% and 1.5% of males, respectively (Cole, 1972). These people are likely to confuse red, yellow, and green (Cole, 1972; Heath and Schmidt, 1959; Marriott, 1976a; Nathan, Henry, and Cole, 1964),while they name blue the most consistently (Heath & Smith, 1959; Shirley & Gauthier, 1966). Furthermore, protanopes (and protanomalous--an additional 1% of the male population, according to Cole, 1972)--have substantially reduced sensitivity for red lights (Cole, 1972; International Commission on Illumination, 1975; Cole and Brown, 1966; Marriott, 1976a). Deuteranomalous observers, constituting the largest group of color abnormals (5% of males and .4% of females, according to Cole, 1972) have spectral sensitivity similar to that of normals (Cole, 1972; Marriott, 1976a). However, their ability to discriminate among colors varies. Deuteranomalous observers may discriminate as many colors as normals or they may have the same problems as deuteranopes (Cole, 1972).

## Effects of Aging

Older people provide additional restrictions on the selection of optimal color for emergency lights. Because of the physiological changes in the eye due to the aging process (i.e., smaller pupil diameter, yellowing of the lens) there is a 2 1/2- to 3- fold decrease of light reaching the retina as one ages from 20 to 60 years of age (Weale, 1961; Crouch, 1945) and 3 1/2- fold decrease of retinal luminance from 20 to 80 years of age (Crouch, 1945). This consideration has an effect primarily on the recommended intensity levels of lights. However, the yellowing of the lens with age also leads to selective loss of sensitivity in the short-wavelength range of the specturm. As a result, older people become less sensitive to greens and blues than to yellows and reds in comparison to younger people (Crawford, 1949). However, Projector and Cook (1972) argue that the decrement is small and confined primarily to very short wavelengths.

Summary and Conclusions

The main findings discussed above will be now summarized in a tabular form, listing the best and the worst colors (based on not always consistent findings) in respect to the specific dimensions evaluated.

| | Best | Worst |
|---|---|---|
| Absolute Threshold | | |
| Peripheral | bluish-green | red |
| Foveal | green | red |
| Effectiveness | | |
| brightness | red | white, yellow |
| reaction time (equal luminance) | red | green, white |
| reaction time (equal brightness) | blue | red |
| localization | contradictory data | |
| color perception threshold | red | yellow, blue |
| conspicuity | little available data | |
| glare resistance | yellow | -- |
| Peripheral color vision | blue, red | green, yellow |
| Abnormal color vision | blue | red |
| Effects of Aging | red, yellow | green, blue |

On the basis of the above review what would be the "best" color for use on emergency and special service vehicles? The decision is not a unanimous one. The green color seems to be best for absolute-threshold measurements. However, as discussed above, the absolute-threshold detection data are rather irrelevant to driving. The blue color results in fastest reaction times (given equal brightness), seems to give least amount of problems to color-defective people, and leads to relatively efficient identification in peripheral vision. The red color is the optimal color on five dimensions: apparent brightness, reaction time (given equal luminance), color-perception threshold, peripheral color vision, and aging effects. (There is not much data available on conspicuity of colors.) If the driving population did not contain color-defective people, red would be the obvious color of choice. Overall, red probably still remains the optimal color. For the benefit of color-defectives, the use of a red light of adequate intensity and/or a supplemental light of another color would be desirable.

In respect to discriminability of colors, Eriksen and Hake (1955) reported that approximately eight different colors are discriminable without error when the task is absolute identification of the color. That means that it is possible to use colors for coding purposes of up to about eight categories (under optimal conditions). Halsey and Chapanis (1951) obtained 97.5% correct judgments using ten different colors. However, the colors used varied in luminance as well. Therefore, as Halsey and Chapanis (1951) have pointed out, it is possible that the luminance differences served as additional cues for distinguishing the colors. This would inflate the obtained number of identifiable colors. The UCB report (1968) recommends using color only as a secondary (redundant) coding dimension, while the basic lighting system should be color independent, since "no color-coded system is suitable for all drivers or driving conditions (p. 140)." More recently, Van Cott and Kinkade (1972) estimate ten as the maximum and three as the recommended number of colored lights for coding purposes (p. 69).

## Intensity Perception

Luminance (intensity) of a signaling/emergency light has an effect on various behavioral indicators. The following discussion shall briefly cover the effect of luminance on size threshold, manual reaction time, eye movement latency, preference/conspicuity, and glare.

A. Luminance and Size Threshold. There is a substantial body of research indicating that increasing the luminance of a target decreases its size threshold and vice versa. There is no general agreement about the precise nature of the trade-off between these two parameters. However, for stimuli smaller than $1^{0}$ of visual angle the relationship area x luminance ≐ constant provides a satisfactory fit to the results of several studies (Brown, 1947; Graham and Bartlett, 1939; Graham, Brown, and Mote, 1939). This reciprocal relationship between luminance and area is known as Ricco's law. For stimuli between $1^{0}$ and $10^{0}$, the best fit is provided by so-called Piper's law which states that $\sqrt{\text{area}} \times \text{luminance} = \text{constant}$ (Baumgardt, 1959; Graham, Brown, and Mote, 1939).

Lash and Prideaux (1943) provide a nomogram from which one can determine the minimum perceptible intensity given the observation distance and the diameter of the circular target area. However, this table is for white light only, seen against a dark background for a dark-adapted observer.

Cole (1972) presents a nomogram for determining the optimal intensity of a red traffic signal light given signal range and background luminance. For example, given a desirable signal range of 500 m and the background luminance of $10^{4}$ cd/$m^{2}$ (high photopic region), the optimal intensity of a red signal light is 200 cd. Fischer (1969) argues that the signal intensities recommended by Cole should be doubled "to take into account the whole driver and vehicle population (p. 47)."

The peripheral eccentricity has an additional effect on the luminance threshold. In photopic and mesopic conditions, the fovea is the most sensitive region of the retina, since the luminance threshold is lowest in the fovea (Aulhorn, 1964). In scotopic conditions the peak sensitivity is obtained at about $15^0$-$20^0$ in the temporal periphery (Aulhorn, 1964; Pirenne, 1967).[1] The scotopic sensitivity decreases as the eccentricity increases from $20^0$ (Aulhorn, 1964; Leibowitz and Appelle, 1969; Middleton and Wyszecki, 1961; Rumar, 1974). However, as several authors have pointed out (Cole, 1972; Projector and Cook, 1972; Schmidt, 1966) most of the driving is done under photopic or mesopic conditions. Therefore it can be concluded that in the driving situations the luminance threshold is lowest at the fovea and luminance sensitivity decreases with increase in the retinal eccentricity. Fisher (1971)[2] provides data which indicate that if the signal is presented at a peripheral angle $\theta$, signal intensity $I_\theta$ for 95 percent probability of seeing is given by the relation $I_\theta = I_0\theta^{4/3}$. (Peripheral stimuli have an additional disadvantage since the reaction time increases as the peripheral eccentricity of the target increases [Kobrick, 1971]).

B. Manual Reaction Time. The psychophysical relationship between stimulus intensity and reaction time (RT) of a manual response has been examined in several studies. Already Cattell (1886) and Froeberg (1907) have shown that the greater the intensity of the light, the shorter the time of the reaction.

Bartlett and MacLeod (1954) investigated simple RT to stimuli of various luminances both in the fovea and the periphery. RT was measured from the onset of a signal flash to the manual release of a microswitch. With dark-adapted subjects RT decreased with increase in luminance for both the foveal and the peripheral presentations. Over the luminance range of 4 log units there was a decrease in RT of

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[1] The nasal peripheral sensitivity reflects the sensitivity of the temporal periphery except for the presence of a blind spot at the nasal periphery at around $15^0$ which contains no light receptors and is therefore functionally blind (Brown, 1965).

[2] Fisher (1971) cited by Cole (1972).

approximately .4 sec. which represents a difference of 32 feet of stopping distance at an initial speed of 55 miles per hour. Dim flashes yielded shorter RTs if presented in the periphery, while bright flashes yielded shorter RTs if presented in the fovea. The luminance of the background was another parameter in this study. The results indicate that for both the foveal and the peripheral stimuli the RT increased with an increase in the background luminance. In other words, with a decrease in the contrast between the signal and the background there was an increase in the RT.

Connors (1975b) examined the effect of luminance of targets on detection and reaction time. The point-source targets were seen against a simulated star background. The targets appeared at random intervals anywhere within a $40^0$ x $35^0$ field of view, while the subject was occupied by an auxiliary mental task. The results indicate that RT decreased (and target detection increased) with increased target intensity.

In an investigation of the optimum intensity of red traffic signal lights, Cole and Brown (1966) measured the RT to 8 in. diameter signals, viewed from 100 m against a simulated sky. With an increase in the luminance of the signal light there was a decrease in the RT (and in errors) eventually reaching an asymptotic value, whether or not the subject was involved in a secondary tracking task. For a sky having a luminance of about 1500 ft-L the optimum intensity was shown to be at least 83 cd and preferably 133 cd; for a sky of luminance 30,000 ft-L the optimum was determined to be 160-260 cd. These values are for red lights and for normal observers, while protanopes required 3 to 4 times the optimal intensity for normal observers.

C. Speed of the Initiation of the Eye Movements. Wheeless, Cohen and Boynton (1967) investigated luminance and contrast of stimuli as parameters of the eye-movement control system. The dependent variable was the saccadic reaction time of dark-adapted subjects to a $6^0$ horizontal step displacement of a central $1/2^0$ target spot. The saccadic reaction time was defined as the time elapsing between an unpredictable target displacement and the beginning of the subsequent saccadic eye movement. The results show the saccadic reaction time decreases with increase in the target luminance. With the background luminance set at zero (providing infinite contrast) the average saccadic reaction time decreased "from about 610 msec at a target luminance of 1.5 log units below foveal threshold, to about 240 msec at a luminance of 2.0 log units above foveal threshold (p. 395). The saccadic reaction time was also investigated as a function of a finite fixed contrast. Again, an increase in target luminance resulted in a decrease in the saccadic reaction time. Namely, an increase of 1.5 log units in the target luminance resulted in about 140 msec decrease in the saccadic reaction time.

D. Preference/conspicuity. In a choice-response experiment where the subject is asked to respond to any one of two simultaneously presented stimuli, Berlyne (1950) have found that subjects are more likely to choose the brighter stimulus. McDonnell (1970) studied the role of albedo (intensity) and contrast in a similar paradigm as the one used by Berlyne (1950). In this study the subject was instructed to respond to any one of four stimuli. The results indicate that subjects most often choose the stimulus of the highest contrast. In the event of equal contrast, the stimulus with the highest intensity was chosen most frequently.

E. Glare. Glare occurs if the luminance of a light close to the line of sight is substantially above the luminance of the background. The magnitude of glare can be evaluated either in terms of a subjective impression of discomfort or annoyance (discomfort glare) or in terms of a decrement in visual performance (disability glare). Schmidt (1966) argues that "all disability glare is also discomfort glare, but glare can cause discomfort without impairing visual functions" (p. 12). On the other hand, there is some evidence (Mortimer and Olson, 1974) that disability glare can occur without discomfort glare. They report that mean high beam glare responses occurred at approximately 1200-1500 ft. (depending on lateral separation), even though, visibility curves for studies 1-4 show that disability glare was evidenced at 3000 ft. by shorter visibility distances than occur shortly after the vehicle meeting point. There have been several attempts at quantification of the conditions for the prevention of glare. For example, Schmidt (1966) recommends that to avoid discomfort glare the difference between the luminance of the background and the glare source should be less than 2 log units. Hartmann (1963) has computed the just tolerable illuminances without disability glare for different glare angles and different road (background) illuminances. Whether any type of glare should be avoided is an open question. It can be argued that emergency lights creating discomfort glare (but not disability) glare would be better at attracting attention and thereby would be more effective than lights not creating any type of glare. Furthermore, since emergency lights are not frequently encountered, there is little need to protect the eye from occasional discomfort.

F. Summary and Conclusions. From the above discussion it is clear that the more intense the light is, the more effective it is on all dimensions evaluated with the possible exception of the glare problem associated with high luminance differences between the light and the background. In addition, high signal to background contrast was shown to lead to reduced reaction time and contrast was also shown to be a greater determinant of preference of one stimulus over another, than was intensity. Therefore, it is recommended that an emergency signaling light should have as high an intensity and contrast as is cost-effective, as long as the resulting luminance differences between the light and its background do not create disability glare. Because of reduced visual sensitivity in the periphery, where most detection of emergency warning lights occurs (Howett, Kelly and Pierce, 1978), intensities greater than those derived from studies involving foveal viewing may be necessary to provide adequate signals.

# REVIEW OF METHODOLOGICAL AND CONCEPTUAL PROBLEMS IN APPLIED CONSPICUITY RESEARCH

Among the few relevant applied research studies available, are two basic types of studies. There are signaling parameter studies involving balanced parametric experiments which were designed to provide information on signal coding and transmission by measuring perceptual effects by varying one parameter at a time. Another type of study is the comparison study where different signaling units are evaluated or where one unit is modified to measure the perceptual effect of one parameter without rigorous control of other parameters;

Many parametric studies of "signal" effect were done to evaluate automotive rear lighting systems (see, for example, a recent literature review by Sivak, 1978). These studies tend to have several major limitations which reduces the potential for information transfer from these studies to the emergency vehicle signaling problem. First, they tend to have a very limited range of parameter values. For example, Mortimer (1973) evaluates signal intensities over the range of 80 to 1000 candlepower (cp), even though his previous work (1970) showed that 6000 cp would be required for amber to reach a 85% percentile level of subjective adequacy. Second, these studies tend to be conducted under unrealistic conditions, including static foveal viewing conditions without distractions as per Mortimer's (1973) evaluation of signal recognition. Third, because the studies primarily involved automotive lighting many of them present signal location and contrast situations representative of rear lighting on a vehicle. In such cases the lights have a more or less constant background and contrast, mainly with the vehicle itself. However, in emergency vehicle signaling the units are often roof mounted where they are seen against relatively light backgrounds which are extremely varying. Last, these studies have tended to concentrate ~~on~~ detection and recognition under ideal conditions of viewing and attention as opposed to conspicuity. The ability of a light signal to elicit a response under dynamic real world conditions is a more proper measure of its conspicuity.

The "comparison" studies include studies done by the California Highway Patrol (1971, 1973a, 1973b, 1974) Muhler and Berkhout (1976), Berkhout (1977), Rumar (1974) and Hörberg and Rumar (1975). This type of study also has several limitations. First, they tend to be limited in their scope of parameters tested since they usually evaluate several whole lighting units. The units are not usually chosen to present a full range of values on any one coding dimension such as intensity. This severely limits the possibility of generalizing from the units tested to other available units and other potential designs. Second, these studies tend to use behavioral measures which may or may not be appropriate to the reality of the situation. For example, a behavioral measure used in the California Highway Patrol studies (i.e., frequency of vehicle lane changing away from a special vehicle with warning lights operating) show that some lighting units lead to increased vehicle lane changing away from the special vehicle. Whether or not this is an appropriate and desirable response to detection of a special vehicle with signals operating is unclear. Such a driver response may in fact cause a hazardous situation by increasing the frequency of motorist maneuvers and vehicle congestion, rather than cause a safer situation by moving vehicles away from an emergency vehicle. Similarly, the Muhler and Berkhout (1976) study used a viewing range of several miles to assess the daytime optimum distance visibility of emergency vehicle lighting devices. However, urban conditions with multiple competing stimuli would seem to be likely to be associated with emergency vehicle accidents more than situations involving unlimited undistracted visibility. It is questionable whether any extrapolation can be made from results in these conditions to pre-crash conditions where over 1/4 mile detection would seem to provide more than adequate distance for accident avoidance. In fact, Muhler and Berkhout (1975) state that:

> "It should be noted that all the systems tested in this study could be considered acceptable for emergency vehicle use since absolute line-of-sight visibility exceeded one mile for all observers on their poorest single trials for any light. The choice of some system over another cannot be made exclusively on the basis of optimum distance visibility, however. Conspicuity against a variety of backgrounds, freedom from obstruction, and the transmission of information concerning vehicle direction and rate of travel must also be considered. The lights identified as having the longest distance thresholds in this study would not necessarily excel (sic) in these other dimensions as well."

Third, even studies which use appropriate behavioral measures may be compromised by conducting the experiments in artificial, usually ideal, conditions. For example, Berkhout (1977) measured direction and speed judgments of subjects in order to extract data about information transfer from various light signaling systems. While these behavioral measures are of importance even Berkhout cautions:

> "Also, it must be emphasized that the lights were observed against a featureless dark background, and their conspicuity against complex backgrounds was not tested."

Last, in comparison studies the results are also often "confounded," in that the cause of a perceptual effect cannot be ascertained as several parameters vary simultaneously. For example, Rumar (1974) confounded color and intensity so that any difference in measured effectiveness is an effect of both parameters acting simultaneously. Rumar, in fact, states "...differences between the three beacons cannot be directly referred to colour alone. This is a limitation that concerns the whole study."

The Hörberg and Rumar (1975) study of running lights is a good example of consideration of the limitations of applied perceptual research discussed above. They have dealt in a reasonable manner with each of these considerations; however, although the results provide insight into peripheral visual detection, color was not an important variable in this study and thus, its implications for emergency vehicle signaling are limited.

Perhaps, the best example of consideration of the limitations of applied perceptual research is contained in NBS Special Publication 480-16 "Emergency Vehicle Warning Lights: State of the Art." This review of relevant research and practical considerations for visual signaling by G. Howett, K. Kelly and T. Pierce of the National Bureau of Standards Law Enforcement Standards Laboratory (U.S. Department of Commerce) was prepared for the Law Enforcement Assistance Administration (U.S. Department of Justice) and is in press. Both the style and content of this report are ideally suited to persons wishing to obtain a knowledge of various aspects of emergency vehicle warning lights. Since this comprehensive report details with both what we know and what we do not know about real world light detection, it behooves persons interested in the present problem of signaling and specification to read the report to understand our basic ignorance of the perceptual processes about which we must be informed in order to develop fully adequate specifications. For these reasons the author hereby encourages anyone interested in signaling specification to read the NBS report since it covers all areas, except the area of signal coding and driver response which is a primary consideration of this DOT report. Thus, the two reports are complementary in scope. Since understanding of the NBS report will enhance an understanding of the DOT report and the problem areas which make the specification process extremely difficult, the reader is provided an abstract in Appendix C in hopes that this inducement will result in wide readership of the NBS report. The NBS report concludes, in part, that there are many gaps in our knowledge of the processes of visual conspicutiy, and that much research needs to be conducted to ensure that we understand the mechanisms of conspicuity.

## OVERVIEW OF LITERATURE REVIEW

In general, the literature review concluded that little applicable data exists regarding the conspicuity of various lighting parameters. Furthermore, most of the basic research data on detection involves the use of shuttered light with 50% on time. The relevance of much basic research is uncertain since most flashing signal applications involve more complex waveforms such as those provided by incandescent flash, strobe, and rotating incandescent lamps. Additionally, the focus of basic research on dark adapted visual threshold determinations may preclude extrapolation of much of our knowledge about vision to typical everyday situations. For example, recent work on visibility being conducted in Australia by B. Cole has indicated that "conspicuity is not directly related to threshold visibility" (Australian Road Research Board, Annual Report 1976-1977). The work conducted by Cole has shown that there is a difference between whether an object can be seen (which is determined by its threshold visibility) and whether it is actually seen. For an object to be actually seen would require that it be conspicuous enough to elicit the visual attention of the observer. Previous research has also to a large extent ignored complex and changing visual background conditions, so that studies with uniform and steady backgrounds predominate the literature, even though, they are of little use in design of vehicle signaling systems.

Perception of signals other than traffic control devices is considered to involve numerous problems. As recently discussed by Hopkins and Holmstrom (1976):

> "The signals at highway intersections generally are referred to as traffic control devices. It is reasonable to assume that motorists generally perceive that an intersection is ahead, that a hazard exists, and that it is prudent to determine whether either active or passive traffic control devices are present.... None of these factors can be assumed at a grade crossing. The presence of a railroad-highway intersection may not be noted until it is quite close, and the situation may be understood poorly.... Thus the function of

> active warnings in this application goes well beyond the normal, informative, traffic control purpose and must include alerting the motorist to a potentially hazardous situation that requires careful attention. In other words, for grade-crossing flashing lights merely to inform vehicle operators that a train is present (or soon will be ) is not sufficient they also must ensure, insofar as possible, that they are first seen."

If a railroad-highway intersection "may not be noted until it is quite close" and "may be understood poorly," consider the perceptual problem posed by the need to respond to an emergency vehicle signal. In the latter case, there is no standardized signal, signal configuration, recognizable structure, mounting location, or typical direction of approach to indicate the potential source of a light signal. It is precisely because of these situational differences that traffic signal data, such as the intensity recommendations of Cole and Brown (1966) cannot be validly applied to emergency vehicle signal lighting.

The meeting of a driver and an emergency vehicle, obviously, occurs under much more diverse circumstances than does the meeting of a driver and a train. The difficulties of perception of an emergency vehicle signal have been adequately discussed by Howett, Kelley, and Pierce (1978) and thus will not be elaborated upon here.

In attempting to increase conspicuity it must be kept in mind that present perceptual research data are not necessarily valid for the lighting conspicuity problem. However, some data may be useful if one is cognizant of the experimental limitations and their effect on the data. Thus, a fruitful step to take at this time is to analyze the characteristics of visual signal parameters which may influence the conspicuity of signal lights. This is done in the next chapter where physical limitations of signal production, research data, and directly applied literature are analyzed to determine their implications for the problem of designing conspicuous signal lights.

## ANALYSIS OF SIGNALING PARAMETER CHARACTERISTICS

It is much more difficult to produce an effective visual daytime signal than a nighttime visual signal due to the lowered contrast, the effect of sunlight on the perceived brightness of colors, and the number of diversity of competing stimuli.

Major current constraints on producing an effective daytime visual signal are lamp output and color production, and the psychophysical effects of intensity and color. In attempting to resolve these issues we are faced with two basic questions. (1) How does color affect the perceived effectiveness of a daytime visual signal? (2) How much intensity would be required to produce an adequate daytime visual signal? Let us look at the effect of color first, since it is of primary interest to many users of signaling systems and because the choice of color will influence the intensity needed from particular light sources.

The following tables concerning the effect of color took the physical and perceptual influence of color into account simultaneously so that the combined effect of light production constraints and visual sensitivity could be ascertained. Note that the earlier chapter on color and intensity perception only sought to clarify the perceptual aspects of vision and did not take into the physical limitations inherent in real world color production.

### Color

Table 12 was derived from several sources to demonstrate the physical limitations and perceptual effects of various color filters which have been used to produce light signals. The relative physical light output data was derived from the transmissivity information which was acquired from various sources as explained in footnote 1. The transmissivity data in column 1 show that contemporary filters of different colors transmit different proportions of the light incident upon them. Because of this, a green-blue light will have much less physical intensity than a red light produced by the same incandescent

## TABLE 12

### Relative Subjective Daytime Effectiveness of Various Colors Produced by an Incandescent Source

| Filter Specification | Color | Incandescent Trans-missivity[1] | Relative Physical Light Output[2] | Relative Subjective $DP_c$ Factor[3] | Relative Subjective Daytime Effectiveness[4] |
|---|---|---|---|---|---|
| SAE | White | .90* | 4.50 | .189 | .85 |
| SAE | Red | .20* | 1.00 | 1.000 | 1.00 |
| SAE | Yellow | .50* | 2.50 | .388 | .97 |
| Mortimer (1970) | Green-Blue | .09*** | .45 | 1.176 | .53 |
| N.B.S. (1978) | Pale Blue | .06** | .30 | .189-1.176 | .06-.35 |
| CIE (1975) | Blue | .03* | .15 | 1.176-1.5 est. | .18-.23 |

[1] transmittance value obtained as per asterisk code as follows:

* transmittance of typical plastic filter (N.B.S. Special Publication 480-16, 1978);

** transmittance of typical plastic filter (personal communication, G. Howett, National Bureau of Standards, Feb. 28, 1978); and

*** author's measurement of plastic filter used in a study reported by Mortimer (1970).

[2] Physical light output relative to red (i.e., column 1 ÷ the transmittance of red, .20) for signals produced by the same incandescent source.

[3] These "daytime perception as influenced by color" ($DP_c$) values were computed by the author to provide a multiplicative factor which takes into account the daytime effect of color on the subjective judgment of signal effectiveness, i.e., adequacy. They are reciprocals of the luminance ratios reported by Mortimer (1970). The white, red, yellow, and green-blue data exhibit a trend with higher $DP_c$ values being associated with colors having wavelengths near the ends of the visible spectrum. Thus, it is assumed that CIE blue will have a higher $DP_c$ value than green-blue, since CIE blue is even closer to the long wavelength end of the visible spectrum; a maximum $DP_c$ of 1.5 was estimated based upon the green-blue and red values. Since pale blue is located at a point between a saturated blue wavelength locus on the CIE curve and the white region of the CIE diagram, it is reasonable to assume that pale blue will have a $DP_c$ value between that for other more saturated blues and white.

[4] Subjective daytime effectiveness relative to red (i.e., column 2 x column 3 ÷ the product for red, 1.00) for signals produced by the same incandescent source.

bulb, while yellow and white lights will be 2.5 and 4.5 times as intense as the red light as shown by the relative physical light output values in column 2. On this basis a white light is superior, however, this does not mean that a white light is a more effective signal; it only means that a light output measuring instrument will record a higher number for white than for the other colors.

The relative subjective daytime effectiveness data was derived from the luminance ratios of equal criterion response for various colors as reported by Mortimer (1970). Mortimer's subjective signal adequacy data appears to be the most pertinent data available concerning color effects in daylight at supra-threshold signal conditions. A recent study by Ramsey and Brinkley (1977) found that emergency lighting devices which were given high subjective ratings for noticeability were also associated with increased looking behavior and remembrance of a test vehicle by naive subjects. Since Ramsey and Brinkley found an association between subjective response and observed behavior and since such an association seems reasonable and no contradictory evidence is apparent, it is reasonable to assume that signals found to be more subjectively adequate by Mortimer (1970) would also be more capable of eliciting looking behavior. In addition, they would be more likely to be remembered as having been noticed. Since it is desirable to have an emergency signal elicit looking behavior and be noticed and remembered, Mortimer's data can guide us in choosing more noticeable signal parameters. Those color and intensity combinations deemed "adequate...certainly attention attracting" by Mortimer's subjects should be more noticeable than signals which were of a lower intensity than was required for a given color to elicit this response.

Thus, Mortimer's luminance ratios were used to compute a relative daytime perception as influenced by color ($DP_c$) value (column 3) which is the multiplicative factor needed to account for the fact that different colors required different intensities to be judged equally adequate as daytime signals. The white $DP_c$ value implies that the intensity that produced an adequate red signal was only

18.9% of the intensity required for white to be judged adequate. Thus, a white signal would have to be over 5 times as intense as a red one to be judged equally adequate. Source intensity can thus compensate for the relative inefficiency of a color to produce an adequate signal. Therefore, if one multiplies the relative efficiency of producing a given color with a given source (e.g., the relative intensity) by the relative efficiency of that color to produce an adequate signal ($DP_C$), one can ascertain the overall relative perceptual effectiveness of a given color. Column 4 of Table 4 presents such overall effectiveness values obtained for each color relative to red. These were obtained by multiplying the relative intensity of that color available from the same incandescent lamp (column 2) by the relative efficiency of that color to produce an adequately intense signal (column 3).

These values show that when subjective daytime effectiveness is used as the criterion (currently, objective daytime conspicuity data do not exist), that white, red, and yellow are nearly equally effective when produced by the same incandescent lamp. Also, white, red, and yellow are in common usage for good reason since they are all much more subjectively effective than the various blues evaluated. The currently used pale blue is only 1/3 (or less) as subjectively effective as white, red, and yellow signals produced by the same incandescent lamp. A better blue for signaling would be the CIE blue (CIE Publication No. 2.2 (TC-1.6) 1975), but this would render blue no more effective as per our criteria, due to severely restricted transmittance for this filter. Note, that while a change from blue to pale blue would approximately double the transmissivity of the filter and thus, would make a given light unit twice as intense (physically), it would also decrease the relative $DP_C$ factor which takes subjective perception into account. The net effect of these changes is that no increase in relative subjective daytime effectiveness is obtained. It is not plausable to opt for using a filter that is more in the green region to obtain a higher daytime effectiveness, as color naming and recognition problems resulting from color confusion will occur in this region (CIE 1975, Mortimer et al., 1973). Thus, any use of incandescent blue must be accompanied by white, red, or yellow to ensure signal effectiveness in applications where it is critical that the signal be effective.

Table 13 exhibits data for xenon based light sources in the same format as the preceding table. The transmittance of red is lower and for the blues is higher than was the case with incandescent lamp. The relative physical light output has approximately doubled for CIE blue and green-blue while the pale blue value has essentially trebled. This is the reason why many people believe that using a strobe source greatly increases the effectiveness of a blue signal. However, we have not shown that its effectiveness has increased, only that its intensity relative to red has increased.

The values in Table 13 show that when subjective daytime effectiveness is used as the criterion (currently, objective daytime conspicuity data do not exist), that white and yellow are about equally effective when produced by the same strobe flash tube. Yellow or white strobes should be better than red due to a significant decrease in red transmittance, which is caused by the lower red wavelength generation of xenon strobe flash tubes compared with incandescent sources. Although CIE blue is near the color locus of the best signal blue, its effectiveness using the adopted daytime criterion is quite low relative to red. Even though its relative effectiveness is increased by use of a xenon strobe source, it is still only about 1/2 as effective as red. Although the green-blue for a strobe source appears effective here it is a relatively poor signal becuase of color confusion in this color region (CIE 1975, Mortimer et al., 1973) and thus, should not be seriously considered as a viable signal. The pale blue has a tabulated relative subjective daytime effectiveness value of between .17 and 1.08. The relative daytime subjective effectiveness could be nearly as low as .17 since the paler the blue becomes, the closer the $DP_C$ value should move from its value somewhere below the 1.176 for green-blue toward

## TABLE 13

### Relative Subjective Daytime Effectiveness of Various Colors Produced by a Xenon[5] Source

| Filter Specification | Color | Xenon Trans-missivity[1] | Relative Physical Light Output[2] | Relative Subjective $DP_c$ Factor[3] | Relative Subjective Daytime Effectiveness[4] |
|---|---|---|---|---|---|
| SAE | White | .90* | 6.92 | .189 | 1.30 |
| SAE | Red | .13* | 1.00 | 1.000 | 1.00 |
| SAE | Yellow | .40* | 3.08 | .388 | 1.19 |
| Mortimer (1970) | Green-Blue | .12-.15*** | .92-1.15 | 1.176 | 1.08-1.35 |
| N.B.S. (1978) | Pale Blue | .12** | .92 | .189-1.176 | .17-1.08 |
| CIE (1975) | Blue | .05* | .35 | 1.176-1.5 est. | .41-.52 |

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[1] transmittance value obtained as per asterisk code as follows:

- * transmittance of typical plastic filter (N.B.S. Special Publication 480-16, 1978);
- ** transmittance of typical plastic filter (personal communication, G. Howett, National Bureau of Standards, Feb. 28, 1978); and
- *** author's estimate based on incandescent to strobe transmittance increases of 33% and 66% for green and CIE blue respectively (N.B.S., 1978).

[2] Physical light output relative to red (i.e., column 1 ÷ the transmittance of red, .13) for signals produced by the same xenon source.

[3] These "daytime perception as influenced by color" ($DP_c$) values were computed by the author to provide a multiplicative factor which takes into account the daytime effect of color on the subjective judgment of signal effectiveness, i.e., adequacy. They are reciprocals of the luminance ratios reported by Mortimer (1970). The white, red, yellow, and green-blue data exhibit a trend with higher $DP_c$ values being associated with colors having wavelengths near the ends of the visible spectrum. Thus, it is assumed that CIE blue will have a higher $DP_c$ value than green-blue, since CIE blue is even closer to the long wavelength end of the visible spectrum; a maximum $DP_c$ of 1.5 was estimated based upon the green-blue and red values. Since pale blue is located at a point between a saturated blue wavelength locus on the CIE curve and the white region of the CIE diagram, it is reasonable to assume that pale blue will have a $DP_c$ value between that for other more saturated blues and white.

[4] Subjective daytime effectiveness relative to red (i.e., column 2 x column 3 ÷ the product for red, 1.00) for signals produced by the same xenon source.

[5] Xenon sources produce a different spectral distribution than incandescent sources and are commonly used in flash tubes and "strobe" lights.

.189, which is the $DP_C$ value for white. The author believes that until research is done on $DP_C$ values for pale blue, that it is reasonable to assume that the relative subjective daytime effectiveness for stroboscopically generated pale blue lies somewhere between .17 and 1.08 and is probably considerably below the values for white, red, and yellow which are 1.00 or greater.

The pale blue generated by filtering an incandescent lamp was computed to have a daytime subjective effectiveness far below the values for white, red, and yellow which were all approximately 1.00. Further quantification that pale blue is less effective than other common signal colors is provided by data derived from informal tests of flashing emergency warning lamps conducted by the SAE Signaling and Marking Devices Subcommittee. These tests are reported in the minutes of the November 1977 meeting of that group. Additional data are contained in the minutes of the November 1978 meeting. Rooftop mounted SAE signal blue was found to require from 2.85 to 1.5 times as much candlepower as red to be judged as equally effective under bright daylight conditions. Thus, the luminance ratio of signal blue to red for equal effect varied from 2.85 to 1.5. Note, that this is equivalent to saying that the DPc value for signal blue, which is a pale blue of approximately 12% transmittance, is between .35 and .67, since the DPc value is the reciprocal of the luminance ratio needed for a color to be judged equally effective as red. Since the signal blue transmittance is .12, the relative incandescent physical light output of signal blue can be computed to be .60 (see Table 12, footnote 2). Furthermore, the relative subjective daytime effectiveness of incandescent SAE signal blue can be calculated (as per footnote 4) to be .21-.40. This agrees quite closely with the value of .06-.35 for relative daytime subjective effectiveness in Table 12 which was derived from Mortimer's 1970 study.

Furthermore, Mortimer (1970) reported luminance ratios of .85 for green-blue and 5.28 for white, while the November 1978 SAE test produced values of .77 for restricted blue and 5.5 for white. Thus, it appears that the test differences between backgrounds and flashing versus steady lights had little affect on the luminance ratios required to produce equally effective signals of these colors. The test agreement on green-blue/restricted blue, white, and the derived values for pale or signal blue shows that Mortimer's 1970 paradigm produced luminance ratio values that are applicable to rooftop mounting of flashing warning lamps. The conclusion that various blues including pale blue have not been shown to be effective daytime colors is supported by the SAE tests and has been extended to cover signal blue, which, although an improvement over CIE blue, is still less effective than white, red and yellow.

Using the DPc value for signal blue derived from the SAE data, the estimated relative subjective daytime effectiveness for signal blue produced by a stroboscopic flash tube can be computed. As in Table 13, transmissivity will be estimated to increase by 33-66% for strobe light sources; thus, the estimated transmittance will be .16 to .20. This means than the relative physical light output will be 1.23-1.54. Multiplying these values by the DPc values of .35-.67 results in an approximate relative subjective daytime effectiveness value of .43-1.03. Although signal blue appears to be an improvement over the pale blue in Table 13, it still seems likely that its daytime subjective effectiveness, even with a strobe flash tube source, is considerably below that of white, red and yellow signals produced by the same source.

Since pale blue is considered to have a much lower relative daytime subjective effectiveness than white, red, and yellow for both incandescent and strobe lamps, it would be unwise to use pale blue as a primary signal color. Since an foreseeable standard will possible allow either incandescent or strobe light sources as long as other criteria are met, pale blue should be considered an undesirable signal since it has problems of both daytime effectiveness and color confusion for both lamp types. Until a minimally adequate blue signal for color recognition is found that can be produced with a filter capable of producing a reasonably high relative subjective daytime effectiveness, blue should only be considered for use as a supplementary signal or as a non-critical signal.

One step toward development of such a signal has been taken by T. Kent and H.V. Hutchens and is reported in Technical Memorandum No. 22/75 published under Crown Copyright by the home office, Police Scientific Development Branch in the United Kingdom. They report that a newly specified pale blue (filter no. 11) with a transmission of 15% performed well subjectively in bright overcast daytime conditions using alerted observers. They found pale blue filter 11 elicited significantly ($\alpha \leq .05$) longer detection and recognition distances than a DIN standard blue filter of 5% transmission and a Lucas standard blue filter of 1% transmission. The authors argue that, "This makes the adoption of the No. 11 filter highly desirable." They also report that subjective evaluations by police officers concluded that "improved performance" was obtained with the new filters.

It must be noted that the "improved performance" was reported relative to the very saturated low transmittance blue in common usage in England. Therefore, the new filters were associated with an increased light intensity output which would make it easy for them to be rated as "improved." Also, the tests trial beacons that reportedly performed well in daylight used 55 watt quartz halogen bulbs which probably had a much greater light output than conventional tungsten bulbs. Furthermore, it was never determined whether the new beacons gave <u>adequate</u> conspicuity, only that the conspicuity of blue appeared to be improved. There was no comparison which attempted to show how blue beacons would fare relative to other colors.

One comparison study which attempted to do that was done by Rumar (1974). His studies showed that even dark blue beacons cause nighttime discomfort and are poorly visible in bright daylight conditions. Use of a lighter blue improved visiblity in daylight somewhat. However, both light and dark blue were associated with color identification difficulties especially in bright sunshine. In daylight a red rotating beacon was judged as appearing twice as bright as the dark blue rotating beacon and over 50% brighter than a light blue rotating beacon. Similarly, the daytime perceived warning effect was greater for the red rotating beacon than either of the blue rotating beacons by similar margins. No significant difference was observed via evaluation of a flashing light blue instead of a rotating light blue in these daytime tests. In darkness, estimates of brightness and warning effect were very similar across the colors discussed here. However, discomfort from beacons observed both directly and indirectly was rated as several times worse for flashing blues than for rotating red beacons. Although rotating blue beacons were not as bad in this regard as the flashing blue beacons, they were still at least twice as discomforting as the rotating red beacons. Similarly, Mortimer (1970) reported that intensities for steady green-blue signal lights had to be approximately one-half of those of red for equal glare discomfort.

Another comparison study (Berkhout, 1977) evaluated nighttime estimation of direction of travel and speed for single beacons, alternating twin beacons, and dual complex beacons. He found that "red lights were generally superior to blue" and "the expected nighttime advantage of blue lights was not observed." In addition, the use of alternating side to side lamps, where one side has a blue beacon and the other side was red beacon, generated considerable confusion as to the vehicles direction of travel (approaching or receding), especially when moving at the "fast" speed. Observers mentioned that the blue light appeared dimmer than the red light making it hard to perceive that the lights were attached to the same vehicle. The blue light was often perceived as an independent light that was further away than the red light.

A subjective study conducted by Castle (1974) for the FAA showed that red was preferred over blue for subjective conspicuity and that a unit with twin red beacons was rated highest in terms of distance estimation and motion detection. This twin red unit ranked just below one with one red and one blue beacon on measures of subjective conspicuity. Although this bicolor red and blue signal was shown to be rated as the most conspicuous by Castle, his observers did not rate the bicolor red and blue signal as high as the twin red beacon signal on distance estimation and motion detection. Berkhout (1977) showed that this same bicolor unit tended to create problems of estimation of direction of travel and distance.

Neither the Kent and Hutchins (1975), the Rumar (1974), nor the Berkhout (1977) comparison study presented any compelling evidence that the use of blue is advantageous. To the contrary, although Kent and Hutchins (1975) showed that pale blue leads to improved performance over standard Lucas blue and DIN blue, numerous perceptual disadvantages relative to other colors were reported by Rumar (1974) for both dark and pale blue signal lights. Similarly, Berkhout (1977) found that blue lights and blue and red combination lights failed to perform as well as red signal lights. Thus, at the present time, evidence indicates that blue should only be used as a supplementary or non-critical signal.

Differential visual sensitivity to various colors can also be applied to the problem of color selection. Present data indicates that the relative visual threshold sensitivities for the colors being investigated varies as is shown in Figure 1.1 (page 46). Note that the figure was based on the threshold sensitivity of specific monochromatic wavelengths. For example, the wavelengths of 660,570 and 470 nanometers can be associated with the following colors--red, yellow and blue, respectively (Jameson and Hurvich, 1972). This sensitivity data indicates that a 470 nanometer (nm) blue light requires less energy to see via rod (scotopic) vision than either a 620 nm (pale)

660 nm (deep) red light. Since the periphery contains mainly rods (Pirenne, 1967) this is often used as an arguement for blue lights. However, Devoe and Abernathy (1975) report that "For increased detection of warning lights in the peripheral visual field, it would seem that color spectral bands for which the periphery is most sensitive should be used. The peripheral region from 25 to 40 degrees from the fovea is most sensitive to narrow spectral bands of first red, then successively, yellow, green, and blue (Marks, 1966, p. 335)." Thus, there is some discrepancy between various reports of peripheral sensitivity to colors in the red and blue regions of the visual spectrum. Additionally, the cones are more sensitive than the rods until after about seven minutes of dark adaptation (Cornsweet, 1970) and are used to give color vision. Under daylight or mesopic (night driving) visual conditions the cones are in use and wavelenths of approximately 620 nm red used for various signal reds (Hopkins and White, 1977) are at least as detectable via the cones as blue wavelengths in the 470-485 nm region.

The information presented in Tables 12 and 13 was based on broadband wavelength color filters which transmitted wavelengths both higher and lower than those given for the colors above. For examples of the broadband transmittance of color filters see Mortimer (1970, page 58), and Hopkins and White (1977, page 23). Thus, detection of signals produced by these filters would not necessarily depend solely on the sensitivity of the eye to any specific wavelength. Detection could perhaps be viewed as the detectability of the most easily detectable wavelength passed by these filters. However, whether this is, in fact, the case hasn't been determined. Furthermore the threshold sensitivity values are all derived from responses to specific wavelengths presented to the dark adapted eye against a black background. Even the photopic curve was measured after five minutes of dark adaptation, (when the cones are fully dark adapted) with maximum contrast monochromatic stimuli (Cornsweet, 1970). To use spectral sensitivity data, the inference must be made that suprathreshold signals will be responded to in a similar manner as signals presented at the threshold of detection. Furthermore, it requires the assumption that there is no difference between responding to signals on a dark background versus a light or varied background. It would appear tenuous to extrapolate from sensitivity under these conditions to real world day and night detectability. Furthermore, after a review of visual luminous efficiency and spectral sensitivity literature, Howett, Kelly, and Pierce (1978) concluded that "The fundamental point that needs to be stressed here is that the conditions applying to the perception of emergency-vehicle warning lights at a distance include peripheral vision and small areas, and we do not really know in detail what the sensitivity of the eye is under those conditions." Research is needed to clarify these issues before we proceed in drawing inferences from visual spectral sensitivity information. In the meantime it may be best to rely upon actual visual observations under the relevant viewing conditions.

The conclusion that blue should not be used as a primary critical signal at the present time is in disagreement with recommendations of The Committee on Ambulance Design Criteria which are contained in "Ambulance Design Criteria" published by the U.S. Department of Transportation, NHTSA, first edition May 1971, revised January 1973. The author believes that this discrepancy was caused by several factors. First, the interim years have provided additional published data and time to assimilate its importance. Also, National Bureau of Standards personnel have assessed the signal color problem and provided unpublished information which may not have been available to the committee. Second, a review of the hardware constraints on producing adequate signals ensured that wavelength generation and filter transmittance factors were considered. Third, a thorough review of the issue of light signal effectiveness versus human eye sensitivity lead to the conclusion that it appears tenuous to make extrapolations from dark adapted visual threshold detection data on specific wavelengths to the light adapted conspicuity of broadband wavelength light signals. Last, there was no predisposition to find a unique signal for an ambulance vehicle. However, the goal of providing a nationally efficient movement of an ambulance through traffic via a "Clear the Right-of-Way" signal is in agreement with the committee's goals. Furthermore, it is agreed that the primary ambulance signal should be in restricted use, so that an ambulance is not mistaken for other vehicles with lower priority missions which are allowed to display signals similar or identical to those now on ambulances.

## Intensity

In depth analyses similar to the one above on color needs to be conducted to determine intensity requirements more clearly than what is indicated in the literature review. While the literature review showed that intensity was a significant variable affecting detection and that increased intensity is needed for conditions of increased ambient illumination (daylight), the precise nature of determining how much intensity would be adequate for vehicular signaling under real world viewing conditions was not clarified by the literature review.

While the intensity value needed for a conspicuous signal is unknown, present flashing lamps are only required at the H-V test point to produce a minimum of 300 candlepower (cp) red light by SAE J595b. Although, this requires light intensity above the minimum 80 cp required of red brake lamps at H-V by SAE J586c, it is only half of that required for school bus red signal lamps by SAE J887 which requires a minimum 600 cp. SAE J845 recommends 200 cp or more for red beacons. Clearly, emergency warning lamps should be more intense than school bus lamps since they have to be detected and recognized while moving at high rates of speed against a non-uniform background.

Measurements made at HSRI (1970) revealed that for steady red lamps to be rated as bright enough to be considered as adequate brake signals (under daylight relatively high background luminance conditions) required approximately 2000-4000 cp for lamp areas of 12.6 to 37.8 square inches to reach a 85%tile adequancy criteria (Mortimer 1970, Table 2.9). A PAR 46 5.75 inch diameter lamp has an area of 26.0 square inches. According to Industrial Testing Laboratories test report 91228, such a lamp mounted in an emergency vehicle signal housing has an effective luminous area of approximately 34 square inches which is a 31 percent increase in effective luminous area. Assuming this increase to hold for PAR 36 lamps of 15.9 $in^2$ area, gives an effective luminous area of 20.8 square inches. A red lamp intensity of approximately 3000 cp would be required to be deemed adequately bright (at the 85%tile level) for luminous areas of 20.8 to 34 square inches (Mortimer, 1970, Figure 2.6); this is the effective luminous area range of PAR 36 and 46 lamps.

Thus, although approximately 3,000 candlepower (cp) seems necessary to produce an adequate steady red vehicular signal of PAR 36 or 46 size under reasonably rigorous conditions, the current SAE standards require emergency warning lamps only 1/10 or less this intense. Lamps minimally meeting the SAE J595b standard would be perceived as approximately 1/2 as bright (Forbes, 1966) as those reported adequate as attention attracting brake signals by Mortimer (1970).

While similar experiments have not been done on the brightness and intensity of emergency vehicle lamps and surrounds, the best estimate that can be made at the present time is that emergency lights should be <u>at least</u> as intense as <u>adequate</u> vehicular signals, e.g., the equivalent of a 3000 cp red light for PAR 36 and 46 lamps.

Note, that this recommendation is based on data for a steady (non-flashing) light. Thus, this should be considered a requirement for 3000 "effective candlepower." This would require a flashing light to have the same signal effectiveness as a red fixed (steady) light of 3000 candlepower. For flashing light units this would require "...calculation of the *effective intensity*, which ideally is the intensity of a fixed light of the same color that produces the same visual effect for the eye as does the flashing light. *Effective intensity* is a particularly useful concept at <u>low levels</u> of illumination at the eye. Any measure of effective intensity of flashing lights must be related to the viewing condition, and the use of the concept should be avoided at high levels of illumination (Illuminating Engineering Society, 1964)." The concept of effective intensity was created to account for the fact that "at near threshold levels, the visual effect depends upon the flash length and the shape of the illumination profile (illumination as a function of time)."

Support for the need for lights with high effective intensities for motorist warning can be found in Hopkins and Newfell (1975). They state that "Both theoretical considerations (Hopkins, 1973) and experimental observations (Hopkins, 1974) indicate that for day use, with margin for severe conditions, effective intensities as great as 4000 candela are desirable (references added)." They further quantify this by stating that the peak candlepower of strobe lights is not adequate as a means of characterizing light intensity since "The eye responds not to an instantaneous brightness, which may last for only microseconds, but to the total light energy received over a time of the order of .1 second - a long period compared to the duration of the flash. Meaningful specification must therefore be in terms of some form of the "effective intensity" concept...."

As summarized by Howett, Kelly, and Pierce (1978):

> "It is important to note that the conditions under which emergency-vehicle warning lights are viewed frequently depart in every particular from those to which the BRD formula (Blondel-Rey-Douglas equation for effective intensity) is thought to apply, and almost always differ from the latter in at least one respect. In the emergency-vehicle warning-light situations of greatest interest (detection), viewing is peripheral rather than foveal; the background is usually spotted with other lights at night and in the daytime may be dazzlingly bright, rather than totally dark; noticing of the signal rarely occurs when it is anywhere near the dimness characterizing dark-background thresholds; and, because the increase of the brightness of an approaching emergency-vehicle warning signal is accompanied by an increase of the angle subtended by the light source at the target driver's eye, detection often takes place when the light is no longer a perceptual point source, but has a visible disk. Moreover, in the classical Blondel-Rey situation, the viewer knows the lights are out there and is looking for them, often in an at least approximately known direction; while, in contrast, a driver is rarely expecting the approach of an emergency

> vehicle, is usually concentrating on other matters, and is obliged to monitor a fairly wide cone of directions that may cover a full 180° at intersections. Some day, undoubtedly very far into the future, sufficient psychophysical data may have been collected to permit the "constant" $a$ in the BRD formula to be replaced by a function of all the relevant viewing variables, so that realistic estimates of equivalent steady-light intensity can be made regardless of viewing conditions. At the present time, however, it is not even known whether the basic form of the BRD equation applies to viewing conditions departing as drastically from the Blondel-Rey situation as those associated with the detection of emergency-vehicle warning lights (underlining added for emphasis); the problem of calculating equivalent intensity for purposes of peripheral conspicuity may go beyond merely finding an appropriate value for $a$. In the meantime, there is no obvious practical alternative to BRD effective intensity as a quantitative specification of the luminous output of a flashing light, and Eq. (10.6-4) is commonly used -- because it is an agreed-upon formal measure -- even when it is known that the flashing light being described will be used under conditions to which the value of $a=0.2$ does not apply, and to which even the basic form of the equation may not apply.
>
> Another basic assumption underlying all the various forms of the Blondel-Rey equation is that it is sufficient to deal with the temporal profile of a single flash; that is, it is assumed that the flash rate is slow enough that the visual effectiveness of each flash is not significantly influenced by earlier or later flashes. With brief flashes (under a hundredth of a second) and long dark intervals between flashes (several tenths of a second), the assumption is probably justified. When the flash duration becomes extended and the dark period shortened, significant interactions between flashes may arise and the BRD formula may give inaccurate predictions.... It would appear reasonable to expect that a more widely valid formula for effective intensity might be based on the temporal profile of a complete cycle, including both the light and dark phases. Unfortunately, no all-inclusive formula of that kind has yet been developed."

Since effective intensity is the only widely accepted concept for quantifying the effectiveness of a flashing light, it must be recommended that it continue to be used to estimate the perceptual effect of various factors which influence the duration of flashes of visual light until an alternative is found. Fortunately, discussions with G. Howett at the National Bureau of Standards (NBS) have revealed that recent work there suggests that the calculated effective intensity of flashing lights also correlates well with observer's impressions of the conspicuity of the lights observed peripherally in the daytime.

Unfortunately, measurements at the National Bureau of Standards (1978) have revealed that few revolving beacon lamp systems in use produce over 3,000 effective candlepower of white light or (about 600 effective candlepower of red light). Thus, any attempt to raise output toward 3,000 effective candlepower of red via use of brighter quartz halogen bulbs, longer flash durations, wider beam spreads or increased number of lamps per turntable will require design of new lamp systems and near total replacement of older less effective systems. However, requiring the following minimum effective candlepowers would eliminate usage of bulbs substantially less intense than the more intense units measured by the National Bureau of Standards while at the same time requiring filters that can produce a relatively high subjective daytime effectiveness:

SAE White - 3,000
SAE Red - 600
SAE Yellow - 1,500
CIE Blue - 400-500
SAE Signal Blue - 1,700

These numbers were derived by rounding off the product of the 600 effective candlepower red that is available times the reciprocal of the relative $DP_C$ factor (the reciprocal of $DP_C$ is the luminance ratio). The DPC values were taken from Table 12, except for signal blue whose value of .35 was derived from the SAE data of Oyler (1977). Recent SAE tests indicate that the luminance ratio for signal blue may be somewhat lower (SAE, November 1978). The above values of effective intensity candlepower would produce nearly equally subjectively adequate signals. Note that the blue minimum is probably impossible to achieve by filtering white light sources typically found on emergency vehicles due to the low transmittance of the blue portion of the spectrum. Even advanced filters would be of little help as blue has a very low theoretical maximum possible luminous transmittance when illuminated by a standard source A ($2854^0$ K) tungsten source (Merick, 1971).

Recent tests have indicated that for effective signal recognition of a $360^0$ emergency warning lamp "...approximately 7500 cd... in red is necessary in the daytime (Oyler, 1977)." This is in contrast to the present SAE J845 specification of 200 minimum candlepower at H-V in red. Note, that the signal blue equivalent of a 7500 cd red is approximately 15,000 candlepower because of the signal blue to red daytime equal effectiveness ratio of 1.5-2.85/1 discussed earlier. Given the low transmittance of signal blue, this would require an extremely high intensity bulb of 125,000 candlepower. Unless adequate bulbs of this intensity are available, signal blue and other blues should not be used as unicolor rotating beacons. Note that the values reported by Oyler are for candlepower, not effective candlepower. If a rotating beacon produced 90 flashes per minute with 2 lamps (as did the SAE $360^0$ test beacon) and contained bulbs with a beam spread similar to #4416 bulbs which are in common usage according to Howett, Kelly and Pierce (1978), it would have a flash duration of .0167 seconds. The bulbs would have to be 37,500 peak candlepower, to produce the 7500 candlepower red signal found necessary in the static 1977 SAE observations and would have an effective intensity of 4.4% of peak intensity or 330 effective candlepower (see Howett, Kelly and Pierce, 1978, page 115-116 for mathematical relationships). Using 4 similar lamps instead of two would give an effective intensity of 8.1% of peak intensity or 608 effective candlepower which would be more appropriate for dynamic viewing of red lamps which will be subject to intensity reductions due to dust and dirt accumulations. Other ways of increasing the effective intensity would be to increase the beam spread and/or to increase the bulb intensity.

On/off flashing lamps do not have a suprathreshold signal effectiveness that is predicted by the Bondel-Rey "effective intensity" formula according to Naus's chapter in "The Perception and Application of Flashing Lights" (1971). He suggests that "Any light flashing longer than 0.15 second, not including incandescent time, should be considered steady burning and assigned the same intensity as a steady light."

For effectiveness as an adequate on/off flashing signal, as judged by 80% of the SAE observers, Oyler (1977) has stated that "500 candlepower in red is necessary in the daytime." This is in contrast to the present SAE J595b specification of 300 minimum candlepower at H-V in red for flashing warning lamps. Furthermore, 1400 cd minimum at H-V was recommended for SAE signal blue "...to overcome, as far as possible the extreme tendency of blue to fade out in bright sunlight. For improved effectiveness blue, if used, should not be used exclusively, but with a signal of another color (Oyler, 1977)."

Thus, it appears that both the current SAE recommended practice of J845 "360 Deg Emergency Warning Lamp" and SAE Standard J595b "Flashing Warning Lamps for Authorized Emergency Maintenance and Service Vehicles" need to be upgraded in terms of intensity requirements. The intensity recommendations tabulated above take into account the subjective effectiveness between different colors. They are substantially higher than current SAE specifications, but are more similar to values being investigated by the SAE. A demonstration of flashing red light units in current usage, which was part of the 1978 November SAE meeting, revealed to the author that in daylight units of 200-300 candlepower (cp) were too dim while units of 500 (cp) were significant improvements. Thus, it may be possible to make significant improvements in subjective effectiveness by requiring values somewhat less than those recommended. Experiments should be conducted to further quantify the intensity desired of rotating and flashing signal lights.

The factor of which lamp type produces a greater effective intensity has been evaluated by NBS personnel who sought to answer the following question: "Given that one has a certain amount of luminous energy to put into a strobe flash or an incandescent flash, which flash will produce the greater effective intensity?" After computing a small (9-18%) effective intensity advantage for strobes as opposed to incandescent lamps, Howett, Kelly, and Pierce (1978) conclude that "an intensity difference of 9% to 18% is not very significant visually, and could easily be outweighed by some other variable in which incandescent lamps might be superior to gaseous-discharge lamps. The problem of what type of emergency-vehicle warning-light unit is best is going to require perceptual experimentation to find a solution; the issue (of lamp type) cannot be settled by effective-intensity computations alone (underlining added for emphasis)."

Furthermore, other calculations by Howett, Kelly, and Pierce (1978) indicate that the effective candlepower of a 1 million candlepower (peak) strobe is approximately 300 cp since effective strobe intensity equals peak intensity times .0003 (rough approximation). Although strobes produce much higher peak candlepower values than incandescent lamps while drawing less electrical current, the effective intensity difference between lamp types is much smaller than their less meaningful peak candlepowers. Thus, there is no obvious advantage to use condenser-discharge xenon strobe lamps. Other conspicuity factors besides intensity will have to be considered decisive in most strobe/incandescent comparisions. Castle's (1974) subjective conspicuity evaluation found that a twin beacon incandescent lamp unit was rated above 11 other configurations which used strobe lights. Recent less well controlled observations (Hopkins and Holmstrom, 1976; Hopkins and White, 1977; California Highway Patrol, 1973a) have indicated that strobes seemed to be highly conspicuous. However, since there is currently no adequate data to support a clear advantage for strobes, their effectiveness relative to other lamp types remains unknown.

An interesting finding of Howett, Kelly, and Pierce (1978) is that for common rotating beacons increasing the flash duration while keeping the flash rate constant will increase the effective intensity. Thus, using a 4 lamp unit at the same flash rate as a 2 lamp unit will increase (nearly double) the effective intensity. Conversely, it can be shown that if one wanted to nearly double the flash rate, i.e., use 150 fpm instead of 90 fpm, one would have to double the number of lamps to keep the duration nearly the same and thus, produce nearly the same effective intensity. However, even though the effective intensity would be nearly the same in a 4 lamp 150 fpm unit and a 2 lamp 90 fpm unit, the marked change in flash rate could make the 150 fpm unit much more conspicuous. Thus, conspicuity should be evaluated empirically under realistic viewing conditions.

It must be remembered that the conspicuity of a lighting system depends on many factors. Among these are: effective intensity, flash rate, duty cycle, waveform, color, duration, area, contrast, motion, multi-lamp configuration, temporal relationships (sequence) between lights, and how all these factors interact with the background. No one yet knows how these factors interact to affect conspcuity and thus, until adequate measurements of conspicuity are made, direct observations are to be relied on much more than predictions based on data from only a limited number of these factors.

## Flash Rate

Flash rates of the lower portion of the 0-1 Hz range may be viewed as steady lights that are turned off or on after a time interval and do not have the conspicuity of a flashing light. Brown and Gibbs (1958) found that when an automobile turn signal is not seen foveally, a flashing light has more attention-getting power. Gerathewohl (1953) reported that at low contrasts, flashing signals were more conspicuous than steady lights even though distraction lights were dotted around the fixation area. However, Crawford (1962, 1963) reported that steady lights were always more effective when 10% or more of the background lights were flashing. This illustrates the effect that could be expected if too many distracting flashing lights are allowed in the visual driving environment.

Gerathewohl (1957) examined the interactions of flash frequency, duration, and signal contrast and found reaction time to decrease with increasing flash frequency and flash duration. The effect of frequency was strongest under low contrast conditions where high frequency flashes were more conspicuous than low frequency flashes. Within the range of the conditions examined, the most conspicuous signal was one flashing at 180 cycles per minute (3 Hz) which was at least twice as bright as its background.

According to a discussion in "The Perception and Application of Flashing Lights" (1971, page 338), a flash rate of 140 fpm was reported to be the best attention getting signal when a flashing neon hazard beacon was viewed both from the ground and the air by a large number of observers who viewed frequencies of 20-200 fpm with various duty cycles.

Similarly, Post (1975) found that flash rates in the 0-1 Hz range produced longer reaction times and greater frequencies of missed signals (non-detection) than signals presented at flash rates of 2-3 Hz. Currently, normal vehicle and other traffic signals generally flash at 1-2 Hz because of recommendations and standards which were promulgated based on the results of subjective tests conducted by the SAE (1953). However, Post's work showed that higher frequencies of 2-3 Hz are capable of eliciting quick response, even though, subjectively they may not be deemed as effective as slower flashing lights, perhaps because of our conditioned stereotype for flashing lights to appear at 1-2 Hz. Higher flash rates may be useful as long as frequencies in the 9-12 Hz range are avoided since they may cause "photopic driving" which is a brain wave phenomena which can precipitate epileptic seizures. Higher frequencies may produce fusion and thus should be avoided. To have an adeuqate safety margin it may be wise to avoid flash rates of 6 Hz or more. Similarly, our stereotype for duty cycle is approximately a 1:1 ratio for on/off cycles, so that, lights with either relatively shorter on or off times might be more conspicuous than normal incandescent signals.

A flash rate of 150 fpm (2.5 Hz) would provide a high flash frequency which should result in a low incidence of missed signals and a fast reaction time. Under the low contrast conditions often encountered in daytime driving, when there is a visual field full of competing stimuli, signals flashing at this rate should be more conspicuous than more slowly flashing lights and steady lights.

Caution must be exercised in increasing the flash rate for flashed lamps, as opposed to rotating lamps, as high intensity incandescent lamps may have problems in maintaining an adequate "on" to "off" light output ratio due to the relatively long incandescence/nigrescence times that are associated with high wattage filaments (Post, 1975).

## Additional Conspicuity Considerations

Although the relative effect of various other factors is unknown, where possible, attempts should be made to produce a signal with increased conspicuity. Contrast should be maximized, even though the magnitude of the improvement has not been quantified under real world viewing conditions used in driving. For example, SAE J595b stipulates that "To improve the effectiveness of the signal, it is recommended that, where practical, the area of the vehicle immediately surrounding the signal be painted black." The signal should also be designed so that it has a low probability of natural or baseline occurrence that is generated by other vehicular or non-vehicular lighting displays. Additionally, its design should be such that it can be distinguished from other vehicular or non-vehicular lights that have one or more features in common with it. Thus, it should be dissimilar to other frequently occurring lights in the drivers environment.

# OTHER SIGNAL DESIGN CONSIDERATIONS

Data presented in the Traffic Laws Commentary (Dec. 1975) indicates that few (7) states have adopted the Uniform Vehicle Code section 12-218 which would require red alternately flashing high mounted pairs of lamps front and rear on authorized emergency vehicles including ambulances. Seven (7) other jurisdictions (6 states and Washington, D.C.) require some type of flashing red lights. Only 3 other states have laws requiring any type of specified signal lights for ambulances. Thus, 34 states have no requirements for specified signal lights although many states permit use of various types of lights, generally of red color.

According to the Summary by Color of Lights table in the Traffic Laws Commentary (Dec. 1975), 41 states mentioned red as the single color which may be used for ambulance lights while 4 states had no relevant law or color specification. Four (4) other states allowed only red or red and white in combination to be used. Two (2) additional states allowed red, but also allowed other colors, such as white or blue to be used singly and one of them gave red and white as an option also. Thus, a total of 47 states mentioned that red could be used alone on ambulances while 6 states allowed red to be combined with other colors. Only 1 state mentioned blue as being permissible as a single color and none allowed a blue signal in combination with another color. Only 1 state allowed use of white as the single color for signal lamps while 5 states allowed white and red combination signals. Preponderantly then, red was the legally acceptable color for ambulance lights.

Thus, retaining use of red as a color for ambulance signaling would be beneficial to changeover considerations of legal policy as defined by state laws. Additionally, changeover costs and time could perhaps be minimized by retaining use of many signaling units currently in use.

If fire and ambulance vehicles were given the same signal to convey the message "Clear the Right-of-Way," then red would be a good choice legally, since fire vehicle requirements are very similar to those for ambulances and 47 states also permitted red to be used as the single color on fire vehicles, 7 of these also permitted red and white combinations. Perhaps, it can be recommended that the police signal for emergency and pursuit use is the same as for the ambulance and/or fire vehicle "Clear the Right-of-Way" signal. Thirty-eight (38) states allowed use of red as a single color police signal while 20 allowed use of blue as a single colored signal. Red was also determined to be the most frequent color in use by Klaus and Bunten (1973) who assessed the colors of signals in use singly or in combination, the number of lights per unit, the number of units per vehicle, and the color of the dome via a survey of police departments.

The extent that financial resources can be saved by specifying signals that were allowed by law according to English, Young and Friedland (1972) cannot be ascertained as there is no data available on the physical specifications of signal units used by ambulance and fire vehicles as there is for police vehicles (Klaus and Bunten, 1973). Surveys should be conducted to determine how colored bulbs, colored domes, and split domes are used to generate colored signals and how the flashing aspect of signals is achieved. This data would allow one to estimate the amount of bulb, dome, or whole light unit replacement that would be necessary to convent current signaling units to a new configuration. Without such information it is impossible to estimate the time required to convert to a specified system.

Proliferation of lamps is common on ambulances, with 10 or more signal lamps being installed on some ambulances. The electrical current shortage problems which have reportedly plagued some ambulances can be reduced most easily by restricting the number of signal lamps to those performing a meaningful function. The utility of the three lamps observed along each side of some van type ambulances

# SIGNAL RECOMMENDATIONS

Since messages F - "Be Prepared to Stop" and G - "Stop - Do Not Pass" were formulated in response to school bus signaling needs, design of signals to meet these needs will be discussed in a separate chapter. There is probably little confusion of school bus signals with signals of other special vehicles because of their location on a vehicle of standardized color and their specific mounting requirements. Furthermore, their usage is already situationally defined, such that, they are only used in fairly well defined situations that involve loading or unloading of pupils. Since the usage of school bus signals does not often mimic the usage of other special vehicle signals, they can best be evaluated in a subsequent chapter, where the various aspects of school bus usage can be explored in depth.

Thus, the remaining messages (A-E) are the messages which need to be developed in such a way that the needs of several special vehicle types will be satisfied. Already, these messages have been assigned to vehicular operations in Table 3 (page 20) in a manner which reserves certain messages for particular vehicles. Since these messages will be assigned distinctive signals, it is important that the more urgent missions be associated with the most conspicuous signals. Thus, the choice of specific signals will attempt to create designs whose functionality is commensurate with the priority of the vehicular mission. Given the classifications assigned in Table 3 (page 20), the following priority ranking of messages seems reasonable -

MESSAGE

1. Clear the Right-of-Way
2. Hazard--Vehicle on Right-of-Way
3. Caution--Slow Moving Vehicle
4. Vehicle Present in Hazardous Location
5. Stop - Immediately

This priority ranking took into account the amount of danger that is inherent in the missions associated with these messages. Therefore, those missions which affect numerous other drivers, who are going much slower or faster than a special vehicle on a public roadway, are considered to be of high priority. Within this group of missions, highest priority was assigned to the "Clear the Right-of-Way" message since the emergency/pursuit driving mission involves violation of other traffic control devices by a vehicle which may approach at high speed from any direction. The "Hazard--Vehicle on Right-of-Way" and "Caution--Slow Moving Vehicle" messages both involve missions where the special vehicle needs to influence the behavior of drivers who come upon the vehicle from a position farther back in the traffic stream. In this case, a higher priority was assigned to the special vehicle with the greater speed differential between it and an approaching motorist. The "Vehicle Present in Hazardous Location" message was assigned a priority above the "Stop - Immediately" message as it needs to be transmitted to numerous approaching vehicles, often at long distances, such as when a patrol car is parked on a freeway. In contrast, the "Stop - Immediately" message is intended to be transmitted to a particular vehicle at relatively short distances in order to apprehend a law violator.

All signal recommendations will be based on maximizing the conspicuity of messages in accord with their priority. It should be noted that this does not ensure that the signal will be conspicuous, e.g., easily detectable under various conditions of driver attention, competing stimuli, or background. It should ensure, however, that based upon the current knowledge of vision and detectability, that the light signals will be reasonably detectable and recognizable given current hardware constraints. Furthermore, the choice of signal parameters restricts the parameters, that are now in use, to values which are better suited for their intended use than those found in many signal lights available today. Also, since the light signals specified below are associated with messages that are assigned to particular vehicles as shown in Table 3 (page 20), the signals are part of a comprehensive signaling scheme which should be capable of improving driver communication.

## Clear the Right-of-Way

Use of dual red beacons of 600 effective candlepower synchronized to flash together at 150 ± 25 flashes per minute (fpm) is recommended for the "Clear the Right-of-Way" signal. These beacons should produce a forward projecting light signal that covers an area of at least $90^{\circ}$ to the right and left of the vehicle centerline. Synchronization will double the light output toward the observer resulting in not only a more intense daytime signal, but also a more distinctive daytime signal. The dual flash should also avoid some of the problems of location and distance estimation which have been shown to occur with some units which alternate side to side flashes. The historical stereotype associated with red shall be retained and enhanced by prohibiting other classes of vehicles, such as wreckers, from displaying flashing red auxiliary signals. In addition, problems of nighttime discomfort and disability glare will be minimized by use of red. Furthermore, the higher 150 ± 25 fpm flash rate may also serve to distinguish the signal more readily from the 90 ± 30 cpm signals used on normal vehicles. Higher flash rates may impart an increased sense of urgency and they are associated with shorter response times and fewer missed signals. The units should be mounted as high and as far apart as practicable near the front of the vehicle. When possible, the units shall be mounted so that a part of the vehicle (for example, the patient compartment of a van type ambulance), serves as a background. The forward facing surface of this compartment should be painted with a large black band to increase contrast which may improve conspicuity of the signal considerably.

In addition, because of the need for signals to be detected in rear view mirrors when drivers are ahead of an emergency vehicle (Howett, Kelly and Pierce, 1978), white high beam headlamps should perhaps be flashed during the daytime. The location and intensity of the headlamps may make them more conspicuous than high mounted vehicular signals during the daytime. Choice of an alternating or synchronized pattern should be experimentally determined. Commercial units are available and have been observed in use which alternately flash the left and right high beams in the daylight operation mode. Additionally, since fender and low mounted beacons and spot lamps which project forward directed beams are already in use on some ambulances, their suitability for night and day use should be evaluated.

Only police, fire and ambulance vehicles should be permitted to display this message.

### Hazard-Vehicle on Right-of-Way

Use of an upper pair of rear facing red lamps of 600 candlepower which shall flash alternately at 90 flashes per minuted (fpm) plus a lower pair of rear turn signal lamps flashing alternately, but out of phase with the upper lamps, is recommended for the "Hazard-Vehicle on Right-of-Way" signal. The upper lamps should be mounted on the rear of an ambulance or fire vehicle as high and as far apart as practicable, and should have a black surrounding background. On a police vehicle the upper lamps should be roof mounted. Only 600 candlepower (not effective candlepower) was recommended here for the upper lamps since the vehicle to be detected is ahead of the driver in his normal line of sight and because the lamps are to be flashed in an on/off fashion. Furthermore, implementation is enhanced by the current availability of such lighting units.

Only police, fire and ambulance vehicles should be permitted to display this message.

### Caution--Slow Moving Vehicle

Use of a pair of rear-mounted yellow beacons of 1500 effective candlepower flashing (synchronously if possible) at 90 ± 15 flashes per minute (fpm) is recommended for the "Caution - Slow Moving Vehicle

Signal. These beacons should be mounted so that they are not obstructed to the rear by any portion of the vehicle. Furthermore, they should be mounted so as to project their beams parallel to the ground. Operation of any portion of the vehicle should not change the mounting height of the beacons substantially. In addition, a roof-top mounted yellow beacon of 1500 effective candlepower shall be mounted to provide a forward projecting light when the dual rear lamp units are mounted so as to have the forward projecting portion of these beams obstructed by any portion of the vehicle or its equipment. These beacons jointly should produce a light signal that covers $360^0$ around the vehicle since the vehicle not only overtakes other vehicles, but also merges from medians and is overtaken by other vehicles. The present stereotype of yellow denoting caution and service operations is retained. This signal should only be allowed on wreckers and maintenance vehicles.

Postal vehicles should continue to use a simultaneously flashing pair of rear mounted yellow automotive signal lamps to convey the "Caution--Slow Moving Vehicle" message. They are not required to use the three beacon system since their usuage is normally during daylight hours, in situations where there is not as great a speed differential as there is between wreckers or maintenance vehicles and passenger vehicles on freeways. Where a postal vehicle will be required to stop in urban traffic, a rooftop mounted lamp shall be provided capable of projecting 600 effective candlepower of yellow light to the rear. This light should be pulsed at 90 ± 30 flashes per minute.

## Vehicle Present in Hazardous Location

Use of simultaneously flashing yellow rear signals should be used to convey the "Vehicle Present in Hazardous Location Signal." The lack of flashing red lamps will help to distinguish this signal from the "Hazard-Vehicle on Right-of-Way" signal as will the use of simultaneous flashing lamps. Furthermore, yellow denotes caution and simultaneous flashing lamps are also associated with the caution message conveyed by vehicular "4-way flashers" or "hazard warning" signals. Yellow turn signals may be used for this function.

### Stop - Immediately

Use of a blue flashing spotlamp with a unique flash pattern is recommended for the "Stop - Immediately" message. This signal should be limited by law to usage on police vehicles only. A 7500 candlepower blue spotlight has been used by the Washington State Patrol according to the Blue Light Study (California Highway Patrol, 1973a). Development of this signal should determine whether the CIE or SAE signal blue would be a better color for this usage, and the candlepower and flash pattern that will be adequate.

# IMPLEMENTATION MEASURES

Since full implementation of the recommended signals may require substantial hardware changes, it is imperative that interim changeover measures be adopted. Adoption of specific requirements and recommendations at this time would serve to limit the further proliferation of dissimilar signals which have come into usage because of a lack of adequate guidelines.

Perhaps the first step that should be taken is for the concept of the use of different signals for different situations to be officially adopted. Specifically, it should be stressed that the current primary 360° warning signals on emergency vehicles should not be used except when it is necessary to "Clear the Roadway." Preserving the primary signals for such usage may have a benefit, even if the primary signals in the emergency vehicle population are a heterogeneous set, since the public would no longer be exposed to these signals when they are not needed. Thus, unidirectional flashing signals should be required to be used when the emergency vehicle is stopped.

Another step that can be taken prior to requiring conversion to a uniform "Clear the Right-of-Way" signal is to limit the parameters available for usage for this primary warning signal. It is suggested as an interim measure that a 360° flashing signal which incorporates red as a component be required and that blue be prohibited. Further intermediate steps to produce a "Clear the Right-of-Way" signal would be to require two 360° flashing warning lights or even dual synchronized 360° warning lights regardless of candlepower or flash rate. However, if the change in signals is not great enough for the public to easily perceive, it is doubtful that their driving behavior will change even if the adopted signals are standardized. For this reason, it is recommended that implementation of the "Clear the Right-of-Way" signal not proceed in a piecemeal fashion.

A viable second step toward implementation would be to require specific "Hazard-Vehicle on Right-of-Way" and "Vehicle Present in

Hazardous Location" signals. Since it appears that the necessary lamps for the recommended signals already exist on most ambulances, only circuitry changes will be required to make these signals operational for ambulances. Other special vehicle types will require the installation of lamp hardware that is readily available.

The "Caution-Slow-Moving Vehicle" signal should be implemented since it only requires use of hardware that is commonly found on maintenance type service vehicles. Implementation of this signal will help to keep the present distinction normally found between maintenance vehicles, and police, fire and ambulance vehicles. This distinction is useful as these vehicles are engaged in dissimilar missions.

Development of a distinctively flashing signal to convey the message "Stop - Immediately" should be undertaken, so that a blue spotlight that is unique to police vehicle operation is available for citizen apprehension. It is considered essential that this unique signal be developed to make impersonation of police officers difficult.

Research should be conducted to determine whether mounting a strobe (perhaps signal blue with day/night intensity capability) between the beacons would increase the conspicuity of the signal. Even if the conspicuity was not increased, the acceptance by various agencies and the driving public of a new "Clear the Right-of-Way" signal could perhaps be enhanced by use of a more novel signal. In addition, since blue is used in various European countries as a police signal, incorporation of a blue light would make the U.S. signal more internationally recognizable. The acceptance of a new signal that is part of a new coding system could also perhaps be enhanced by alternating red and blue bulbs in the revolving beacons since this would produce a more novel signal. A novel signal may facilitate the learning of new driver responses, since signal recognition of the signal as a "new" signal which may require a new response may be enhanced. Agencies may be more willing to accept a novel modern signal as "the answer" to their signaling needs than an improved version of an old signal. Both of these options are available as evaluationary changes to the recommended signal. It must be stressed that recommendations for signaling are necessarily conservative since when evidence is lacking it is best to proceed with caution. Although some people may be disenchanted with red signals since they still experience collisions, it is not justified to think that simply changing the color to blue, or alternating red and white, or using strobe lights will miraculously make their vehicle signals more conspicuous. Changes can be detrimental, as well as advantageous, and until more conspicuity research is conducted, standardization must rely on information available. Currently, little advantage is seen to alternating a red signal with a white signal since the white signal would convey glare effects at night while only providing a signal nearly equally adequate to the red in the daytime.

Mortimer's (1970) assessment of suprathreshold responses of color-blind observers showed that similar levels of intensity were required to produce an adequate red daytime signal for both color-blind and color-normal subjects. A somewhat less intense white was needed in daylight for the color-blind subjects to rate the light as adequate, than was the case for the color-normals. However, at night, whereas, the color-blind subjects took higher red intensities than the color-normals before experiencing "intolerable" glare, they reported that the white light was intolerable at intensity levels far below those responded to by the color-normals. Thus, these data show that color blind persons may be even more subject to discomfort glare than color-normals. Thus, use of a high intensity white light at night may create more problems for the color-blind (and color-normals) than use of such a light might alleviate during the daytime.

Serious consideration was given to alternating red and blue, however, there are distance perception problems associated with sequential side to side alteration of red and blue. The possibility of alternating simultaneous red flashes with simultaneous blue flashes was considered, but this signal hasn't been evaluated for conspicuity, distance estimation, perceived importance or subjective acceptance.

Even though subjective research is relatively inexpensive, there apparently are few, if any, studies which have looked at things as simple as the association of perceived importance with flash rate. The relative impact of signaling possibilities such as alternating incandescent flash with strobe flash instead of having sequential incandescent or strobe flashes cannot even be guessed at until more controlled observations have been conducted. Even relatively simple things, such as, providing a fixed high contrast background has not been evaluated under realistic conditions similar to those imposed by rooftop mounting of signal lamps. Conspicuity research should be encouraged so that conspicuity measures that can improve signal adequacy can be more fully understood. Additionally, there appears to be a need to document the current signaling hardware in use and practices of signal usage before the implications of changeover to any required system can be fully understood.

As suggested by Howett, Kelly, and Pierce via personal communication, neither current scientific information nor user experience provide a clear-cut solution to design of a light signal vehicular warning system. They felt that four main obstacles stood in the way of an optimal signaling system: the wide variety of systems in use, an operating environment which has no standardization and little control of signal usage, the need for important signal messages to be delineated, and the need to understand conspicuity and how it depends on physcially measured variables.

This report has delineated the agency missions and vehicular messages which are necessary for driver warning. The recommendations made should facilitate standardization and control of signal usage by limiting certain signals to particular types of vehicles and suggesting that signal usage be situationally determined. Adoption of such standardized signaling procedures will reduce the wide variety of systems in use and increase the consistency of driver communication.

While none of the recommended signals can be said to be optimal designs, they are designed based on our current knowledge of detectability and conspicuity to be improvements on current systems. These signals are not the final answer, but only an interim best solution until research on conspicuity provides more firm guidelines for system design.

Standards need to be promulgated to control the usage and quality of signal lighting units on authorized vehicles. Uniformity between various jurisdictions needs to be increased via adoption of uniform vehicle codes and equipment standards. Minimum performance standards specifying color, flash rate, flash sequence and candlepower need to be established for authorized emergency and other special vehicles, as they have been for school bus signals. FMVSS 108 should have provisions for signals used on vehicles manufactured as special vehicles. Additionally, specifications should be developed for equipment or vehicles purchased with federal funds and/or used by federal agencies.

# CUES FOR SCHOOL BUS IDENTIFICATION AND DRIVER ACTION REQUIREMENTS

Of the cues used by drivers to identify the behaviors required of them as they approach a vehicle that is possibly a school bus, the most consistently perceived and comprehended cues are probably the -

1. alternating red signal lamps
2. yellow vehicular color, and
3. the wording "school bus."

Driver actions as one approaches a maneuvering bus are probably determined by these cues in this order with the first two cues nearly always determining the driver's actions. The written label cue is probably used very infrequently to clarify ambiguous situations. Other written instructions used in various states are probably rarely useful in determining driver action in a given situation, although they may serve instructional purposes by informing drivers of actions that they may have to take at sometime in the future.

When viewed under marginal visibility conditions such as fog and snowstorms, the words "school bus" are probably undetectable. Thus, regardless of the size of the bus, the color and alternating flashing of lights are the aspects most likely noticeable. The school bus yellow color must be retained as its stereotype is well established, furthermore, yellow is one of the most easily detectable of colors because its wavelengths are near the region in which the human eye is most sensitive. Red lamps are similarly stereotypical of important messages such as "Danger" and "Stop." Thus, this cue is particularly well suited for conveying the messages necessary to safely conduct school bus loading operations. However, red has its problems as an effective cue as discussed in the literature review and for these reasons should be enhanced by the following countermeasures -

1. Ensure that the possibility of color confusion with lamps

that flash in a similar manner are reduced or eliminated.

2. Ensure that the red lamps have an effective intensity at least equal to that required by current SAE standards. Note that many strobe lamps would produce values below current requirements because of the low amount of red wavelength genration in xenon flash tubes.
3. Ensure that intensity is enhanced by requiring that lamps be reasonably aimable and project a reasonable effective intensity in the driver's line of sight.
4. Ensure that signal lamps are likely to be located in a frequently used region of the drivers line of sight near the region of maximum attention.
5. Maximize color contrast around the school bus signaling lamps.

The recommended and proposed school bus signaling system incorporates these features by specific design and via reference to appropriate standards.

# SCHOOL BUS SIGNALING REQUIREMENTS AND RECOMMENDATIONS

As shown in the Analysis of Signal Requirements section of this report, a school bus is generally involved in four actions or operations: stopping in right-or-way for loading, stopped in right-of-way for loading, stopped off right-of-way for loading, and stopped off the right-of-way. The analysis indicated that during these operations the school bus would most likely be involved in one of two missions, STOPPING FOR LOADING (F) or STOPPED FOR LOADING (G), and the messages BE PREPARED TO STOP (F) and STOP-DO NOT PASS (G) should adequately cover these signaling situations. What needs to be developed are signal specifications that can adequately be used in this situation while taking into account the extenuating circumstances of existence of other traffic controls,such as crosswalks, and pedestrian "WALK/DON'T WALK" signals, the direction of the flow of adjacent lane traffic, the existence of divided highways and weather conditions,such as fog (a frequent rural occurance).

Answering the question "should the front lamps on school buses flash alternating red or yellow on divided highways?" involves several factors. First, the Uniform Vehicle Code Section 11-706(d) states that drivers need not stop when encountering a bus on a different roadway of a divided highway where pedestians are not permitted to cross the roadway. Therefore, little need must have been seen for oncoming drivers to stop on a divided highway under these conditions. Secondly, according to Yaw (1972) a total of forty-six (46) states permit passing of school buses on 3 or more lane highways, different roadways, or divided highways. For drivers traveling in the opposite direction to a school bus on a divided highway, 43 states permit drivers to pass the bus. A full 35 of these 43 states likewise permit passing even when drivers are traveling in the same direction as the bus, but on a separate roadway. Another 3 states permit passing of school buses traveling the opposite direction even on non-divided highways. Thus, current legislation suggests that there may not be a need for oncoming drivers to stop on divided highways. Lastly, alternative school bus routing procedures are generally available so that any need for pedestrians to cross a divided highway may be obviated (Shinder et. al, 1975).

In conclusion, there is little (if any) perceived need for use of forward facing red alternately flashing school bus signals on a divided highway. In cases where children must cross a divided highway the signals on the bus should not be relied upon, but should be supplanted or correlated with the use of other pedestrian crossing signaling measures such as crossing guards or light installations.

Assuming that divided highway loading situations are necessary to transport children in situations where crossing would not be required, it would be advisable to provide a forward facing light under all ambient lighting conditions to warn wrong way drivers of an obstacle. For this purpose either headlamps or other lamps, other than red flashing lamps, could be used. However, use of yellow flashing lamps could additionally provide a caution signal for oncoming drivers and serve as an alerting signal that could be correlated with the use of other pedestrian protection measures.

Currently, according to the Michigan publication "What Every Driver Must Know" (1976), use of yellow in an overhead traffic signal requires a driver to "slow down and stop" in response to a steady circular yellow indication as defined in the FHWA 1971 Manual on Uniform Traffic Control Devices. Although the MUTCD doesn't define the driver action for the yellow circular signal, it makes it clear that it is intermediary between the "may proceed" and "shall stop... before entering the intersection." Thus, driver behavior should include caution and slowing down, but in no case should include speeding up. Nevertheless, this is known to be a relatively common and seldom enforced traffic violation. According to the MUTCD (1971) use of flashing yellow with rapid intermittent flashes, means that drivers of vehicles "may proceed...past such signal only with caution."

Only three states specified duties for drivers approaching a school bus with alternately flashing yellow lights in operation and one other specifies behavior for drivers to the "stop warning signal lights" whether or not they are yellow (Yaw, Traffic Laws

Commentary, 1972). Furthermore, Yaw states:

> "The Alaska law provides that a driver meeting or overtaking a school bus which is displaying flashing amber lights shall slow down and be prepared to stop but the driver may pass a school bus displaying alternately flashing amber lights provided he can do so safely. Iowa provides that a driver meeting a school bus on which the amber lights are in operation is required to reduce his speed to not more than 20 miles per hour and to bring his vehicle to a complete stop when the bus stops and a signal arm is extended. However, the Iowa law provides that a driver overtaking a school bus from the rear shall not pass a school bus when red or amber lights are flashing and shall bring his vehicle to a complete stop when the bus stops and the stop arm is extended. The Montana law provides that the driver of a vehicle meeting a school bus preparing to stop as indicated by amber flashing lights must slow and proceed with caution. Nebraska requires that a driver approaching any school bus on which the stop warning signal lights are flashing must reduce the speed of his vehicle to not more that 25 miles per hour and must stop upon the display of the stop arm."

The ambiguity between various definitions of driver actions required by yellow signals mentioned above and more recently by Kearney (1978), and the lack of sanctions applied to violators leads one to be cautious of use of yellow where specific driver behaviors are desired. Use of yellow flashing pre-stop lamps on school buses may lead to potentially unsafe driver acceleration and passing behavior since one could thus avoid being delayed by the stopped school bus. There should be some reluctance to require yellow pre-stop lamps without measured tests to assess the affect on improper driver behavior. Among conditions that should be assessed are improper passing maneuvers -

a) during an alternately flashing yellow pre-stop phase of 200 feet,

b) during an alternately flashing red pre-stop phase of 200 feet,

c) without any pre-stop signal for 200 feet prior to stop,

d) during the stop phase using red alternately flashing loading lamps,

e) during the stop phase using an octangular red stop arm with and without red flashing lights attached,

f) during the stop phase using both stop arm and red alternately flashing loading lamp signals.

Until such tests are conducted it is difficult to assess the relative merits of various signaling procedures for school buses. For example, although stop arms are not required in most states, recent tests have shown them to be effective in reducing illegal passing (School Bus Fleet, April/May 1976, National School Bus Report, December 1976, Bequette, 1976).

Thus, at this point in time, the effect of the use of yellow pre-stop lamps on school buses is not well enough quantified to recommend that yellow lamps be required. On the other hand, the use of a pre-warning signal is generally considered beneficial, as pre-stop signals are permitted or required in most states. Yellow is authorized or required in 36 states (D. Soule, 1978) while red is similarly specified by 18 states plus Wash., D.C. (Kearney, 1978). If a viable deceleration signal system should be developed and applied to school buses, it could be considered to be the pre-stop warning, thus possibly obviating the need for yellow or red pre-stop alternately flashing warning lamps. While most states require use of red warning lamps when stopped, many states permit the use of special vehicle signals prior to the time the bus stops. In Michigan, for example, the red warning lamps are turned on approximately 200 feet prior to the stop point and allowed to flash while the vehicle slows and after it is stopped for loading. This use of a red pre-stop warning signal may obviate the need for yellow pre-stop warning signals and at the same time may reduce vehicle passing during the pre-stop phase via the association of red with stop. One criticism advocated by Yaw (1972) of this approach is that red is no longer reserved for the stopped vehicle. Quoting from Yaw (1972):

> "Under the Uniform Vehicle Code, these special flashing red lights are to be used only after the bus has stopped as an indication to other drivers <u>that they must stop</u>. Their use on a moving school bus is a serious and dangerous departure from the code."

However, if laws require of drivers "that they must stop" when "special flashing red lights" are used while a bus is slowing, then the message of the lamps as specified by the Uniform Vehicle Code is preserved, since display of the "special flashing red lights" will provide an indication to other drivers "that they must stop" (whether or not the bus is stopped). Thus, a legal stopping requirement as discussed would seem to remove the seriousness and dangerousness of the use of alternately flashing special red lights on moving school buses.

The author would agree that use of such lamps by moving school buses without a "must stop" law as per Michigan practice would seem to cause ambiguity to the red flashing signal and raise the legal question of whether a bus displaying the alternating flashing special red lights was moving or stopped when overtaken by another driver. The legal ambiguity would arise because the overtaking driver could legally pass the bus if it was moving, but he would be required to stop if it was stopped.

It is recommended that headlamps be considered as running lamps and that front yellow turn/hazard warning or high mounted pre-stop lamps (if present) should only be used where there is a need to suggest caution and slowing behavior to an oncoming driver. The yellow and red front mounted forward projecting lamps should <u>not</u> be used on divided highways when there is no pedestrian crossing desired. In cases where crossing is required, it is recommended that the front yellow lamps be used in conjunction with other non-vehicular pedestrian crossing signals. Therefore, the normal (non-crossing) meaning of vehicular signals on a divided highway would be identical to that of rural/suburban/urban school bus slowing and loading signals. Thus, the driver action required would be uniform in all road situations where the alternately flashing red lamps are used and there would no longer be instances of contradictory legal requirements and signal meaning for the front red school bus lamps on a divided highway.

Namely, it is recommended that a law requiring that drivers must stop whenever alternately flashing red lamps are in operation as per Uniform Vehicle Code section 11-706(a) should be implemented in conjunction with equipment requirements for red alternately flashing lamps as per UVC section 12-228(a). UVC section 11-706--*Overtaking and passing school bus* states in subsection (a) (Supp. II, 1976):

> "The driver of a vehicle meeting or overtaking from either direction any school bus stopped on the highway shall stop before reaching such school bus when there is in operation on said school bus the flashing red lights specified in section 12-228(a) and said driver shall not proceed until such school bus resumes motion or the flashing red lights are no longer actuated (Revised, 1971 & 1975.)

while UVC section 12-228--*School buses* states in subsection (a) (Supp. II, 1976):

> "Every school bus shall, in addition to any other equipment and distinctive markings required by this act, be equipped with signal lamps mounted as high and as widely spaced laterally as practicable, which shall display to the front two alternately flashing red lights located at the same level and to the rear two alternately flashing red lights located at the same level, and these lights shall be visible at 500 feet in normal sunlight. (Formerly section 12-218(b); Revised, 1968.)"

Perhaps the lamps in UVC 12-228(a) should be required to be in operation during the Stopping for Loading (Mission F) and Stopped for Loading (Mission G) vehicular operations in rural and suburban open road and uncontrolled intersection locations as per UVC 11-706(b). Thus, to increase safety, drivers would be required to heed the "Stop--Do Not Pass" (Message G) during both of these operations and no distinction would be required of the driver as to whether the vehicle was stopping/slowing or stopped. The driver would no longer have to be able to distinguish the message Be Prepared to Stop (Message F) from Stop--Do Not Pass (Message G) and Message F could be eliminated simplifying the drivers perceptual and cognitive task. This should result in reduced confusion and increased safety during school bus operations where specific approaching driver action is desirable to ensure that the safety of pupils is not compromised while they are crossing the street, waiting near the street, and loading the bus. This change can be instigated by removing the word "stopped" from UVC 11-706(a) [see page 122] and inserting the words "stopping or" into UVC 11-706(b) *Overtaking and passing school bus* as shown on page 124. Before adopting such changes, alternative ways of controlling driver behavior during the pre-stop phase should be explored.

To prevent the use of red visual signal lamps on divided highways, where no pedestrian crossing is required, requires that subsection (b) of UVC 11-706 be changed to prohibit use of signals that require drivers to stop, in situations where such usage is inappropriate. Currently, a driver may pass a school bus in such situations, even though the flashing red lights are operating, as shown in UVC 11-706(d) (1968):

> "The driver of a vehicle upon a highway with separate roadways need not stop upon meeting or passing a school bus which is on a different roadway or when upon a controlled-access highway and the school bus is stopped in a loading zone which is a part of or adjacent to such highway and where pedestrians are not permitted to cross the roadway. (Section Revised, 1954; Renumbered, 1968.)"

This provision requires the driver to make too many distinctions in situations where it may be difficult to determine whether the extenuating conditions exist, especially prohibition of pedestrian crossing. Deleting the whole subsection "d" and adding a 4th restriction to the signal actuation requirements of UVC subsection 11-706 (b) (as shown in italics on the next page) will eliminate the conflict between the desirable driver response (i.e., not stopping) and the current signal message (i.e., stop) in situations where a driver meets a school bus that is stopping or stopped for loading passengers on a divided roadway where pedestrian crossing is not permitted.

To further prohibit inappropriate signal messages, it is necessary to add a 5th restriction (as shown in italics below) to UVC 11-706 (b) to prevent the use of forward projecting red lamps on divided highways, since little need for this signal is evident and use of this signal might give children the idea that they have the uncontested right-of-way where they have to cross a divided highway. Since oncoming drivers may have trouble seeing signals across a median, it is highly recommended that any pupil crossing of a divided highway rely on crossing guards, ground based signals, or other means to provide a stop signal to oncoming traffic.

Section (b) of UVC 11-706 (Supp. II, 1976) "Overtaking and passing school bus" follows with suggested revisions in italics:

> "Every school bus shall be equipped with red visual signals meeting the requirements of section 12-228(a) of this act, which may be actuated by the driver of said school bus whenever but only whenever such vehicle is *stopping or* stopped on the highway for the purpose of receiving or discharging school children. A school bus driver shall not actuate said special visual signals:
>
> 1. In business districts and on urban arterial streets designated by the (State highway commission) or local authorities:

2. At intersections or other places where traffic is controlled by traffic-control signals or police officers; or

3. In designated school bus loading areas where the bus is entirely off the roadway. (Revised, 1971.)"

4. *When a school bus is stopping or stopped at a loading zone which is apart of or adjacent to a separate roadway or divided highway where pedestrian crossing is not permitted.*

5. *On the front of the bus when the bus is on a highway that is divided or separated from oncoming traffic.*

It is recommended that, because of the effectiveness demonstrated for stop arms[1] and the general consideration that signals should be at driver's eye level (Allen 1966), the use of alternately flashing brake lamps which would flash out of sequence with the upper "loading lamps" should be evaluated as well as stop arms. Many school districts do not feel that the upper placement of "loading lamps" or adoption of the "8-lamp system" has obviated the need for stop arms, presumably because they are not only closer to the drivers line of sight, and use a coding dimension less dependent on red/amber color distinctions, but also because the intent of stop arms is less ambiguous than that of color coded lamp signaling systems. These characteristics are also possessed by a four lamp system which flashes red signals in the upper left corner and lower right corner alternately with those in the lower left and upper right corner. This system makes use of the railroad stereotype for horizontal alternately flashing lamps which convey a "stop" message when operating. A recent study of improved grade crossing warning, Hopkins and Holmstrum (1976) found that the x-shaped pattern described not only was in keeping with the normal grade crossing symbol, but was also one of the configurations preferred in preliminary studies. This system has several advantages:

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[1] School Bus Fleet, April/May, 1976; Good Humor Corp. and Suffolk Co., New York Police Department as referred to by Dunlap and Associates, Inc., Model Ice Cream Truck Ordinance (1976) unpublished; Bequette, 1976 and National School Bus Report, December 1976.

1. The lower signal lamps operate in a fashion redundant to the upper lamps, thus each set of lamps is a back-up for some malfunctioning problems that may be experienced by the other set, i.e., lamp burn out, wire corrosion, etc.
2. A set of signals is provided relatively close to the driver's line of sight which should provide more intensity to following drivers since the greatest lamp intensity is projected near the H-V axis of most signal lamps. Also, it is likely that the lower lamps will have a greater probability of detection.
3. The height and width of the vehicle will be defined by the simultaneous operation of lamps in opposing horizontal and vertical corners of the vehicle.

An experimental determination should be made as to whether use of brake lamps which alternately flash in conjunction with the high mounted loading lamps (but out-of-phase) would be effective in reducing rear-end impacts which have been found to be the most prevalent multi-vehicle school bus collsion by Garrett et al. (1974). Prior to addressing the issue of whether stop arms should be prohibited, permitted, or required, the use of lower red alternately flashing lamps could be adopted since the benefits already outlined will accrue with only circuitry changes being required. Since no additional lamps or body cutouts need to be incorporated, school buses should be able to accommodate the change in the near term. If newly manufactured buses are required to adopt such a signal system, retrofit of older buses should be required because of the long life of school buses. It is urged for the sake of signal uniformity (which has positive safety considerations), that if new buses are required to have any new signal system, that older buses be given sufficient lead time to convert their circuitry (in order to accomodate fiscal and installation constraints). This would prevent there being a long period of mixed systems on the nation's roads while buses with the current signal system are slowly phased out.

By adding a phrase such as "In addition, the brake lamps shall be capable of alternately flashing out of phase laterally with the rear high mounted red lamps whenever the latter are in operation." to UVC 12-228 (a)--*School buses* (for content of this section refer to pg. 122), the required equipment change could be affected. Operation of the alternating brake lamps would be required whenever the rear high mounted red alternately flashing lamps are operational. Since UVC 11-706 (b) already specifies actuation requirements for the "red visual signals" as specified in UVC section 12-228(a), no change would be required to define the operational requirements for these signals. This would not compromise the function of the brake lamps as they would still operate as steady brake lamps in normal traffic situations as per FMVSS #108, except in instances where a school bus slows and stops for loading of passengers; at which time the 4 rear alternating lamp system would override the steady brake signal current. Since during this vehicle maneuver the vehicle signaling is enhanced by adding a distinctive flashing pattern, the lack of a steady brake signal should not be considered dysfunctional to conveying the slowing or stopped message normally conveyed by brake lamps. Thus, FMVSS #108 S4.1.4 would have to be revised accordingly, so that section (a) would require the discussed signal lamps in addition to those already specified. Since the proposed lamp system derives its improved signaling capability from lessening the distinctions required by automobile drivers and does not require yellow lamps, section (b) of FMVSS #108 S4.1.4 which allows yellow signal lamps should be deleted when section (a) has been revised along with the previously mentioned sections of the Uniform Vehicle Code. If SAE J887 were revised to include the additional red signal lamps in the "General Signal System Recommendations," these lamps would be mendatory as part of the FMVSS #108 section 4.2 Other Requirements which sets forth as mandatory all SAE J887 recommendations, except two provisions to be discussed later.

Since SAE standard J887 refers to lamp operation via the phrase "controlled by a manually operated switch" this is a requirement of FMVSS 108 as per reference to that standard in section 4.1.4(a). It is recommended that this form of operation be retained since it is relatively easy for the driver to operate this switch type without mistake and in addition no other foot and/or door switches need to be operated or monitored by the driver. This simplifies the drivers task since both of these types of switches have been known to freeze up in winter weather conditions and may thus require driver vigilance to ensure operation. The required switch should probably be labeled "RED FLASHING LAMPS" or "LOADING LAMPS." To accomodate the divided highway situation where the forward projecting red visual signals should not be used, a switch position that will prevent flashing of those lamps should be provided for in all applicable standards. To minimize improper usage, this switch should be clearly labeled with "REAR LAMPS ONLY" and "ALL LAMPS" positions and be connected to illuminated indicators which would flash "REAR LAMPS ONLY" or "ALL LAMPS" to provide driver feedback of system status and operation. Flashing illumination of either of the indicators would be associated with system usage and would provide feedback to the status of the system in operation. While some fiber optic or electrical feedback modules are available which provide visual feedback of the operation of each individual signal lamp which flashes alternately, this type of display is at this time recommended only as a supplementary measure. Rear lamp system redundancy along with feedback indicators and lamp inspection measures prior to trip initiation make such systems superfluous.

Although not specifically required, the turn/hazard warning lamp on many school bus vehicles are yellow. Front fender mounted yellow double facing lamps are often used in combination with yellow arrow markings on the rear turn indicators. For the sake of uniformity, and considering the current trend to yellow for vehicular turn signals, and current legislation directed toward adoption of a yellow standard for school bus signals (e.g., Rule R340.1213 paragraph 4(ii) of the Michigan Administrative Code as effective January 1, 1978), it is recommended that yellow be required for turn signals and hazard warning signals on school buses. Various research efforts have shown that such a change to yellow is not detrimental and many reports conclude that use of color and separation of coding dimensions is beneficial for signal information transfer (see, a recent literature review by Sivak, 1978). Tables I and III as referred to in Section S4.1.1 of FMVSS #108 may require revision so that the red or yellow rear turn color choice available via SAE J 588e is restricted to yellow for school buses.

Furthermore, it is recommended that NHTSA reconsider the exemption in S4.2.1 of FMVSS #108 which allows that the black lamp surround and aiming pads recommendations of SAE J887 are not mandatory requirements. It would seem that projecting the desired intensity requires proper aim which is facilitated by aiming pads. The use of a high contrast background is well known to enhance detection and no reason is seen for excluding its mandatory use on school bus signaling systems. Regulation VESC-13 of the Vehicle Equipment Safety Commission goes beyond the requirements of FMVSS 108 in adopting a Section 58.6 to require black lamp surrounds. The VESC obviously considers contrast to be an important issue as they also specify lamp hoods in Section 58.5 to further ensure adequate contrast.

It is recommended that school bus signals and procedures for their use be uniform across various jurisdictions. While being uniform across jurisdictions the signals may nevertheless be operated differently in some circumstances than in others, i.e., the front lamps should be operated in rural areas, but not on divided highways. Similarly, the meaning of signals in urban areas should be uniform across political jurisdictions, even though the specification of when signals are to be operated could vary from one jurisdiction to another. Currently, considerable variance exists in some areas in regard to the usage and meaning of signals in an urban environment. It is recommended that the decision of when to use signals could be left up to local areas, as long as they specify that the signals will operate in a manner consistent with the U.V.C. Consistent driver behavior to operating signals should be required by law across various jurisdictions. Further attention needs to be devoted to school bus signaling problems, especially those associated with signal usage in an urban environment.

## SCHOOL BUS SIGNALING ERROR ANALYSIS

It should be noted that failure of the bus driver to properly operate the proposed signaling system can take several forms -

1. A bus driver on a divided highway activates the signal system in the "ALL LAMPS" position while stopping (or stopped) -

   Result: All red lamps will flash as is the case now and oncoming drivers will perform with uncertainty as they do now. Upon correcting the mistake brought to the bus driver's attention via the alerting visual feedback, the automobile drivers would be presented with a signal consistent with the behavior desired of them.

   In no case is a worse situation created under these circumstances than that which is common now. Upon mastery of the switch system, which should occur rapidly due to the feedback indicators, oncoming automobile drivers would not have to contend with the current situation of ambiguous signal usage on divided highways.

2. A bus driver does not turn the red flashing lamps on via the "ALL LAMPS" switch position during the stopping (slowing) phase, but only after the bus has stopped -

   Result: The red flashing lamps will operate while the bus is stopped as normally occurs in all states now. Thus, no situation is created that is different than that in effect now when a bus is stopped.

   No hazard is created since the signal lamps are operating as is now required; however, the pre-stop warning that would have been provided by usage of the signal system while the bus was in the process of stopping would be lost. Since operation of a yellow pre-stop signal is optional under FMVSS #108 and since neither yellow nor red pre-stop signals are uniformly required under state laws, it must be concluded that lack of the pre-stop warning is not a serious consequence of driver error in this situation. However, as the system comes to be used correctly, safety should be enhanced.

3. A bus driver operates the switch in the "REAR LAMPS ONLY" position when stopping in rural/urban areas -

   Result: Upon operating the signal system during the stopping maneuver only the rear lamps will flash, however, the bus driver will receive visual feedback (which possibly should be supplemented with auditory feedback) and can correct his mistake, so that by the time he has stopped the front lamps are operating with the rear lamps. If the bus driver did not realize his error, oncoming cars would pass the bus creating a hazardous situation since they are required to stop in rural/urban areas unless extenuating circumstances apply (as per UVC 11-706(b) which specifies situations where the bus driver should not activate the signals).

Assuming the typical case in which the signals should operate and drivers should stop, each time the driver stops he must activate one manual switch to the correct position. Since he now operates one manual or foot switch, he would be required to remember to activate the proposed switch just as he is now required to do. Requiring him to select a correct switch position on a clearly labeled switch which gives him a flashing feedback indicator as to his position selection after typical training in bus and signal operation should be well within his capability. Clearly distinquishable auditory signals could further serve as a warning device to alert the driver when he is using the "REAR LAMPS ONLY." Since this usage should only occur in divided highway situations, the noxious stimulus aspect of the auditory alarm would be infrequently experienced by most bus drivers on rural/urban routes. This would tend to ensure that rural/urban route drivers would be quickly made aware of an incorrect choice of switch position.

## SUMMARY OF PROPOSED SCHOOL BUS SIGNALING CHANGES AT RESTRICTED AND UNRESTRICTED LEVELS OF MODIFICATION

At the restricted modification level (assuming continued use of 4 and 8 lamp systems), a two poisition (REAR LAMPS ONLY/ALL LAMPS) manual switch with feedback indicators should be required on all school buses. This will bring both systems into conformity with the desired divided highway signal usage. It is recommended that only the rear lamps be used on a divided highway where no pedestrian crossing is to take place. This will prevent unnecessary "stop" or "caution" messages from being communicated to oncoming drivers.

At a semi-restricted level (assuming modifications of a bus equipped with a 4 or 8 lamp system) it is additionally urged that alternately flashing low mounted lamps be considered as previously outlined to operate in conjunction with the upper rear lamps, so that, a 4 lamp rear array is presented. It has been proposed that the red brake lamps may be well suited for this purpose because of their color and location, although separate lamps could be used.

At the unrestricted level it should be determined whether octangular stop arm configurations offer any improvement over the semi-restricted level and whether additional front facing signal lamps are necessary to supplement the high mounted lamps. Additionally, the need for and utility of white or yellow roof mounted high intensity lamps for vehicular marking in severely visually degraded weather conditions should be evaluated as some regions are already requiring such use. The Iowa Code 1975 Section 321.373 is a new subsection spelled out in House File 628 of the 66th General Assembly which required white rooftop strobes as of January 1, 1977 on all new school buses put into service. The usage of this lamp when visibility is restricted is outlined in paragraph (n) on page 32 of the publication "TR-B-3R (Revised) 1974--Minimum Standards for Construction of School Transportation Equipment."

# RECOMMENDATIONS FOR RESEARCH

The applied research reviewed abounds in subjective comparisons of conspicuity of signals whose parameters are not varied systematically or even specified in adequate terms. While an objective measure of conspicuity is desirable (i.e., electro-physiological measures of cortical visual response, correlation of eye movement activity or reaction time with visual stimuli), such research is complex and costly and would require a great deal of effort to quantify the influence of how various factors affect conspicuity. It appears that subjective ratings or measures of signal detection could yield valuable information if such studies are conducted under realistic conditions and fully specify the signals being used as stimuli.

The concept of "effective intensity" should be validated under conditions of high illumination. Also, methods should be developed so that effective conspicuity or relative effective conspicuity can be assessed. These methods should be applied to the type of light signaling units now available and should include the range of parameter values available for specific types of units. Specifically, the "Clear the Right-of-Way" signal requires further evaluation as to design,and evolutionary improvements in this signal should be undertaken as applicable relative effective conspicuity data becomes available. However, changes should not be implemented until valid data are obtained, since any change will not only be costly, but will also create changeover problems and perhaps preclude implementation of subsequent solutions.

Recently reported advantages (Hopkins and Holmstrom, 1976) and disadvantages (potential for evoked seizures according to Dr. Stephen Solomon in private communications during 1977) associated with the pulse shape and intensity of a strobe flash need to be further quantified. Glare effects produced by the higher intensity signals being recommended and by much higher intensities that may be advisable in the future should be evaluated. The effective conspicuity of strobe, quartz-halogen, and incandescent lamps needs to be evaluated, as does the effect of flashing, rotating, or oscillating the lamps. Similarly, signal configurations which entail combinations of lamp types and/or colors need to be evaluated.

The effectiveness of various school bus signals needs to be ascertained both in terms of reducing rear-end accidents and illegal or unsafe passing maneuvers. The 2 upper rear red lamp "Stop-Do Not Pass" signal required by FMVSS 108 should be compared with a system which uses 2 lower rear red lamps in conjunction with the upper red loading lamps. Use of pre-stop signals should be evaluted including use of the yellow lamps allowed by FMVSS 108 and use of red pre-stop signals. Note, in both cases several levels of signal meaning are possible and should be evaluted. Since Bequette (1976) has shown that illegal passing occurs at similar rates for both approaching and overtaking drivers and stop-arms are more effective in reducing the passing violations of overtaking vehicles, additional countermeasures to control approaching traffic, such as low mounted signal lamps, should be evaluated as should signal systems on stop-arms.

Demonstrations of the various recommended signals and comparisons of other signals could be very informative to users of signal systems and other interested parties. Demonstrations or guidelines should be provided to users as soon as possible to reduce the likelihood that use of inappropriate lighting devices, signal systems, and signal configurations will increase.

Accident data should be coded so that the type of special vehicle and condition of the light signals can be ascertained. This would permit determinations of accident rate and type for police, fire, ambulance, maintenance and wrecker type vehicles. Such data could provide insight into signaling design, signal usage, and driver training problems.

# APPENDIX A

## WASHINGTON STATE PATROL
## LIGHT USAGE TABLE

Received from:

Will Bachofner, Chief

December, 1976

# WASHINGTON STATE PATROL

## Light Usage

| | Headlights - High Beam | Headlights - Low Beam | Spot Light | Revolving Blue Light | Visibar Emergency Lights | Flarestats | Interior Lights | Parking Lights |
|---|---|---|---|---|---|---|---|---|
| Stopped Violator | X | X | X | X | X | | | |
| Violator Stopped Night | | X | | X | X | X | | |
| Violator Stopped Day | | | | | X | | | |
| Accident Scene | | | X | X | X | X | | |
| Emergency Run | X | X | | X | X | X | | |
| Escorting Slow-Moving Vehicle | | X | | | X | X | | |
| Light Into Stopped Vehicle | X | | X | | | | | |
| Identification of Officer | | | | | | | X | |
| Parked | | | | | | | | X |

1/ Flicking headlights from low to high beam is used at times to get the attention of a violator to stop or yield the right-of-way for a patrol car.

2/ The revolving blue light is, at times, turned off and the remaining lights are left on.

3/ The revolving blue light and flarestats are occasionally used, depending on the circumstances and location where the violator is stopped.

# APPENDIX B

# LISTING OF LIGHTING MANUFACTURERS WHOSE PRODUCT INFORMATION WAS OBTAINED

Mars Signal Light Co.
General Offices
Plant I/Dept. E
1224 Industrial Blvd.
Naples, Florida 33940
813-774-1811

R.E. Dietz
Emergency Lighting Equip. Div.
225 Wilkinson Street
Syracuse, N.Y. 13201

Q Beam
The Brinkmann Corp.
4215 McEwen Road
Dallas, Texas 75240
214-387-4939

Lectric Lites Co.
2504 W. Vickery Blvd.
Fort Worth, Texas 76102
817-332-7961

Unitrol
Dunbar-Nunn Corp.
1108 Raymond Way
Anaheim, California 90801
714-871-3336

Whelen Engineering Co.
Deep River, Conn. 06417

Signal Division
Federal Signal Corp.
136th and Western Ave.
Blue Island, Ill. 60406

Optronics Inc.
350 North Wheeler
Fort Gibson, Oklahoma 74434

Smith & Wesson
Dept. EL-575
2100 Roosevelt Ave.
Springfield, Mass. 01101

Sireno
ITT Jabsco Products
1485 Dale Way
Costa Mesa, California 92626

Aeroflash Signal Corp.
3900 W. Palmer Street
Chicago, Ill. 60647
312-342-4806

Police Utility Bar Co.

Signal Stat Corp.
1200 Commerce Avenue
Union, N.J. 02083
201-964-1576

Public Safety Equipment Inc.
11632 Fairgrove Industrial Blvd.
St. Louis, MO 63043
314-432-6200

North American Signal Co.
2700 N. Pulaski Road
Chicago, Illinois 60639
312-278-5171

Northern Signal Co.
350 S. Tower
Saukville, Wisconsin 53080

Yankee Metal Products Corp.
25 Grand Street
Norwalk, Conn. 06852
203-847-5841

Utility Manufacturing Co.
1260 North Clybourn Ave.
Chicago, Ill. 60610
312-943-5200

The Doran Manufacturing Co.
2851 Massachusetts Ave.
Cincinnati, Ohio 43225

School Bus Parts Co.
62 Trenton Ave.
Frenchtown, N.J. 08825
800-631-7687

Midwest Electronic Industries Inc.
Manufacturing Division
4945 West Belmont Ave.
Chicago, Ill. 60641
312-685-3500

# APPENDIX C

## ABSTRACT OF

## NBS Special Publication 480-16

## "EMERGENCY VEHICLE WARNING LIGHTS: STATE OF THE ART"

by

G. Howett, K. Kelly, and T. Pierce

1978

# ABSTRACT

Information is presented concerning all aspects of emergency vehicle warning lights (EVWLs). A survey of the present situation includes: the non-uniformity of state EVWL laws; the factors entering into the choice of an EVWL configuration; a list and photographs of a variety of EVWL devices and a list of EVWL manufacturers and distributors. Background material relating to the perception of EVWL signals includes: an analysis of general warning signal perception; a description of the visual stimulus pattern confronting a driver being approached by an emergency vehicle from various directions; and a summary of the characteristics of peripheral vision (including luminous efficiency, color perception and discrimination, and flicker and movement perception). Perceptual factors affecting the conspicuity of EVWL signals are discussed, including: effective intensity; flash rate; on-off ratio; pulse shape and flash duration; spatial sweep of beam; color; number and spatial pattern of lights; cross-sectional area; motion; temporal phase relations; and the role of the background. Physical measurements on EVWL units are described, including: angular intensity distribution and beamspread; flash rate; pulse shape and flash duration; effective intensity; color; and variables in rotating devices. A glossary, extensive enough to be helpful in reading the technical literature, is included.

KEY WORDS: Color; conspicuity; emergency vehicle; flashing light; lights; motor vehicle; photometry; signal light; standards; vehicle, emergency; vision, peripheral; warning light.

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