Human Factors Considerations in Arrow-Board Design and Operation

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This paper addresses three questions: (a) Does the flashing arrow board have more than one inherent meaning to the driver, according to the display configuration? (b) Can certain design characteristics of arrow boards be optimized to convey the desired message? and (c) Will certain operational characteristics of arrow boards optimize the communication of the display message? A threefold approach was taken: (a) a review of pertinent literature, (b) performance of some limited field studies, and (c) application of human factors expertise and judgments. The two experimental studies attempted to discern meanings associated with arrow-board configurations. Subject responses to film clips of arrow-board operations were gathered. The results indicate that the arrow board is strongly associated with lane closure and that the use of an on-off blinking arrow is favored over the sequencing chevrons or sequencing arrow stem followed by the stem plus head. Arrow-board design and operation can be manipulated and optimized as long as drivers can perceive a discrete, clear directional arrow as an indication of lane closure. Violation of this for other traffic management purposes leaves drivers uncertain as to exactly what their behavior should be. The following key recommendations are made: (a) the preferred operation of the arrow board is in the single on-off blinking arrow mode, (b) the blinking arrow should not be used as a cautionary display only, (c) 360° lens hoods should be used to cap dispersing light to passing drivers and to direct the flashing lights outward in a straight line perpendicular to the arrow board, (d) dimming of luminance could be upgraded to be more sensitive to inclement weather conditions and to begin dimming with lesser diminution of daylight, and (e) arrow boards should be placed at the beginning of the taper (construction zone).

This paper addresses human factors considerations regarding the design, use, and operation of flashing arrow boards. These traffic-control devices typically are used either alone or in conjunction with other devices to alert and guide the driver safely through a hazardous highway construction or maintenance zone. The arrow signal is used to attract attention to an aberrant situation in the roadway ahead that is a violation of the driver's expectation.

The literature (1) and our field observation document that arrow boards are warning signals that have very high target value. They present a visible image capable of being detected from distances of over 1.6 km (1 mile) (2). Various state highway traffic manuals and state-conducted studies (3-5) recommend the use of arrow boards for driver management through hazardous zones. Closer scrutiny of the types of arrow boards available (6-9) and their actual use on the roadway reveals a marked diversity in displays and messages communicated to the driver. For example, an arrow board may be used to close one or more lanes of traffic, to protect equipment and workers on a highway shoulder, or simply to reinforce a driver's position to the right or left of a given lane line or barrier. In turn, this arrow board may flash a single on-off arrow, a series of sequencing chevrons, a sequential arrow stem followed by the stem with the arrow head, or simply an array of lights in a square or bar configuration, which indicates no direction (see Figure 1). The question then arises because of varying arrow configurations available for use and various placements of arrow boards (on the shoulder or in the lane), How effective are these devices in conveying their intended meanings to the driver? Does the arrow board inherently connote lane closure, lane diversion from a given path but requiring no merge, or just a caution to be cognizant of shoulder work? Does the chevron or the on-off arrow convey the desired meaning more effectively or are they interchangeable?

Since the use of arrow boards is becoming more widespread, there seems to be a particular need to specify and examine the different arrow configurations and the situations in which they are used to determine how effectively they communicate a given message to the driver.

DRIVER UNDERSTANDING AND EXPECTANCY OF ARROW BOARDS

The arrow board is a specific example of a high-target-value advance warning device used to alert individuals to a hazard zone ahead. Much has been documented about its use in hazard zones (3, 5, 10, 11). These documents and others consist of state highway department research field studies and construction zone field manuals that encourage and advocate the use of arrow boards to divert traffic around a hazardous zone. The salient point of these studies is that the arrow board is a powerful advance warning device, easily detectable from distances of 1.6-4.8 km (1-3 miles) away.

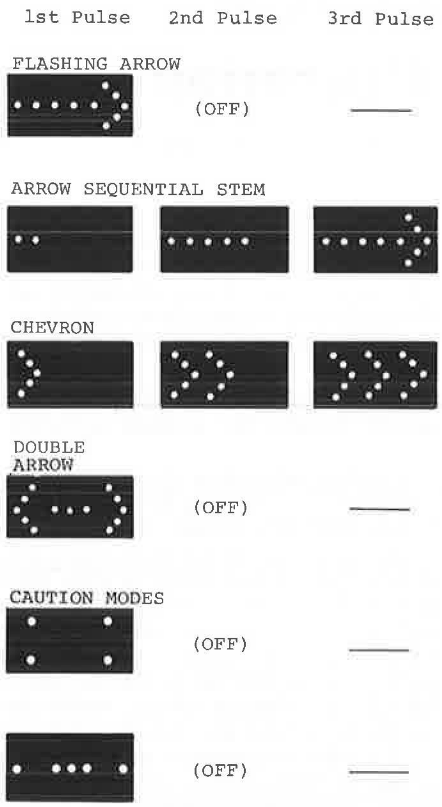
The high target value of these devices is in direct accordance with human factors principles, which dictate that an individual must be given a strong, clear signal in order to elicit his or her proper response (12, 13). Although applied human factors and perceptual psychological literature do not address arrow boards as such, the use of such signals is analogous to presenting to the individual any strong target signal in the midst of visual noise so that he or she may recognize an aberrant, hazardous, and novel situation and respond to it properly (14-18).

Essentially, then, highway studies and documents promote the arrow board as an effective device for diversion of traffic around work zones, and theoretical human factors literature supports the arrow board as an effective example of an easily detectable target in an advance warning system. Neither source, however, focuses on exactly what a given arrow configuration tells the driver to do when he or she detects this strong signal.

In Figure 1 a process of deduction is required to determine, from current literature, what each configuration may be telling the driver to do. Although various field studies have shown that the arrow board seems to tell drivers "get out of your lane—merge ahead" (1, 4, 5, 19, 20), only passing reference to the kind of arrow board most useful in doing this is found. This is most notable in the California study (5), where the arrow board caused drivers to merge even though, in certain conditions, the device was not actually placed in a lane (i.e., it was placed on the shoulder). No inherent superiority of flashing arrows over sequencing arrows or sequencing chevrons was truly shown, except for a slight but significant degradation of the chevrons during nighttime operation.

Considerable emphasis has been placed on target potency, and this is well established. However, once a driver sees the arrow board, his or her subsequent behavior depends on what meaning is attached to the arrow. It is particularly important, then, to determine whether a meaning is attached to the arrow and which configuration conveys a unitary message to the greatest number

Figure 1. Various flashing arrow-board modes.



of drivers. To this end, two small-scale studies were performed.

Study Number 1

The first study attempted to ferret out the actual meaning of the arrow-board configuration and arrow-board placement (i.e., on the shoulder or in the lane). Nine short film clips were made from the driver's view as he or she approached an arrow board on the same stretch of roadway. Each of the nine clips represented a different mode of the arrow board in combination with placement either in the lane or on the shoulder. Figure 2 shows the nine conditions along the abscissa of the summary graph. Each condition was presented twice, in random order. The 20 respondents consisted of 9 females and 11 males, who ranged in age from 18 to 50 years (mean 29.7) and had a mean driving experience of 13.8 years. After each film clip was shown, subjects were required to select one of four responses, as shown in Figure 2. In addition, each subject was to indicate how confident he or she was in this response on a scale of 1 to 5. Essentially, three hypotheses were tested:

1. There is no difference in accuracy and confidence in interpretation of different arrow configurations;
2. There is no difference in the meaning associated with blinking arrows, sequencing arrows, chevrons, and blinking lights; and
3. There is no difference in the meaning between arrows placed in a lane and those on the shoulder.

Figure 2 is a summary of the results obtained. About 95 percent of the subjects were confident that the arrows and chevrons connoted a lane closure ahead. Mere blinking lights stirred more confusion than they aroused meaning. Arrows and chevrons seem to indicate a lane closure for roughly 75 percent of the subjects, even when the arrow board was in fact placed on the shoulder and a merge was not actually required. This is a reinforcement of the California findings (5). Here is empirical evidence that drivers mainly understand that the flashing arrow means a lane closure ahead. Unanswered questions and problems remain, however.

1. Simple inspection shows no clear superiority of arrows over chevrons (or vice versa),
2. Respondents do not seem to be able to recognize when the lane is open or closed by virtue of arrow-board placement, and
3. The role of the caution or blinking lights needs in-depth examination in terms of its usefulness, in view of the apparent confusion that surfaced.

The first consideration, a rank order of effectiveness among blinking arrows, sequencing arrows, and sequencing chevrons in effecting the lane closure, spurred us to perform a second study, which used a forced-choice technique to single out a superior arrow configuration.

The second and third considerations, shoulder placement and caution mode presentation, dictate further refinement and replication of the study to make definitive conclusions. This was not within the scope or the resources of this project. However, the shortcomings of this study should be pointed out so that future efforts can attempt to clarify these points.

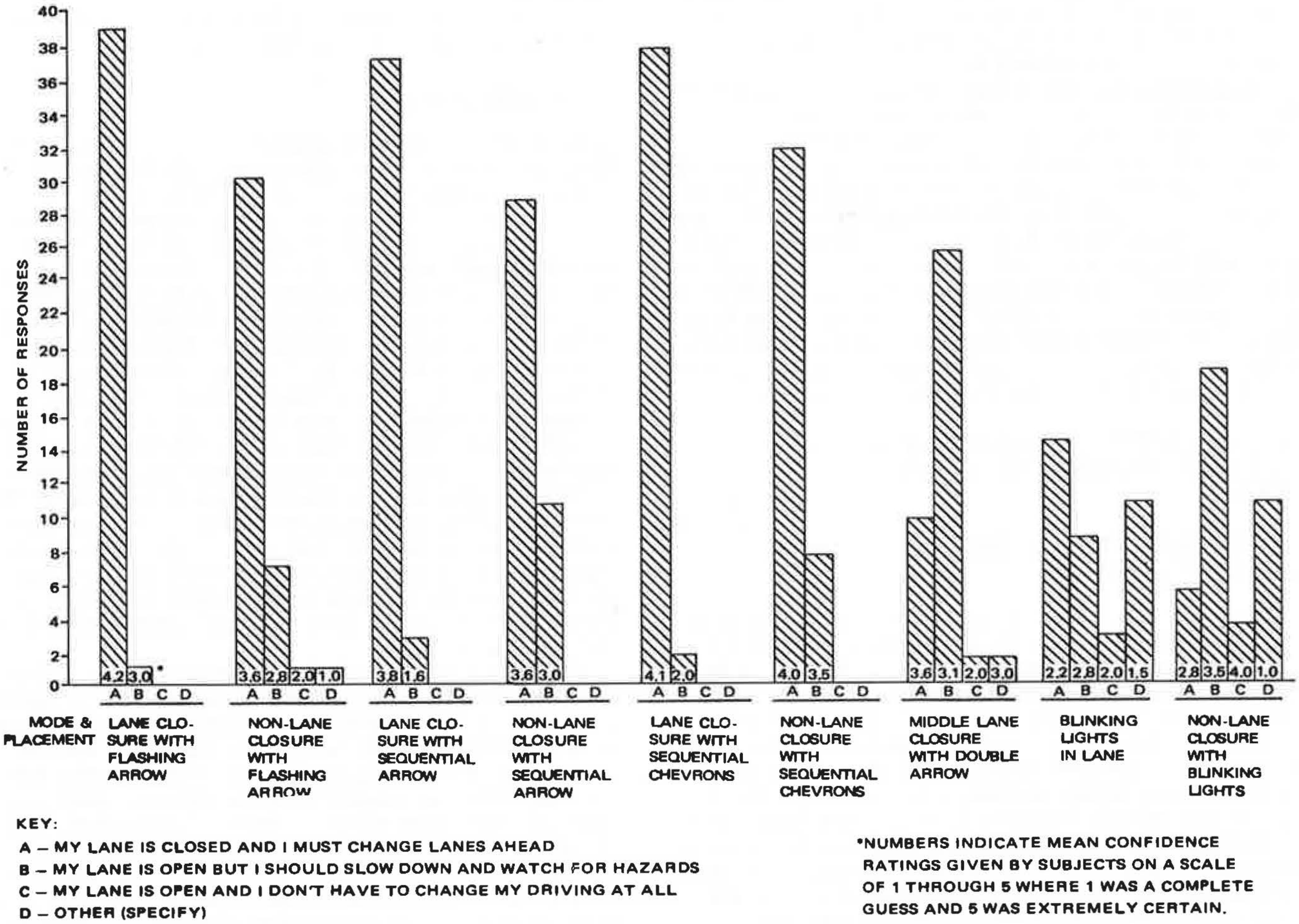
Since the film efforts, sample size, and composition were limited and unrefined, data analysis did not proceed beyond qualitative inspection. Given the opportunity to repeat this study, the first refinement would be a much improved series of film clips, which would clearly show the difference between shoulder placement and lane placement. The respondents who viewed the film clips expressed much confusion on this matter. The second refinement would be to obtain a larger, more representative sample of the driving population, perhaps as many as 100 respondents. In this way, some statistical stability in responses would be gained, and some analysis could be made of the demographic variables of age, sex, and driving experience. Finally, the confusion about the caution mode-blinking lights configuration suggests that this display ought to be evaluated as a separate entity to determine optimum caution configurations and whether, in fact, the arrow board is appropriate for this message at all. The need for experimental investigation into this matter is apparent.

Study Number 2

This study addressed the question of whether the three arrow configurations (blinking arrow, sequencing arrow, and sequencing chevrons) relay essentially interchangeable messages in directing the driver to vacate a lane, or whether one mode is clearly superior and more effective in conveying this meaning. Six short film clips were prepared to present two modes simultaneously, side by side, so respondents could choose one in a paired-comparison experimental model. Given three modes, six pairs for comparison required evaluation (22):

Trial	Left	Right
1	Sequential arrow	Blinking arrow
2	Sequential arrow	Sequential chevron
3	Blinking arrow	Sequential arrow
4	Blinking arrow	Sequential chevron
5	Sequential chevron	Sequential arrow
6	Sequential chevron	Blinking arrow

Figure 2. Summary of results, analytical study no. 1.



Consequently, two arrow boards, side by side, were filmed flashing the above pairs. The six short clips were then shown to a subject sample of 109 drivers at the Midwest Research Institute and the Federal Highway Administration (FHWA). The respondent's task was simply to indicate, by checking either left or right, which mode of the two presented in each film clip best conveyed the meaning of lane closure. A summary table of results in Table 1 shows the proportion that selected each mode for each of the six cells.

It was judged appropriate to go no further in data analysis than simple inspection since this was a preliminary study and the sample was not representative of the driving public. As can be seen, the blinking arrow and the sequential chevrons clearly outdistance the sequential arrow. However, the blinking arrow and the sequential chevrons do not separate out significantly between themselves, which indicates that these might be interchangeable in their use. These data, added to evidence available from the literature, suggest some reasons to advocate the blinking arrow over the chevrons: (a) the California study (5) showed the superiority of a blinking mode at night; and (b) human factors design principles suggest some target-value advantage for a single on-off flashing operation rather than a multiflashing array (12, 13, 22).

Summary

It is apparent that the flashing arrow board, operating in a directional mode, connotes lane closure ahead. Other uses of the board, such as cautionary devices on a shoulder or flashing a cautionary display, are confusing to the driver, interfere with other necessary control functions, and may even cause him or her to initiate and negotiate a lane merge when one is not necessary (5). The presence of an arrow board that does not serve as part of a lane closure operation is a particularly hazardous situa-

Table 1. Selection of arrow-board display modes in six-paired comparison trials.

Trial Number	Left	Proportion Selecting (%)	Right	Proportion Selecting (%)
1	Sequential arrow	23	Blinking arrow	77
2	Sequential arrow	30	Sequential chevron	70
3	Blinking arrow	63	Sequential arrow	37
4	Blinking arrow	55	Sequential chevron	45
5	Sequential chevron	67	Sequential arrow	33
6	Sequential chevron	41	Blinking arrow	59

tion. The use of arrow boards for other than lane closures (e.g., diversion or detour) should be addressed by further research. It seems most efficacious to restrict its use to lane closure to conform with the meaning drivers now associate with it.

In addition, the arrow-board display seems to convey its message best when it operates in a single on-off blinking-arrow mode. Although the sequential chevron provides a strong directional indication to the driver, it must go through three pulses to convey its message as opposed to two pulses for the blinking arrow. The meaning of the three pulses has a greater tendency to be degraded if displayed at night, blocked by large trucks, or when diffused under adverse weather conditions (because of the tremendous amount of light given out on the final pulse) (2). Further research into these questions with a larger, more representative sample of drivers under various ambient light conditions is recommended.

HUMAN FACTORS CONSIDERATIONS RELATED TO DESIGN OF ARROW BOARDS

Performance Criteria Versus Engineering Criteria

The crucial issue, from a human factors point of view, is simply to ensure that the arrow board displays its directional image well in advance of the hazardous lane closure ahead, so that the driver is able to safely and effectively merge his or her vehicle into a parallel lane. The actual engineering details of how the board is made to operate in this fashion are secondary to its effectiveness in conveying this warning message to the driver. The human factors research does not, therefore, suggest quantitative absolute dimensions for building arrow boards. What it does is dictate how arrow boards must perform so that engineers can build them to meet these performance criteria as technologically and cost-effectively as possible.

The basic concept behind use of the arrow board is to warn of a hazard and to effect a proper behavioral response from the driver. Viewed in this context, then, the sighting of an arrow board is subject to principles developed in decision sight distance (DSD) research. DSD has been defined in concept as (23)

> The distance at which a driver can detect a signal (hazard) in an environment of visual noise or clutter, recognize it (or its threat potential), select appropriate speed and path, and perform the required action safely and efficiently.

As applied to arrow boards, these devices serve as warnings of the hazard ahead, and thus their signal must be detectable from recommended distances, which are derived from experimental research on DSD. One useful table of such design distances is found in a report by McGee, Moore, Knapp, and Sanders (24), which found that, at an operating speed of approximately 90 km/h (55 mph), DSD for the hazard should be approximately 305 m (1000 ft). A table of similar values for various design speeds is found in Table 2. In essence, the flashing signal must be detectable and clearly recognized by 99 percent of the drivers at an absolute minimum distance of 2.4 km (1.5 mile). To provide for high traffic densities, which limit safe gaps for merging, and occasional high-speed drivers, an optimum performance standard is as follows:

1. Presence of blinking lights detectable at 2.4 km,
2. Arrow symbol and direction of arrow recognizable at 1.6 km (1 mile),
3. Above conditions possible for 98 percent of the driving public, and
4. Above conditions possible for both day and night conditions, urban and rural freeways.

Design Characteristics

In light of the above recommendations of a DSD guideline, the literature demonstrates that flashing warning lights have a high attention value well in excess of that required for detection (2, 14). Many research studies in the applied psychological literature indicate the assets of flickering lights (25) and brightness contrast in this original detection task (26). In fact, Swezey (27) speaks of the crucial importance of brightness contrast of the target against its background: Flashing lights against a flat black produce maximum effectiveness. In this same vein, target size and luminance are addressed as a signal detection task by recent researchers (28, 29). Also, Benignus and others (30) demonstrated experimentally that steady-rate signals are superior in influencing and capturing the attention of subjects as the rate of on-off flashes increases. This is in agreement with the findings of Ruden and others (14). When these experimental findings are matched with current design specifications available on arrow boards now in use, no drastic design changes from a human factors point of view are necessary.

Consider a brief inventory of five typical arrow-board manufacturers' design specifications, as given in Table 3 (6-9, 34). The size of the boards available [all approximately 123×246 cm (48×96 in)], the lens size, and the flash rates (for warning devices only—no symbolic message included—flash rates in the 50-230/min range are optimum, but where an arrow must be recognized, slower rates of 40-50/min are optimum) are all reasonable for signal detection well in advance of the prescribed minimum sight distance of 305 m (1000 ft). Current arrow boards are more than adequate as detectable light sources for the optimum sight distances noted earlier. However, research does not describe arrow recognition distances. Our informal observations suggest that arrows are recognizable at approximately 1.6 km (1 mile) away, but further testing is recommended.

A note may be made here about manufacturers' visibility specifications. Some definition should be given of visibility: detection of the signal lights themselves or recognition of the arrow as a signal. The latter should be specified as the criterion, and a standard method should be established for testing conformance to the criterion.

Human factors considerations may be centered around some degradation of the board's capabilities, as a function of placement and sight distance available. Two points might be made. First, on a high-speed, controlled-access facility, where a lane closure is initiated by the flashing arrow, a sight distance of more than 1.6-3.2 km (1-2 miles) for the arrow board may actually constitute a hazard, since this sighting is usually not a recognition of the arrow image (2, 14). In this regard, a bigger, more powerfully flashing target, upgraded from those already available, might inspire a real hazard too far in advance of proper assimilation of the intended message. Second is a point related to the high-powered nature of the image displayed and questions arrow board use on freeways versus arterial locations. It seems intuitively obvious that in most urban arterial locations, other devices for channelizing and diverting traffic would be much more cost-effective than an arrow-board display in an already close-up, slow-moving corridor. These questions of excessive sight distance in

Table 2. Recommended DSD.

Design Speed (km/h)	Premaneuver: Detection and Recognition (s)	Premaneuver: Decision and Response Initiation (s)	Maneuver—Lane Change (s)	Total (s)	DSD (m): Computer	DSD (m): Rounded for Design[a]
40	1.5-3.0	4.2-6.5	4.5	10.2-14	113-156	120-160
60	1.5-3.0	4.2-6.5	4.5	10.2-14	170-233	170-230
80	1.5-3.0	4.2-6.5	4.5	10.2-14	227-311	230-310
100	2.0-3.0	4.7-7.0	4.3	11.2-14.5	306-397	310-400
120	2.0-3.0	4.7-7.0	4.0	10.7-14	357-467	360-470
140	2.0-3.0	4.7-7.0	4.0	10.7-14	416-544	420-540

Note: 1 km/h = 0.62 mph; 1 m = 3.28 ft.

[a] Rounded up to the nearest 10 m for the low value and up or down to the nearest 10 m for the upper value.

Table 3. Inventory of typical arrow-board specifications.

Manufacturer/Model	Size of Board (cm)	Lens Size (cm)	Lens Type/Color	Lens Lamp[a] (cd)	Flash Rate per min	Duty Cycle, On/Off (%)	Visibility (km)	Contrast (color of back panel)
Casell Early Warner III	99 × 192	12.8	PAR 46 amber	8630	30-40	50	Arrow—4.8 Chevron—3.2	Flat black
Dietz arrowboard	123 × 246	12.8	PAR 46 amber	8630	30	50	N/A	Flat black
EMPCO-Lite #6075 "The Hydra"	123 × 246	12.8	PAR 46 amber	8630	30-55	50	N/A	Flat black
Protect-O-Flash Advance Warner	123 × 230	12.8	PAR 46 amber	8630	50	50	N/A	Flat black
Royal Signal System's Tri-Function	123 × 246	12.8	PAR 46 amber	8630	35-50	50	N/A	Flat black

Note: 1 cm = 0.39 in; 1 km = 0.62 mile; 1 cd = 1.02 candle power.

[a] All manufacturers' specifications state that automatic dimmers are available and that they commence dimming when ambient light drops below 4.9 cd.

arterial situations should be resolved by further research. No available literature documents this question.

Since typical arrow boards, such as those specified, generally display as much as approximately 129 400 cd (132 000 candlepower) at a flash rate of 30-55 flashes/min, this powerful image may need to be dimmed as ambient light conditions darken. Thus, the automatic dimming feature found in most boards is commended and advocated (see note to Table 3).

Summary

The current design specifications for arrow boards are more than adequate to meet display criteria. In fact, the displayed image may be overwhelming in some situations (i.e., urban arterials) and indiscernible as an arrow, if even detectable as flashing lights [i.e., >3.22 km (2 miles) sight distance]. To reiterate the salient point, the arrow board is in service to divert traffic from a lane to be closed ahead. Manipulation of lenses, board sizes, heights, lens spacings, and board mountings conceivably may be manipulated for optimization from a technical viewpoint.

However, the key is that the arrow be displayed clearly and distinctly, so that drivers recognize a need to perform a safe merge maneuver. This decision point will be dependent on the geometries of the lane closure involved and, therefore, an individual judgment in each situation, based on the performance criteria supplied above.

HUMAN FACTORS CONSIDERATIONS RELATED TO ARROW-BOARD OPERATION

Design and operations of any system are contingent on one another. For example, currently available and recommended flash rates for arrow boards are found in Table 3 and mentioned previously, but these are also items of arrow-board operation. The flashing lights themselves, in terms of luminance, intensity, and glare, are important to vehicle control as the driver encounters the flashing display. Other variables to be addressed in arrow-board operation pertain to placement, angularity, and ambient light conditions.

Light Intensity-Glare

The arrow board displays as many as 10 bulbs of 8630 cd (8800 candlepower) each at once, which is an intensity of approximately 86 300 cd (88 000 candlepower). This is intense enough to capture the attention of the driver, as shown in various studies (2, 14, 32, 33). Again, the power of the flashing image is such that a vehicle passing close up may be subjected to a glare condition, especially at night or in inclement weather (2). Also, this much light completely eliminates a driver's adaptation to darkness. This could pose a problem for drivers when it is quite dark (i.e., no artificial illumination) past the arrow board. Two simple design principles address this potential problem: (a) lens hoods found on arrow boards and (b) automatic dimmers found on most arrow boards. The lens hoods recommended are the 360° type, which encase the entire lens, and not the 180° traffic light type found on some boards. The 360° lens hoods are best at capping dispersed light to passing drivers and, in turn, direct the flashes outward in a straight line, perpendicular to the board. Other techniques could be used but are probably not as cost-effective. One alternative is a focused lens and the other is a polarized lens. If an arrow is not recognizable at 1.6 km (1 mile), these same techniques could be used to improve arrow definition and, hence, recognition distance.

Since no empirical data were found to document the glare problem of arrow boards, particularly at night, we conducted a brief field investigation of this phenomenon. In this investigation photometer readings of the ambient conditions, the background of the board, and the lamps themselves were recorded. These readings were taken after dark. Various subjects were asked to drive toward the arrow board and tell when they experienced

1. Detection of the arrow board as a flashing signal,
2. Recognition of the arrow image,
3. Beginning of image deterioration (glare or distortion), and
4. Any discomfort because of light intensity (glare).

The experiences reported by the subjects were expected. First detection from afar consisted of a flashing set of lights. Second response, some distance later, was the resolution of an arrow board. Not until in very close proximity to the arrow board did the subjects experience a discomforting glare sensation—from approximately 30.5-61.0 m (100-200 ft) up to parallel with the board. This was a conservative situation, in that heavy traffic created ambient light before and after the arrow board. This item is crucial, however, since motorists can be blinded in a split second and perform a dangerous swerving maneuver or completely lose their adaptation to the dark after going past the arrow board. We can assume that the glare effect near the arrow board is enhanced in fog and other inclement conditions (2). Since the effect occurs only in fairly close proximity to the arrow board, it seems particularly imperative to use the 360°-lens hood on each lamp. This way, the driver will be protected from the then extraneous flashes when he or she is parallel to the arrow board. A final word might be said to advocate a further dimming potential of the boards. Current capabilities commence dimming of luminance as ambient conditions fall below 4.9 cd (5 candlepower). This could be upgraded to be more sensitive to inclement weather conditions and begin dimming with lesser diminution of daylight. Also, a further reduction of intensity (5 to 10 percent) at night would probably not degrade arrow-board performance and would have a small impact on glare reduction but probably would not result in design or operational savings.

Angularity and Placement

The literature addresses the question of angularity of alignment with respect to the oncoming driver, in most cases, based on the general human factors design principles for visual displays. In general, a driver is best attracted by a straightforward, direct image, which attracts his or her attention and conveys the intended message (13). This means that optimum placement of the arrow board is head-on to the driver, perpendicular to the shoulder of the roadway. Any slight deviation of this would probably be appropriate only in a curved roadway situation, where the driver might encounter the arrow board from other than exactly head-on. This is consistent with the intent of the arrow board to move drivers out of a lane, not to change driver behavior in all lanes of travel.

The placement issue can be looked at from two dimensions: (a) shoulder versus lane placement and (b) beginning of cone taper in a construction zone versus deeper into the zone. The shoulder versus nonshoulder question is directly related to the meaning conveyed by the directional arrow board. Since the empirical data and various literature sources indicate that the arrow board connotes lane closure, the most effective placement of the board is directly in the lane that is being closed. The role of the arrow board on the shoulder to indicate some warning of hazards was discussed earlier. Placement of the arrow board at the beginning of the lane closure in a construction zone is the most effective position for the driver. This is documented by various research reports [i.e., Graham and others (19)] and many state highway traffic manuals [i.e., New York State (3)], which advocate this placement. This placement is also in accordance with experimental evidence (33). In this study, the symmetry of the visual pattern of the construction zone was violated if an arrow board was placed deep in the zone. The primary function of the arrow board is to give the driver initial warning from afar that a hazard situation is ahead and that a lane shift is required. After the driver nears the zone, the other channelizing devices, such as cones and barricades, direct the driver. Therefore, arrow-board placement is most efficacious at or very near the beginning of the lane closure because it is the first signal to be recognized and processed.

The implementation of arrow boards must be correct or their advantages will be lost. For example, on local highways, a contractor was observed to have placed an arrow board and other devices at exactly the distances specified by a state-prepared plan. However, the arrow board was over the crest of a hill and could not be seen until drivers were within a few hundred meters of the zone.

Ambient Light Conditions

Most factors of importance related to the use of arrow boards under varying ambient conditions have been alluded to in previous sections. The California study (5), for example, tested the effectiveness of arrow boards in causing drivers to shift lanes and demonstrated the superiority of the flashing or blinking on-off arrow over sequencing chevrons at nighttime. It is also documented that flashing lights, in general, are a strong beacon and attract immediate attention at night (2, 14) but fade to near indiscernibility in bright sunlight. Since most arrow boards have automatic dimming features, which can also revert to manual controls, the primary recommendation in this regard is to expand both the upper and lower limits of intensity capabilities so that the arrow board may be automatically or manually as sensitive as possible to changing ambient conditions. As stated in one report (2): "Viewing conditions are often far less than optimum due to glare, fog, and rain, and moving or intermittent visual signals are several times more likely to be detected than nonmoving or steady signals under the same viewing conditions." As such, this information is adapted from research on barricade flashing lights and railroad grade-crossing signal lights. No empirical evidence exists about signal detection of the arrow image under various adverse ambient conditions, except in the California study (5), which was limited in scope.

Arrow-Board Height

Current mounting heights, whether on a trailer or truck, appear adequate for arrow boards to meet the performance criteria recommended above. Further raising of the board would not prevent possible visual blockage by trucks but would add to the expense of the device. Therefore, no changes are recommended, at least from a human factors viewpoint.

CONCLUSIONS

The human factors considerations relevant to the flashing arrow board are exclusively devoted to enhancement of its performance as a powerful advance warning signal of a hazardous zone ahead. It was deemed crucial to determine the exact nature and meaning that the directional arrow image conveys to the driver. Initial empirical evidence was presented to show that it most often means to vacate a lane ahead. Since the use of the arrow board is becoming more widespread and encouraged by various highway agencies, it is most beneficial to exploit the power of this device to connote lane closure, and lane closure only, and to use other methods for other traffic hazard situations.

The arrow-board design and operation can be manipulated and optimized according to engineering expertise, but drivers require a discrete, clear directional arrow as an indication of lane closure. Violation of this, either in design, operation, or use of arrow boards for other traffic management purposes, places an uncertainty within drivers as to exactly what their behavior should be.

Recommended Arrow-Board Practices

1. The preferred operation of the arrow board is in the single on-off blinking-arrow mode;
2. The blinking arrow should not be used as a cautionary display only (i.e., for shoulder work);
3. A 360°-lens hood should be used to cap dispersing light to passing drivers and to direct the flashing lights outward in a straight line, perpendicular to the arrow board;
4. Dimming of luminance could be upgraded to be more sensitive to inclement weather conditions and to begin dimming with lesser diminution of daylight; and
5. Arrow boards should be placed at the beginning of the taper (construction zone).

The other typical design features (i.e., board size, color, lens type, and flash rate) of arrow boards meet basic human factors recommendations.

Recommendations for Further Research

1. Can arrow boards be used on arterial streets?
2. What configuration should be used for other than lane closure? (All possible light configurations for an arrow-board matrix were described and judged by two traffic engineers and two human factors engineers as candidates for a warning signal. Two candidates survived, and are suggested for further developmental research. The first is two "X" symbols wig-wagging back and forth. The second candidate is slashes, which would angle away from the shoulder or in the direction of a diversion. Both symbols would be used in the blinking, not sequential, mode.)
3. How are arrow boards detected under various ambient conditions?

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Experimental Evaluation of Markings for Barricades and Channelizing Devices

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The study reported in this paper attempts to determine quantitatively the optimum design characteristics of channelizing devices. This was accomplished by performing a series of four laboratory studies. The following marking parameters were studied: (a) the design and configuration of stripes, (b) the width of stripes, (c) the color ratio of stripes, (d) the meaning of various design configurations, and (e) the detectability of visible areas (height to width combinations). For each of the experiments, 30 drivers recorded their detection and identification responses to stimulus slides, which were presented tachistoscopically. Data reduction consisted of analyses of a derived index score, which was a summary of the total response. The results allow some limited recommendations regarding channelizing: (a) optimal stripe width is a 20- or 15-cm (8- or 6-in) stripe for 15 cm or greater rails, (b) desirable ratio of white-to-orange coloring favors equal white to orange or more white, (c) optimal stripe design configurations are first vertical then horizontal, (d) chevrons connote directional meaning to drivers, (e) vertical panels elicit better performance than horizontal bars or trapezoid shapes, (f) there was little useful difference between type 1 and type 2 barricades, and (g) a tall, narrow vertical panel image is recommended over a shorter, wider device.

This research consists of four laboratory examinations of the design and marking configuration of orange and white stripes as displayed on a number of panel and barricade forms. This research serves a need to standardize and make uniform the displays on traffic controls through and around construction zones, since the safe and efficient movement of traffic through these zones is a crucial issue today. The objective is to provide a quantitative evaluation and recommend optimal designs for use of traffic-control devices in work zones. The recommended designs will be further tested later in the closed and full field evaluation tasks of the National Cooperative Highway Research Program (NCHRP) study on evaluation of traffic controls for street and highway work zones.

EXPERIMENTAL METHOD

A primary driver activity is the acquisition of visual information about the highway and its immediate environs. A wide variety of visual configurations confront the driver, who must constantly search the roadway for appropriate guidance and navigational cues. This search and detection process is particularly important in a work or construction zone setting, where there are unexpected changes in the roadway and many distracting visual cues.

A laboratory setting was used to investigate traffic-control-device markings for construction zones. Although a laboratory experiment is not intended to be a direct simulation of the driving task, it can be made more relevant if the subjects' tasks are similar and the information load is similar to that of driving. To accomplish this, a general experimental method that emphasizes search and detection performance was designed.

A visually noisy and fairly abstract background was created. Four of these pictures were placed together to form a square; each quadrant of the square was the same picture. Small stimuli [e.g., bar or panel of a particular stripe width, orange-to-white color ratio, height-to-width ratio, and stripe design (horizontal, vertical, 45° slant, chevron)] were placed on one quadrant of the square, and another picture was taken. The resultant slide was then projected tachistoscopically at a fast speed (0.4 or 0.8 s). The subject's task was to search the four quadrants, identify the type of design, and identify the shape (bar or panel). Figure 1 presents selected samples of the device stimuli used for each of the four studies. The placement of device stimuli was completely random in the slides both for choice of quadrant and placement within the quadrant.

The measures of performance by subjects responding to these stimuli were, thus, a Q-score-quadrant detection, C-score-configuration identifica-