Photometric Requirements for Arrow Panels and Portable Changeable Message Signs

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Arrow panels and portable changeable message signs are often used in work zones to inform drivers of the need for a lane change or caution. The *Manual on Uniform Traffic Control Devices* (MUTCD) requires that Type C arrow panels have a minimum legibility distance of 1.6 km (1 mi). However, the MUTCD does not provide a subjective means for determining whether an arrow panel meets this criterion. Nor are there industry photometric standards for message panels. The purpose of this project is to develop a reliable and repeatable objective method for measuring the photometrics of arrow and message panels to ensure adequate performance. The research project tasks include a review of the state of the art, reviews of existing pertinent specifications, development of initial test methods, evaluations of arrow and message panel visibility and the effectiveness of the test methods, revisions and modifications of the test methods, and documentation of research activities and findings. The research findings will be described in a research report and a project summary report. The recommended test methods will be included in both documents.

Arrow panels (APs) and portable changeable message signs (PCMSs) are often used in work zones to communicate important information to road users. An AP is used to indicate the need for a lane change or caution on the part of the driver, whereas a PCMS is used to convey dynamic information that is not effectively communicated through static signing. Portable changeable message signs are sometimes referred to as message panels, and that term is sometimes used in this paper to denote a PCMS.

Although arrow and message panels have been used in traffic control applications for many years, there are no established photometric standards for either device that can be used as the basis for a procurement specification. For example, with arrow panels, the only provision related to visibility of these devices is a requirement in the *Texas Manual on Uniform Traffic Control Devices* (MUTCD)—*Part V1* W that indicates the minimum legibility of a Type C panel is 1.6 km (1 mi). There are no specifics that indicate how that legibility distance is measured. For message panels, the Texas MUTCD requires the sign to be visible at 0.8 km (½ mi) and the sign message to be visible at 200 m (650 ft). Again, there is no guidance on how these visibility requirements should be measured.

As a result of the lack of detailed measurement requirements, transportation agencies experience difficulty developing specifications that ensure that all arrow and message panels purchased by the agency will communicate the desired information to drivers in an effective and consistent manner. This research presents Texas Transportation Institute's (TTI's) plan for developing test methods for measuring the photometric properties of Type C arrow panels and portable changeable message signs. The intent of the test method is to provide the Texas Department of

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Transportation (TxDOT) with a measurable criterion for qualifying arrow and message panels for use on TxDOT projects.

Background and Significance of Work

Compared with most other types of traffic control devices, arrow and message panels are relatively new. Arrow panels were added to the national MUTCD in the late 1970s, and PCMSs were added in 1993. The body of research literature on arrow and message panels has primarily addressed the placement and effectiveness of the devices, with little research on their legibility and photometric properties. This can be attributed to the fact that, until recently, arrow and message panels used diesel-powered incandescent lamps, and the performance was sufficient. However, the introduction of solar-powered arrow and message panels, combined with the use of flip-disk and light-emitting diode (LED) technologies, has created concerns about the ability of these devices to meet the minimum legibility requirements.

MUTCD Principles for Arrow and Message Panels

The unique characteristics of work zones require a level of traffic control that is beyond that normally required for a typical roadway. Many work zones present conditions that drivers would not typically expect to encounter. To provide drivers with the information needed to safely maneuver through a work zone, traffic engineers in the United States have developed a series of traffic control standards and guides for work zones. These guidelines, which are part of the MUTCD, address the traffic control elements of work zones and the use of various traffic control devices in the work zones. These principles are known as Part VI of the MUTCD. At the national level, Part VI was revised in 1993 and published by FHWA as a stand-alone document. In Texas, the TxDOT version of Part VI establishes the practices for work-zone traffic control. As with the national version, TxDOT recently revised Part VI and published it as a stand-alone document. There are only minor differences between the national and Texas documents.

Arrow panels are unique to work zones. They present a flashing or sequential display that informs drivers of the need to change lanes or drive with caution. The current guidelines for the design and application of arrow panels are contained in Section 6F-3 of the Texas Part VI. There are three types of arrow panels: A, B, and C. The Type C arrow panel, which is the subject of this proposal, is intended for use in high-speed, high-volume work zones. It has a minimum size of 2438 by 1219 mm (96 by 48 in.), with a minimum of 15 elements, and has a "minimum legibility distance" of 1.6 km (1 mi). Each type of arrow panel is capable of displaying a single flashing arrow (left or right), sequential chevron (left or right), a flashing double arrow (left and right), and caution (bar or four-corner box). The national Part VI also defines a sequential arrow, but this display has been dropped from the Texas Part VI.

Portable changeable message signs are described in Section 6F-2 of the MUTCD. This section requires the PCMS to be visible at 0.8 km (½ mi) and the sign messages to be legible at 200 m (650 ft).

Arrow and Message Panel Technologies

The early arrow panels and many message panels were diesel-powered and used incandescent lamps. These devices could produce displays seen at great distances and wide angles. They also produced operational and maintenance difficulties, creating environmental nuisances with fuel spills, fumes, noise, and glare. The lamps used in these panels were typically automotive fog lamps, which could be purchased easily at an automobile parts store but had little quality control for lens color, intensity, or filament orientation.

With the development of solar technology in the last few years, solar-powered arrow and message panels have been introduced as alternative traffic control devices for work zones. These units were quiet and environmentally friendly, requiring no fueling and little maintenance compared with their diesel counterparts. However, as with most new technologies, performance and quality were spotty across the breadth of the early manufacturers. When they were required to meet the same MUTCD legibility requirements as the diesel-powered arrow panels, issues of lamp intensity and lamp angularity emerged. Lamps used in diesel-powered arrow panels are higher wattage than the lamps used in solar-powered arrow panels and therefore have a much greater luminous intensity. Furthermore, diesel-powered arrow lamps can typically maintain visibility with an angularity of more than ±20 degrees horizontal and ±5 degrees vertical, whereas solar lamps typically maintain visibility with an angularity of ±12 degrees horizontal. Newer generations of solar-powered arrow panels have increased lamp technology research to address these visibility concerns, which in turn produced higher levels of quality control in lamp design and engineering. LED lamps are one of the lamp innovations that have become common, particularly in PCMSs.

NCHRP Arrow Panel Research Project

Concerns over the visibility of the solar-powered arrow panels led to a recent research project on arrow panel visibility sponsored by NCHRP. Before the initiation of the NCHRP study, there had been very little research on the luminous intensity required to provide visibility of arrow panels. Commercially available arrow panels using different bulbs and power systems provide varied levels of visibility because there are no performance standards. This variation is most evident in solar-powered arrow panels, which offer operational advantages but may not provide visibility levels comparable with those of generator- or line-powered units. The project was needed to ensure that arrow panels provide adequate visibility and adhere to performance requirements based on the critical visibility factors, and because of a need for practical procedures that can quickly and easily evaluate in-service performance of arrow panels. NCHRP Project 5-14, Advance Warning Arrow Panel Visibility, was conducted to

- Identify and evaluate the factors affecting the detection and recognition of arrow panels,
- Develop performance requirements for arrow panels operating under various conditions, and
- Develop practical, reliable means for checking arrow panel visibility, as perceived by the motorist.

Research Activities

The research plan for this project was developed and conducted by the Last Resource, Inc. (LRI) of Bellefonte, Pennsylvania. The research activities took place over a period of 3 years and were funded at $275,000. (It is worth noting that LRI will be the subcontractor to TTI for the proposed TxDOT arrow panel research project.) The NCHRP research included the following research activities:

- Review existing literature and current practices to identify factors that affect arrow panel visibility, including light source, intensity, beam pattern, color, electrical power consumption, panel size, panel and light source orientation, ambient lighting levels, dimming capabilities, sun shading, and power characteristics.
- Identify current practices for utilization, placement, maintenance, and in-service evaluation of arrow panels by contacting public agencies, utility companies, construction and maintenance contractors, and other users.
- Prepare an experimental plan and conduct the evaluation of the factors affecting the visibility of arrow panels. The evaluations include laboratory experiments; laboratory and field tests, analytical studies, computer simulations, or other procedures that cover a practical range of field situations; driver characteristics; day, night, and transitional ambient lighting conditions; and other environmental situations.
- Based on the findings of previous tasks, develop technical requirements necessary to ensure adequate arrow panel visibility.
- Develop simple, straightforward procedures for use by maintenance and field personnel to assess the adequacy of in-service arrow panel visibility and to initiate simple corrective actions to improve visibility, if necessary. Because arrow boards must provide reliable, consistent operation under a variety of field conditions, including highly variable ambient light levels and different roadway geometry, the procedures must be sensitive to these conditions.
- Prepare a final report that includes the requirements and procedures developed as appendices.

An arrow panel mock-up was an important tool in the conduct of the static field evaluations of arrow panel visibility. The mock-up was used to determine the optimal and minimal photometric requirements for daytime legibility among younger and older drivers. It was built to the specifications of a typical Type C AP and was mounted on top of a van at the recommended MUTCD specification for height. A laptop computer controlled the flash rate and stimulus, and set intensity levels through a digital interface that varied the voltage by pulse width modulation. When equipped with GE 4412A diesel-type lamps, the mock-up panel is capable of producing lamp intensities of more than 2,000 candelas. The evaluation results indicated that the lamp intensity needed to accommodate virtually all drivers at a threshold level was in the range of 30 to 50 candelas.

In a follow-up dynamic evaluation, LRI evaluated performance as a function of arrow panel model with test subjects in a moving vehicle. The results indicate that the 100-candela arrow panels had a 95th-percentile identification distance of 473 m (1,552 ft), which is greater than the decision sight distance of 457 m (1,500 ft). In the dynamic evaluation, arrow panels with the 50-candela intensity established by the static evaluation had a 95th-percentile identification distance of 296 m (971 ft), a distance too low for high-speed roads but acceptable for low-speed roads.

Current Status

This project has been completed by LRI, and the report is currently under review by the NCHRP panel. Included in the report are procedures for

- Arrow panel photometric measurements,
- Maintenance personnel (to ensure proper visibility of arrow panels during repair), and
- Field personnel (to ensure visibility of arrow panels while in service).

The report is expected to be published by NCHRP in the near future.

Project Results

The results of the research have been summarized in one published paper. The research supports the use of 100 candelas as the minimum arrow panel intensity needed for daytime identification in high-speed situations and 380 candelas/lamp as the maximum allowed to control glare at night. The research suggests the intensity requirements shown in Table 1. These recommendations are based on the assumption that, for high-speed roads, the arrow panel message must be properly identified at 457 m (1,500 ft) at any viewing angle that meets appropriate geometric design standards. This distance provides a more-than-adequate decision sight distance for driver safety. With regard to angularity, accepted geometric standards indicate that arrow panels should be legible at ±8 degrees horizontal and ±3 degrees vertical on high-speed roads.

In summarizing the project findings, the researchers stated "that an arrow panel with lamps that meet the minimum intensity requirements within the suggested beam width requirements will not only better provide for motorist safety than the requirement for 1 mile legibility in the MUTCD, but also enable more cost-effective operation. The MUTCD requirement for 1 mile of legibility should be changed because it fails to guarantee visibility at any angle of viewing other than on-axis. 1 mile off-axis requirement is just not practical or necessary." The researchers also note that most, if not all, arrow panels that conform to the proposed requirements will also meet the current MUTCD 1-mi legibility requirement because the MUTCD does not specify observer age or viewing angle.

Arrow Panel Specification

The researchers considered two approaches for developing photometric specifications for arrow panels: in terms of either the entire panel or each individual lamp. Due to the ease of testing, the individual lamp approach was selected. The photometric requirements for arrow panels can be represented in terms of luminance (candelas per square meter) or in terms of luminous intensity (candelas). Luminous intensity was selected because at 300 m (984 ft) and beyond, the lamps on an arrow panel are clearly point light sources. The specification is based on the intensity and angularity requirements shown in Table 1. The required intensity levels in the specification were developed from the static and dynamic evaluations. However, the angularity requirements were developed from typical road geometries described in the AASHTO Green Book. The intention was to provide a structured framework for a department of transportation to develop its own angularity requirements based on typical road geometries found in the state.

Arrow Panel Photometric Measurement Procedures

One of the results of the NCHRP project is a potential procedure for measuring the photometric properties of arrow panels. An early version of the procedure is described in an appendix of the NCHRP report, and a more refined version of the procedure was presented at a recent Illuminating Engineering Society of North America conference and has been published in its publication. In essence, the procedure uses a luminance meter to measure the luminance and converts the measurement to an intensity value. The procedure can be used when the target source is small and does not fill the aperture of the luminance meter.

Unanswered Questions

As with most research projects, the NCHRP/LRI effort was not able to address all the issues associated with the visibility of arrow panels. A few of the unresolved issues that remain after completion of that study include the following:

- The legibility evaluations were conducted only in the daytime. The nighttime intensity levels were developed using the method for traffic signals, which is basically a 30 percent reduction from the daytime values. There is a need to evaluate legibility under actual nighttime conditions.
- The angularity requirements were developed from the geometric conditions that might reasonably be expected to occur in the field. The legibility evaluations did not include the effects of angularity on identification of the arrow panel message.
- The researchers focused attention on the use of intensity as the basis for the specification. Methods of specifying photometric performance for the entire panel were not developed.

NCHRP Project Implementation

Because the NCHRP project results have yet to be published, it is difficult to predict how the results will be implemented. Because the NCHRP research program is funded through AASHTO, it is expected that state transportation agencies will look closely at the results and consider adoption of the recommended arrow panel specification.

TABLE 1 Minimum Arrow Panel Luminous Intensity Requirements for High-Speed Roads

Situation and Angularity	Minimum (on-axis)	Minimum off-axis (➡8°horizontal, ➡3° vertical)	Maximum (within maximum angularity zone)
Daytime	500 candelas	100 candelas	none
Nighttime	150 candelas	30 candelas	380 candelas/lamp

In October 1998, NCHRP funded a small implementation effort ($15,000) to develop a procurement specification and application guideline for arrow panels from currently available information. This implementation effort, being conducted by TTI, is essentially a paper study to bring all available information together into a format that can be used by transportation agencies for procurement and application purposes.

Validity of Minimum Legibility Requirement

From the initial inclusion in the MUTCD, Type C arrow panels have had a requirement for a minimum legibility distance of 1.6 km (1 mi). Before the NCHRP project described previously, however, there was little research to support the use of this distance. A paper addressing the human factors considerations of arrow panels indicated that the optimal performance standard for high traffic density conditions should be that drivers identify the presence of flashing lights at 2.4 km (1.5 mi) and recognize the arrow symbol and direction at 1.6 km (1 mi). But that paper stated that "research does not describe arrow recognition distances. Our informal observations suggest that arrows are recognizable at approximately 1.6 km (1 mi) away, but further testing is recommended." It appears that the 1-mi legibility requirement was implemented because the arrow panels of that time (i.e., diesel-powered) were legible to most individuals at 1 mi. With the advent of solar power, the legibility requirement has become more difficult to meet, and manufacturers have begun to question the origin and validity of the 1-mi requirement for Type C arrow message panels.

As indicated by the NCHRP arrow panels research, the 1-mi minimum legibility distance requirement for Type C arrow panels is not justified. A more appropriate distance is 457 m (1,500 ft), which is consistent with the decision sight distance for high-speed roads in the original decision sight-distance research and the current AASHTO policy on geometric design.

As with arrow panels, there is little documented research that supports the 650-ft legibility requirement for PCMSs. Again, the requirement is probably based on an assessment of the best visibility distance that can be achieved with current technology.

Photometric Measurement of Arrow and Message Panels

As mentioned previously, the MUTCD requires that arrow and message panels meet a minimum legibility distance requirement. However, the MUTCD does not define the meaning of "minimum legibility distance." Nor does the MUTCD provide specifications for lamp sizes, lamp spacing, luminous intensity (candelas), or power supply. As a result, transportation agencies have difficulty enforcing this requirement when purchasing arrow and message panels. What is legible to one person at the required distance may not be legible to someone else (typically with poor eyesight). Or what is legible when viewed head-on may not be legible when viewed at an angle.

Providing a simple and consistent method of measuring the legibility of arrow and message panels is a complicated undertaking. It is especially complicated for the message panel. An arrow panel can be treated as a point light source, but a PCMS cannot. This makes it difficult to establish a photometric requirement for the overall unit. Some of the factors that complicate the legibility measurement include the following:

- Variations in observers, such as age, acuity, glare sensitivity, and contrast sensitivity;
- Variations in arrow and message panel technologies, such as incandescent lamps, LED lamps, flip-disk, diesel power, and solar power;
- Different displays (arrows, chevrons, and caution);
- The extended length of the legibility requirement;
- Restrictions imposed by the roadway geometry;
- Differences in performance characteristics between arrow panels and PCMSs; and
- Variations in the legibility characteristics of individual characters that can be used in a message panel.

Other complicating factors are the terminology and units associated with photometric measurements. Although the terms "luminance" and "illuminance" sound similar, for example, they have different photometric meanings. A term that is typically used by laypersons, such as "brightness," has no actual meaning. Figure 1 presents a few of the more basic terms used in photometric measurements. The use of metric units is another complicating factor. Photometric measurements have adopted metric units to a much wider extent than most other types of measurements.

Full-System Versus Multilevel Photometric Measurement

A number of methods can be used to measure the photometric quality of arrow and message panels. These methods can be divided into two types: full-system and multilevel. Both methods have advantages and disadvantages. Full-system measurements test the arrow and message panels as a complete system and may be the preferable method from a procurement perspective, but they are also the most difficult to achieve. Multilevel testing makes certain assumptions about how the arrow and

Brightness - The subjective attribute of light sensation by which a stimulus appears more or less intense or to emit more or less light.
Illuminance (E) - The amount of light falling upon an object. It is derived from luminous intensity by the "inverse square law" ($E=I/d^2$) where d is distance. It is expressed in foot candles (fc) or lux (lx).
Luminance (L) - A measure of light reflected from a surface or emitted by a light source, roughly equated to "brightness." It is not affected by distance and is derived from luminous intensity by dividing the luminous intensity by the source area. It is expressed in foot Lamberts (fl) or cd/m^2.
Luminous intensity (I) - A measure of the strength of a light source. It is expressed in candelas (cd).
Point light source - A light source whose detection is not affected by size, only luminous intensity.

FIGURE 1 Photometric terminology.

message panels will work as a system to reduce the test measurement difficulties.

When operating under real-world conditions, the arrow/message panel is functioning as a collection of several different subsystems. Each subsystem directly affects the performance of the panel as a whole. Because of these effects, the photometric quality is best tested when the arrow or message panel is functioning as a complete system. Under these conditions, the interaction of the power supply system and lamp system can be measured and monitored easily. The limitations to the types of measurements that can be made in a full-system test include the following:

1. Sensors cannot be used to measure the individual elements under full-system conditions unless the test setup blocks all extraneous light from the other elements from entering the measurement area of the sensor in question. Due to the close spacing of the elements, blocking extraneous light is very difficult. This means that the panels must be measured as a whole unit by a single sensor device. Accurate methods exist for completing such a test using various types of sensor devices. As with nearly all photometric measurement techniques of this type, a minimum separation distance is required between the sensor and the light source. Because the light source is an approximately 2.4-m (8-ft) wide panel, the separation distance is quite large, approaching at least 30.5 m (100 ft).

2. Assuming the above conditions are met, another limitation of a full-system test deals with the positioning of the panel under test. Arrow and message panels are large and heavy pieces of roadway construction equipment. There are two options for positioning the arrow or message panel for testing at various vertical and horizontal angles. The first is to move the arrow/message panel, but to do this accurately would require a specialized goniometer capable of moving the weight of the panel. Although this is not impossible, few if any independent photometric laboratories are equipped for such a task. Therefore, building specialized equipment would be required. The second approach is to move the sensor. It is much easier to move the sensor through the vertical and horizontal circular paths required to measure various angles. However, if the sensor is placed at 30.5 m (100 ft), an 11-m (36-ft) ceiling would be required in order to measure ±10 degrees vertical. The same is true for horizontal angles. If the laboratory is capable of such dimensions, then accurate full-system measurements are possible.

An alternative to full-system testing is to test the subsystems separately for certain test conditions and to test the complete system only under limited conditions. The main benefit of this approach is that certain tests that are difficult in full-system testing can be easily completed as subsystem tests. Then the required amount of full-system testing can be limited to monitoring the interaction of subsystems under a very limited and easily handled set of conditions. Such a hybrid method of testing could involve the following:

1. The photometric quality of the arrow and message panel lamp system would be measured using multilevel tests on a small number of actual lamps that are used in the panel. These lamps would be tested by independent photometric laboratories using standard testing procedures and standard goniometer equipment. Standard practices already exist for photometric testing of sealed-beam and other types of lamps commonly used in arrow panels. The resultant data would be used to determine whether the lamp under test meets the photometric requirements over the specified vertical and horizontal angular range. If the sample of lamps does not meet the photometric requirements, the arrow/message panel would fail the specification because placing the lamps in the actual arrow/message panel would not increase their effectiveness.

2. After a sample of lamps has passed the multilevel tests, simplified full-system testing would begin. This endurance-type test would monitor the interaction of the

power supply and lamp systems. However, because angularity was previously measured, light output would be monitored only at a single angular coordinate, preferably [0°, 0°]. Monitoring would be completed with an integrating sensor device, such as that developed for traffic signals. Such a device can be placed directly over the hood of an arrow panel lamp. This device can measure only at a single angular coordinate, but this limitation is not a problem for this type of test. After testing commenced, the light output at [0°, 0°] would be monitored until it fell below the required minimum level. Integrating devices can be placed on more than one lamp, if more lamp data are desired. For a message panel, only one element of the matrix would be illuminated for measurement.

The hybrid test method does have some drawbacks. The first is the assumption that the lamps used in the lamp system will all have nearly the same performance characteristics. Another is that the integrating sensor would have to be built for this application. These drawbacks are minor when compared with the simplification in testing. The lamp assumption is not unreasonable for two reasons: (*a*) lamp quality control achieved by solar panel manufacturers is very high, and therefore lamp-to-lamp uniformity is very good; and (*b*) multilevel photometry is standard practice in the automotive industry, where vehicle light sources, including headlamps, are tested at multilevel and not as a full system.

PROJECT IMPLEMENTATION

The sole purpose of this project is to provide implementable test methods that TxDOT can use in the procurement process for arrow and message panels. Providing the test method will help TxDOT ensure that arrow and message panels used on its projects will meet the performance criteria contained in the MUTCD and meet the needs of drivers approaching a work zone.

WORK PLAN

Any research project must have a clearly defined goal that provides an overall focus to the research activities. All activities must contribute to the realization of the research goal. Progress toward meeting the goal is measured through quantifiable objectives, which are used to determine the necessary research activities. With this in mind, the following goal has been established for this research project:

> Develop photometric test methods that will provide objective means of ensuring that arrow panels and portable changeable message signs used on TxDOT projects meet the visibility needs of drivers.

Using this goal, the following specific and quantifiable objectives have been established for this research project:

- Maintain continuing and effective communication with the TxDOT project director and project advisors.
- Identify relevant findings from previous evaluations of arrow panels and portable changeable message signs.
- Identify relevant arrow and message panel practices in other state transportation agencies.
- Synthesize pertinent information from the NCHRP arrow panel research project.
- Identify previous research on the legibility of arrow and message panels, and determine an appropriate legibility distance to be used as the basis for a test method.
- Develop arrow and message panel photometric test methods for evaluation.
- Evaluate the visibility of various arrow and message panels in field experiments, and determine an appropriate minimum legibility requirement for the test methods.
- Evaluate the relative performance of full-system and multilevel photometric test methods and the ability of commercial laboratories to implement each method.
- Develop a reliable, repeatable, and defensible arrow and message panel photometric test method that can be performed at a reasonable cost.
- Document the activities and findings of the research project.

The objectives of this research project will be met through the conduct and completion of a carefully formulated work plan. This work plan has been structured to provide TxDOT with a useful, practical, and reliable method for testing arrow and message panel photometrics.

The project will consist of two phases. In the first phase, researchers will develop the photometric requirements for arrow panels. This work will take place during the first year of the project. The second phase will address the photometric requirements for portable changeable message signs and will take place primarily during the second year. However, some work on this phase will occur during the first year when there is overlap with the arrow panel effort. Research continues. The project is scheduled to be completed in August 2001.