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16. Abstract

Glance legibility studies conducted at the TTI Proving Grounds examined the legibility of three commercially available LCS with respect to symbol, signal type, subject gender, and subject age. Also, the effect of ambient light conditions was also explored. Symbols on all three signals resulted in median glance legibility distances of 304.8 meters (1000 feet) or greater, whereas the 85th percentile glance legibility distance was 213.4 meters (700 feet) or greater. Of the various factors examined, only the age of the subject significantly influenced legibility distances. In general, drivers 65 years and older had to be 91.5 to 198.1 meters (300 to 650 feet) closer to the signals to correctly identify the symbols being displayed than drivers aged 16 to 44 years.

The report also contains the results of a meeting of TxDOT operations personnel involved in freeway LCS design and operation. Panel members identified a number of specific problems and concerns regarding LCS on freeways, and brainstormed about potential solutions and countermeasures to address these concerns.

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VISIBILITY AND SPACING OF LANE CONTROL SIGNALS FOR FREEWAY TRAFFIC MANAGEMENT

by

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Research Report 1498-1
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IMPLEMENTATION STATEMENT

Based on the results of the first year effort on this study, a number of recommendations are made regarding Lane Control Signals (LCS) for freeway traffic management. Among the most important is the establishment of a regular cleaning and bulb replacement schedule to maintain maximum LCS brightness; the utilization of positive guidance principles in the selection of LCS mounting locations; and the use of back plates or a back panel behind LCS mounted on overhead sign structures that are oriented in a east-west direction to help counter driver difficulties with sun interference. Other suggestions to improve LCS effectiveness as a freeway traffic management tool are provided in Chapter 4.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report is not intended to constitute a standard, specification, or regulation, nor is it intended for construction, bidding or permit purposes. The engineer in charge of the study was Dr. Gerald L. Ullman, P.E. #66876.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Glance legibility studies conducted at the TTI Proving Grounds examined the legibility of three commercially available LCS with respect to symbol, signal type, subject gender, and subject age. Also, researchers explored the effect of ambient light conditions existing when each subject participated in the study upon glance legibility of the LCS. Symbols on all three signals resulted in median glance legibility distances of 304.8 meters (1000 feet) or greater. Meanwhile, the 85th percentile glance legibility distance was 213.4 meters (700 feet) or greater in each case. Generally speaking, the yellow X was visible to motorists at the greatest distance. The green arrow provided the next longest legibility distance, and the red X resulted in the lowest legibility distance. The design of one of the signals, however, was such that the glance legibility distances for each of the symbols were nearly identical.

A few of the individual symbol indications on certain signals generated legibility distances that were somewhat lower than the same symbol on the other signals. Possible reasons for the lower legibility distances for those indications are discussed at appropriate sections within the text. Of the various factors examined, only the age of the subject significantly influenced legibility distances. In general, drivers 65 years and older had to be 91.5 to 198.1 meters (300 to 650 feet) closer to the signals to correctly identify the symbols being displayed than drivers aged 16 to 44 years. None of the three signal designs provided consistently better results from older drivers in terms of glance legibility.

A panel of eight TxDOT managers and engineers with expertise relating to the design and operation of LCS in freeway traffic management met in Fort Worth to discuss problems and potential solutions regarding LCS. Members of the panel agreed that the existing level of brightness of the LCS installed in Fort Worth is adequate when sun interference is not a factor. Potential countermeasures suggested to help alleviate the sun interference problem and increase overall LCS conspicuity included frequent cleaning of the pixel lenses on the front of the LCS, using a covering on the LCS face plate that does not fade in the sun, and the installation of back plates or back panels behind the LCS when installed on overhead sign structures to increase their target value.

Panel members emphasized that selection of mounting locations for LCS must be based first and foremost on the information needs of the driver. Positive guidance techniques should be consulted whenever LCS locations are being selected. Panel members also agreed that exit lane drops should not have LCS installed over them to avoid confusing unfamiliar motorists into

believing that the lane is an open through lane under incident conditions. However, panel members could not agree on whether LCS should be placed on all lanes upstream of a major freeway split, nor did they agree on where LCS should be installed in the vicinity of the split. Additional research will likely be necessary to resolve this issue.

1. INTRODUCTION

The Texas Department of Transportation (TxDOT) is installing freeway surveillance and control systems in several of the major metropolitan areas in Texas. Fort Worth, Houston, and San Antonio have portions of their systems on-line or nearing operational status. Officials in Dallas, Austin, and El Paso have begun planning for systems in their jurisdictions as well. These systems will allow TxDOT personnel to monitor traffic conditions along the freeway, control freeway traffic demands via ramp metering, and communicate to motorists about downstream traffic conditions and about suggested diversion routes. TxDOT will communicate with the motorists through changeable message signs (CMSs) installed at strategic decision points along the freeway and though lane control signals (LCS) mounted periodically over each travel lane.

Although many transportation agencies throughout the United States use or are planning to use CMSs to communicate with freeway drivers, TxDOT is one of the few to rely heavily on LCS to provide real-time motorist information regarding conditions in each travel lane. LCS rely on both color and symbols to indicate lane status information. The *Manual on Uniform Traffic Control Devices* (MUTCD) *(1)* currently allows three color/symbol combinations to be displayed on an LCS head over a freeway:

- a red X to indicate that a lane is closed and that drivers should not travel in that lane,
- a yellow X to indicate that a lane is about to be closed and that drivers should vacate that lane, and
- a green arrow to indicate that a lane is open for travel.

LCSs are smaller than typical CMSs, and so are considerably cheaper to purchase and maintain. This means that LCSs can be installed more frequently along a freeway than can larger and more expensive CMSs. Also, since LCS use symbols and colors rather than words to convey information, they can be more readily understood by non-English speaking motorists. However, the amount and type of information that can be displayed via LCSs is much more limited than a typical CMS. Therefore, TxDOT systems incorporate both technologies in a manner designed to provide both flexibility and efficiency in disseminating important information to freeway motorists.

Previous TxDOT-Sponsored LCS Research

To date, TxDOT experiences in planning and designing freeway traffic management systems have generated a number of questions as to how best design, install, and operate freeway LCS. These questions range from basic LCS design issues for freeway applications (i.e., the symbols that should be used as well as their color, size, and brightness), to proper installation principles (including spacing, mounting location, and orientation), to strategies for safe and efficient operations (i.e., which symbols to display, how they should be sequenced, how far upstream they should be displayed, etc). Some of these issues were explored in previous research sponsored by TxDOT in cooperation with the Federal Highway Administration (FHWA) (*2, 3*). Based on the results of that earlier research and upon other questions that have arisen, TxDOT and FHWA sponsored a second research study on freeway LCS. This report is a product of that second study.

Content of the Report

The current research study on freeway LCS being sponsored by TxDOT and FHWA has two main focus areas:

- the development of improved design and installation guidelines to assure adequate visibility and spacing of LCS for effective freeway traffic management; and
- the field evaluation of certain LCS symbols not currently included in the MUTCD section on LCS but which appear to be more intuitive to motorists and which offer promise in promoting more consistent motorist response to freeway LCS.

This report addresses research activities undertaken to address the first item listed. Chapter 2 describes the results of legibility studies conducted at the Texas Transportation Institute (TTI) Proving Grounds. TTI researchers examined the legibility of three commercially-available LCS heads provided on loan by the manufacturers/suppliers of LCS equipment. In most cases, LCS designs can be customized by each of the manufacturers according to the specifications of the purchaser. Therefore, product names were not used in the description of the studies or the results. Rather, results for each LCS examined were described relative to the design characteristics of the signal heads.

Chapter 3 presents a summary of a meeting of a panel of experts held during the summer of 1994 to discuss the problems and concerns regarding freeway LCS visibility, mounting location, spacing, and application to special geometric situations. The panel also discussed various solutions or potential solutions to the problems and concerns that were raised. The expert panel consisted of TxDOT personnel located throughout the state who have responsibility for the installation or operation of freeway LCS or who have extensive knowledge of traffic control devices (and typical driver response to them) for freeway operations.

The report concludes with Chapter 4 which integrates the findings from Chapters 2 and 3 into a set of candidate guidelines and recommendations for inclusion into current Departmental purchase specifications and into the *Highway Operations Manual* (*4*).

2. LCS GLANCE LEGIBILITY STUDIES

The effectiveness of LCS as a traffic management tool on Texas freeways depends on the ability of motorists to adequately detect and recognize the displays they encounter while driving. On most urban freeways, LCS are but one of many visual information sources that confront drivers in their travels. Consequently, LCS displays must be visible enough to compete with the many traffic control devices present in this type of driving environment, yet not be so overbearing so as to overpower the other information sources that drivers need to access as well. In this chapter, TTI researchers describe the methodology and results of LCS legibility studies conducted to evaluate the visibility of commercially available LCS being used in freeway traffic management systems throughout Texas. These studies were conducted at the TTI Proving Grounds, Texas A&M University Riverside Campus.

Study Objective

The objective of this particular study was to evaluate the glance legibility distance of three commercially available LCS, and to determine any differences in the median glance legibility distances as a function of:

- symbol (i.e., red X, yellow X, green arrow, yellow downward arrow, yellow downward diagonal arrow),
- signal type (reflecting differences in design characteristics among the three signals evaluated),
- subject gender, and
- subject age.

Although not a variable that could be controlled for in this particular evaluation, the data were also examined in terms of the overall ambient light conditions existing when each subject participated in the study. Ambient light conditions were determined subjectively by the study administrator as either 1) bright midday sunlight, or 2) midday overcast.

Study Procedure

Description of the Glance Legibility Evaluation Measure

TTI researchers measured LCS visibility with a glance legibility study conducted during the middle of the day in late summer in Texas. Subjects, positioned as drivers in a TTI vehicle a given distance away from the LCS head, viewed a symbol presented to them for a brief (1.5-second) interval. If the subject could not correctly identify the color *and* symbol displayed, he or she moved closer to the LCS. The process was repeated until the color and symbol were correctly identified.

This approach differs from a true glance legibility study in which the exposure time of a visual image is manipulated to ascertain the minimum time needed to correctly identify the image. The distance at which an LCS symbol can be identified is believed to have more direct relevance to driver behavior and system operations than does minimum recognition time, which is the reason why the study was conducted in the aforementioned manner. A 1.5-second interval was used to mimic a scenario where a driver traveling on the freeway would "glance" at a given LCS indication before moving his or her eyes to a new visual target.

Choice of Sample Size

A statistically valid sample size was selected for the legibility study. An attempt was made to obtain a demographically balanced sample with regards to gender and age for a specified total sample size. This sample size necessary to achieve statistically significant comparisons between the displays is defined by the following equation:

$$n = \frac{(Z_{\alpha/2})^2 \ \sigma^2}{E^2}$$

where

n = sample size required,
Z = area under the standard normal curve at the desired level of significance,
α = experiment-wide level of significance desired (0.025),

σ = standard deviation of the population (assumed to be equal to the expected range of responses divided by 4), and

E = tolerable error (selected as 30.5 meters [100 feet]).

Based on the assumptions listed, a minimum 35 subjects viewed each display. However, because of the study schedule, approximately 70 subjects were able to view the three symbols on Signal #2 (Figure 2-3) as well as the green arrow on Signal #1 (Figure 2-2).

Subject Selection Process

The selection of the participants used in the laboratory study was based on the age distribution of Texas drivers (see Table 2-1). The education level of the participants was not expected to significantly affect distance measurements, and so was not considered in the subject selection process.

Table 2-1. Age Distribution of Texas Drivers

Age Group	1990 Estimates [1]
16 - 24	18.9%
25 - 34	24.4%
35 - 44	20.1%
45 - 54	12.9%
55 - 64	10.2%
65 - 74	7.9%
75 and above	5.7%

[1] Source: 1990 U.S. Census of Population and Housing

Laboratory Equipment and Arrangement

The LCS heads from each manufacturer were mounted side-by-side on an overhead sign structure at the TTI Proving Grounds. Figure 2-1 illustrates the sign structure installation.

Figure 2-1. Sign Structure Installation of LCS at the TTI Proving Grounds

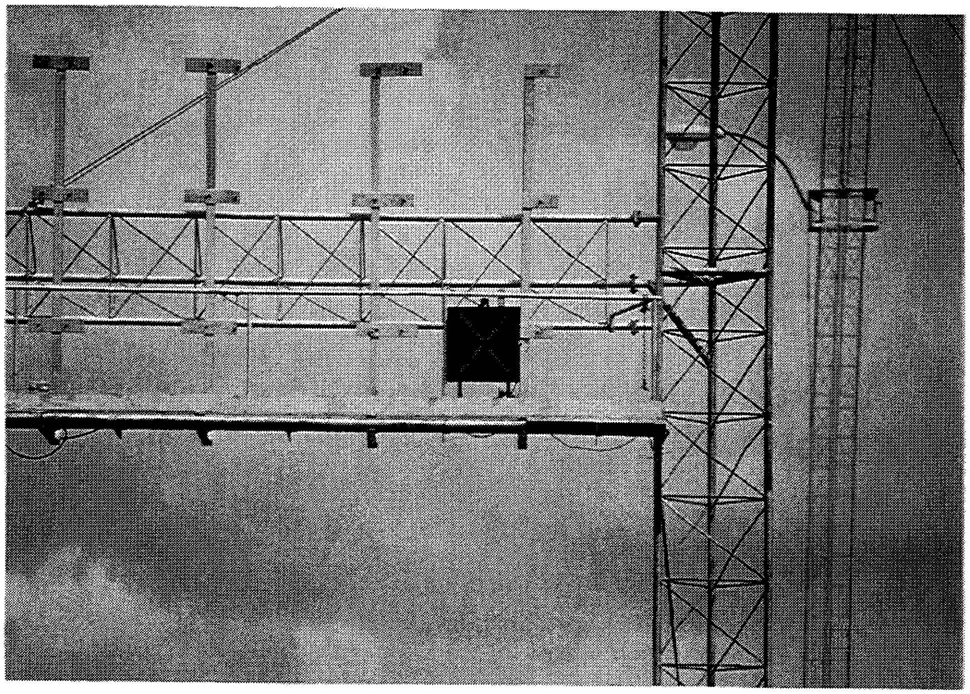
TTI researchers mounted the signals 5.8 meters (19 feet) from the bottom of the signal to the pavement, in conformance with the MUTCD (*1*). Subjects began 457 meters (1500 feet) away from the signals, viewing one of the symbols on one of the signals for 1.5 seconds. If the color and symbol could not be identified, subjects moved 30.5 meters (100 feet) closer to the signal (markings and traffic cones placed adjacent to the driving path identified these intervals). This process was repeated until the subject correctly identified the indication being presented, after which he or she returned to the starting location to begin another symbol. Researchers randomized the sequence of the symbols and signals displayed to each subject so as to prevent any learning effects.

Design Characteristics of the Fiberoptic LCS

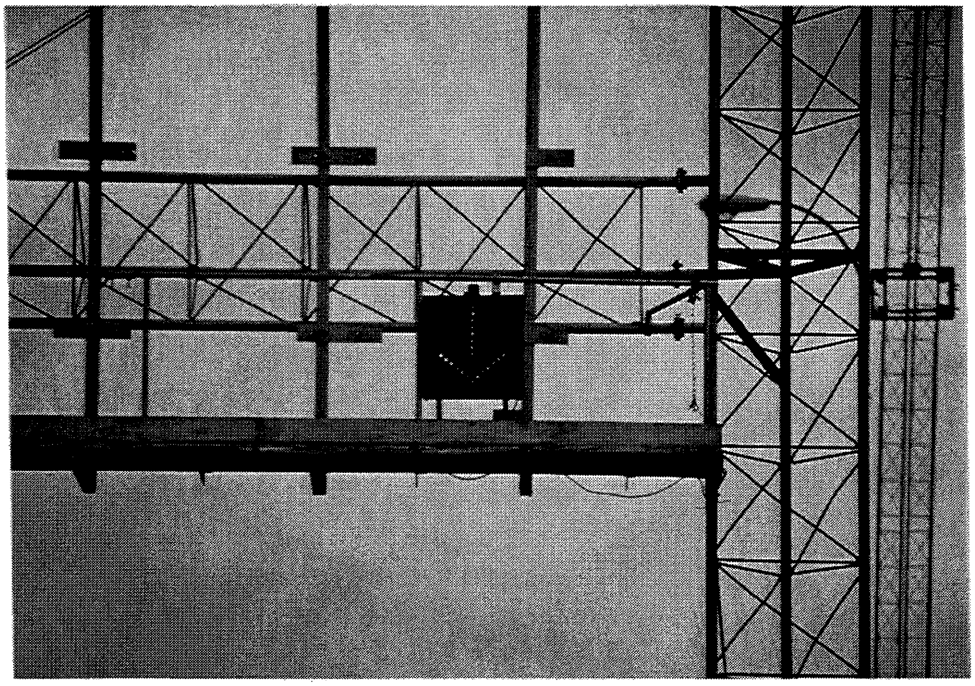
Commercial manufacturers and suppliers provided three different fiberoptic LCS for legibility testing. All three signals could display the three standard MUTCD symbols used for freeway traffic management (i.e., red X, yellow X, and green arrow). In addition, one of the signals could display a yellow downward arrow (identical in shape to the green arrow), and a yellow diagonal arrow pointing downward to the left or the right. All three signals had a 457 mm (18 in) square display face plate. The actual symbols themselves measured 356 mm in height (14 in).

Some of Figures 2-2 through 2-4 illustrate the symbols that each signal could display. Table 2-2 presents some of the salient design characteristics of each of the signals evaluated. As can be seen from the figures, each symbol consists of a group of light pixels arranged in a specific order so as to form the appropriate message. These arrangements consist of either a single line of pixels (i.e., a single-stroke symbol) or by two sets of pixels placed side by side (i.e., a double-stroke symbol). Figure 2-2 shows that Signal #1 utilized a single-stroke arrangement for all of the symbols. Conversely, Signal #2 (Figure 2-3) utilized a double-stroke arrangement of pixels. Signal #3 utilized a double-stroke arrangement for the green arrow as well as the red and yellow X, but a single stroke arrangement for both yellow arrows (downward and diagonal). The spacing between the double-strokes on Signal #2 was 38.1 mm (1.5 in), compared to a 12.7 to 17.8 mm (0.5 to 0.7 in) pixel spacing of the strokes on Signal #3.

The output lens on the end of the fiberoptic bundles also differed by signal type. For Signals #1 and #2, the output lenses were 15.9 and 12.7 mm (0.6 and 0.5 in), respectively. For Signal #3, the output lens was 4 mm (0.2 in). Signal #3 utilized more pixels placed close together to generate a symbol (see Figure 2-4). However, all three signals utilized two 50-watt, 10.8-volt halogen quartz lamps as the source of illumination. All symbol colors reportedly complied with ITE chromaticity standards for LCS (*5*). TTI researchers did not attempt to validate these reports with their own independent measurements. Unfortunately, researchers also did not have the equipment available to measure overall output illuminance of the symbols on each signal or the illuminance of the individual pixels themselves.

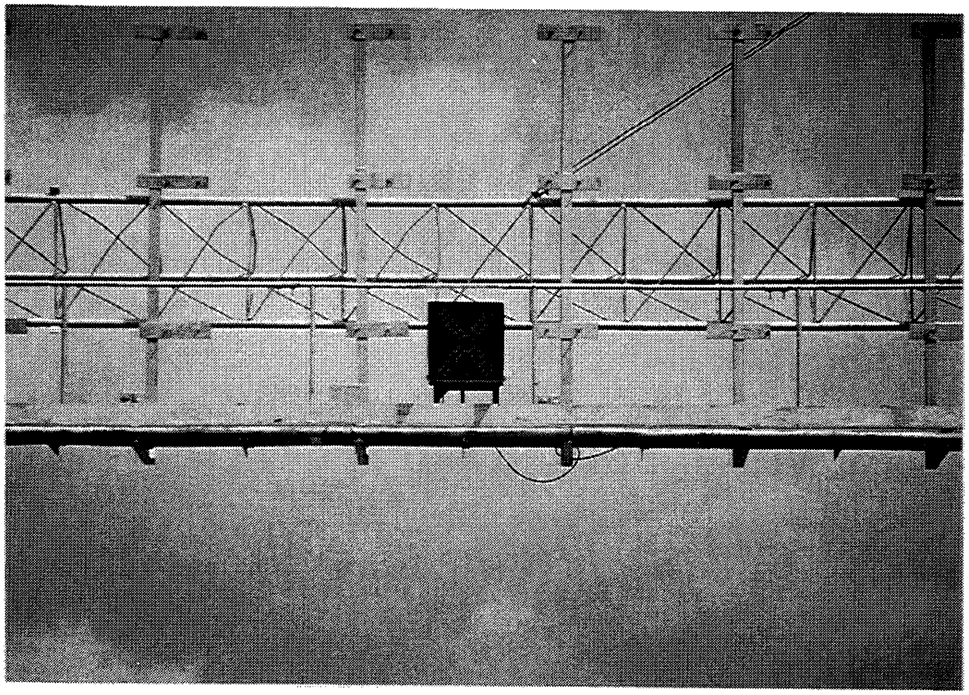


(a) red and yellow X configurations

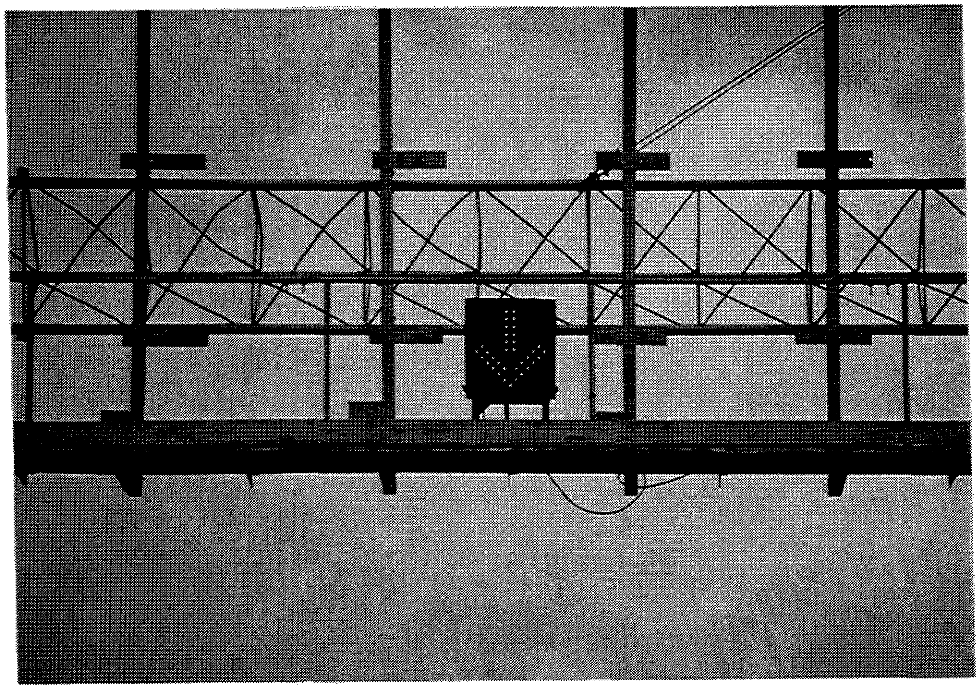


(b) green arrow configuration

Figure 2-2. Symbol Configurations for Signal #1

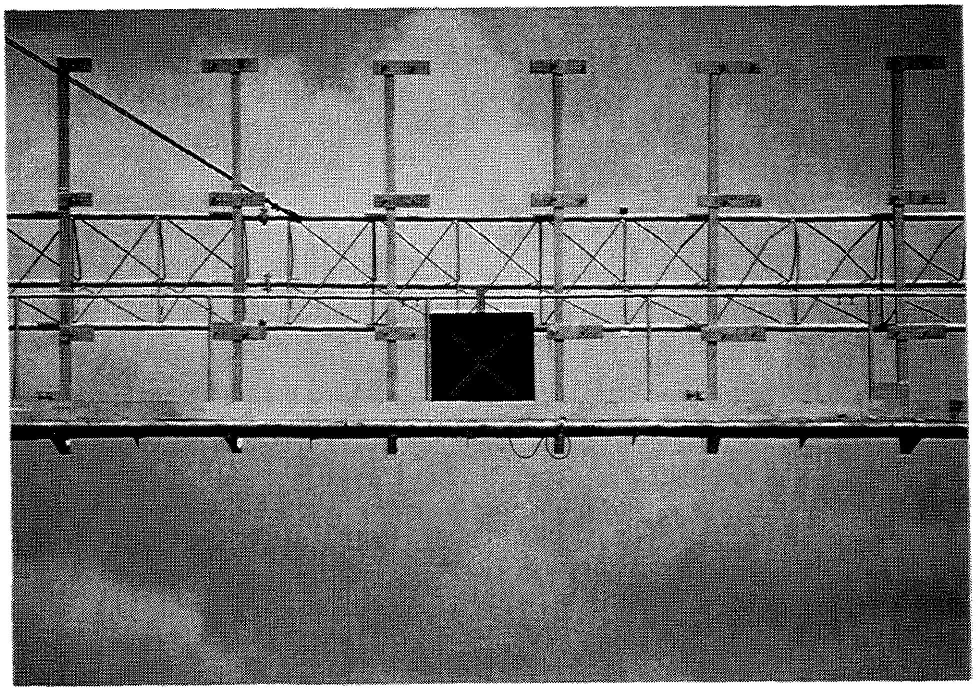


(a) red and yellow X configurations

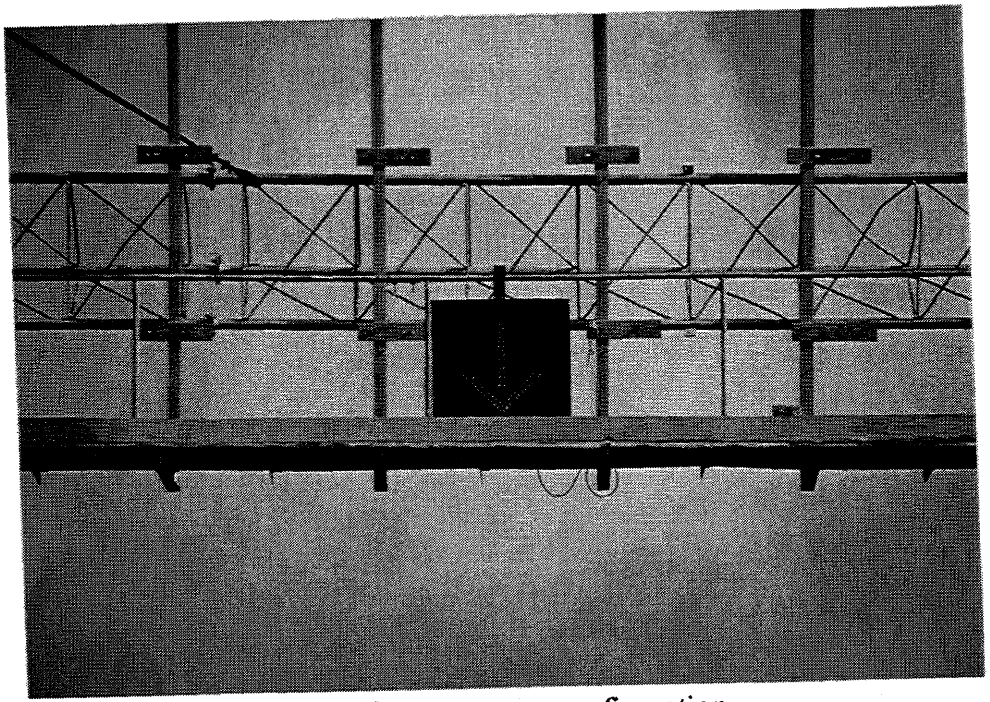


(b) green arrow configuration

Figure 2-3. Symbol Configurations for Signal #2

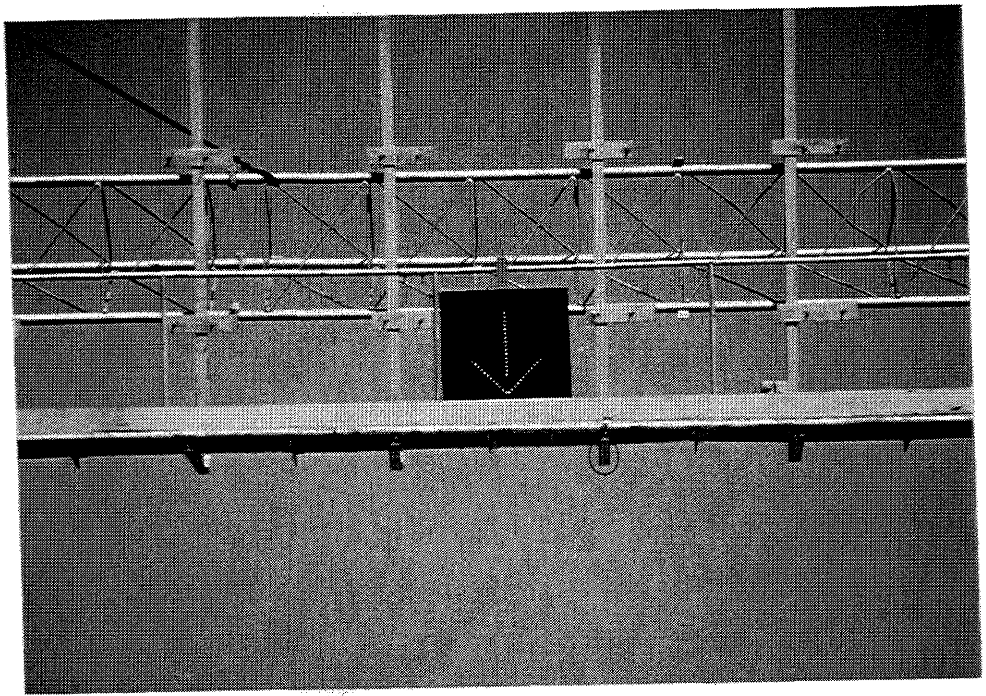


(a) red and yellow X configurations

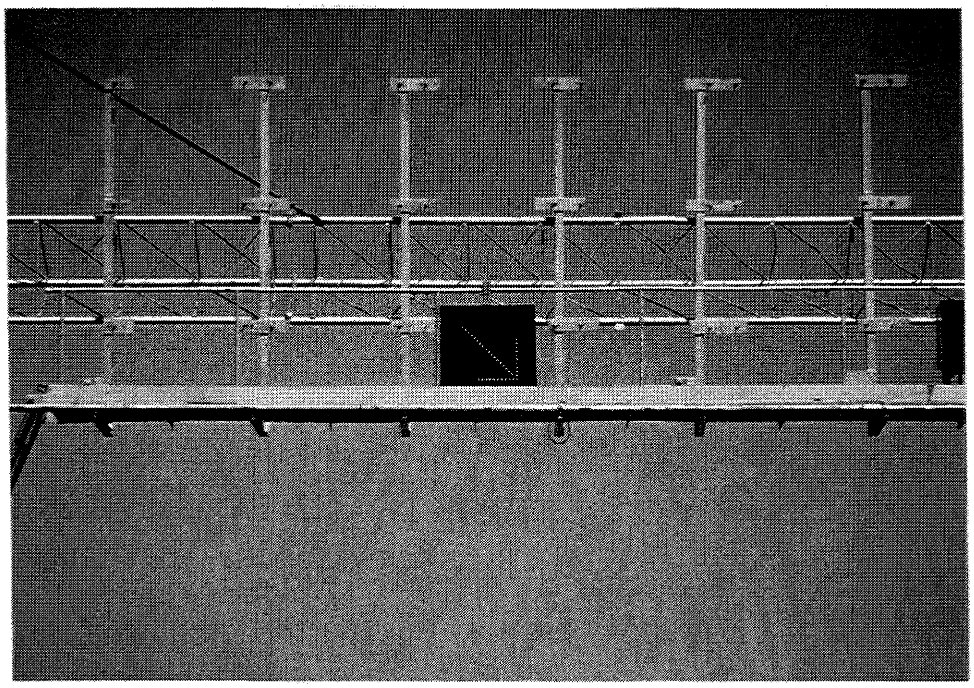


(b) green arrow configuration

Figure 2-4. Symbol Configurations for Signal #3



(c) yellow downward arrow configuration



(d) yellow diagonal arrow configuration

Figure 2-4. Symbol Configurations for Signal #3 (Cont'd)

Table 2-2. Summary of Design Features of the LCS Tested

Signal Features	Signal #1	Signal #2	Signal #3
Diameter of the Pixel Output Lens	15.9 mm (0.6 in)	12.7 mm (0.5 in)	4 mm (0.2 in)
Pixel Spacing	25.4 mm (1.0 in)	38.1 mm (1.5 in)	12.7 to 17.8 mm (0.5 to 0.7 in)
Stroke Configuration	Double Stroke	Single Stroke	Double and Single Stroke[a]

[a] the green arrow, yellow X, and red X are double stroke symbols; the yellow arrows are single stroke

Study Results

Comparison of Green Arrow, Yellow X, and Red X Displays

Table 2-3 summarizes the median glance legibility distances for the green arrow, yellow X, and red X indications on each of the LCS tested in this evaluation. Median values are reported, rather than averages, because of the non-normal distribution of the data (when frequency data are not normally distributed, the median value is often a better indication of the central tendency of the distribution than the average value).

The data from Signals #1 and #2 show a small difference in glance legibility distance from symbol to symbol. In contrast, subjects could see all three symbols on Signal #3 equally well. For Signals #1 and #2, the yellow X provided the greatest legibility distance, followed by the green arrow and finally the red X. For Signal #1, the difference in legibility distance between the yellow and red X amounts to 121.9 meters (400 feet); for Signal #2, the difference between the yellow and red X was 152.4 meters (500 feet). These differences in legibility distance from symbol to symbol are consistent with what would be expected based on the sensitivity of the human eye to light of different electromagnetic wavelengths associated with each color (*6*). As illustrated in Figure 2-5, the eye is most sensitive to wavelengths in the yellow range. Conversely, the eye is less sensitive to wavelengths at the higher end of the visual spectrum associated with the color red, or at the lower end where the color green exists.

Table 2-3. Comparison of Median Glance Legibility Distances

Symbol	Median Glance Legibility Distance (meters)		
	Signal #1	Signal #2	Signal #3
Red X	335.3	304.8	426.7
Yellow X	457.2	457.2	426.7
Green Arrow	365.8	426.7	426.7

note: 1 meter = 3.28 feet

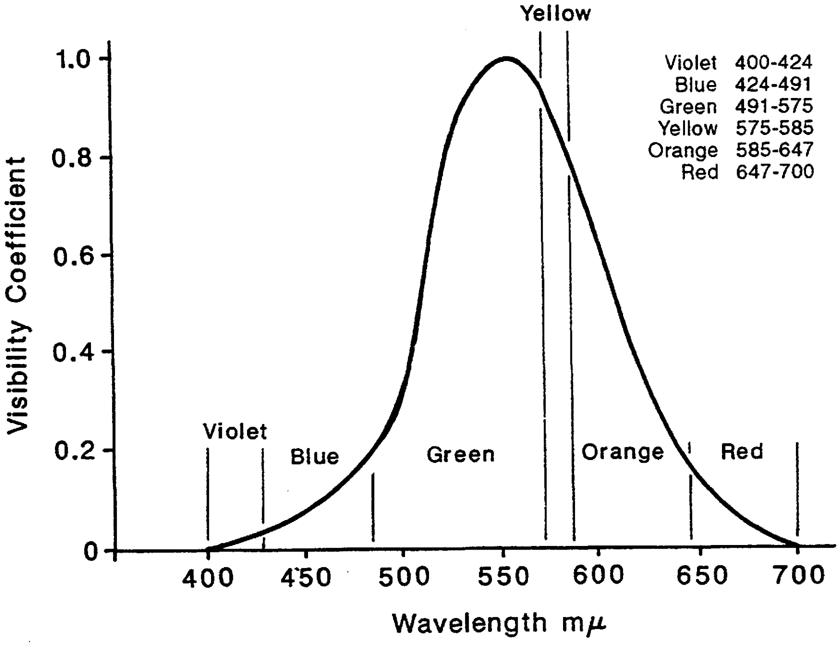


Figure 2-5. Relationship Between Electromagnetic Wavelengths and Visual Sensitivity to Color

Comparing each symbol individually, median legibility distances for the yellow X on each signal are nearly equal (only differing by 30.5 meters [100 feet] or less). However, sizeable signal-to-signal differences are shown in Table 2-3 for both the green arrow and red X. Specifically, the median legibility distance of the green arrow for Signal #1 was 60.9 meters (200 feet) shorter than either Signal #2 or Signal #3. Similarly, the median legibility distance for the red X on Signal #3 was as much as 121.9 meters [400 feet] greater than for Signals #1 and #2.

The median glance legibility distances reported in Table 2-3 provide an indication of how far the "typical" driver can see the displays. As defined, then, approximately one-half of the driving population have visual capabilities that are less than this "typical" driver. Therefore, it is also important to consider the distance at which the majority of drivers are able to correctly identify the display. For many traffic studies, the 85th-percentile value is often used as an indication of a majority of drivers. Consequently, Table 2-4 presents the 85th percentile glance legibility distance by symbol and signal type.

Table 2-4. Comparison of 85th-Percentile Glance Legibility Distances

Symbol	85th-Percentile Glance Legibility Distance (meters)		
	Signal #1	Signal #2	Signal #3
Red X	274.3	213.4	274.3
Yellow X	365.8	365.8	274.3
Green Arrow	243.8	274.3	274.3

note: 1 meter = 3.28 feet

As expected, the distances reported in Table 2-4 are significantly less than those reported in Table 2-3. However, the same trends in the distances are evident by symbol type and by signals. Specifically, all symbols for Signal #3 were equally visible (with the 85th percentile driver able to identify them from 274.3 meters [900 feet] away). For Signals #1 and #2, the yellow X was somewhat more visible than for Signal #3. In contrast, the green arrow for Signal #1 was less visible than for the other two signals, whereas the red X was significantly less visible on Signal #2. The researchers did notice that the green arrow for Signal #1 had a more bluish tint to it than did the other indications. Referring back to Figure 2-5, the human eye becomes less sensitive to the electromagnetic wavelengths that constitute the color green as it transitions into the color blue (i.e., the wavelengths become shorter). This may at least partially explain the lower legibility distance for that indication. In addition, the intensity of light passing through the color filters may have differed as well.

With respect to the red X for Signal #2, the arrangement of the double-stroke pixels spaced 38.1 mm (1.5 in) apart created a lower effective stroke-width-to-letter-height ratio for that symbol. At higher viewing distances, this increased stroke width thickness caused significant blurring (irradiation) of the red X, to the point where the symbol shape could not be recognized. Since this did not occur with the yellow X on that same signal, it appears that irradiation effects are more significant with red indications. Since the wider stroke width of Signal #2 did not yield significantly greater legibility distances for the yellow X and resulted in a lower legibility distance for the red X, its use on future LCS installations should be discouraged unless the overall letter height is increased and/or width between pixels is decreased.

Performance of the Yellow Downward and Downward Diagonal Arrows

Of the three signals evaluated, only Signal #3 could display yellow arrow indications (downward or downward diagonal). Table 2-5 summarizes the median and 85th-percentile glance legibility distances for these symbols on that signal.

Table 2-5. Glance Legibility Distance of Yellow Arrow Indications on Signal #3

Measure	Glance Legibility Distance (meters)	
	Downward Arrow	Diagonal Arrow
Median	457.2	396.2
85th-Percentile	365.8	274.3

note: 1 meter = 3.28 feet

The data in Table 2-5 illustrate that the yellow arrow pointing directly downward was slightly more visible than the yellow arrow pointing diagonally downward. The median glance legibility distance for the downward arrow was 61 meters (200 feet) greater than for the diagonal arrow. Likewise, the 85th-percentile legibility distance for the downward arrow was 91.5 meters (300 feet) greater than for the diagonal arrow. It should be noted that these values are also quite close to the legibility distances obtained for the other symbols on that signal (including the yellow X).

Effect of Subject Gender, Subject Age, or Ambient Light Condition

The results of the glance legibility studies demonstrated no significant differences in median or 85th percentile distances for any of the symbols or signals based on subject gender or ambient lighting condition (sunny or cloudy). Summary tables of these values by symbol, signal, and subject variable are presented in the appendix. Although gender and lighting condition had no substantial effect on visibility, the data from the studies indicate a significant difference in legibility depending on the age of the subject. In particular, older drivers (those 65 years or older) had much poorer glance legibility distance capabilities than their younger (i.e., those 45 years or younger) counterparts. As illustrated in Table 2-6, median legibility distances for the over 65 age drivers viewing the red X, yellow X, and green arrow were 91.5 to 198.1 meters (300 to 650 feet) lower than for the 16-44 year old age group. Consistent with other studies examining older driver performance (7, *8*), drivers between 44 and 65 years old were not included in this comparison. During this period of life, the visual capabilities of drivers deteriorate most rapidly (although the rate at which this deterioration occurs varies from person to person) and are most difficult to characterize in terms of central tendencies, variability, etc.

As a measure of the capabilities of the "majority" of drivers, Table 2-7 presents the 85th percentile glance legibility distances for the two age groups by symbol and signal type. The difference in visual capabilities for the younger and older driving groups is even more evident in Table 2-7. Comparing the distances for each individual signal and symbol type, the 85th percentile legibility distance for the older driver group is between 91.4 and 274.3 meters (300 to 900 feet) less than that of the younger driving group.

Table 2-6. Effect of Subject Age on Median Glance Legibility Distances

Symbol	Median Glance Legibility Distance (meters)		
	Signal #1	Signal #2	Signal #3
Red X:			
16-44 yrs	365.8	335.3	426.7
> 65 yrs	274.3	167.6	304.8
Yellow X:			
16-44 yrs	457.2	457.2	457.2
> 65 yrs	274.3	350.5	274.2
Green Arrow:			
16-44 yrs	396.2	457.2	457.2
> 65 yrs	198.1	289.6	335.3

note: 1 meter = 3.28 feet

Table 2-7. Effect of Subject Age on 85th Percentile Glance Legibility Distances

Symbol	85th Percentile Glance Legibility Distance (meters)		
	Signal #1	Signal #2	Signal #3
Red X:			
16-44 yrs	274.3	274.3	396.2
> 65 yrs	152.4	121.9	152.4
Yellow X:			
16-44 yrs	426.7	396.2	396.2
> 65 yrs	213.4	213.4	121.9
Green Arrow:			
16-44 yrs	304.8	365.8	396.2
> 65 yrs	152.4	243.8	182.9

note: 1 meter = 3.28 feet

The values for the over 65 age group in the Signal #3 column should be interpreted with caution, as these represent a rather small sample size. However, it is clear that older drivers were not able to correctly identify the symbols displayed until they were much closer to the signals. Overall, it appears that the majority of older drivers need to be as close as 152.4 meters (500 feet) in order to properly identify certain symbols.

The values in Table 2-7 reflect similar experiences of other researchers who have examined older driver visual capabilities. For example, other studies have shown that the static sign legibility distance of an older driver is 65-75 percent of the legibility distance of a driver aged between 18-24 years (*9*). Also, the eyes of an older driver receive only one-third of the light that the eyes of a younger driver receives, due to the hardening and yellowing of the lens and fluid within the eye (*10*). As the data from this current study suggests, both of these factors also have an impact upon older driver recognition of light-emitting signal displays.

Table 2-8 presents the median and 85th percentile glance legibility distances of the younger and older driving groups for the yellow downward and diagonal arrows. Generally speaking, the difference between the two age groups was less pronounced for these symbols. Median glance legibility distances for the older driver group were only 30.5 meters (100 feet) lower than the younger driver group. Meanwhile, the difference in 85th percentile legibility distance of the yellow downward arrow by age group was 91.4 meters (300 feet). The only sizeable difference by age group detected occurred with the 85th percentile legibility distance of the yellow diagonal arrow. However, it should be noted that the very low distance reported for the older driver group viewing this symbol may be biased in part by how it was installed on the sign structure during the studies. A large number of older motorists apparently only saw the diagonal body of the arrow and the vertical portion of the arrow tip (i.e., a check mark). The horizontal portion of the arrow tip paralleled a bracket underneath the LCS, which may have made it difficult for the older drivers (with degraded contrast sensitivity) to discern that horizontal portion of the arrow tip. Thus, a different mounting arrangement (i.e., without the supporting bracket visible to drivers) may improve this reported legibility distance considerably.

Table 2-8. Effect of Subject Age on Glance Legibility Distance of Yellow Arrow Indications on Signal #3

Measure	Glance Legibility Distance (meters)	
	Downward Arrow	Diagonal Arrow
Median:		
16-44 yrs	457.2	426.7
> 65 yrs	426.7	396.2
85th-Percentile		
16-44 yrs	396.2	304.8
> 65 yrs	304.8	91.4[a]

note: 1 meter = 3.28 feet

[a] many subjects mistook the diagonal arrow for a check (✓) until they were very close to the signal

Summary

This chapter has documented the procedures and results of glance legibility studies performed on three commercially available LCS at the TTI Proving Grounds. Subjects viewed one of the symbols on one of the signals for a 1.5-second interval, and tried to identify the color and shape of the symbol displayed. If the subjects could not identify the symbol, they moved closer to the signal and had the symbol redisplayed. The distance at which they could correctly identify the symbol was taken as the glance legibility distance for that symbol. This procedure was repeated for all symbols on all three signals (with the sequence order randomized).

Overall, all symbols on all three signals resulted in median glance legibility distances of 304.8 meters (1000 feet) or greater. Meanwhile, the 85th percentile glance legibility distance, assumed to reflect the majority of the driving population, was 213.4 meters (700 feet) or greater.

For Signals #1 and #2, the results of the legibility studies indicated significant differences in legibility distance depending on the symbol displayed. Generally speaking, the yellow X was visible to motorists at the greatest distance. The green arrow provided the next longest legibility distance, and the red X resulted in the lowest legibility distance. The design of the third signal, however, generated nearly equal glance legibility distances for each of the symbols.

The data suggested that the green arrow on Signal #1 and the Red X on Signal #2 were somewhat less visible than the same indications on the other signals. Researchers hypothesize that the lower legibility distance for the green arrow may be due in part to a slight difference in the color of the green filter and/or difference in output luminance provided by that display. Conversely, the lower legibility distance of the red X is most likely caused by the double-stroke pixel arrangement utilized on Signal #2. The increased width of the double-stroked X, combined with a greater irradiation effect caused by the red indication, made it difficult to discern the features of the symbol at any substantial distance away from the signal. Because of the different signal head design, the double-stroke arrangement of the red X on Signal #3 did not cause this same difficulty.

Subdividing the subject sample according to gender or the ambient lighting conditions under which they viewed the LCS (sunny or cloudy) did not significantly affect the glance legibility distances obtained. Subject age did influence the legibility distances, however. In general, drivers 65 years and older had to be 91.5 to 198.1 meters (300 to 650 feet) closer to the signals to correctly identify the symbols being displayed than drivers aged 16 to 44 years. Older drivers could not see any of the three signal designs any easier in terms of glance legibility.

3. RESULTS OF THE EXPERT PANEL MEETING

TTI held a one-day meeting on August 12, 1994 to explore problems and potential solutions relating to the use of lane control signals for freeway traffic management. The meeting was held in Fort Worth, Texas, where TxDOT has installed a number of LCS over freeway lanes throughout the system. The installations include different signal manufacturers, mounting locations and spacings, sun orientation, and other characteristics that provided a good overview of the technology and state-of-the-practice regarding the implementation of freeway LCS. An expert panel, consisting of personnel employed by TxDOT Districts and Divisions throughout the state, was created and invited to Fort Worth to participate. The individuals invited to participate represented several of the urban areas in Texas that have installed or will be installing LCS on freeways within their jurisdiction. The Traffic Operations Division of TxDOT was also represented on the panel. Table 3-1 identifies the individuals who served as panel members.

Table 3-1. TxDOT Panel Members

Name	TxDOT District/Division
Abed Abukar	Fort Worth District
Carlton Allen	Houston District
Brian Burk	Austin District
Rick Cortez	Dallas District
Brian Fariello	San Antonio District
Tai Tan Nguyen	Fort Worth District
Lewis Rhodes	Traffic Operations Division - Austin
Melanie Young	Dallas District

Group discussion methods such as an expert panel provides several advantages to researchers:

- it allows for the generation of ideas, analysis approaches, and/or solutions without restrictions or concerns by members regarding cost, practicality, or feasibility;
- it allows members to build upon the ideas of others by suggesting embellishments, improvements, or modifications (rather than having to fully develop ideas and concepts from scratch); and
- it allows for the exploration of perceptions, attitudes, and opinions in an environment that is less threatening and obtrusive than one-on-one interviews or other individual evaluation methods.

Panel Protocol

The overall goal of the one-day panel meeting was to bring to the forefront the various difficulties TxDOT had or was currently encountering relating to the installation and operation of LCS. At the same time, an exchange of ideas was desired about the many factors that relate to these difficulties. Finally, the meeting would hopefully generate potential solutions and agreement regarding how these difficulties should be treated in the future. The TTI research supervisor for this study moderated the panel meeting, but attempted to let the panel members themselves guide the overall direction of the discussion.

The panel discussed four major topic areas during the day-long meeting. These topics included:

- visibility,
- spacing,
- mounting location, and
- LCS applications in unusual geometric situations.

At the beginning of the meeting, panelists were driven around the freeways in the Fort Worth area to view the various LCS installations. Figure 3-1 identifies the Fort Worth freeways with the LCS installed at the time of the meeting. The intent of the drive-throughs was to assist panelists in reflecting upon their own experiences and perceptions regarding freeway LCS, and to let them see firsthand how some of the topics that were going to be discussed looked in an actual installation.

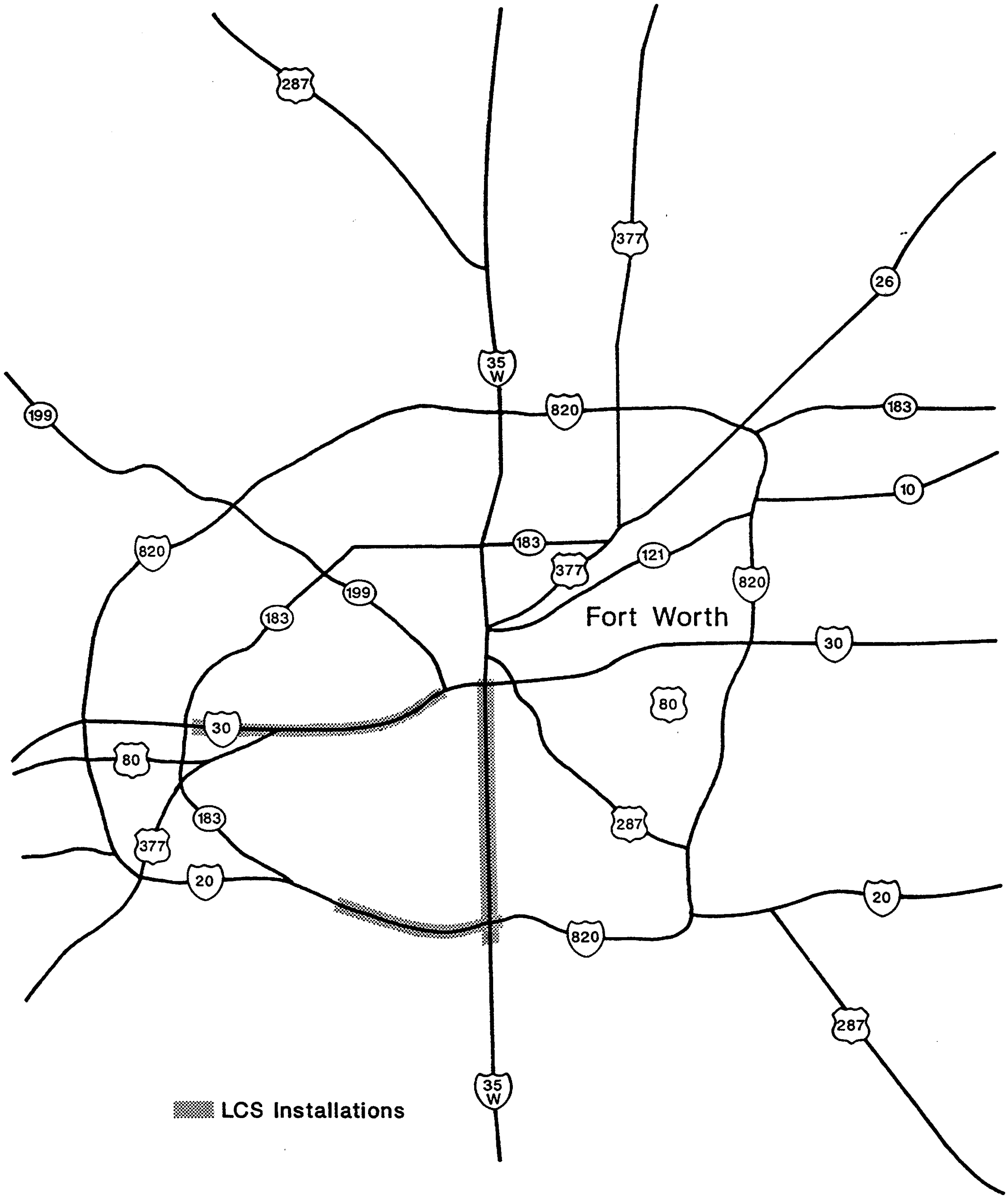


Figure 3-1. Location of the Freeway LCS in Fort Worth

Upon completion of the drive-throughs, panelists returned to the meeting room to begin discussions. A second drive-through made immediately after the lunch break helped refresh the panelists' memory of the LCS features and let them view the LCS under slightly different traffic conditions and sun orientation.

The following sections summarizes the key points made during the panel meeting regarding each of the above topic areas. For each topic area, the problems and/or concerns various panel members raised are presented first, followed by the possible solutions or countermeasures suggested to treat those problems/concerns.

LCS Visibility

Problems and Concerns

Research on LCS visibility was initiated as a result of earlier LCS field studies conducted on I-35W in Fort Worth (*3*). In those studies, the northbound LCS displays were nearly impossible to see and determine what symbol was being shown. The poor visibility was evident in terms of driver response as well; the LCS had very little effect upon vehicle lane distribution upstream of the lane closure during those studies.

During subsequent conversations with TxDOT personnel in the Fort Worth District, it became apparent that the specific visibility problems of the I-35W LCS were due to a large accumulation of road grime on the LCS pixel lenses. The signals on I-35W had not been cleaned since their installation (approximately 5 years earlier). TxDOT maintenance crews cleaned each signal face by hand, which significantly improved their visibility. However, it was not immediately apparent whether this improved visibility was adequate from a driver's perspective when trying to assimilate all types of visual information obtained when traveling on an urban freeway. Therefore, panelists were asked about their perceptions of the visibility of existing LCS displays.

Generally speaking, panelists agreed that the existing brightness of the LCS signals in general was quite adequate. The panelists did note that visibility was more of a problem for the east-west freeways in the morning due to sun interference. With the sun at their backs, panelists noted that the LCS indications tended to "wash out." Conversely, when facing the sun, panelists had difficulty seeing the LCS because of the extreme sun glare. These types of problems are consistent with those reported elsewhere in the literature (*11*). However, the panel had concerns that increasing the LCS brightness to combat sunlight glare during certain hours of the day for those east-west signals would cause the signals to be too bright and overpowering during other hours of the day and when oriented in a different direction.

A few of the LCS viewed by the panelists were not as bright as the others, either because of a burned-out light bulb (each of the LCS symbols is normally illuminated by two quartz-halogen bulbs during daylight hours) or because the signal head was misaligned. One panelist noted that these dimmer signals were a distraction in comparison to the other signals displayed at a location.

Several panelists indicated that they felt the contrast between the signal symbol and the background was not adequate. The Fort Worth District personnel did acknowledge that the flat black paint on the face plates of the signals was fading. They were looking at upgrading their sign specifications as well as some simple countermeasures to combat this contrast deficiency.

One panel member pointed out that the common fiberoptic LCS that has a narrow cone of vision (typically 20° centered about the optical axis) may not be appropriate for all freeway applications. This is particularly true for very wide freeways and those having a more rolling alignment. The concern centers around a driver's ability to see the LCS indications over all travel lanes. Laboratory research (*2*) and field experience have both demonstrated the importance of having the entire LCS array visible to drivers so that they can evaluate the overall display and move to an appropriate lane if necessary. This can become a problem when trying to view the LCS on a wide urban freeway. Figure 3-2 illustrates this problem graphically. A signal in the far right lane will be visible to a driver in each of the travel lanes over the distance shown by the two-headed arrow. By assuming a normal freeway travel speed, the amount of time that a signal is visible to drivers can then be easily determined.

Even if the LCS is aligned perfectly, the available viewing time diminishes dramatically as one moves laterally away from the optical axis. Furthermore, small deviations in the alignment of LCS reduces viewing time dramatically. Figure 3-3 presents the available viewing time a driver has to view an LCS with a 20° cone of vision as a function of a) the number of travel lanes over from the signal he or she is located, and b) the aiming error of the signal head. As the figure illustrates, a perfectly aligned signal will be visible to drivers in other lanes a maximum of 6 to 8.5 seconds (with large trucks, sign structures, etc., reducing this viewing time by some amount). However, a small five-degree misalignment in the signal (an angle of the magnitude shown in Figure 3-3) will reduce this maximum viewing time to only about three seconds for drivers four lanes over from the signal. If the LCS are more than five degrees misaligned, some drivers may not be able to see them at all.

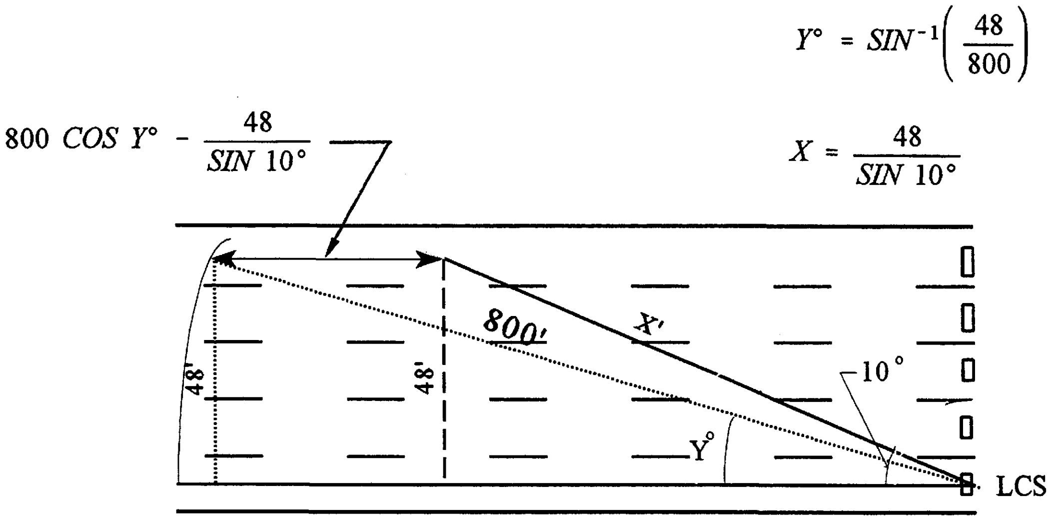


Figure 3-2. Layout of LCS Visibility to Drivers in Other Lanes

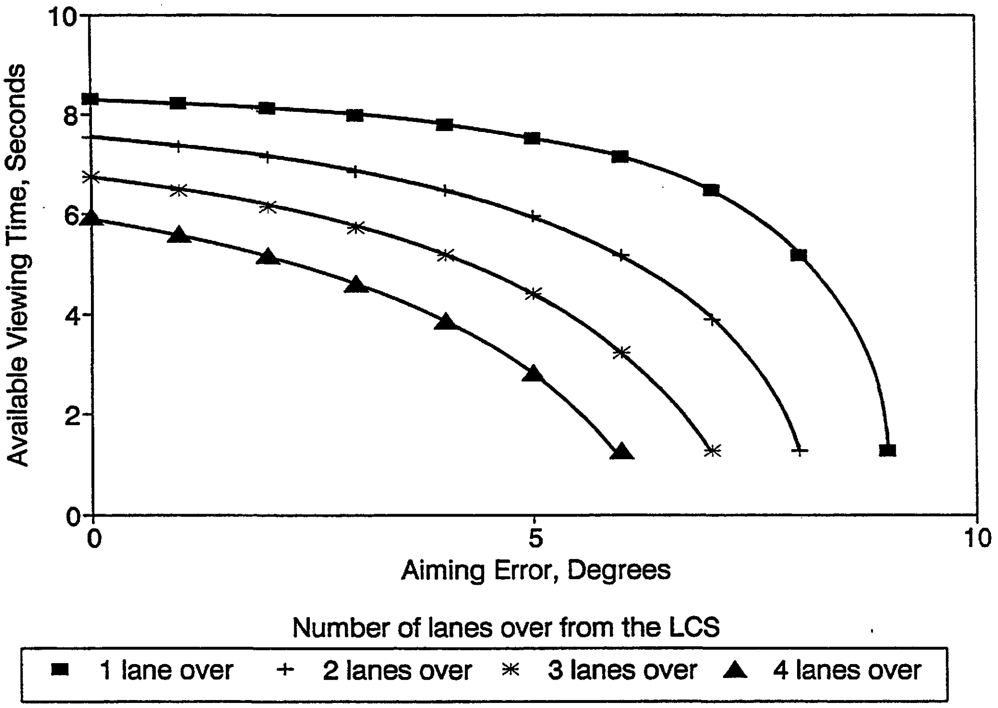


Figure 3-3. Available Viewing Time When LCS Heads are Misaligned

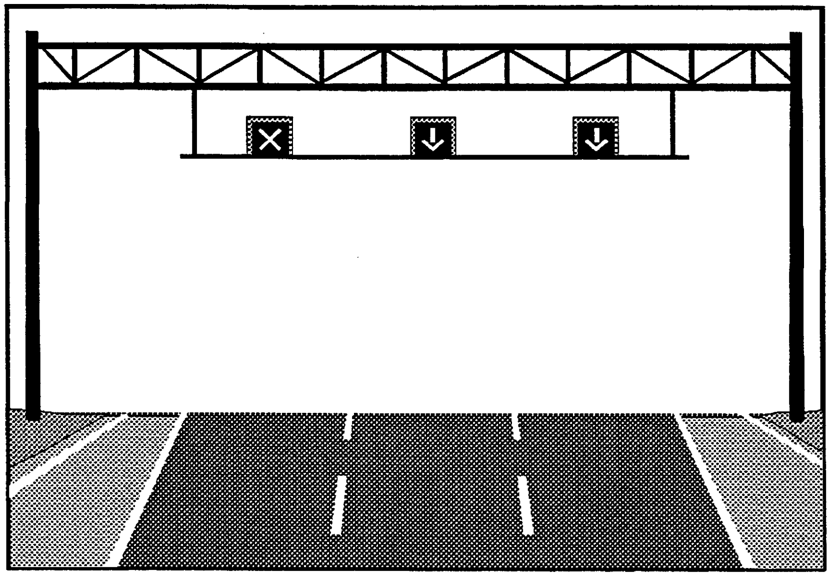
Potential Solutions

Several ideas were offered in response to the above problems relating to LCS visibility. As one example, the Fort Worth District now schedules maintenance of the LCS every six months to change out all bulbs in each signal and to clean the pixel lenses. This maintains the LCS at their highest brightness level and helps to maintain a uniform appearance across all of the signals at a given location.

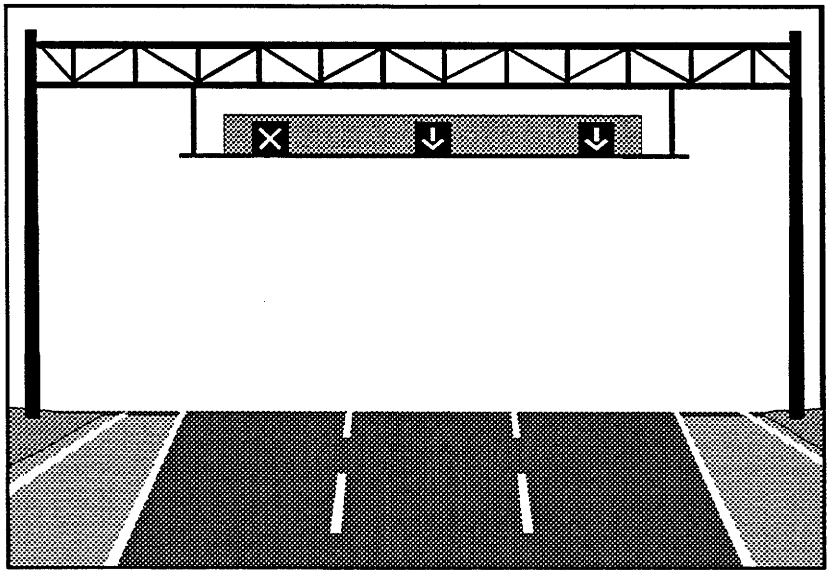
The Fort Worth District is also planning to install back plates on their LCS mounted on overhead sign structures. It is more difficult to obtain the desirable contrast between the symbols and the blue sky background for these types of mountings. Two types of back panels are being considered. Both types are illustrated in Figure 3-4. The first consists of a 150 to 200-mm (6- to 8-inch) border mounted around each individual display (Figure 3-4a), whereas the second is a louvered panel installed across the length of the sign structure behind the signals (Figure 3-4b).

Another suggestion discussed at the meeting was the improvement in face plate materials that resist fading from the sun. The flat black paint used on the faces of the LCS installed in Fort Worth have faded dramatically over the six years they have been in place. Other methods of covering the face plate (i.e., a plastic material or a higher quality paint) need to be considered to help reduce sun fading and maintain adequate contrast for a longer period of time.

The final suggestion presented by the panel regarding LCS visibility was to explore the possible advantages of using LCS that have wider cones of vision, particularly for wide freeways and those carrying a large amount of heavy truck traffic. One panel member did note that this could create difficulties for maintenance crews in the future if different LCS heads having different specifications were mixed within the overall system. Also, a wider cone of vision distributes the light output over a wider viewing range, and reduces the legibility distance unless brighter quartz - halogen bulbs are used.



(a) individual back plates



(b) louvered back panel

Figure 3-4. Proposed Back Plate/Back Panel Configurations in Fort Worth

LCS Spacing and Mounting Locations

Problems and Concerns

Another area of concern about freeway LCS relates to the need for, and appropriate specification of, spacing criteria. Although some panel members felt that consistency in LCS spacing promoted driver expectancy of lane status information and thus the potential utilization of the LCS, other members felt that it was far more important to focus on where to install the signals rather than attempt to strive for uniform spacing. Early on in the discussion, the point was made that cost considerations currently control most LCS location decisions. Existing overhead sign structures, overhead bridge structures, etc., are commonly relied upon for LCS installations, and these limit the flexibility that the Department has in where the LCS are provided. At least one member noted difficulties in utilizing the LCS currently in operation because most of the lane-blocking incidents in the vicinity occur just upstream of the LCS installations, rendering them useless for warning approaching motorists of the lane blocked conditions at that location.

Another problem cited by the panel with respect to LCS spacing was in how these signals should fit into the overall information package presented to motorists as they traverse a section of roadway. Specifically, concern was raised over the placement of LCS on overhead sign structures where a large number of sign panels are already installed. Given that drivers have limited capacity for storing and processing information (*12*), the latest edition of positive guidance principles from FHWA indicates that a roadway information system begins to reach an overload condition when it contains more than five information sources (*13*). These information sources are not only limited to the LCS and other signing installed on the roadway, but include pavement markings, geometric features, and even certain structural elements. As an example, Figure 3-5 depicts an LCS installation on an overhead sign structure. According to positive guidance principles, drivers in this situation are being presented the following seven pieces of information at approximately the same location on the freeway:

- the horizontal curve (depicted by the lane markings),
- the exit ramp and gore area (depicted by the pavement markings in the exit only lane and by the markings in the gore),
- the sign structure at the gore area,
- the guide sign panel for exiting to Crowley Road,
- the Lane Ends 1/4 mile sign panel,

- the guide sign panel to McCart Avenue, and
- the LCS at the array.

In addition, it is conceivable that a more complex LCS array (such as a middle lane closure) might require a greater information processing effort by drivers, further increasing the information overload potential at this location.

A final concern noted by panel members with regard to LCS spacing and mounting location involved the use of overhead bridge structures (roadway cross-streets, railroad overpasses, pedestrian walkways) as LCS supports when the structure is skewed relative to the freeway alignment. Of course, the LCS heads must be oriented perpendicular to the oncoming flow of traffic. What is less apparent is whether an adverse visual effect is caused by mounting the heads next to the structure and thereby creating an offset between heads, as depicted in Figure 3-6.

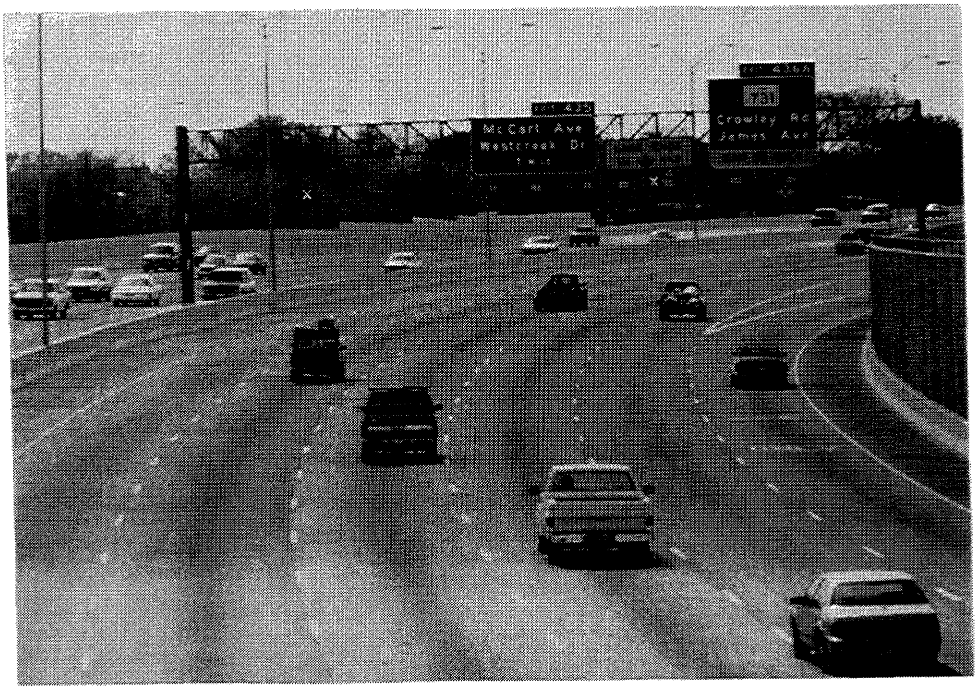


Figure 3-5. LCS and Other Information Sources Competing For Driver Attention

Potential Solutions

After some discussion, the panel agreed in principle that LCS spaced somewhere between 0.8 and 1.6 kilometers (0.5 to 1.0 miles) apart appear to function adequately in urban areas. It was noted that most of the LCS viewed along the Fort Worth freeways were spaced about this far apart, and appeared to present lane status information to motorists at a reasonable rate. Also, the limited short--term memory span of drivers (30 seconds to 2 minutes [*12*]) suggests that this range of spacings is beneficial to information retention, as drivers encounter LCS displays at normal operating speeds every 30 to 60 seconds.

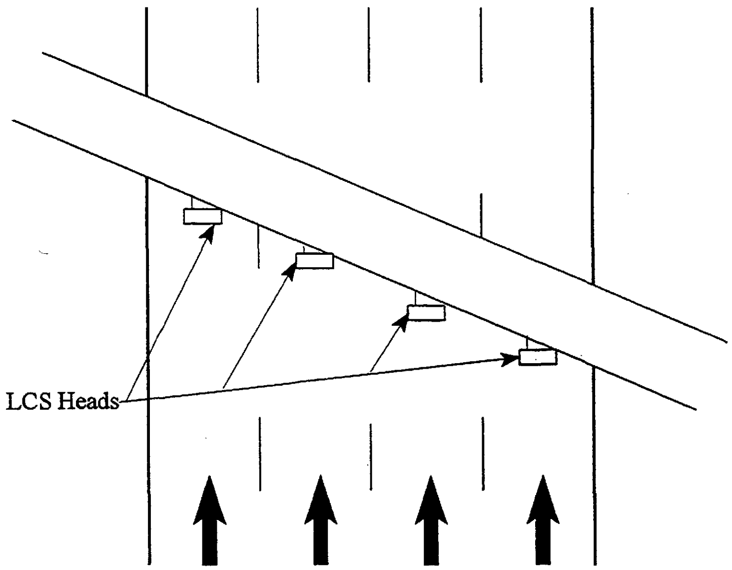


Figure 3-6. LCS Mountings on Skewed Bridge Structure

The actual location of LCS should be based on the following criteria:

- ramp spacing,
- location of other major driving decision points,
- available sight distance, and
- location of other information sources (guide signs, changeable message signs, etc.).

Specifically, overhead sign structures already containing the maximum number of guide sign panels and located at complex decision points such as shown in Figure 3-5 should not be used to support LCS as well if there is an alternative choice available. For this reason, most of the panel members seemed to prefer the use of bridge structures for LCS mounting, if they are located in appropriate positions along the freeway.

With respect to the use of skewed bridge structures as LCS supports, one panel member suggested the use of a cantilever support arm extending out from the bridge structure. As shown in Figure 3-7, a design of this type would maintain uniformity in the LCS displays. However, this design would only be appropriate for structures having a moderate degree of skew; more oblique skews would necessitate the use of a different support structure.

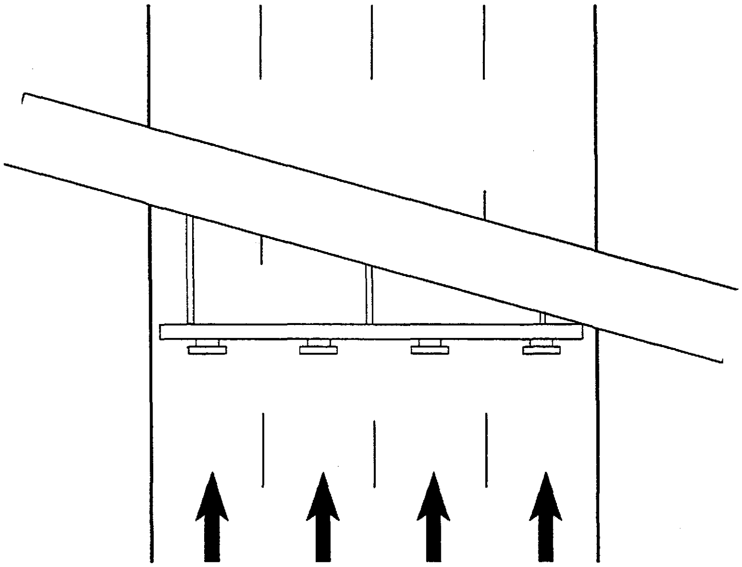


Figure 3-7. Cantilever LCS Mountings on Skewed Bridge Structure

A final point of discussion regarding the spacing and mounting location of LCS focused around the potential design and use of a smaller overhead sign support built just for LCS. As one panel member noted, the wind loads associated with the LCS would be much less than for typical guide sign assemblies. This should make the required support structure cheaper and less extensive than the typical overhead sign structure now used. Related to this discussion, the issue of LCS maintenance was also brought up. Panel members suggested the potential design of a cantilever type of structure that could be rotated over to the side of the freeway to allow maintenance crews to access the LCS heads without closing travel lanes. However, the overall feasibility of such a system with respect to cost and the ability to return the heads to their proper orientation (a major concern with the narrow cone of vision provided by many fiberoptic LCS) would first need to be explored.

LCS Use at Unusual Geometric Situations

Problems and Concerns

The panel also spent time identifying and discussing some of the unusual geometric situations that are difficult to treat with LCS. A considerable amount of discussion centered around the use of LCS over auxiliary lanes and lane drop locations. Placing LCS over the exit lane could lead to driver confusion, particularly during conditions when all but one of the freeway main lanes are blocked. In this situation, drivers may perceive a green arrow over the exit lane and over the remaining open through lane as indicating that two lanes are open on the freeway downstream. This incorrect perception could then lead to increased erratic maneuvers at the exit lane gore area as drivers fooled by the LCS display attempt to get back into the freeway traffic flow. In general, it was the opinion of the panel that LCS should not be placed over exit only lanes.

The panel was in less agreement as to whether LCS should be displayed over all lanes upstream of a major freeway-to-freeway bifurcation. Many bifurcations involve splitting away two or more lanes. Placing LCS only over through lanes upstream of the bifurcation limits the information that can be displayed to just the through travel lanes. Often, incidents occur on one of the exiting lanes connecting the two freeways, and it would be desirable to inform motorists of the lane blocked condition upstream of the interchange as well. However, the same argument exists concerning the possible driver misinterpretation of green arrows over lanes that are to exit. The panel discussed whether LCS displays should be placed immediately after the bifurcation, such as illustrated in Figure 3-8, but no consensus was reached on this issue.

The final special situation discussed involved the installation and use of LCS during the actual freeway reconstruction process. Generally speaking, LCS are intended to provide real-time lane status information. Consequently, some means of monitoring traffic conditions and lane status must be in place in order to utilize the LCS. However, the Fort Worth District chose to install LCS at selected locations early on in their reconstruction of I-20 on the west side of the city (see Figure 3-1). Rather than use the LCS in real-time to indicate lane status, they have configured the LCS displays to coincide with the long-term lane closures required for the project. In this way, the LCS reinforce the complement of advance warning signs for the lane closures. TxDOT officials in Fort Worth believe that the early implementation of LCS for this purpose is worthwhile. However, some concerns were expressed as to whether this reduces the credibility of the signals in terms of presenting real-time information to motorists on other freeways in the system.

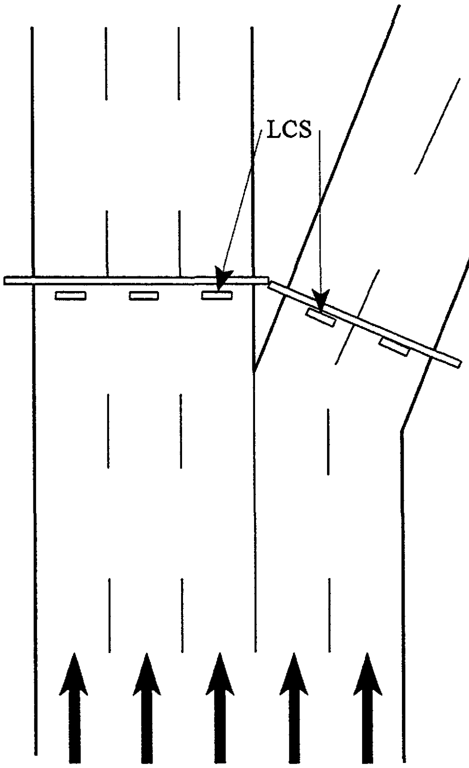


Figure 3-8. Placing LCS After Major Freeway Bifurcations

Potential Solutions

Very few ideas or proposed solutions (other than those discussed above) were generated as part of this discussion. Some additional research was suggested to determine likely driver interpretation and behavior in response to alternative LCS displays upstream of major freeway bifurcations. The Fort Worth District believes that the temporary installation of LCS early in the construction project to support the advance warning signs and overall traffic control plan for lane closures would be cost-effective if the construction project will last several (i.e., four to five) years. If the LCS remain as part of the permanent freeway traffic management system, District personnel believe it would be useful to install them as soon as possible after construction begins if long-term lane closures are included in the overall traffic control plan.

Concluding Remarks

One final topic discussed by the panel during the meeting was the importance of knowing and understanding the appropriate target audience for which the LCS are intended, and to design the LCS system for that audience. In general, panel members identified three types of drivers, each potentially having a very different need for, and response to, LCS:

Unfamiliar drivers (maybe older drivers as well) -- those who hardly ever travel on the freeway system and who would not even be expected to be looking for lane status information via LCS. For these drivers, it is essential that LCS displays and the operation of the system be designed to maximize quick and common driver understanding, as there will be little opportunity to teach or train these drivers about what certain symbols, arrays, or sequences are intended to convey.

Occasional drivers -- those who drive on the freeway on occasion, but not on a regular enough basis to be totally familiar with the specific freeway section they are on to know about downstream bottlenecks, lane drops, etc. These individuals may be looking for lane status information, but may become confused at certain locations if the information system (i.e., LCS) is not designed properly.

Repeat drivers -- those who travel the section of freeway on a regular basis and who are familiar with the various geometric features present, available alternative routes in the corridor, and available traffic information (including LCS displays). These individuals will likely learn over time what various displays mean in terms of expected delays, congestion, etc., and may become particularly responsive to those displays. Conversely, inconsistent utilization of the LCS from location to location or from one incident to the next will likely decrease the credibility of the displays with this driving group and reduce the overall effectiveness of the real-time information system.

4. SUMMARY AND RECOMMENDATIONS

Summary

Glance Legibility Studies

Glance legibility studies were conducted at the TTI Proving Grounds to examine the legibility of three commercially available LCS with respect to symbol, signal type, subject gender, and subject age. Also, the effect of ambient light conditions existing when each subject participated in the study upon glance legibility of the LCS was also explored. The symbols presented by the three LCS heads were an identical 356 mm tall. However, the signal heads differed in terms of how each created the symbol image (i.e., fiberoptic output bundle lens diameter, pixel configuration, pixel spacing, etc.).

Overall, all symbols on all three signals resulted in median glance legibility distances of 304.8 meters (1000 feet) or greater. Meanwhile, the 85th percentile glance legibility distance, assumed to reflect the majority of the driving population, was 213.4 meters (700 feet) or greater in each case. Generally speaking, the yellow X was visible to motorists at the greatest distance. The green arrow provided the next longest legibility distance, and the red X resulted in the lowest legibility distance. The design of one of the signals, however, was such that the median and 85th percentile glance legibility distances for each of the symbols were nearly identical.

A few of the individual symbol indications on certain signals generated legibility distances that were somewhat lower than the same symbol on the other signals. A lower legibility distance for a green arrow on one of the signals appeared to be due to a slight difference in the color of the green filter and/or difference in output luminance provided by that display. Conversely, a lower legibility distance of a red X on another signal was most likely caused by the double-stroke pixel arrangement utilized. The increased width of the double-stroked X, combined with a greater irradiation effect caused by the red indication, made it difficult to discern the features of the X at any substantial distance away from the signal.

The data did not suggest that gender or the ambient lighting conditions significantly affected glance legibility of the LCS. The age of the subject did influence legibility distances, however. In general, drivers 65 years and older had to be 91.5 to 198.1 meters (300 to 650 feet) closer to the signals to correctly identify the symbols being displayed than drivers aged 16 to 44 years. None of the three signal designs appeared to provide any consistent benefit to older drivers in terms of glance legibility.

Findings of the Expert Panel Meeting

A panel of eight TxDOT managers and engineers with expertise relating to the design and operation of LCS in freeway traffic management met in Fort Worth to discuss problems and potential solutions regarding LCS. Panel members were driven around portions of the Fort Worth freeway system to view LCS installations under a variety of mounting positions, spacings along the freeway, signal manufacturers, and orientations to the sun. Panel members then discussed problems and solutions relative to three main focus areas:

- visibility,
- mounting position and spacing, and
- applications to special geometric situations.

Based on the drive-throughs and subsequent discussion, members of the panel agreed that the existing level of brightness of the LCS installed in Fort Worth is adequate when sun interference is not a factor (i.e., when motorists are not driving directly into or away from the early morning or late evening sun). Potential countermeasures suggested to help alleviate the sun interference problem and increase overall LCS conspicuity included the following:

- frequent cleaning of the pixel lenses on the front of the LCS,
- using a covering on the LCS face plate that does not fade in the sun, and
- installing back plates or back panels behind LCS on overhead sign structures to increase target value.

Panel members also liked the higher contrast that an overhead bridge structure afforded the LCS. However, selection of mounting locations for LCS must be based first and foremost on the information needs of the driver. One of the important points raised during the panel discussion was the need to use caution when locating the LCS so as not to overload the information processing capabilities of the drivers. This can happen if LCS are indisciminantly installed on overhead sign structures already containing several guide sign panels. Positive guidance techniques should be consulted whenever LCS locations are being selected.

Panel members agreed that exit lane drops should not have LCS installed over them to avoid confusing unfamiliar motorists into believing that the lane is an open through lane under incident conditions. However, panel members could not agree on whether LCS should be placed on all lanes upstream of a major freeway bifurcation, nor did they agree on where LCS should be installed in the vicinity of the bifurcation. Additional research will likely be necessary to resolve this issue.

Recommendations

As a result of the glance legibility studies and the expert panel meeting, the following recommendations are presented for consideration by TxDOT. These recommendations may be useful enhancements to current Department purchase specifications regarding LCS, and may be relevant information to include in the Departments *Highway Operations Manual* that is being maintained by TTI.

LCS Visibility

1. Acceptance of LCS installations by TxDOT should include drive-throughs by TxDOT personnel when the LCS is displaying a red X. This symbol tends to have the lowest legibility distance of all of the symbols that the LCS can display.

2. If the Department chooses to require double-stroked symbols for LCS displays, a maximum pixel spacing and/or effective stroke-width-to-letter-height ratio should be specified as well. Although the maximum allowable ratio could not be determined within the constraints of this study, an approximate ratio of one inch of stroke width for every seven inches of symbol height was too wide to be adequately seen by many motorists at a reasonable distance away from the signal.

3. A regular cleaning and bulb-replacement schedule should be established for LCS. Their relatively close proximity to the travel lanes (in comparison to CMSs) causes dirt and grime to accumulate relatively quickly on the output lenses of the fiberoptic pixels. Furthermore, the quartz-halogen lamps used to illuminate the LCS lose a portion of their intensity over time. The Fort Worth District of TxDOT cleans and replaces the lamps in their LCS every six months to one year.

4. The Department should consider the installation of back plates or a back panel behind LCS on overhead sign structures, particularly if the LCS are oriented east and west where sun

interference will be a problem during certain times of the day. If a back panel is to be installed along the length of the structure behind the LCS, it must be louvered or otherwise designed to reduce wind loads.

LCS Spacing and Mounting Locations

1. As a general rule-of-thumb, it is desirable to place LCS every 0.8 to 1.6 kilometers (0.5 to 1.0 miles). However, the actual location of the LCS must take into consideration general freeway alignment (for visibility purposes), driver decision points, and the other components of the overall information system being presented to the driver as he or she travels the freeway.

2. If the criteria listed above are met, mounting LCS on a cross-street bridge structure will provide better contrast and target value than mounting them on an overhead sign structure.

3. Also relating to the criteria listed in item #1, positive guidance principles should be employed when determining the appropriate location for LCS. LCS should not be installed on overhead sign structures if the overall information system at that location equals or exceeds five units of information. As a general rule, LCS should not be placed on structures having more than three guide sign panels.

5. REFERENCES

1. *Manual on Uniform Traffic Control Devices*. Federal Highway Administration, Washington, DC. 1988.

2. Ullman, G.L., S.D. Wohlschlaeger, C.L. Dudek, and P.B. Wiles. *Driver Interpretations of Existing and Potential Lane Control Signal Symbols for Freeway Traffic Management.* Report No. FHWA/TX-93/1298-1. Texas Transportation Institute, College Station, Texas. November 1993.

3. Ullman, G.L. and P.B. Wiles. *Operation of Lane Control Signals for Freeway Traffic Management.* Report No. FHWA/TX-94/1298-2F. Texas Transportation Institute, College Station, Texas. November 1993.

4. *Highway Operations Manual.* Report No. FHWA/TX-92/1232-3. Texas Transportation Institute, College Station, Texas. August 1992.

5. Institute of Traffic Engineers Technical Council Committee 4K-S. "Lane-Use Traffic Control Signal Heads." *Traffic Engineering*, Vol. 47, No. 1, January 1977. pp. 48-52.

6. Kaufman, L. *Sight and Mind: An Introduction to Visual Perception.* Oxford University Press, New York, New York. 1974.

7. Tallamraju, S.S. *Legibility of Lane Control Signals.* Master of Science Thesis. Department of Civil Engineering, Texas A&M University, College Station, Texas. December 1994.

8. Hostetter, R.S., M.T. Pietrucha, and L. Staplin. *Pavement Markings and Delineation for Older Drivers.* Draft Final Report submitted to the Federal Highway Administration from the Pennsylvania Transportation Institute for Contract No. DTFH61-90-R-00062. May 1994.

9. Sivak, M., P.L. Olson, and L.A. Pastalan. Effect of Driver's Age on Nighttime Legibility of Highway Signs. *Human Factors*, Vol. 23, No. 1, 1981. pp. 59-64.

10. *Transportation In An Aging Society, Improving Mobility and Safety for Older Persons: Volume 1, Committee Report and Recommendations.* Transportation Research Board Special Report 218. Transportation Research Board, Washington, D.C. 1988.

11. Dudek, C.L. *Guidelines on the Use of Changeable Message Signs.* Report No. FHWA-TS-90-043. Federal Highway Administration, Washington, D.C. May 1991.

12. Klatzky, R.L. *Human Memory: Structures and Processes.* W.H. Freedman and Co., New York, New York. 1975.

13. H. Lunenfeld, and G.J. Alexander. *A User's Guide to Positive Guidance (3rd Edition)*. Report No. FHWA-SA-90-017. Federal Highway Administration, Washington, D.C. September 1990.

APPENDIX - GLANCE LEGIBILITY DISTANCES BY GENDER AND AMBIENT LIGHT CONDITION

Table A-1. Effect of Subject Gender on Median Glance Legibility Distances

Symbol	Median Glance Legibility Distance (meters)		
	Signal #1	Signal #2	Signal #3
Red X:			
male	335.3	335.3	457.2
female	274.3	304.8	426.7
Yellow X:			
male	457.2	457.2	457.2
female	457.2	426.7	426.7
Green Arrow:			
male	365.8	457.2	457.2
female	365.8	426.7	426.7
Yellow Downward Arrow:			
male	n.a.	n.a.	457.2
female	n.a.	n.a.	426.7
Yellow Diagonal Arrow:			
male	n.a.	n.a.	426.7
female	n.a.	n.a.	396.2

note: 1 meter = 3.28 feet

Table A-2. Effect of Subject Gender on 85th Percentile Glance Legibility Distances

Symbol	85th Percentile Glance Legibility Distance (meters)		
	Signal #1	Signal #2	Signal #3
Red X:			
male	274.3	213.4	274.3
female	243.8	213.4	274.3
Yellow X:			
male	426.7	426.7	396.2
female	304.8	304.8	365.8
Green Arrow:			
male	243.8	365.8	335.3
female	213.4	274.3	335.3
Yellow Downward Arrow:			
male	n.a.	n.a.	365.8
female	n.a.	n.a.	396.2
Yellow Diagonal Arrow:			
male	n.a.	n.a.	274.3
female	n.a.	n.a.	243.8

note: 1 meter = 3.28 feet

Table A-3. Effect of Ambient Light on Median Glance Legibility Distances

Symbol	Median Glance Legibility Distance (meters)		
	Signal #1	Signal #2	Signal #3
Red X:			
sunlight	335.3	304.8	426.7
cloudy	304.8	304.8	457.2
Yellow X:			
sunlight	457.2	457.2	426.7
cloudy	457.2	457.2	457.2
Green Arrow:			
sunlight	365.8	426.7	426.7
cloudy	365.8	426.7	457.2
Yellow Downward Arrow:			
sunlight	n.a.	n.a.	457.2
cloudy	n.a.	n.a.	457.2
Yellow Diagonal Arrow:			
sunlight	n.a.	n.a.	396.2
cloudy	n.a.	n.a.	426.7

note: 1 meter = 3.28 feet

Table A-4. Effect of Ambient Light on 85th Percentile Glance Legibility Distances

Symbol	Median Glance Legibility Distance (meters)		
	Signal #1	Signal #2	Signal #3
Red X:			
sunlight	243.8	213.4	274.3
cloudy	274.3	213.4	396.2
Yellow X:			
sunlight	304.8	304.8	365.8
cloudy	365.8	396.2	365.8
Green Arrow:			
sunlight	213.4	304.8	335.3
cloudy	274.3	304.8	396.2
Yellow Downward Arrow:			
sunlight	n.a.	n.a.	365.8
cloudy	n.a.	n.a.	396.2
Yellow Diagonal Arrow:			
sunlight	n.a.	n.a.	274.3
cloudy	n.a.	n.a.	274.3

note: 1 meter = 3.28 feet