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16. Abstract

In this report, researchers document the results of a laptop-based human factors study of alternative formats of presenting advance notice work zone information on portable changeable message signs (PCMSs) and a Texas Transportation Institute (TTI) driving simulator study of the ability of motorists to capture and process information on two PCMSs used in sequence to convey information about upcoming traffic situations. Based on the studies, researchers recommend that messages that require the display of calendar dates for future roadwork and other traffic control activities should utilize a message format consisting of the three-character abbreviation of the month (e.g., APR for April) in conjunction with the date. When future work activities span several days all in the same month, the month needs be noted only once in the message (i.e., APR 21-23) rather than repeating the month (i.e., APR 21-APR 23). The TTI driver simulator study results indicate the need to keep overall messages at or below the four-unit maximum recommended in existing guidelines. Researchers found that presenting five units of information on sequential PCMSs resulted in low comprehension rates, below what would be acceptable for highway applications. However, by keeping the message length to four units, it does appear that the use of sequential PCMSs will result in comprehension rates comparable to those obtained by presenting the same information at a single location on a large dynamic message sign (DMS), and is recommended as an acceptable formatting approach for TxDOT. Comprehension may be enhanced by repeating one of the units of information on both PCMSs.

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# ADVANCED NOTIFICATION MESSAGES AND USE OF SEQUENTIAL PORTABLE CHANGEABLE MESSAGE SIGNS IN WORK ZONES

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# INTRODUCTION

## STATEMENT OF THE PROBLEM

Portable changeable message signs (PCMSs) have become an integral part of work zone traffic control in Texas, advising motorists of unexpected traffic and routing situations. When used properly, these signs can command additional attention over that achievable through regular static work zone signing. Furthermore, PCMSs can present a wide variety of information to motorists, making them a highly versatile tool to traffic control designers and to work crews. PCMS have been used in a variety of applications in both construction and maintenance work zones. Some of these applications are to (*1-8*):

- warn of a new detour or of a change in a detour,
- warn of a ramp closure,
- identify the presence of a lane drop where a continuous lane once existed,
- emphasize the existence of reduced speed limits within a work zone,
- warn of downstream traffic queues (especially due to lane closures),
- warn of the presence of downstream flaggers or work crews,
- notify motorists to turn to a highway advisory radio (HAR) station for more details, and
- alert motorists of future changes which will be made to current traffic conditions (i.e., that road work will occur at a future date).

Whereas PCMSs can be highly effective tools when used properly, improper use of PCMSs can destroy their credibility with the motoring public. Also, in a worst-case scenario, improper PCMS usage can contribute to motorist confusion, which can ultimately degrade the safety of motorists and workers as well as the operational efficiency of the overall traffic control plan.

To be effective, a PCMS must communicate a meaningful message that can be read and comprehended by motorists within a very short time period. Fundamental human factors principles that take into consideration motorist vision, information processing, and cognitive capabilities govern proper PCMS use. These human factors principles have been identified

through extensive research and field validation, much of it by the Texas Transportation Institute (TTI) (*1-18*). Specific factors that enhance understanding of PCMS messages include the following:

- simplicity of words,
- brevity,
- standardized order of words,
- standardized order of message lines, and
- use of understood abbreviations when needed.

Despite the knowledge that does exist regarding proper PCMS application, a mid-1990s survey of a number of transportation agency officials identified ongoing concerns as to how PCMSs are used (or misused) in work zones (*19*). These officials noted that a number of impediments to effective PCMS usage still exist (*19*):

- Personnel who are expected to operate the PCMS come from a variety of educational backgrounds and types of experience. As a result, it is difficult to ensure that those who are given PCMS responsibilities (or inherit them by default) are provided adequate levels of training.
- Those expected to operate the PCMS also typically have many other responsibilities. This limits their time available to effectively evaluate site conditions, develop concise and useful messages, and monitor the relevancy of the messages on a continuous basis.
- PCMSs are used quite often to emphasize lower speed limits or advisory speeds in work zones. In many instances, the speed limits adopted through the work zone are much lower than the normal speed of traffic, and very little active enforcement of the lower limit is provided. Presenting information that is neither accurate nor relevant to the motorist degrades the overall credibility of the PCMS.
- PCMSs can be useful as tools to help notify drivers of future changes in traffic conditions in the work zone. Unfortunately, due to the many other responsibilities of those who operate the PCMS, roadwork messages are often designed to be very

generic so that very little thought about the message is required. As a result, the PCMSs lose effectiveness with the motorists.

Recent studies of driver understanding of traffic control devices through several work zones on high-speed roadways in Texas further suggest that misapplications of PCMSs in work zones are quite common and that these misapplications often contribute to driver confusion and anxiety about their appropriate travel paths (*20*). Some of the types of PCMS misapplications identified through that research are listed below:

- PCMSs were often placed too close or too far from the features that they were trying to provide motorists with information about.
- PCMSs were sometimes positioned as part of a system of traffic control devices within a long work zone in such a way that it was not clear how the message was to be interpreted or how the information being conveyed on the other traffic control devices was to be interpreted. In one instance, the presence of a PCMS with an advisory speed limit upstream of a portable speed display trailer created confusion for the drivers as to what all of the "numbers" meant.
- PCMS messages that could have been adequate under low-volume conditions were too long to read in high traffic volumes when there were many large trucks present to obscure the sign.
- Some PCMS messages presented within freeway interchange areas could not adequately convey to motorists which lane was closed ahead (i.e., the right lane of a two-lane left exit was closed).

Clearly, these issues and others regarding the proper application of PCMSs in work zones needed additional research and field-level guidance. This report contains the documentation of the results of research sponsored by the Texas Department of Transportation and conducted by TTI to address key research needs in this area.

## PROJECT OBJECTIVES

The objectives of this research project were two-fold:

- Identify and prioritize key research gaps that still exist regarding the effective use of PCMS in work zones, and conduct human factors studies to address those research gaps; and
- Develop appropriate field-level guidance regarding the effective PCMS use in work zones.

This report describes the results of tasks performed to address the first objective. The second objective is being addressed through ongoing research activities that will be documented in later reports and project deliverables.

**CONTENTS OF THIS REPORT**

In the remainder of this report, researchers document the results and findings of the following research tasks:

- an inventory and human factors critique of existing PCMS use in work zones in several TxDOT districts;
- interviews of TxDOT personnel in several districts regarding the key issues they struggle with regarding PCMS use in work zones;
- description and results of a laptop-based human factors study of alternative formats of presenting advance notice work zone information on PCMS; and
- description and results of a TTI driving simulator study of the ability of motorists to capture and process information on two PCMS used in sequence to convey information about upcoming traffic situations.

Key findings and recommendations from these research activities are then summarized at the end of the report.

# INVENTORY OF PCMS MESSAGES DISPLAYED IN TEXAS WORK ZONES

## OVERVIEW

TTI researchers conducted field reviews of PCMS usage in the following six districts:

- Austin,
- Bryan,
- Corpus Christi,
- Dallas,
- Houston, and
- San Antonio.

The purpose of the field reviews was to identify the various types of messages and applications for which PCMSs are actually being utilized in work zones in the state and to critique how well these messages and applications meet guidelines currently available regarding PCMS use. The *Dynamic Message Sign Message Design and Display Manual* served as the primary document against which the PCMS messages and applications were compared (*1*). This document is the most current and comprehensive manual available of human factors principles and requirements regarding message design on all types of dynamic message signs, including PCMSs.

In each district, researchers identified work zone locations via the TxDOT road condition internet website and the monthly construction and maintenance contract status reports. Researchers then traveled to each location to determine whether PCMSs were in use on that particular day or night. For each PCMS identified, researchers recorded the messages displayed (exactly as they appeared on the sign), display characteristics (i.e., duration of each phase, flash rates, any words or characters that were bolded, etc.), and location of the sign relative to key features such as intersections, exits, lane closures, etc. Researchers observed the use of 47 PCMSs during the inventory process.

Back in the office, researchers then categorized the PCMS applications and performed a human factors critique of each. Researchers found that the PCMS applications identified through this inventory effort fell into one of five general categories:

- lane closure messages,
- advance notice messages of traffic conditions or traffic control,
- speed-related messages,
- road and ramp closure and detour messages,
- exit-related messages, and
- general work zone warning and other miscellaneous messages.

In the following section, researchers summarize the key human factors principles of PCMS message design and use that were not fully followed in these various applications.

## HUMAN FACTORS CRITIQUE OF PCMS APPLICATIONS

### Lane Closure Messages

Of the 47 PCMS observed in the field, 18 (38 percent) provided information about current or future lane closures in the work zones. The most common issue the researchers identified with these applications was that messages consisting of more than two phases of information were displayed. The latest version of the *Manual on Uniform Traffic Control Devices* (MUTCD) specifies that a message shall consist of either one or two phases (*21*). However, eight of these 18 PCMS observed displayed three phase messages, and two actually displayed four phase messages.

In three of the eight cases, the messages could have easily been reduced by eliminating generic warning statements that were included, such as “EXPECT DELAYS” or “CAUTION/CAUTION/CAUTION” which were presented on one phase of a message. Two other messages could have been formatted using standard accepted abbreviations. For example, the following three-phase message could be reduced to a two-phase message by deleting a few unnecessary words and utilizing abbreviations as shown below.

| Original PCMS Message: | | | | |
|---|---|---|---|---|
| CAUTION<br>LEFT<br>LANE | | CLOSED<br>300 FT.<br>AHEAD | | MERGE<br>RIGHT |
| Possible Reduced PCMS Message: | | | | |
| LFT LN<br>CLOSED<br>300 FT | | MERGE<br>RIGHT | | |

In actuality, the message could have been further reduced to a single phase by eliminating the "MERGE RIGHT" second phase, since the information that the left lane is closed automatically implies that it is necessary to merge right  However, researchers assumed that redundancy of this information was a desired part of the message in this instance.

As another example, a three-phase message that included the days of the week and times that lanes would be closed could have been reduced to two phases using appropriate abbreviations.

| Original PCMS Message: | | | | |
|---|---|---|---|---|
| RIGHT<br>2 LANES<br>CLOSED | | MONDAY<br>THROUGH<br>FRIDAY | | 9 AM<br>THROUGH<br>4 PM |
| Possible Reduced PCMS Message: | | | | |
| RIGHT<br>2 LANES<br>CLOSED | | MON-FRI<br>9 AM –<br>4 PM | | |

Researchers identified other types of PCMS formatting issues as well.  For example, they observed the use of ALTERN and ALT abbreviations for the term *alternate* on two of the PCMSs, even though prior research has determined that ALT is not an acceptable abbreviation (*1*).  It is interesting to note that messages on two other PCMS contained the phrase "VARIOUS LANES CLOSED" to convey similar information as the term *alternate* within the constraint of eight characters per line that typically exists on PCMSs.  Another formatting issue observed was that in some messages a single unit of information was split, showing part of the information on one phase and the other part on the second phase.  This practice is contrary to existing PCMS

message guidelines (*1*). This issue could have also been rectified through elimination of unnecessary words or the appropriate use of acceptable abbreviations, as shown below.

| Original Format | | |
|---|---|---|
| 2<br>LEFT<br>LANES | | CLOSED<br>AHEAD |
| Possible Improvement A | | |
| LEFT 2<br>LANES<br>CLOSED | | |
| Possible Improvement B | | |
| LEFT 2<br>LN CLSD<br>AHEAD | | |

A final issue researchers noted was the wide range of formats used to convey actual calendar dates about lane closure activity. In particular, researchers observed the following messages displayed on PCMSs in the districts surveyed:

| Format A | | |
|---|---|---|
| SATURDAY<br>SUNDAY<br>31-01 | | 8:00 AM<br>TILL<br>7:00 PM |
| Format B | | |
| 01/05<br>THROUGH<br>02/01 | | 8PM-5AM |
| Format C | | |
| 2/4 AND<br>2/5 9 PM<br>TO 6 AM | | |

In Format A, the numbers "31-01" referred to the 31st day of January and the 1st of February (based on when the researchers observed the PCMS), although this intent is not immediately evident from the message itself. Formats B and C do appear to convey calendar dates more directly, although subtle distinctions are evident in the number of characters used to convey month and date. Presumably, Format C utilized the month-date format without zeroes in

order to allow the times of work to be included on the same phase. Previous TTI research has determined that most motorists are not able to translate calendar dates to specific days of the week, which suggests that the value of displaying calendar dates may be limited (*18*). However, it is current TxDOT policy to provide at least 7 days advance notice of lane closures to the public. Some districts provide even longer advance notices when possible. Obviously, this practice requires that calendar dates be displayed in some cases, and the best formats to convey this information has not been previously researched.

**Advance Notice of Changes in Traffic Conditions or Control**

Researchers observed 10 PCMS that displayed messages with advance notice about upcoming changes in traffic conditions or control. Five of the PCMSs (50 percent) also exceeded the two-phase maximum specified in the MUTCD. The messages used to display calendar dates again varied among the applications. Four of the calendar date messages are shown below. In the first two messages (Formats A and B), the month is displayed as either full or abbreviated text rather than numerals. In the third message (Format C), both the day and the date are presented (the presentation of "CLOSED" here was the result of splitting information across phases, something that is undesirable in PCMS formatting). In the fourth message (Format D) dashes are used instead of slashes between month, date, and year numerals.

| Format A | |
|---|---|
| MARCH<br>15,16,17 | |
| Format B | |
| SH 21<br>CLOSED<br>NOV 15 | |
| Format C | |
| CLOSED<br>TUESDAY<br>02/03/04 | |
| Format D | |
| 10-25-03<br>9-PM TO<br>5:AM | |

In three of the messages, units of information were again split with part of the information presented on the first phase and the rest displayed on the second phase.

**Speed-Related Messages**

Researchers encountered five PCMSs that displayed speed-related messages. On two of the PCMS (40 percent), three phases of information were displayed rather than the maximum of two phases specified in the MUTCD. Again, these applications could have easily been brought into compliance by eliminating unnecessary wording in the message.

**Road and Ramp Closure or Detour Messages**

Researchers encountered a total of 13 PCMSs that displayed information about road or ramp closures and detours. Four of the 13 applications (31 percent) displayed messages with more than two phases. The same types of issues that were previously noted (multiple formats of calendar dates, splitting information across phases, failure to utilize abbreviations or eliminate unnecessary words when possible, etc.) were also evident in these applications

**Exit Messages**

Researchers observed seven PCMS messages that provided information about exit ramps within the work zone. None of these messages exceeded the MUTCD specification for maximum phases allowed. There was one instance where a two-phase message could have been rearranged to fit onto a single phase if desired. However, the message was acceptable as designed and appeared to serve its intended purpose. Researchers have heard anecdotal comments by some practitioners that they prefer to utilize more than a single phase on the PCMS because they believe the switch between phases provides additional attention-getting value for the message.

**General Warning and Other Miscellaneous Messages**

Researchers observed a total of 8 messages containing general warning or miscellaneous information about the work zone, 2 of which (25 percent) exceeded the MUTCD limit of two phases. In one instance, the third phase could have easily been eliminated. The other instance presented information about a truck crossing, the presence of a flagger, and the need to prepare

to stop. In this situation, it would be possible to eliminate the truck crossing information in order to emphasize the fact that a flagger was present and the potential need to stop, as shown below.

| Original PCMS Message: | | |
|---|---|---|
| TRUCK CROSSING | FLAGGER AHEAD | BE PREPARED TO STOP |
| Possible Reduced PCMS Message: | | |
| FLAGGER AHEAD | BE PREPARED TO STOP | |

**SUMMARY OF ISSUES IDENTIFIED**

Based on a review of several PCMS messages in work zones in the districts that were visited, researchers determined that most of the messages failed to meet one or more guidelines regarding good PCMS message design and application. In particular, researchers identified the following key issues:

- Many of the PCMS messages observed (40 percent) exceeded the MUTCD specification of using no more than two phases for a given message. Researchers found two instances where four-phase messages were used on a PCMS.
- Improper splitting of information units across phases of the PCMS was another common issue, observed in 19 percent of the messages observed.
- A key issue that did arise from this investigation was the need for better guidance on the most appropriate format to use to convey calendar dates. Related to this, it is also not clear whether conveying calendar dates only, or calendar dates and days, would best benefit motorists. Finally, questions remain as to how much advance notice information motorists can actually process. For example, it is not known whether motorists can comprehend calendar days and dates as well as times of work activity from a PCMS display.

# INTERVIEWS OF TXDOT PERSONNEL REGARDING PCMS APPLICATION ISSUES

## OVERVIEW

Researchers conducted both person-to-person interviews as well as e-mail and telephone interviews with TxDOT resident and area engineers in the Bryan, Corpus Christi, Houston, and San Antonio Districts. The purpose of the interviews was to identify additional TxDOT issues and concerns pertaining to the use of PCMSs within Texas work zones that warranted additional investigation through this research project. Specific questions asked of TxDOT staff were as follows:

- What are the typical applications of PCMSs used at work zones within your district?
- Does your district use any guidelines when deciding what to put on the PCMS and where to use them?
- Have you encountered and specific problems or issues when using PCMSs in work zones?
- What are your suggestions to overcome the problems and issues identified above?
- What are your suggestions to improve the effectiveness of PCMSs in general?
- What type of guidelines would you consider useful in you work with PCMSs?
- What guideline format would you recommend?

## SURVEY RESULTS

### Typical PCMS Applications

Some of the types of situations for which PCMSs were reportedly used were to:

- provide advance notice to motorists about expected future changes in traffic and traffic control due to planned construction and maintenance activities or special events;
- provide detour information during incidents and road and bridge construction;

- warn motorists of holiday traffic conditions (using different messages for different times of the day);
- inform motorists about possible delays;
- temporarily prohibit various turning movements (e.g., No U-Turn);
- warn of ramp closures;
- warn of lane drops;
- warn of change in direction of traffic (i.e., when converting two-way frontage roads to one-way operation);
- encourage motorists to reduce their speed;
- provide advance warning of all-way-stop signs at intersections previously having different traffic control; and
- notify of public meetings (e.g., major investment studies, environmental impact studies, sound wall hearings), using PCMS located adjacent to heavily traveled roadways and freeways.

Generally speaking, these applications are consistent with usage characteristics in other jurisdictions nationwide (*3*). Some of the applications can be quite lengthy. For example, one respondent noted that they had once displayed a detour message for a period of 1.5 years in a single location while work progressed on a particular roadway segment.

**PCMS Guidelines Used**

At the time of the interviews, the *Dynamic Message Sign Message Design and Display Manual* had not yet been published (*1*). However, researchers had expected the respondents to note other documents they used to decide on appropriate PCMS messages and applications (such as references *21-23*). However, researchers did not find this to be the case. Other than one participant who did note the availability of limited PCMS guidance in the MUTCD, responses to this question indicated that participants did not rely on any of the available guidelines that are available. Several participants indicated that they used "common sense" guidelines such as keeping the message simple, not using slang or derogatory words in the message, etc. None of the respondents indicated the availability of district-specific guidance on this topic.

**Specific PCMS Issues or Problems Encountered**

This particular question generated a wide variety of responses from the interview participants. Representatives from the Bryan, Corpus Christi, and Houston Districts all noted the difficulties created by the minimum one-week advance notice of lane closures or traffic control changes on high-volume roadways. Interviewees noted that weather and other factors often require a traffic change or lane closure to be delayed a day or two, which negates the effect of having the PCMS displaying in advance when the activity would take place and which could lead to the use of more generic messages that are less effective. In some cases, respondents believed that only a few days notice might be all that is needed. However, respondents believed that drivers using other facilities benefit from having advance notification available to them for periods even longer than one week in advance.

Another issue raised by the respondents regarding advance notification information was the most effective format to use when conveying the days, dates, and times of the future traffic control activities. As was found during the district inventories described earlier in this report, the survey respondents indicated that field personnel were utilizing many different formats to convey this information because no clear guidance on the subject has been established.

At least one survey respondent noted the difficulty in trying to convey all of the information that should be provided to motorists about a particular situation within the two-phase limitation specified in the *MUTCD*. In addition, the decision about when and what abbreviations to use within a particular message was cited as troublesome by one of the respondents. In many instances, respondents said that they determined what should be displayed on the PCMS using "common sense." Respondents also reported checking with family members and friends as whether the messages were understandable. The recent publication of the TxDOT *Dynamic Message Sign Message Design and Display Manual* should help practitioners with such difficulties in the future, provided that the field personnel are made aware of its existence and can obtain access to the manual (or someone who is familiar with its contents) in order to determine the appropriate message to present on the sign.

Practitioners in two of the TxDOT districts noted difficulties in deciding when to use official route numbers in a message (i.e., FM 1179) and when to use local street names (i.e., Briarcrest Drive). Opinions differed as to the best approach, although the majority of respondents tended to believe that use of the route designations was appropriate more often as a

way to ensure that non-local drivers who rely on such route numbers receive the needed information. The main argument of these respondents was that most local drivers will know both the local street name and route designation and so can use the information regardless of which roadway-naming convention is followed.

Questions also arose regarding the appropriate length of time to leave PCMS in a given location with the same information being presented. Several of the respondents were aware of reduced effectiveness and credibility of the messages the longer they are used at a particular location, but do not have any way of knowing how long is "too long." Respondents also noted occasional difficulties in finding suitable locations to place PCMSs adjacent to roadways, especially on farm-to-market roads that do not provide wide earth shoulders and have steep side slopes into open drainage ditches. Researchers noted that such practical concerns, although important, were generally outside the scope of what could be accomplished with this particular research project.

One respondent noted that PCMSs were not always available for use on a particular project because not all contractors have purchased them. This did appear to be a rather localized concern, however, and again something outside the scope of this research project.

**Suggestions to Overcome Issues and Difficulties**

Many of the suggestions made to address the above issues and difficulties were very practical recommendations, such as moving the PCMS more frequently and requiring better communication between TxDOT and the highway contractor regarding PCMS needs on a particular project. Some of the respondents also believed that the one-week advance notification policy needed to be relaxed somewhat.

Several respondents did note that it would be desirable to have message libraries standardized across the state to simplify the message selection and application process. There was some disagreement as to whether the library should be as comprehensive as possible or limited to only 10 or 20 of the most common situations in order to ensure that the document not be too large and unwieldy for field use.

One significant research question raised during the interviews related to the current wording in the MUTCD which limits PCMS displays to no more than two phases. If it is necessary to present more than two phases of information to the motorist, the MUTCD directs

practitioners to use a second PCMS in sequence to convey the information. As correctly noted by the interview respondents, there has not been adequate investigation as to whether this approach truly works for motorists approaching a particular work zone hazard. If the splitting of information across sequential PCMS results in acceptable motorist comprehension and response, then additional guidance is needed to determine exactly how a sequence of information can and should be split between the two signs to most effectively convey the necessary information.

### Guideline Desirability and Format

The final few questions of the interview focused on specific content and format of any guidelines developed through this particular research effort. Although some respondents felt that adequate guidance was available, others indicated that better guidance would be useful. The respondents were in general agreement that such guidance must be kept to a minimum in order to ensure that it reaches and is utilized by the field personnel who have direct implementation responsibility for the signs and the information that is ultimately put on them. Researchers received a few suggestions about incorporating aspects of the guidance into construction documents to ensure better compliance by the highway contractors. However, most of the respondents did not believe that a series of new traffic control plan (TCP) standard sheets were needed in the contracts.

## SUMMARY

The results of the interviews with TxDOT personnel generally echoed the concerns identified in the previous discussion of PCMS message applications in the TxDOT districts. Questions arose about appropriate formatting of day, date, and time information for advance notification messages, ,as did the desire for better guidance about using two PCMS in sequence when it is necessary to present more information than can be displayed on two phases of a single PCMS. In the remainder of this report, researchers describe the methodology and results of two driver comprehension studies conducted to provide improved guidance for the advance notification displays and for the sequential PCMS applications.

Finally, interviewees saw the development of implementation guidelines as a potentially valuable contribution, provided that the information was as simple as possible and provided in a format that allowed field personnel to have immediate access (i.e., such as within the PCMS

control phase housing itself or in a glove box of a work vehicle). Researchers are addressing this issue in ongoing research activities for delivery at the conclusion of this research project.

# EVALUATION OF ALTERNATIVE DATE, DAY, AND TIME DISPLAYS FOR ADVANCE NOTIFICATION PCMS MESSAGES

## QUESTIONS INVESTIGATED AND STUDY OBJECTIVES

TxDOT/contractor policy requires more than 7 days notice about upcoming lane closures and other major traffic control changes on high-volume roadways. It is often desirable to use PCMSs for this purpose. This policy implies that date information as well as the days needs to be displayed, contrary to existing guidelines prepared by TTI (*1*). In addition, there was also concern that the typical messages displayed by TxDOT are too long and complex and exceed the reading and comprehension capabilities of drivers

The objectives of this study were to determine whether dates and day information should be displayed, and if so, then the manner in which date references should be included in a message. Study questions include those listed below.

- What should the order be of days and dates when they are in the message (i.e., days, then dates, or vice-versa)?
- How should dates be formatted (APR21 or 4/21)?
- Should the month always be before the date (APR21-APR25 or APR 21-25)?
- Can drivers recall certain types of information better than others (dates, times, etc.)?
- Can drivers determine if a given date applies today?
- Can drivers determine if a date applies to travel planned on that road again one week from tomorrow?

## STUDY BACKGROUND

Dudek (1999) reported on studies conducted in New Jersey to evaluate messages displaying times of day, weekdays, and month dates (*23*). He found that drivers have difficulty relating calendar dates (e.g., Sep 25-Sep 28) to specific days of the week. Only 11 percent of the subjects were able to give the correct days of the week when calendar dates were displayed. When days of the week were displayed, 97 percent gave the correct days. Dudek, et al. conducted a similar study was conducted in Texas in the cities of Dallas, El Paso, Fort Worth,

Houston, and San Antonio. Only 21 percent of the subjects correctly identified the days of the week when calendar dates were shown in the message (*18*).

The results led the author to make the following recommendation in both the TxDOT *Dynamic Message Sign Message Design and Display Manual* and the New Jersey *Variable Message Sign Operations Manual*: days of the week should be used in the message rather than calendar dates (*1*, *24*). However, given current TxDOT policy, this current study is designed to provide improved guidelines when it is necessary or desirable to provide advance notification information farther than 7 days in advance of a traffic control event.

## STUDY APPROACH

The laboratory study involved the use of a laptop computer programmed with software developed at TTI to evaluate alternative dynamic message sign (DMS) (and PCMS) message displays. The software allows display of one- or two-phase messages of fixed duration. In addition, a secondary task loading activity (following and clicking of on-screen "buttons" via the computer mouse) simulates the effects of attention-sharing and task loading as is required while operating a vehicle. Figure 1 illustrates a subject participating in the laptop study.

**Figure 1. Laptop Study Participant.**

There were two sessions to the study. Session 1, Fixed Viewing Time, involved a study in which the subjects were presented messages displayed for a fixed time. Session 2, Preference, involved subjects looking at alternative messages side-by-side and providing preferences. As shown in Table 1 (configured for the San Antonio study), the message set consisted of four messages along with an alternative for each. In addition, Message 5 consisted of a message containing the date, day, and time and was probably much longer than what could be read and recalled by drivers, but was considered worth testing. The messages were two-phase messages and cycled through the message twice. Each phase appeared for 2 seconds. The order in which the message phase began was counterbalanced among two groups of subjects, Group A and Group B. Each group consisted of 16 subjects balanced according to age, education, and gender. Group A viewed Message Set A, while Group B viewed the alternative message. Researchers changed the actual roadway locations and dates displayed in each study location. Researchers conducted studies in Austin, Arlington, Laredo, San Antonio, El Paso, and Houston. A total of 192 subjects participated in the study.

**Table 1. Test Messages from San Antonio.**

| Message Set | Message A | | Message B | |
|---|---|---|---|---|
| | **Phase 1** | **Phase 2** | **Phase 1** | **Phase 2** |
| 1 | ALT LANES CLOSED | *[4/21]* TO *[4/25]* | ALT LANES CLOSED | *[APR 21]* TO *[APR25]* |
| 2 | *[I-410 W]* EXIT CLOSED | *[MON] [APR 27] [9AM-3PM]* | *[I-410 W]* EXIT CLOSED | *[APR 27] [9AM-3PM*] |
| 3 | LEFT 2 LANES CLOSED | *[MON-FRI] [APR25-APR29*] | LEFT 2 LANES CLOSED | *[MON-FRI] [APR25-29]* |
| 4 | *[1-410 W]* ROADWORK | *[MAY17-MAY19*] *[TUE-THUR]* | *[I-410 W]* ROADWORK | *[MAY17-MAY19] [10AM-6PM]* |
| 5 | ALT LANES CLOSED | *[MAY9-11*] *[MON-WED] [11AM-8PM*] | | |

With two-phase messages, it is possible that some drivers will first see the message during the second phase. To account for this possibility, researchers subdivided Group A into Groups A1 and A2 with eight subjects each, balanced according to age, education, and education as much as possible. Researchers also subdivided Group B into Groups B1 and B2 with eight

subjects each. The subjects in Group A1 and Group B1 saw the messages starting from the first phase. The subjects in Group A2 and Group B2 saw the messages starting from the second phase. The secondary task loading activity began 8 seconds before the message was displayed. The secondary task loading level was held constant for all participants throughout the study.

Appendix A provides additional details regarding the study administration protocol.

## STUDY RESULTS

### Message Set 1: Numeral versus Text Month Displays

As illustrated in Table 1, Message Set 1 provided direct comparison of subject recall and comprehension of messages utilizing only numerals for upcoming calendar dates (i.e., 4/21 for April 21) to messages using text to indicate the month (i.e., APR 21). Researchers examined recall and comprehension of information in both phases of the message. In addition, researchers queried each subject whether the message indicated that the work activity was occurring on the day the study was performed or would be occurring one week from tomorrow should they be traveling that facility.

In Table 2, researchers summarized the percent correct recall of both the problem (alternate lanes closed) and dates of the lane closure by study participants. Both formats resulted in similar percentages of correct responses of the problem and calendar dates, at or near 85 percent recall levels. Interestingly, however, the text and numeral date format (Message Format B) yielded more correct responses to the question "does this message indicate that work activity is occurring today?" Whereas 92 percent of the subjects viewing the text and numeral format correctly responded to this question, only 72 percent of the subjects viewing the numeral date format responded correctly. This difference was highly significant (p-value < 0.001). On the other hand, both formats yielded similar response rates to the question "does this message indicate that work activity will be occurring one week from tomorrow?" As shown in Table 2, 81 percent of the subjects viewing Message Format B (without day information) correctly identified whether work would be occurring then, compared to 79 percent of subjects viewing Message Format A (with day information also presented). The differences cannot be considered to be significant (p-value = 0.730).

Study results also indicated strong driver preference for the date and numeral format for calendar dates over the completely numeral format, 83 versus 17 percent, respectively. The most common reason given for the text and numeral format was that it was much easier to view and comprehend as a calendar date. Interestingly, neither format resulted in subjects being able to convert the calendar dates into the specific days of the week that work would be occurring. This result is consistent with previous research by Dudek (*18*, *23*). Only 13 percent of the subjects who viewed the numeral format for month and date (Format A) could indicate the days of the week for which the message would be valid. Similarly, utilizing a text/numeral format for the month and date (Format B) yielded only slightly higher percentages (12 percent) of subjects who could do so.

**Table 2. Driver Responses to Message 1 Comparisons.**

| | **Message Format 1A Numeral Dates** | **Message Format 1B Text/Numeral Dates** | **Level of Significance (p-value)[a]** |
|---|---|---|---|
| Correctly Recall Problem? | 78% | 88% | 0.066 |
| Correctly Recall Dates? | 88% | 84% | 0.426 |
| Correctly Recognize if Activity is Today? | 72% | 92% | < 0.001 |
| Correctly Recognize if Activity is 1 Week from Tomorrow? | 79% | 81% | 0.730 |
| Correctly Identify Days of the Week of Activity? | 13% | 12% | 0.834 |
| Format Preferred? | 17% | 83% | --- |

[a] based on a test of proportions

**Message Set 2: Calendar Dates with and without Day of Week Included**

As indicated in Table 1, Researchers designed Message Set 2 to assess how the addition of day-of-week information influenced subject driver abilities with regard to information recall and comprehension. The addition of day information could presumably facilitate interpretation of calendar date information for those messages about future events. Researchers added time information about the activity (9AM – 3PM) to this message set to allow testing under a higher information load condition.

The results of the study for Message Set 2 are illustrated in Table 3. The addition of day information (Format A) did not degrade subject ability to recall the problem from the message. Correct recall of the problem was 33 percent when the day of the week was included in the message (Format A), compared to 35 percent without the day information presented (Format B).

The inclusion of day information did not result in different recall rates of the calendar date (58 percent for Format A versus 65 percent for Format B), or the times of activity (30 percent for Format A versus 26 percent for Format B). Researchers did note a significant difference in the percent of subjects who could identify the day of the week that work would occur. Whereas 44 percent of subjects who viewed Message Format A could identify the day of week, only 29 percent of subjects viewing Message Format B could do the same. Researchers expected such a difference to exist, given that Message Format A actually included the day of week in the message. However, the fact that only 44 percent of those subjects could actually recall that information suggests that many subjects were overloaded with the information presented and could not properly recall it after viewing the message.

Strangely, the message that did not include day information (Message Format B) actually yielded a higher percentage of correct responses than did Message Format A to the question "does this message indicate that work activity is occurring today?" Eighty-three percent of the subjects viewing Message Format B correctly responded to this question, compared to only 67 percent of subject drivers who viewed Message Format A. Meanwhile, the percent of subject drivers who could correctly determine whether work would be occurring one week from tomorrow was also slightly higher for Format B (76 percent versus only 65 percent for Format A).

**Table 3. Driver Responses to Message 2 Comparisons.**

| | **Message Format 2A Day, Date, and Time** | **Message Format 2B Date and Time** | **Level of Significance (p-value)[a]** |
|---|---|---|---|
| Correctly Recall Problem? | 33% | 35% | 0.770 |
| Correctly Recall Dates? | 58% | 65% | 0.320 |
| Correctly Recall Times? | 30% | 26% | 0.538 |
| Correctly Recall Day? | 44% | 29% | 0.031 |
| Correctly Recognize if Activity is Today? | 67% | 83% | 0.011 |
| Correctly Recognize if Activity is 1 Week from Tomorrow? | 65% | 76% | 0.096 |

[a] based on a test of proportions

**Message Set 3: Repeating Month Information in the Message**

In Message Set 3, researchers examined whether advance notice messages that span several days in the same month should repeat the month before each calendar date, versus only indicating the month once. Eliminating the replication of the month information does save space in the message, but may make it more difficult for drivers to assimilate the date information itself. Researchers also included days of the week in this message set to keep the overall information load at a fairly high level.

Table 4 presents the results of the Message Set 3 study. Overall, researchers found the results of this particular part of the study to be mixed. On one hand, the replication of the month information in Message Format A did not yield significantly higher recall of the reported problem (64 percent versus 52 percent for Message Format B), days of work (63 percent for Format A, 72 percent for Format B), or dates (68 percent for Format A, 56 percent for Format B). Similarly, there were not significant differences in the ability of subjects to recognize if the activity is occurring today (84 percent for Format A versus 76 percent for Format B) or occurring one week from tomorrow (72 percent for Format A, 73 percent for Format B). However, researchers found an overwhelming preference for Message Format B over Message Format A (93 percent versus 7 percent, respectively). Subject drivers strongly indicated that they preferred not having to read the same month twice in the message.

**Message Set 4: Including Days versus Times in a Message**

As can be seen in Table 1, the purpose of the evaluation of Message Set 4 was to determine whether there were any differences in message comprehension and preference between providing day information or time information in conjunction with date information in advance notification messages on a PCMS. In Table 5, researchers present the results of the evaluation of this message set. Overall, the substitution of work activity times for days of the week in the message had no appreciable effect on subject driver ability to correctly comprehend the problem, calendar date, or in determining whether work would take place on the roadway today or one week from tomorrow. Interestingly, subject drivers preferred time information to be included in the message, even though most could not correctly recall that information from the message. Of course, most subjects could not correctly recall the day either when presented that information in the message.

**Table 4. Driver Responses to Message 3 Comparisons.**

| | Message Format 3A Month Repeated | Message Format 3B Month Not Repeated | Level of Significance (p-value)[a] |
|---|---|---|---|
| Correctly Recall Problem? | 64% | 52% | 0.236 |
| Correctly Recall Days? | 63% | 72% | 0.349 |
| Correctly Recall Dates? | 68% | 56% | 0.228 |
| Correctly Recognize if Activity is Today? | 84% | 76% | 0.330 |
| Correctly Recognize if Activity is 1 Week from Tomorrow? | 72% | 73% | 0.913 |
| Format Preferred? | 7% | 93% | --- |

[a] based on a test of proportions

**Table 5. Driver Responses to Message 4 Comparisons.**

| | Message Format 4A Day Information Included | Message Format 4B Time Information Included | Level of Significance (p-value)[a] |
|---|---|---|---|
| Correctly Recall Problem? | 52% | 49% | 0.770 |
| Correctly Recall Days? | 42% | --- | --- |
| Correctly Recall Times? | --- | 39% | --- |
| Correctly Recall Dates? | 61% | 55% | 0.554 |
| Correctly Recognize if Activity is Today? | 86% | 80% | 0.436 |
| Correctly Recognize if Activity is 1 Week from Tomorrow? | 72% | 73% | 0.913 |
| Format Preferred? | 21% | 79% | --- |

[a] based on a test of proportions

### Message Set 5: Inclusion of Day, Date, and Time Information in Message

The evaluation of this final message type further explores the ability of drivers to assimilate and comprehend a large amount of information about an upcoming work activity. The message is similar in style to those used in Message Set 2, but includes a range of calendar dates and days rather than the single day and date previously tested (it can be argued, however, that the problem statement in Message Set 2 is more complex than in Message Set 5). As such, Message Set 5 contains the greatest amount of information among the messages tested.

The results of this study are presented in Table 6. Overall, subject recall rates of the various information units in the message ranged between 7 and 85 percent. It is interesting to note the order in which subjects did remember the information in the message. The problem statement (ALT LANES CLOSED) was remembered most often, followed by day information. Only 29 percent of the subjects correctly recalled the dates included in the message, and only 7 percent could correctly recall the times of work that were specified in the message. Based on the information they processed from the message, 70 percent of the subjects correctly identified whether the message meant that work was occurring that day. Similarly, 69 percent were able to correctly determine whether the message indicated that work would be occurring one week from tomorrow.

**Table 6. Driver Responses to Message Set 5.**

| | **Day, Date, and Time Information Included** |
|---|---|
| Correctly Recall Problem? | 85% |
| Correctly Recall Days? | 47% |
| Correctly Recall Dates? | 29% |
| Correctly Recall Times? | 7% |
| Correctly Recognize if Activity is Today? | 70% |
| Correctly Recognize if Activity is 1 Week from Tomorrow? | 69% |

## INTERPRETATION OF RESULTS

Based on the results of the laptop study, researchers have drawn the following inferences regarding the presentation of advance notification information about future roadwork and other traffic control activities on PCMS:

- The results validated previous research findings that most drivers cannot identify specific days of the week of the road work activity when calendar dates are displayed.
- Messages that require the display of calendar dates for future roadwork and other traffic control activities should utilize a message format consisting of the three-character abbreviation of the month (i.e., APR) in conjunction with the date. This

format appears to be somewhat easier for motorists to interpret than using all numerals for both month and date, and was the greatly preferred format during subject driver testing.

- When future work activities span several days all in the same month, it appears appropriate to only indicate the month once in the message (i.e., APR 21-23) rather than repeating the month (i.e., APR 21-APR 23). The former is shorter and easier to incorporate into a PCMS message. Repeating the month before each date does not significantly improve subject comprehension and recall, and driver preference overwhelmingly prefers the single-month format. Of course, if the work activity will span two months, both months have to be included in the message.
- Attempts to present day, date, and time information about upcoming roadwork activities appear to approach the upper limit of driver information processing capabilities. Researchers found rather low comprehension and recall rates for some of the message elements when this type of information was presented together in a two-phase PCMS message. However, subjects appear to naturally retain day information easier than time information, when both are included in the message. Subject drivers were evenly split as to whether they preferred day or time information when compared directly with each other.
- Regardless of the format used, only about two-thirds to three-fourths of the drivers viewing the PCMS message were able to correctly interpret whether the work activity noted in the message will affect their current trip or a future trip. TxDOT may need to reconsider the value of its current policy to require at least 7 days advance notification in light of these rather low comprehension rates.

# DRIVER COMPREHENSION OF USING TWO PCMS IN SEQUENCE

## INTRODUCTION

One of the issues raised during the district observations of PCMS use and the TxDOT interviews was the difficulty that field personnel have in conveying important information within the two-phase limitation the MUTCD imposes on PCMS usage. When information needs dictate the presentation of more than two phases, the MUTCD recommends that two PCMS be used in sequence to convey that information. However, only limited research has been performed to evaluate whether such a practice would result in adequate driver interpretation and comprehension of split messages. Questions remained as to whether drivers, viewing two PCMSs in sequence, would relate the separate pieces of information on the two signs into a cohesive message.

In previous work using New Jersey drivers, Huchingson and Dudek investigated differences between stand-alone messages (which repeat a particular unit of information on each phase of a PCMS) and distributed messages (which do not repeat any units of information) using laptop surveys (*25*). They found that subjects had similar comprehension and recall rates of information for both types of display formats. However, these rates were often below the 85 percent correct level desired for good message design, especially when more than two phases were presented to drivers. They also found that presenting information that does not apply at the time the message is displayed can confuse some drivers into thinking that it currently applies. Unfortunately, the use of laptop surveys to investigate these issues proved somewhat problematic for the subjects, limiting the extent of the researchers' findings.

Although not a direct investigation of the ramifications of using PCMSs in sequence, that previous study suggests that drivers may have some difficulties in adequately processing multiple phases of information. The findings also suggest that both stand-alone and distributed information formats should be researched as viable message design approaches in sequential PCMS applications. Consequently, researchers designed and conducted a study using the TTI Driving Simulator to test this practice on a sample of driver subjects from the Bryan-College Station area.

## STUDY OBJECTIVE

The objective of this study was to assess whether drivers are able to effectively "piece" the information from two PCMSs displayed in sequence upstream of a particular traffic situation into a single cohesive message. A secondary objective was to determine whether utilizing redundancy between the two PCMSs (i.e., using an identical key information element in one phase of both PCMSs) improved the driver's ability to link the messages together and fully comprehend its intended meaning.

## STUDY METHODOLOGY

### Overview

Based on a previous pilot test, researchers determined that traditional methods of evaluating PCMS message effectiveness, such as pen-and-paper evaluations or the laptop laboratory studies conducted and described earlier in this report, would not be sufficient for evaluating if and how well a driver is able to link the information together from two PCMSs in sequence (*26*). Therefore, researchers opted to study this question indirectly by immersing subject drivers in a more realistic driving environment in which PCMSs had been placed in sequence at strategic points along the travel route. Using carefully worded exploratory questions about conditions referred to in the PCMS displays, researchers hoped to assess whether the subject drivers had truly compiled information from both PCMSs into a single cohesive message and could properly interpret and process that information. To establish a baseline of expected performance, researchers also included larger signs replicating the information and display characteristics of full-size permanent dynamic message signs (DMSs) in the study environment at other locations along the travel route. By counterbalancing the information presented on the sequential PCMSs and the larger DMSs, researchers then compared the sequential PCMS responses to those obtained as subjects traveled past the full-size DMS messages. To avoid having the subjects focus exclusively on the PCMSs and DMSs, researchers designed the overall study protocol to query drivers about all types of traffic control devices presented in the driving environment.

**Description of the TTI Driving Simulator**

The driving simulator at the Texas Transportation Institute is produced by DriveSafety™ and runs through a 1995 Saturn SL mid-sized sedan. The driving simulator is illustrated in Figure 2. It is instrumented as an actual operating vehicle and provides an interactive driving experience. The system includes a 150-degree wraparound visual field with high-resolution (1024 × 768 pixels) projectors for each of the three integrated screens. Research participants control the accelerator and brake pedals and the steering wheel exactly as they do when driving in the real world. The simulator is fixed-based and provides no kinetic motion cues such as tire vibrations, vehicle pitching during braking, etc. A subwoofer speaker located behind the driver's seat provides simulated road and engine sounds. For the present study, researchers created the custom driving environments using the HyperDrive™ Authoring Suite software.

**Figure 2. TTI's Driving Environment Simulator.**

As the subject "controls" the vehicle, the driving simulator's integrated computer calculates several characteristics such as vehicle velocity, acceleration, steering, braking, lane position, etc. in real time. An intercom system in the vehicle allows the experimenter and participant to easily communicate during the study.

**PCMS Messages Tested**

Researchers tested a total of eight messages during this study. Also, researchers used two different methods for the design of the sequenced PCMS messages. The first set of PCMS messages split a standard message onto two PCMSs with comparable amounts of information on each PCMS. In the second design, researchers included one of the units of information in both the first and second PCMSs, similar to the study of the stand-alone messages by Huchingson and Dudek as reported above. With the messages that did not have repeating units of information, the messages created were in relation to an event occurring on a cross-highway, and for the messages that did have a repeating component the messages related to events on the same road as the driver.

As a means of comparison, the same type of message displayed on the sequenced PCMSs was also formatted to be displayed on a standard DMS. In Tables 7 and 8 below, researchers illustrate the messages used in for this study. As Table 7 illustrates, Messages 1 and 4 are identical, designed to be presented either sequentially on two two-phase PCMS or on two phases of a single DMS. Researchers used a similar counterbalancing process for Messages 2 and 3. Meanwhile, Table 8 illustrates how researchers counterbalanced the messages that replicated one of the units of information unit on the sequential PCMSs. Note that in Table 7, the message presented on the full-size DMS consisted of only a single phase. It should also be noted that the messages shown in Table 7 all contain 5 units of information, which exceeds recommended maximum levels for highway speeds 55 mph or greater *(1)*. Figures 3 and 4 contain examples of how the PCMS and DMS were represented within the driving world.

**Table 7. PCMS with Nonrepeating Information Units.**

| **Group 1:** | | | | |
|---|---|---|---|---|
| Message 1 | | | | |
| PCMS 1 | | | PCMS 2 | |
| Phase 1 | Phase 2 | | Phase 1 | Phase 2 |
| ROADWORK<br>ON<br>I-40 EAST | 2 LANES<br>CLOSED | | OAKDALE<br>TRAFFIC | USE<br>OTHER<br>ROUTES |
| Message 2 | | | | |
| Phase 1 | | | Phase 2 | |
| ACCIDENT<br>ON US 87 S<br>LEFT LANE CLOSED | | | DOWNTOWN TRAFFIC<br>EXPECT DELAYS | |
| **Group 2:** | | | | |
| Message 3 | | | | |
| Sign 1 | | | Sign 2 | |
| Phase 1 | Phase 2 | | Phase 1 | Phase 2 |
| ACCIDENT<br>ON<br>US 87 S | LEFT<br>LANE<br>CLOSED | | DOWNTOWN<br>TRAFFIC | EXPECT<br>DELAYS |
| Message 4 | | | | |
| Phase 1 | | | Phase 2 | |
| ROADWORK<br>ON I-40 EAST<br>2 LANES CLOSED | | | OAKDALE TRAFFIC<br>USE OTHER ROUTES | |

**Table 8. PCMS with Repeating Information Units.**

| **Group 1:** | | | | |
|---|---|---|---|---|
| Message 5 | | | | |
| PCMS 1 | | | PCMS 2 | |
| Phase 1 | Phase 2 | | Phase 1 | Phase 2 |
| ROADWORK PAST MAIN | RIGHT 2 LANES CLOSED | | RIGHT 2 LANES CLOSED | BE PREPARED TO STOP |
| Message 6 (DMS) | | | | |
| Phase 1 | | | | |
| ACCIDENT AT KENT<br>LEFT LANE CLOSED<br>EXPECT DELAYS | | | | |
| **Group 2:** | | | | |
| Message 7 | | | | |
| Sign 1 | | | Sign 2 | |
| Phase 1 | Phase 2 | | Phase 1 | Phase 2 |
| ACCIDENT AT KENT | LEFT LANE CLOSED | | LEFT LANE CLOSED | EXPECT DELAYS |
| Message 8 (DMS) | | | | |
| Phase 1 | | | | |
| ROADWORK PAST MAIN<br>RIGHT 2 LANES CLOSED<br>BE PREPARED TO STOP | | | | |


**Figure 3. Representation of a Full-Size DMS in the Driving World.**


**Figure 4. Representation of Sequential PCMS in the Driving World.**

**Experimental Design**

For this study, researchers created four simulator driving environments or "worlds." Each world consisted of identical roadways and landscapes as well as 10 sign stimuli, 6 of which were static signs that were the same graphics and location for all of the worlds. As noted above, the purpose of these six signs was to keep the participants' attention on all signs along the roadway, not just the PCMSs and DMSs. The remaining four stimuli consisted of the DMSs and PCMSs.

Researchers designed the four simulator worlds in a circular pathway with traffic moving in a clockwise direction. This layout allowed for multiple starting points within each world. Table 9 illustrates how the DMS and PCMS messages corresponded to the four sites in the worlds. Figure 5 shows the layout of the worlds and the location of both the fixed sign stimuli and the DMSs and PCMSs (Sites 1-4).

**Table 9. DMS and PCMS Sign Locations Corresponding to the Simulator Map.**

| Group/Simulator World | Site 1 Signs | Site 2 Signs | Site 3 Signs | Site 4 Signs |
|---|---|---|---|---|
| **W** | Message 1:<br>2 PCMSs | Message 2:<br>1 DMS | Message 6:<br>1 DMS | Message 5:<br>2 PCMSs |
| **X** | Message 4:<br>1 DMS | Message 3:<br>2 PCMSs | Message 5:<br>2 PCMSs | Message 6:<br>1 DMS |
| **Y** | Message 2:<br>1 DMS | Message 1:<br>2 PCMSs | Message 8:<br>1 DMS | Message 7:<br>2 PCMSs |
| **Z** | Message 3:<br>2 PCMSs | Message 4:<br>1 DMS | Message 7:<br>2 PCMSs | Message 8:<br>1 DMS |

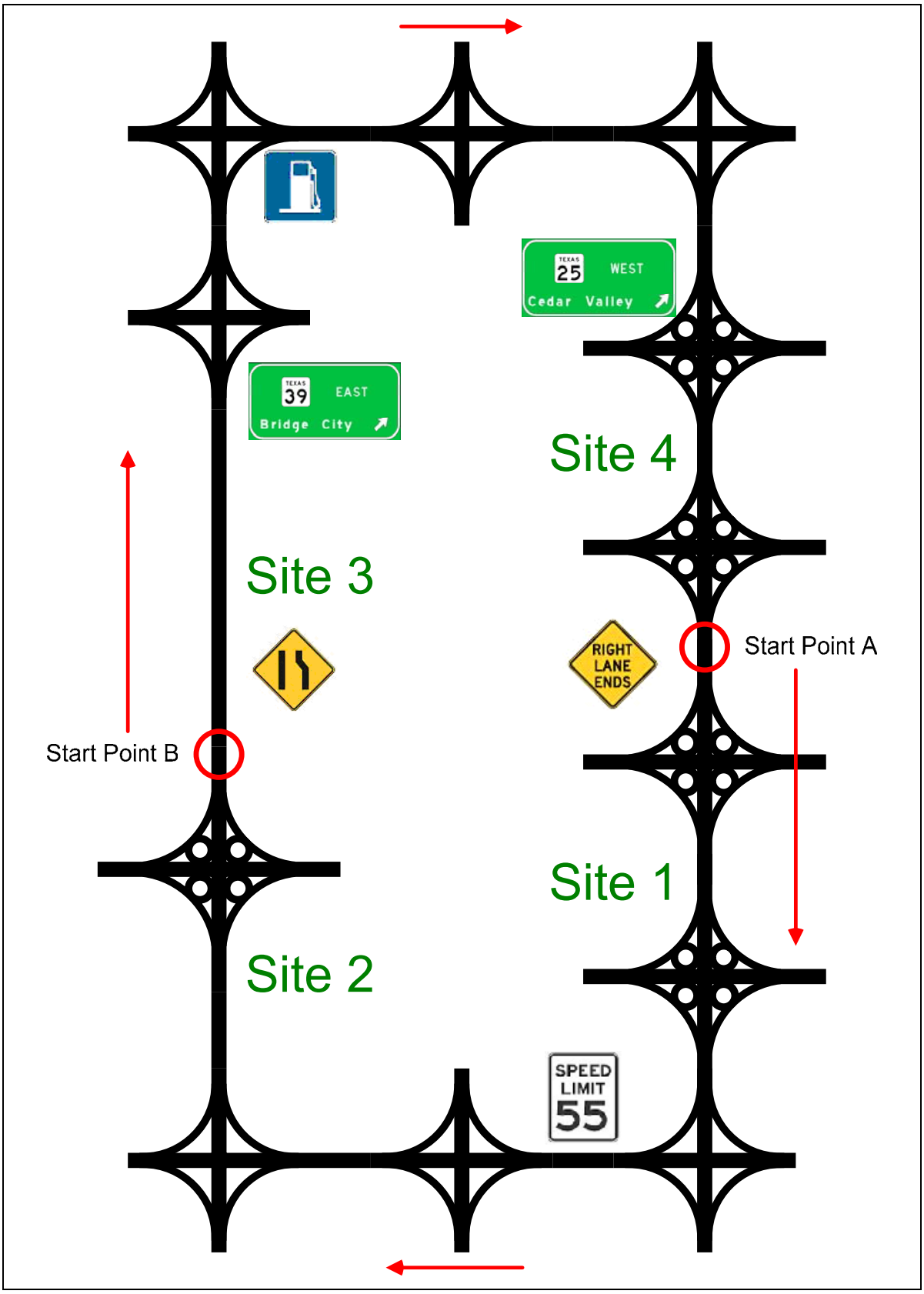



**Figure 5. Schematic Map of Travel Route in Simulator.**

The creation of four separate worlds gave flexibility to test more variations in the DMS and PCMS messages and also allowed for increased counterbalancing. Also, there were two different starting points within each world, to further balance the order of the test signs. The list of subjects, their demographic categories, and their assigned group are shown in Appendix B. The group identifier consists of each participant's world (W, X, Y, or Z) and their starting point (a or b) within that world.

**Participant Recruitment**

Researchers recruited participants by word of mouth and flyer distribution. Appendix B also includes the informational flyer used. The flyer included information concerning compensation of $20 for the participants' time. The participants recruited for this study were based on a demographic sample of the driving population in Texas with relation to age, education, and gender as shown in Table 10 below.

**Table 10. Participant Demographics.**

| Age | High School Diploma or Less (50%) | | Some College or more (50%) | | Total |
|---|---|---|---|---|---|
| | M | F | M | F | |
| 18-39 (47%) | 4 | 4 | 4 | 3 | 15 |
| 40-54 (29%) | 2 | 2 | 2 | 3 | 9 |
| 55+ (24%) | 2 | 2 | 2 | 2 | 8 |
| Total | 8 | 8 | 8 | 8 | 32 |

A TTI employee served as a point of contact for all participant recruitment. At this time, the participants went through a process of pre-screening and scheduling for the study. As with all TTI simulator studies, the pre-screening not only ensured that the subjects met the proper requirements for the study, but also identified them as unlikely to experience Simulator Induced Discomfort (SID). Researchers performed this screening process prior to scheduling the participants for the study. The phone pre-screening questionnaire is included in Appendix B. Only 1 of 33 subjects did not complete the experiment due to discomfort.

## Study Procedures

### *Predrive Paperwork*

Upon arrival to the simulator, the participant first read and signed an informed consent form. The participant then completed a Simulator Sickness Questionnaire. This questionnaire contained a list of possible simulator-induced discomfort symptoms for the participant to be aware of prior to entering the simulator.

### *Practice Session*

Before beginning the experiment, the participants drove a practice session to become familiar with the test vehicle and with the simulator itself. The practice session consisted of roadways, signs, landscaping, buildings, etc. similar to those included in the experimental worlds. The practice began with the test vehicle parked in front of three types of signs (see Figure 6) illustrating different features the participant would encounter during the experiment. Before beginning the practice session, the participants listened to the following recorded instructions:

> *Currently, you are seated in the driving environment simulator test vehicle. It is an interactive simulator, which means the driving scenes you experience react to your steering and pedal inputs just like a normal vehicle would. This will help to provide a more realistic driving experience for you. During your time in the simulator, please drive in a normal fashion and obey all traffic laws.*
> *For the practice session your task is to get comfortable with driving the simulator vehicle. The driving scene that will be presented to you begins with the vehicle stopped on the side of the road.*
> *As you travel on the freeway you will see different signs that are located on the side of the freeway. Some examples of the types of signs that will be displayed during the study are shown in front of you now. The sign on your left is an example of a changeable message sign with only a single screen message. The sign directly over the road is an example of a guide sign that will be used to indicate exits and freeway names. Finally, the sign on your right is a second example of a changeable message sign; this one is a*

*smaller sized portable sign. You'll notice that this sign alternates between two screens of a single message.*

*During the experiment please read these and other signs as you are driving. You will be asked questions about many different types of signs. Examples of questions that might be asked are: "What is the traffic problem?" or "What does this sign mean to you?"*

*If you have any questions regarding the practice session feel free to ask the study administrator. Please stop the tape now.*


**Figure 6. Display Shown during Practice Instructions Illustrating Sign Types.**

*Experimental Session*

As with the practice session, before beginning the experimental session, the participants listened to recorded instructions. The researcher then added some additional instructions and reminders. The recorded experimental instructions were as follows:

*We are now ready to begin the driving study. When the driving scene begins, the simulator vehicle will be stopped on the side of the roadway, just like in the practice session. Place the vehicle in 'drive,' drive onto the roadway, and proceed through the driving environment.*

*As you begin the study, you will be traveling on an Interstate. As you are traveling, the study administrator will give you driving directions through a speaker system in the simulator vehicle. A microphone in the vehicle will pick up your voice if you have any questions. We ask that you drive 55 mph while you are on the freeway; however, do not feel that you need to obsess over your speed. Remember, you are to drive in a normal fashion and obey all traffic laws.*

*As mentioned earlier, when you are traveling this route, you will see different signs along the roadway. The study administrator will ask you questions about the signs that you encounter.*

*At the end of the experiment the study administrator will ask you to bring the vehicle to a complete stop and place it in 'park.' The experiment will take approximately 20 minutes. If you have any questions regarding your task feel free to ask the study administrator. Please stop the tape now.*

During the participants' session, the experimenter asked the appropriate questions over an intercom system and recorded the participants' responses after passing each of the stimuli signs. Along with the data collected from the verbal responses, the simulator program recorded speed, lane position, and brake and accelerator response during the drive.

*Post-Drive Paperwork*

After finishing the drive, the participant completed another Simulator Sickness Questionnaire to identify any post-drive symptoms. Researchers compensated participants $20 for their time and obtained the participant's signature to indicate receipt of compensation.

## RESULTS

As discussed in the protocol, each subject participant saw two of the four messages tested in this study, one each from the two different formatting options (five units of information with

no redundancy in information between sequential PCMSs versus four units of information and with redundancy of one of the information units between the sequential PCMSs). The results of the study are presented below for each of the formatting options.

**Presenting Five Units of Information with No Redundancy in the Message**

In Appendix C, researchers summarized the specific responses to each of the messages utilized in this study. In Table 11, researchers present the overall results of the correct responses to each of the questions submitted to the subject participants for the sequential PCMSs and the single large DMSs. These response rates shown in Table 11 represent the combination of both message types used in this portion of the study (recall that researchers utilized a counterbalanced experimental design of both message types to account for learning effects and other potential biases in the responses). The information presented in Table 11 is subdivided to illustrate how subject drivers were able to comprehend and recall information from either the first PCMS in sequence or the second, in contrast to the large DMS when all information was presented at one location in two phases.

As shown in Table 11, researchers found that subject drivers were less likely to correctly recall the information from the first PCMS in sequence than they were from the large DMS. Whereas more than 84 percent of the subject drivers were able to identify the problem on the large DMS, only about 63 percent of the subjects could do so from the information presented on the first PCMS. Likewise, more subject drivers could recall the location of the problem from the large DMS than from the first PCMS (59 percent versus 31 percent, respectively). These differences appear to be highly significant (p-values 0.057 and 0.024, respectively). The percent of subjects who correctly recalled which lanes were to be affected were similar from the first PCMS and the DMS (69 percent versus 75 percent, respectively).

Further examination of Table 11 results suggests that these differences were indeed due to the sequential nature in which the PCMS information was presented, since subject recall of the information presented on the second PCMS was similar to that obtained from subjects viewing the same information on a two-phase DMS. Specifically, subject recall of the intended audience for the message was 53 percent from the second PCMS and 47 percent from the DMS. Similarly, subject recall of the effect of the problem on traffic or the action that the audience of the message

should take was 53 percent from the PCMS message 50 percent from the DMS. As indicated by the large p-values in Table 11, none of these differences are highly significant.

Examining total subject recall of information on each PCMS overall, Researchers found that subjects recalled only 54 percent of the information presented in the first PCMS versus 73 percent of that same information when presented on the two-phase DMS, a difference of nearly 20 percent (corresponding to moderately significant p-value of 0.114). For the second PCMS, the comprehension and recall rates of information were much closer to that of the two-phase DMS: 54 percent versus 63 percent (with the p-value a much less significant 0.689).

**Table 11. Subject Driver Correct Response Rate: 5 Units of Information, No Redundancy.**

| Information Presented | Percent of Subjects Correctly Recalling and Comprehending the Information | | Level of Significance (p-value) |
|---|---|---|---|
| | Sequential PCMS Format | Single, Two-Phase DMS Format | |
| *Information on 1st PCMS:* | | | |
| What is the Problem? | 63 | 84 | 0.057 |
| Where is the Problem Located? | 31 | 59 | 0.024 |
| What and How are Lanes Affected? | 69 | 75 | 0.593 |
| TOTAL 1st PCMS | 54 | 73 | 0.114 |
| *Information on 2nd PCMS:* | | | |
| Who is the Intended Audience for Message? | 53 | 47 | 0.631 |
| What is the Effect of Problem/Desired Action? | 53 | 50 | 0.810 |
| TOTAL 2nd PCMS | 53 | 48 | 0.689 |
| OVERALL MESSAGE COMPREHENSION | 54 | 63 | 0.465 |

It is important to again reiterate that these messages contained five units of information, which is more than the maximum four units of information recommended in the TxDOT *DMS Message Design and Display Manual (1)*. The results of this test provide further evidence of the importance of complying with these guidelines. Even for the large DMS, overall recall and comprehension rates were lower than the 85 percent correct responses that are desired for message design purposes. It is clear from this portion of the study that attempting to provide

more than four units of information to motorists via PCMS displays, even if physically possible by using two signs in sequence, will not yield satisfactory information transmission to the motoring public. In fact, it could be argued that such a practice would actually be detrimental to the overall long-term credibility and target value of PCMS operations and should be avoided.

**Presenting Four Units of Information with Redundancy in the Message**

The second portion of the driving simulator study also tested sequential PCMS versus identical information presented on a large DMS. However, the overall information load was only 4 units, consistent with existing guidelines. This allowed the information to be presented as a single phase on the DMS, and to repeat one of the units of information on both of the PCMSs in sequence. Researchers again analyzed the responses for each message, which are in Appendix C. In Table 12, researchers present the percent correct responses for the sequential PCMSs versus the single-phase DMS.

**Table 12. Subject Driver Correct Response Rate: 4 Units of Information, With Redundancy.**

| Information Presented | Percent of Subjects Correctly Recalling and Comprehending the Information | | Level of Significance (p-value) |
|---|---|---|---|
| | Sequential PCMS Format | Single, Two-Phase CMS Format | |
| *Information on 1st PCMS:* | | | |
| What is the Problem? | 94 | 94 | 1.000 |
| Where is the Problem? | 72 | 72 | 1.000 |
| What Lanes are Affected? | 88 | 81 | 0.439 |
| TOTAL 1st PCMS | 84 | 82 | 0.831 |
| *Information on 2nd PCMS:* | | | |
| What Lanes are Affected?[a] | 88 | 81 | 0.439 |
| How is Traffic Affected? | 59 | 59 | 1.000 |
| TOTAL 2nd PCMS | 73 | 70 | 0.790 |
| OVERALL MESSAGE COMPREHENSION | 78 | 77 | 0.924 |

[a] information presented in both PCMS messages

For this format, researchers found a much higher level of comprehension. In addition, the correct response rates were very similar between the sequential PCMSs and the single-phase

DMS. Researchers found that 94 percent of the subjects could correctly recall the problem displayed on the sign, regardless of whether it was on the first PCMS in sequence or the large DMS. Similarly, 88 percent of the subject drivers were able to recall the lanes that were closed from the PCMS, compared to 81 percent of the subject drivers seeing the information on the large DMS. Of course, the lanes closed information was presented twice in the PCMS sequence (once on each sign), and was displayed continuously on the large DMS. Overall, subject drivers recalled 84 percent of the information on the first PCMS in sequence and 82 percent of the same information from the large DMS. As shown in the last column of Table 12, none of the differences was highly significant.

## SUMMARY

In this section of the report, researchers described the design and results of a driver simulator study to evaluate the ability of motorists to correctly interpret and comprehend messages placed on two PCMSs located in sequence on the side of the road. Researchers tested both four- and five-unit messages. Researchers also tested the benefits of replicating one of the information units on both PCMSs. Researchers then compared comprehension and recall rates of the information placed on PCMSs in sequence to the same information placed on large DMS on either one or two phases.

The results of the study indicate that presenting five units of information on sequential PCMS will result in substantially lower comprehension rates than if the information is presented at one location on a large two-phase DMS. However, the overall comprehension rates for both PCMSs and the |DMS are below what would be acceptable for highway applications. The results strongly indicate the need to keep overall messages below the four-unit maximum recommended in existing guidelines.

If message length is kept to four units, it does appear that the use of sequential PCMSs will result in comprehension rates comparable to those obtained by presenting the same information on a large single-phase DMS. The format of the sequential PCMSs tested in this study included replication of one of the units on both PCMSs. However, given the fact that subject drivers were able to recall the information from the first PCMS that was not replicated (i.e., the problem), such replication may not be required as long as the overall length of the message is kept below the recommended maximum. It is also important to recognize that this

study did not include the use of calendar dates. As noted previously, driver abilities to recall and interpret calendar dates tend to be lower than for other types of information. Incorporating calendar dates into sequential PCMSs is likely to result in low comprehension rates, even if the amount of information presented is kept to four units or less.

# SUMMARY AND RECOMMENDATIONS

In this report, researchers documented the results of the following research tasks:

- an inventory and human factors critique of existing PCMS use in work zones in several TxDOT districts;
- interviews of TxDOT personnel in several districts regarding the key issues they struggle with regarding PCMS use in work zones;
- description and results of a laptop-based human factors study of alternative formats of presenting advance notice work zone information on PCMS; and
- description and results of a TTI driving simulator study of the ability of motorists to capture and process information on two PCMS used in sequence to convey information about upcoming traffic situations.

Researchers found that that the majority of PCMSs observed in the districts failed to meet one or more guidelines regarding good PCMS message design and application. Many of the PCMS applications reviewed (40 percent) exceeded the MUTCD specification of using no more than two phases for a message. Researchers found two instances where four-phase messages were used on the PCMS. Improper splitting of information units across message phases was another common issue, as was inconsistency in how calendar dates of upcoming work activities were displayed on the signs. The results of the interviews of TxDOT personnel generally echoed the concerns identified in the district observations. Questions about appropriate formatting of date, day, and time information for advance notification messages was recognized as an unresolved issue, as was the need for better guidance about using two PCMS in sequence when it is necessary to present more information than can be displayed on two phases of a single PCMS.

To address the issues identified in the inventory and interviews, researchers conducted a laptop laboratory study in Houston, San Antonio, and El Paso as well as a driver simulator study in College Station. Researchers designed the laptop study to investigate motorist comprehension and preferences of alternative formats for conveying calendar date information when more than 7 days of advance notice is needed of upcoming work activities.

The results validated previous research findings that most drivers cannot identify specific days of the week of the road work activity when calendar dates are displayed. If calendar dates are displayed, then the following recommendations are offered based on the studies:

- Messages that require the display of calendar dates for future roadwork and other traffic control activities should utilize a message format consisting of the three-character abbreviation of the month (i.e., APR) in conjunction with the date.
- When future work activities span several days all in the same month, the month should be noted only once in the message (i.e., APR 21-23) rather than repeating the month (i.e., APR 21- APR 23). Of course, if the work activity will span two months, both will have to be included in the message.
- Attempts to present day, date, and time information about upcoming roadwork activities appears to approach the upper limit of driver information processing capabilities. Researchers found rather low comprehension and recall rates for some of the message elements when this type of information was presented together in a two-phase PCMS message.
- Regardless of the format used, only about two-thirds to three-fourths of the drivers viewing the PCMS message will be able to correctly interpret whether the work activity will affect their current trip or a future trip. TxDOT may need to reconsider the value of its current policy to require at least 7 days advance notification in light of these rather low comprehension rates.

With regard to the use of two PCMSs in sequence to convey a single message to motorists, researchers found the following:

- The results strongly indicate the need to keep overall messages below the four-unit maximum recommended in existing guidelines. Researchers found that presenting five units of information on sequential PCMSs resulted in low comprehension rates, below what is acceptable for highway applications.
- By keeping the message length to four units, it appears that the use of sequential PCMSs will result in comprehension rates comparable to those obtained by presenting the same information at a single location on a large DMS, and is

recommended as an acceptable formatting approach for TxDOT. Comprehension may be enhanced by repeating one of the units of information on both PCMSs, although it is not clear whether this approach would result in acceptable driver comprehension rates if the message includes calendar dates.

# REFERENCES


1. Dudek, C.L. *Dynamic Message Sign Message Design and Display Manual*. Report No. FHWA/TX-04/0-4023-P1. Texas Transportation Institute, College Station, TX, March 2004.

2. Dudek, C.L. *Guidelines on the Use of Changeable Message Signs*. Report No. FHWA-TS-90-043. FHWA, U.S. Department of Transportation, Washington, DC, May 1991.

3. Dudek, C.L. Changeable Message Signs. *NCHRP Synthesis of Highway Practice 237*. TRB, National Research Council, Washington, DC, 1997.

4. Dudek, C.L. Changeable Message Signs. *NCHRP Synthesis of Highway Practice 61*. TRB, National Research Council, Washington, DC, 1979.

5. Dudek, C.L., R.D. Huchingson, et al. *Human Factors Requirements for Real-Time Motorist Information Displays, Vol. 1 -- Design Guide*. Report FHWA-RD-78-5. FHWA, U.S. Department of Transportation, Washington, DC, September 1978.

6. Dudek, C.L., R.D. Huchingson, R.D. Williams, and R.J. Koppa. *Human Factors Design of Dynamic Visual and Auditory Displays for Metropolitan Traffic Management, Vol. 2 -- Dynamic Visual Displays*. Report No. FHWA-RD-81/040. FHWA, U.S. Department of Transportation, Washington, DC, January 1981.

7. Dudek, C.L., and R.D. Huchingson. *Manual on Real-Time Motorist Information Displays*. Report FHWA-IP-86-16. FHWA, U.S. Department of Transportation, Washington, DC, August 1986.

8. Dudek, C.L. *Guidelines on the Use and Operation of Changeable Message Signs*. Report No. FHWA/TX-93/1232-9. Texas Transportation Institute, College Station, TX, 1992.

9. Dudek, C.L. *Guidelines on the Selection and Design of Messages for Changeable Message Signs*. Report No. FHWA/TX-93/1232-10. Texas Transportation Institute, College Station, TX, 1992.

10. Dudek, C.L., G.D. Weaver, D.R. Hatcher, and S.H. Richards. Field Evaluation of Messages for Real-Time Diversion of Freeway Traffic for Special Events. In *Transportation Research Record 682*. TRB, National Research Council, Washington, DC, 1978.

11. Dudek, C.L. *Portable Changeable Message Signs at Work Zones*. Report No. FHWA/TX-85/07+292-4. Texas Transportation Institute, College Station, TX, July 1984.

12. Turner, J.M., J.D. Carvell, and C.L. Dudek. Real-Time Diversion of Freeway Traffic During Maintenance Operations. In *Transportation Research Record 683*. TRB, National Research Council, Washington, DC, 1978.

13. Dudek, C.L., W.R. Stockton, and D.R. Hatcher. Real-Time Freeway-to-Freeway Diversion: The San Antonio Experience. In *Transportation Research Record 841*. TRB, National Research Council, Washington, DC, 1982.

14. Richards, S.H., R.C. Wunderlich, and C.L. Dudek. Field Evaluation of Work Zone Speed Control Techniques. In *Transportation Research Record 1035*. TRB, National Research Council, Washington, DC, 1985.

15. Hanscomb, F.R. *Effectiveness of Changeable Message Displays in Advance of High-Speed Freeway Lane Closures.* NCHRP Report 235. TRB, National Research Council, Washington, DC, September 1981.

16. Garber, N.J., and S.T. Patel. Control of Vehicle Speeds in Temporary Traffic Control Zones (Work Zones) Using Changeable Message Signs with Radar. In *Transportation Research Record 1509*. TRB, National Research Council, Washington, DC, 1995.

17. Durkop, B.R., and C.L. Dudek. *Texas Driver Understanding of Abbreviations for Dynamic Message Signs.* Report No. FHWA/TX-00/1882-1. Texas Transportation Institute, College Station, TX, February 2000.

18. Dudek, C., N. Trout, S. Booth, and G. Ullman. *Improved Dynamic Message Sign Messages and Operations*. Report No. FHWA/TX-01/1882-2. Texas Transportation Institute, College Station, TX, October 2000.

19. Halloin, D.M. Impediments to the Effective Use of Portable Variable Message Signs in Work Zones. In *Compendium of Graduate Student Papers on Advanced Surface Transportation Systems.* Southwest Region University Transportation Center, Texas A&M University, College Station, TX, August 1996.

20. Helmuth, J.L. *Visual Complexity in Highway Work Zones: An Exploratory Study*. Master of Science Thesis, Department of Civil Engineering, Texas A&M University, College Station, TX, May 2002.

21. *Manual on Uniform Traffic Control Devices.* FHWA, U.S. Department of Transportation, Washington, DC, 2003.

22. Morales, J.M. *Portable Changeable Message Sign Handbook.* American Traffic Safety Services Association, Fredricksburg, VA, 2004.

23. *Portable Message Sign Handbook PCMS.* Report No. FHWA-RD-03-066. FHWA, U.S. Department of Transportation, Washington, DC, 2003. Accessible at http://www.tfhrc.gov/pavement/ltpp/reports/03066/.

24. Dudek, C.L. Changeable Message Sign Messages for Work Zones: Time of Day, Days of Week, and Month Dates. In *Transportation Research Record 1692*. TRB, National Research Council, Washington, DC, 1999.

25. Huchingson, R.D. and C.L. Dudek. Preliminary Results of Human Factors Studies in New Jersey: Response Time to Key Information: Stand-Alone vs Distributed Messages, Two-Frame and Three-Frame Messages. Technical Memorandum 7296-5-12 Prepared for the New Jersey Department of Transportation. Texas Transportation Institute, College Station, TX, 1998.

26. Story, B. Evaluation of the Effectiveness of Dual Portable Changeable Message Signs (PCMS) in the Display of a Single Message. In *Compendium of Student Papers: 2004 Undergraduate Transportation Engineering Fellows Program.* Southwest Region University Transportation Center, Texas A&M University, August 2004.

# APPENDIX A: LAPTOP STUDY PROTOCOL

## WORK ZONE MESSAGES TESTED

The work zone messages tested are shown below

**Work Zone Messages.**

| Message Set | Message A | | Message B | |
|---|---|---|---|---|
| | **Phase 1** | **Phase 2** | **Phase 1** | **Phase 2** |
| 1 | ALT LANES CLOSED | *[4/21]* TO *[4/25]* | ALT LANES CLOSED | *[APR 21]* TO *[APR25]* |
| 2 | *[I-410 W]* EXIT CLOSED | *[MON] [APR 27] [9AM-3PM]* | *[I-410 W]* EXIT CLOSED | *[APR 27] [9AM-3PM*] |
| 3 | LEFT 2 LANES CLOSED | *[MON-FRI] [APR25-APR29*] | LEFT 2 LANES CLOSED | *[MON-FRI] [APR25-29]* |
| 4 | *[1-10 W]* ROADWORK | *[MAY17-MAY19*] *[TUE-THUR]* | *[I-410 W]* ROADWORK | *[MAY17-MAY19] [10AM-6PM]* |
| 5 | ALT LANES CLOSED | *[MAY9-11*] *[MON-WED] [11AM-8PM*] | | |

***Note: the dates and day of the week will change at each study city. Also, they may change based on the day of the week that the study is conducted in the city. Also, the freeway name will change in each city. The items that will change in each city are shown in italics.***

### Study Administrator Instructions

During this study, you are to assume that you are in [San Antonio] and driving [westbound] on [Interstate 410]. As you travel on the freeway you will see small changeable message sign messages on the side of the road similar to the ones you might see in construction zones. These messages will be shown on the computer monitor.

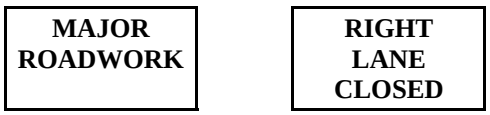
As part of this study, you are to use the mouse to click on the red dots that appear in the box on the screen. Your job is to click on as many of the red dots as possible. We will be keeping an electronic count of the number of dots that you click on during the study.

The messages on the changeable message signs will stay on for a few seconds and then will automatically turn off. After the message turns off, you will be asked questions about the information in the message. So try to remember the information in the message. Do you have any questions at this time?

Press the space bar when you are ready to begin.

***TL***

*At the appropriate time,* ***Test WZ Message 1*** *is projected. Each phase of the message is displayed for* ***2*** *seconds;* ***the entire message is repeated once****.*




*Phase 1* *Phase 2*

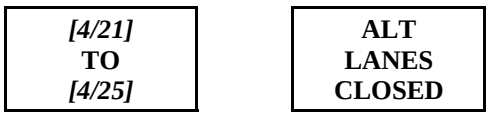
**Question Asked by Study Administrator**
***Test WZ Message 1***
1. What was the message on the screen?
2. Are the lanes closed today?
3. If you plan on traveling on the freeway one week from tomorrow, will the lanes be closed?

*(Study supervisor records answers.)*

Instructions by Study Administrator
Press the space bar to view your button pushing score.

Instructions by Study Administrator:
Press the space bar to view the next message.

***TL***
*At the appropriate time,* ***WZ Message 1A*** *is projected. Each phase of the message is displayed for 2 seconds; the entire message is repeated once.*




*Phase 1* *Phase 2*

**Question Asked by Study Administrator**
***WZ Message 1A***
1. What was the message on the screen?
2. Are the lanes closed today?
3. If you plan on traveling on the freeway one week from tomorrow, will the lanes be closed?
4. What days of the week are the lanes closed?

*(Study supervisor records answers.)*

Instructions by Study Administrator
Press the space bar to view your button pushing score.

Instructions by Study Administrator:
Press the space bar to view the next message.

***TL***
*At the appropriate time,* ***WZ Message 2A*** *is projected. Each phase of the message is displayed for 2 seconds; the entire message is repeated once.*

| | |
|---|---|
| ***[MON]*** <br> ***[APR 27]*** <br> ***[9AM-3PM]]*** | ***[I-410 W]*** <br> **EXIT** <br> **CLOSED** |
| *Phase 1* | *Phase 2* |

**Question Asked by Study Administrator**
***WZ Message 2A***
1. What was the message on the screen?
2. Is the I-410 East exit closed today?
3. If you plan on traveling on the freeway one week from tomorrow, will the exit be closed?
4. What day of the week is the exit closed?

*(Study supervisor records answers.)*

Instructions by Study Administrator
Press the space bar to view your button pushing score.

Instructions by Study Administrator:
Press the space bar to view the next message.

***TL***
*At the appropriate time, **WZ Message 3A** is projected. Each phase of the message is displayed for 2 seconds; the entire message is repeated once.*

| | |
|---|---|
| ***[MON-FRI]*** <br> ***[APR25-*** <br> ***APR29*** | **LEFT** <br> **2 LANES** <br> **CLOSED** |
| *Phase 1* | *Phase 2* |

**Question Asked by Study Administrator**
***WZ Message 3A***
1. What was the message on the screen?
2. Are the lanes closed today?
3. If you plan on traveling on the freeway one week from tomorrow, will the lanes be closed?
4. What days of the week are the lanes closed?

*(Study supervisor records answers.)*

Instructions by Study Administrator
Press the space bar to view your button pushing score.

Instructions by Study Administrator:
Press the space bar to view the next message.

***TL***
*At the appropriate time, **WZ Message 4A** is projected. Each phase of the message is displayed for 2 seconds; the entire message is repeated once.*

| *[MAY17-MAY19]* *[TUE-THUR]* | *[I-410 W]* **ROADWORK** |
|---|---|
| *Phase 1* | *Phase 2* |

**Question Asked by Study Administrator**

***WZ Message 4A***

1. What was the message on the screen?
2. Is the roadwork taking place today?
3. If you plan on traveling on the freeway one week from tomorrow, will the roadwork be on the freeway?
4. What days of the week is the roadwork?

*(Study supervisor records answers.)*

Instructions by Study Administrator

Press the space bar to view your button pushing score.

Instructions by Study Administrator:

Press the space bar to view the next message.

***TL***

*At the appropriate time,* ***WZ Message 5A*** *is projected. Each phase of the message is displayed for 2 seconds; the entire message is repeated once.*

| *[MAY9-11]* *[MON-WED]* *[11AM-8PM]* | **ALT LANES CLOSED** |
|---|---|
| *Phase 1* | *Phase 2* |

**Question Asked by Study Administrator**

***WZ Message 5A***

1. What was the message on the screen?
2. Are the lanes closed today?
3. If you plan on traveling on the freeway one week from tomorrow, will the lanes be closed?
4. What days of the week are the lanes closed?

*(Study supervisor records answers.)*

Instructions by Study Administrator

Press the space bar to view your button pushing score.

Instructions by Study Administrator:

This is the end of this session of the study.

**END OF SESSION A**

**WORK ZONE DATE, DAY, TIME PREFERENCES**

**Study Administrator Instructions**

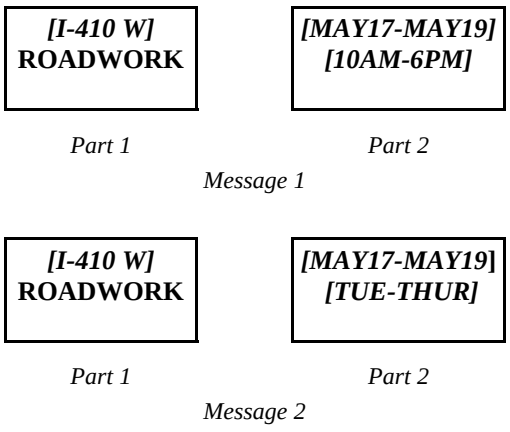
During this part of the study, you will again assume that you are near downtown [San Antonio] driving [westbound] on [Interstate 410] freeway. *(Note: names will change in each study city.)*

In this study, you will see two ways of showing the same information for a number of signs. You will be asked your opinion about which of the ways of displaying the message that you prefer. During this session you will not need to click on the red dots. Do you have any questions at this time?

OK, we are now ready to begin the study. When you press the space bar, you will see two changeable message sign messages on the screen.

Press the space bar when you are ready to see the two messages.

*At the appropriate time,* ***WZ Message 4B and WZ Message 4A*** *are projected. Messages are displayed until subject answers the questions and presses the space bar*

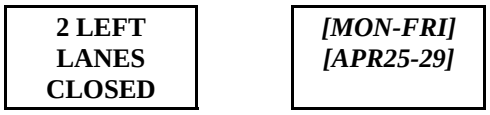



**Questions Asked by Study Administrator**
***WZ Message 4B and WZ Message 4A***:
1. Which of the two messages do you prefer?
2. Why do you prefer the message you selected? Be very specific.

*(Study supervisor records answers.)*

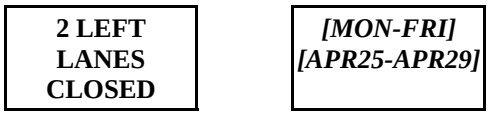
Press the space bar when you are ready to see the next two messages.

*At the appropriate time,* ***WZ Message 3B and WZ Message 3A*** *are projected. Messages are displayed until subject answers the questions and presses the space bar*




*Part 1* *Part 2*

*Message 1*




*Part 1* *Part 2*

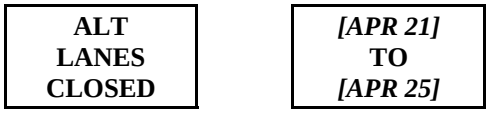
*Message 2*

**Questions Asked by Study Administrator**
***WZ Message 3B and WZ Message 3A***:
1. Which of the two messages do you prefer?
2. Why do you prefer the message you selected? Be very specific.

*(Study supervisor records answers.)*

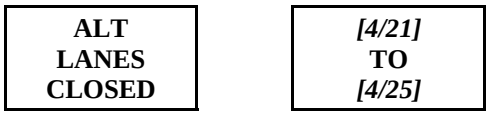
Press the space bar when you are ready to see the next two messages.

*At the appropriate time,* ***WZ Message 1B and WZ Message 1A*** *are projected. Messages are displayed until subject answers the questions and presses the space bar*




*Part 1* *Part 2*

*Message 1*




*Part 1* *Part 2*

*Message 2*

**Questions Asked by Study Administrator**
***WZ Message 1B and WZ Message 1A***:
1. Which of the two messages do you prefer?
2. Why do you prefer the message you selected? Be very specific.

*(Study supervisor records answers.)*

Instructions by Study Administrator:
This is the end of this part of the study. We will take a break if you need one.

**END OF SESSION B**

# APPENDIX B: DRIVER SIMULATOR STUDY DEMOGRAPHICS, INFORMATIONAL FLYER, INFORMED CONSENT, AND PRE-SCREENING QUESTIONAIRE

## Counterbalancing of Participants.

| Subject # | Group # | Demographic Category | | |
|---|---|---|---|---|
| | | Age | Gender | Education |
| 1 | Wa | A | M | HS |
| 2 | Xb | A | M | HS |
| 3 | Ya | A | M | HS |
| 4 | Zb | A | M | HS |
| 5 | Wb | A | F | HS |
| 6 | Xa | A | F | HS |
| 7 | Yb | A | F | HS |
| 8 | Za | A | F | HS |
| 9 | Wb | A | M | C |
| 10 | Xa | A | M | C |
| 11 | Yb | A | M | C |
| 12 | Za | A | M | C |
| 13 | Wa | A | F | C |
| 14 | Xb | A | F | C |
| 15 | Ya | A | F | C |
| 16 | Xa | B | M | HS |
| 17 | Yb | B | M | HS |
| 18 | Za | B | F | HS |
| 19 | Wb | B | F | HS |
| 20 | Wa | B | M | C |
| 21 | Zb | B | M | C |
| 22 | Xb | B | F | C |
| 23 | Ya | B | F | C |
| 24 | Zb | B | F | C |
| 25 | Wa | C | M | HS |
| 26 | Zb | C | M | HS |
| 27 | Xb | C | F | HS |
| 28 | Ya | C | F | HS |
| 29 | Xa | C | M | C |
| 30 | Yb | C | M | C |
| 31 | Wb | C | F | C |
| 32 | Za | C | F | C |

Age Categories: A=18-39, B=40-54, C=55+

Education Categories: HS= High School or Less, C= Some College or more

# DRIVERS NEEDED
# FOR TRANSPORTATION STUDY

Purpose:

- To obtain driver's understanding of highway signs.

Compensation:

- Participants will receive **$20.00** upon completion of the study.

Requirements:

- Current drivers license
- 18 years old or older

When:

- April 2005
- Approximately 1 hour
- Schedule a time convenient for you!

Where:

- Driving Simulator
- Gibb Gilchrist Building, Texas A&M University - West Campus

**If you would like more information or are interested in participating, please contact:**

**Carol Coker, Texas Transportation Institute, Texas A&M University**
**Phone : (979) 845-0913**
**Email : c-mendezcoker@tamu.edu**

**DRIVING SIMULATOR STUDY CONSENT FORM**
**Project 4748**

I have been asked to participate in a research study to obtain motorist's understanding of traffic control devices on highways as presented in a driving simulator. The experiment is to take place in the Gibb Gilchrist Building. I am being selected as a possible participant because I am over the age of 18, I possess a valid driver's license, and I have no apparent limitations impeding my ability to drive. I have the demographics required to provide the sample needed based on the Texas driver license population. Approximately 35 subjects from the Bryan/College Station, Texas area have been asked to participate in the study.

This research study is being conducted by the Texas Transportation Institute (TTI), which is part of the Texas A&M University System (TAMU). It is sponsored by the Texas Department of Transportation (TxDOT).

**Background Information**: The purpose of the study is to obtain drivers' understanding of traffic control devices on highways in a driving simulator.

**Compensation**: I will be compensated $20.00 for my participation in the study. Payment will be made upon my completion of the study. In the event I choose to end participation before completion of the experiment, I will be compensated $10.00. If the test administrator terminates the study due to unforeseen circumstances I will be compensated $20.00. Other than monetary compensation, I understand there are no special benefits to me for participating in the study. I understand that I may incur travel costs to the study location and that these expenses will not be reimbursed.

**Procedures**: If I agree to be in this study, I am asked to participate in a brief instructional session, a practice session, and the experimental session in the driving simulator. This entire study will take no longer than 60 minutes (one hour).

*Introductory Session*: During the introductory session I will read this consent form. I will indicate my willingness to continue with the experiment by signing this form. Before proceeding, I will receive a copy of the form if I wish.

*Driving Simulator Practice Session*: During the practice session I will be shown the driving simulator and I will receive instructions on how to operate the controls. This practice session will provide the opportunity to become familiar with driving the simulator and will last approximately 5 minutes.

*Driving Simulator Experimental Session*: During the simulator portion of the experiment, I will be asked to drive through a simulated driving environment. I will be asked questions about various traffic control devices encountered while driving. This portion of the experiment will take approximately 1 hour.

**Risks:** I understand that the only risk associated with this study is a temporary condition named 'Simulator Induced Discomfort' (SID) which is characterized by feelings of dizziness and increased body temperature. The potential for this discomfort is minimal as it only mildly affects about 10 persons out of every 100 simulator participants. I understand that I am to indicate to the investigator if I experience any of these symptoms, and that the study will be stopped to prevent any further discomfort to me. I understand that it is my right to stop the study because I am not feeling well, the experiment will end immediately, and I will receive $10.00 for my participation.

In the case of an accident or medical emergency, appropriate emergency medical services will be called. However, neither TTI nor Texas A&M University will assume financial responsibility for any medical costs incurred due to my participation in this study. Continuing medical care and/or hospitalization for research-related injury will not be provided free of charge nor will financial compensation be available, or be provided by Texas A&M University, TTI, TxDOT, or the investigators.

**Confidentiality:** This study is confidential. The records of this study will be kept private. No identifiers linking me to the study will be included in any sort of report that might be published. Research records will be stored securely in Room 410 of the CE/TTI Building on the Texas A&M University campus and only TTI personnel working on the project will have access to the records. I will be asked to sign a form acknowledging payment for my participation. These forms are kept separate from this signed consent form and any other data that would identify me by name. I understand that if I accept payment for participating in this study, the fact that I participated in this study may be obtained under the Texas Open Records Act, even though any information that I give the investigator is confidential.

**TTI Subject Pool:** I understand that the Texas Transportation Institute conducts many research projects throughout the year and may contact me again to participate in another study. I am under no obligation to participate in future studies. My name, contact information, responses to demographic and driving habits questionnaires, and performance on any vision tests will be retained to assist

in my potential selection for inclusion in future studies. If I do **not** wish to be contacted in the future I may indicate this by marking the box below.

____ I do **not** wish to participate in any further studies. Do not retain my personal information nor contact me for participation in any future studies.

**Voluntary Nature of the Study**: My decision whether or not to participate will not affect my current or future relations with Texas A&M University, TTI, or TxDOT. If I decide to participate, I am free to refuse to answer any of the questions that may make me uncomfortable. I can withdraw at any time without my relations with the University, TTI, or TxDOT being affected.

**Contacts and Questions**: The researcher conducting this study is Gerald Ullman Ph.D., P.E. If I have questions now or later, I may contact Gerald Ullman at the Texas Transportation Institute, Texas A&M University, College Station, Texas 77843-3135, (979) 845-9908, g-ullman@tamu.edu.

**I will be given a copy of this form for my records.**
A copy of this form will be given to me if I wish to keep one.

I understand that this research study has been reviewed and approved by the Institutional Review Board – Human Subjects in Research, Texas A&M University. For research-related problems or questions regarding subjects' rights, I can contact the Institutional Review Board through Ms. Angelia Raines, Director of Research Compliance, Office of the Vice President for Research, at (979) 458-4067 (araines@vprmail.tamu.edu).

Statement of Consent: I have read and understand the explanation provided me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study. I have been provided a copy of this consent form.

_____

Signature of Subject Date

_____

Printed Name of Subject

_____

Signature of Principal Investigator or Authorized Representative Date

# Phone Pre-Screening Questionnaire

Age _____ Gender_____ Education_____

**Inclusion Criteria**

If a participant fails to meet one of the criteria, stop, skip the Health Screening and proceed to the Closing

If all inclusion criteria are meet proceed to the Health Screening.

"There are several criteria that must be met for participation in this study. I will need to ask you several questions to determine your eligibility."

1. Do you possess a valid driver's license within Texas?

   [Exclude is no current valid driver's license]

2. How many times per week do you drive?

   [Exclude if less than one time a week]

3. Do you work for any department in the Texas A&M University System?

   [Instruct the participant that they cannot be compensated if they work for the University, and ask them if they still want to proceed]

4. Are you able to read English?

   [Exclude if the subject can not read English]

# Phone Pre-Screening Questionnaire cont'd

**General Health Exclusion Criteria**

If a participant fails to meet one of the criteria, stop and proceed to the Closing.

Before this list of questions is administered, please communicate the following:

"Because of pre-existing health conditions, some people are not eligible for participation in this study. I need to ask you several health-related questions before you can be scheduled for a study session. Your response is voluntary and all responses are confidential. This means that you can refuse to answer any questions that you choose and that only a record of your motion sickness susceptibility will be kept as part of this study. No other responses will be kept. Please answer yes or no to the following questions:"

1. If the subject is female:
   Are you, or is there a possibility that you are pregnant?

   [Exclude if there is any possibility of pregnancy.]

2. Have you been diagnosed with a serious illness that might cause dizziness or motion sickness? If yes, is the condition still active? Are there any lingering effects? If yes, do you care to describe?

   [Exclude if there is any current serious condition.]

3. Do you suffer from inner ear, dizziness, vertigo, or balance problems? If yes, please describe.

   [Exclude if there is any recent history of the above symptoms]

4. Do you ever suffer from motion sickness? If yes, on what mode of transportation and what were the conditions? What symptoms did you experience? How old were you when this occurred?

   [Exclude if there are any recent history of motion sickness]

5. Are you currently taking any medications that might contribute to dizziness or motion sickness?

   [Exclude if medication is for motion sickness, psychiatric disorder, including anti-depressants, heart conditions, seizures or epilepsy, respiratory disorder, frequent headaches, or insulin for diabetes.]

# Phone Pre-Screening Questionnaire cont'd

**Closing**

If participant MEETS ALL criteria (Driving Inclusion and General Health Exclusion Criteria):

- Inform the participant to refrain from alcohol and drug intake for the 24 hours preceding the session.
- Schedule the appointment.
- Give directions
- Stress the importance of attending the session and provide a contact name and number
- Bring eyeglasses if required for driving

If the person DOES NOT meet one or more of these criteria, explain that this study requires meeting all of these conditions, thank the person for their time, and, if reasonable ask if they wish to remain on the list of participants for other TTI studies.

# APPENDIX C: DRIVER SIMULATOR STUDY SUBJECT RESPONSES

**Table C.1. Message 1 and 4 Comprehension Comparisons.**

| Question | Responses | Message1 – Sequential PCMSs (%) | Message 4- Standard CMS (%) |
|---|---|---|---|
| What is the problem? | **Roadwork** | **10 (63)** | **10 (63)** |
| | Lanes Closed | | 2 (12) |
| Who is affected? | **Oakdale** | **8 (50)** | **1 (6)** |
| | Oaklawn, Roadale, etc. | 2 (12) | 2 (12) |
| | I-40 | 1 (6) | 1 (6) |
| | Not me | | 1 (6) |
| Where is the problem? | **I-40** | **4 (25)** | **4 (25)** |
| | Oakdale | 5 (31) | 1 (6) |
| What are you told to do? | **use other routes** | **7 (44)** | **3 (19)** |
| | Merge, exit | | 4 (25) |
| What were you told about the lanes? | **2 lanes closed** | **10 (63)** | **9 (56)** |
| | Lanes closed, 2 lanes | 2 (12) | 4 (25) |

**Table C.2. Message 3 and 2 Comprehension Comparisons.**

| Question | Responses | Message3 – Sequential PCMSs (%) | Message 2- Standard CMS (%) |
|---|---|---|---|
| What is the problem? | **Accident** | **9 (56)** | **15 (94)** |
| | Lanes Closed | 1 (6) | |
| Who is affected? | **Downtown Traffic** | **6 (38)** | **7 (44)** |
| | Left lane | 1 (6) | 5 (31) |
| | US 87 | | 2 (12) |
| Where is the problem? | **US 87 S** | **6 (38)** | **15 (94)** |
| | Downtown | 3 (19) | |
| What is the effect on traffic? | **Delay** | **10 (63)** | **9 (56)** |
| | Merge, obstructed | 1 (6) | 1(6) |
| What were you told about the lanes? | **Left lane closed** | **10 (63)** | **11 (69)** |
| | 2 lanes closed | 1 (6) | |

**Table C.3. Message 5 and 8 Comprehension Comparisons.**

| Question | Responses | Message 5 – Sequential PCMSs (%) | Message 8- Standard CMS (%) |
|---|---|---|---|
| What is the problem? | **Roadwork** | **12 (75)** | **13 (81)** |
| | Lanes closed | 3 (19) | 1 (6) |
| How is the problem affecting traffic? | **Be prepared to stop** | **8 (50)** | **11 (69)** |
| | Right lane closed | 7 (44) | 1 (6) |
| What lane is affected? | **2 right lanes** | **15 (94)** | **11 (69)** |
| | 1 right lane | 1 (6) | |
| | 2 left lanes | | 1(6) |
| Where is the problem located? | **Past main** | **6 (38)** | **6 (38)** |
| | Right lane | 1 (6) | |

**Table C.4. Message 7 and 6 Comprehension Comparisons.**

| Question | Responses | Message 7 – Sequential PCMSs (%) | Message 6- Standard CMS (%) |
|---|---|---|---|
| What is the problem? | **Accident** | **14 (88)** | **16 (100)** |
| | Lanes closed | 1 (6) | |
| How is the problem affecting traffic? | **Delays** | **15 (94)** | **12 (75)** |
| | Lane closed, merge | | 3 (19) |
| What lane is affected? | **Left lane** | **13 (81)** | **15 (94)** |
| Where is the problem located? | **At Kent** | **13 (81)** | **13 (81)** |