FINAL
CONTRACT REPORT

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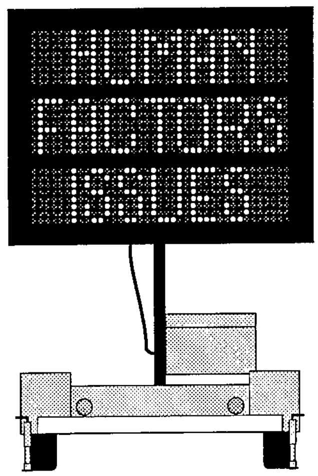
CREATING EFFECTIVE VARIABLE MESSAGE SIGNS: HUMAN FACTORS ISSUES



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Supplementary Notes

Abstract

This report addresses the human factors issues related to the reading and comprehension of variable message sign (VMS) messages. A review of the literature was conducted on factors that affect how people read VMSs. Several topics were reviewed. The first topic was literacy. Since reading literacy is not a requirement for obtaining a driver's license, VMS composition should reflect the varied reading competence levels of motorists. It was found that about 25% of Virginians over the age of 16 are weak readers and will likely encounter problems reading VMSs.

The second topic addressed how people read. Reading is an interactive process that derives much of its speed and accuracy from implicit knowledge acquired through familiarity. This implies that VMS messages should present familiar, standardized content whenever possible.

A review of the literature on warning signs was the third topic. Effective warning signs should have several properties: Short, concise messages are both easier to read and more likely to be read. Signal words, such as CAUTION, are not effective.

Finally, areas for further research were identified. Symbolic messages and abbreviations are worthy of further investigation as they have the potential for easy recognition, provided they are familiar to motorists and can be accommodated by the VMS. In addition, although the MUTCD advises angling the VMS away from the roadway to reduce headlight glare, angling the VMS toward the roadway could be desirable for increasing readability. In both these areas, theoretical and practical work is needed.

The report recommends that these human factors characteristics and limitations be taken into consideration in the deployment of VMSs and in the composition of their messages.

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ABSTRACT

This report addresses the human factors issues related to the reading and comprehension of variable message sign (VMS) messages. A review of the literature was conducted on factors that affect how people read VMSs. Several topics were reviewed. The first topic was literacy. Since reading literacy is not a requirement for obtaining a driver's license, VMS composition should take into consideration the varied reading competence levels of motorists. It was found that about 25% of Virginians over the age of 16 are weak readers and will likely encounter problems reading VMSs.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) has been steadily increasing its use of variable message signs (VMSs) to provide advance warning in construction zones, to better manage incidents, and to assist in traffic management of special events. Of course, the characteristics of VMSs that make them so valuable to VDOT are that they can be mobile, can be programmed to display a message dealing with current conditions, and then can be quickly reprogrammed as conditions change. This versatility makes VMSs preferable to stationary, static signs in many situations. However, it is this versatility that results in increased responsibility of those employees in charge of VMSs to correctly determine where and in what situations they can be best used and what messages they should display. In most instances, considerable decision making is required to make these determinations.

Because VMSs will display any message they receive (within their programming parameters) and because there are so many different employees programming the signs, the content and layout of the messages displayed could potentially vary widely. This variation has caused some VDOT personnel to call into question the quality of the messages VDOT is sending to the public. There has always been a temptation when dealing with VMSs to try to provide a set of standard messages that correspond to the most common situations in which they are used. In terms of static signs, the *Manual on Uniform Traffic Control Devices (MUTCD)* set out standard messages and formats so that the message and appearance of static signs will be consistent from state to state. Because VMSs are designed to be responsive to changing situations and because VMS technology is relatively new, standards are only recently beginning to be developed.

There are two schools of thought concerning the standardization of VMS messages. Field personnel sometimes feel that standardizing messages would defeat the flexibility of VMSs, which is the very characteristic that makes their use appealing to VDOT. On the other hand, those who have received complaints from the public concerning uninterpretable or misleading messages often feel that standardization would reduce human error. It may be that the answer to this dilemma lies somewhere between these two positions. In either case, because the technology now allows for immediate, real-time communication between VDOT and its motoring customers, and because customer expectation is high, it is critical that VDOT ensure that accurate and understandable information is conveyed to motorists in a way that provides the least distraction from the driving task.

A considerable amount of research is being conducted nationwide on the issue of optimal use of VMSs. At the Virginia Transportation Research Council (VTRC), a program of research has been undertaken that has resulted in guidelines for VMS decision making and in a series of workshops for VDOT personnel on how best to approach the task of designing messages for VMS display. In addition, a body of traffic engineering research on the character legibility of the currently available VMSs has developed.

Much of this research has dealt with letter recognition issues, such as how quickly an observer can recognize a letter given its stroke width, letter size, and distance. This research contributes to issues of sign legibility, but it does not fully account for the factors that influence reading comprehension. This is because skilled readers do not read words by first identifying the individual letters of which they are comprised. This report addresses the human factors issues related to the reading and comprehension of VMS messages.

PURPOSE AND SCOPE

The purpose of this report is to provide a synthesis of the psychological research on how people read as it relates to reading VMS messages. This literature review is intended to be of use to administrators and researchers concerned with VMS use. The implications of this review are not limited to current VMS technologies. Rather, the scope of the report's recommendations is also intended to inform the use and development of technologies that could be available in the near future. Four distinct topics will be reviewed.

1. Literacy. Since reading literacy is not a requirement for obtaining a driver's license, VMS composition must reflect the varied reading competence levels of motorists.

2. How people read. Skilled readers do not first recognize all of the individual letters in a word and then determine the word they comprise. Rather, they simultaneously integrate letter recognition processes with knowledge about language, expectations based upon an interpretation of the situation, and familiarity with words and their likelihood of occurrence. Optimal messages engage these factors and, thereby, promote effective reading.

3. Warning signs. There are a number of agreed-upon properties that effective warning signs should have. These properties should be incorporated into VMS composition.

4. Placement of VMS signs. Currently, VMSs are oriented perpendicular to the roadway as are fixed static signs. VMSs should be oriented so as to maximize the time they are optimally oriented with respect to a driver's line of sight. This report presents a geometrical analysis showing how this can be done.

LITERATURE REVIEW

Literacy

The field personnel who compose messages for VMSs must often rely on their own intuition about what constitutes a good message given the situation that is to be described. These intuitions are influenced by their own reading level, which is probably a good deal higher than that of many Virginia motorists. Depending upon how literacy is defined, between 8% and 25% of Virginians are functionally illiterate or very weak readers. The reading requirements of these individuals should be taken into account when VMS messages are composed.

Literacy Rates

Defining *illiteracy* continues to be a problem for educators and administrators in this country. Research on literacy rates has employed a variety of different criteria including grade-level equivalency, reading performance on standardized tests, and the ability to use written information to function in the environment (Irwin, 1991; Kirsch, Jungeblut, Jenkins, and Kolstad, 1993). Across all of these studies, it is estimated that approximately 8% to 25% of Americans are illiterate. For example, in 1982, following an English Language Proficiency Survey conducted with 3,400 Americans, the U.S. Department of Education estimated that 13% of Americans ages 20 and older were illiterate (Irwin, 1991). Seventy percent of those individuals rated as illiterate had never completed high school, and 30% were over the age of 60.

More recently, the National Adult Literacy Survey (NALS) was conducted by the National Center for Education Statistics (Kirsch et al., 1993). More than 26,000 American adults, ages 16 and older, were tested to estimate national proficiency levels. The overall results indicated that 25% of Americans (approximately 40 million people) function at the lowest literacy level. Similar to the 1982 results obtained by the Census Bureau, 62% of these low-functioning individuals never completed high school and 30% were over the age of 65. Moreover, 23% of these individuals reported that they request assistance from family and friends on a daily basis for reading (Kirsch et al., 1993).

Using 1990 census data obtained by the Virginia Department of Education (Thorne and Fleenor, 1993), it is possible to obtain information related to adult illiteracy rates in Virginia. Of the 4.2 million adults in Virginia, ages 16 and over, approximately 1.1 million (26%) have not completed high school, approximately 8% have not completed schooling beyond the eighth grade, and 2.5% have not completed schooling beyond the fourth grade.

Given these diverse surveys, it is reasonable to estimate that about 25% of Virginians over the age of 16, and thereby eligible for a driver's license, are weak readers. In addition, about 8% of Virginians in this age group have profound difficulty reading.

Reading by Low-Skill Readers

There are three characteristics of weak readers that are especially relevant to the composition of VMS messages. The first is that they are more reliant on context in interpreting written messages, the second is that they are more disrupted by degraded print, and the third is that reading places greater memory demands on weak readers than on more skilled ones. (Before elaborating on these three issues, it is important to note that the research on reading across literacy levels has been mostly conducted with school-age children and, thus, not all of the findings can be generalized entirely to adults. On the other hand, there are no reasons to assume that the following three findings do not generalize.)

Readers at all levels read faster and with better comprehension when they have background information about what the message is about. For example, the sentence "The haystack was important because the cloth ripped" is difficult to comprehend when presented in isolation. What happened? If the sentence is preceded by a context—it is about a parachutist—then the sentence becomes easy to understand (Bransford and McCarrell, 1974). Reread the sentence to confirm that this is so. Weak readers depend more upon context to comprehend text than do more skilled readers (Perfetti and Roth, 1981).

Weak readers are also more affected by a text degradation. Degradation was manipulated by randomly deleting varying percentages of the dots used to generate dot-matrix fonts (Perfetti and Roth, 1981). This manipulation ought to generalize to bulb burnout in VMSs employing bulbs or to degradation in any sign because of dirt. It was found that degradation hindered effective reading in weak readers to a greater degree than in more skilled ones.

In part because weak readers read more slowly, they must hold information in memory for longer durations (Crowder and Wagner, 1992). This added burden further taxes the cognitive resources they can bring to the reading task. Working memory is generally viewed as the principal bottleneck in complex cognitive processing. Reading expertise results in an automization of subtasks and faster reading performance that, in turn, frees space in working memory.

Implications

There are five implications of these literacy findings for VMS composition.

1. *Field personnel cannot rely on their own intuition about what is easy to read.* The literacy level of these personnel is higher than a sizable proportion of the Virginia

driving population. What is deemed easy to read by field personnel may be uninterpretable by 10% to 25% of drivers.

2. *Providing context to the message will help low-skill readers.* A context provides background information on what the message is about such as a lane closing or a change in the speed limit. Here and throughout this report, it will be recommended that, whenever possible and within the constraints of the VMS technology available, symbols be used to convey essential information about driving directives. For example, if the intent of the VMS message is to inform motorists of the need to change lanes, then a symbol such as an arrow that invariably denotes this directive ought to appear in a prominent place on the sign.

3. *Providing standardized messages will help low-skill readers.* If a directive is always written in the same way, it will become familiar to motorists and will, thereby, come to be recognized more easily by everyone, including those with minimal reading skill. The more a message relies on careful reading, the more likely it is that weak readers will have problems deciphering it.

4. *Messages having different imperatives should be as distinct as possible.* VMS signs that state "Left lane closed," "Merge right" present two statements related to the directions, left and right. The reader must hold one statement in memory while deciphering the other. The task of reading places greater demands on the memory of weak readers than it does on those with more skill. Thus, weak readers have a greater potential to become confused about whether "right" refers to the closed lane or to the direction that they should merge.

5. *Low legibility in a VMS is especially problematic to weak readers.* Whenever the legibility of a VMS messages is low, it will likely pose a much greater problem to weak readers.

How People Read

It is important to recognize that learning to read well requires considerable effort and practice. It is not like learning spoken language, which is spontaneously acquired without much effortful attention or instruction. Learning to read is hard, and skillful performance requires years of practice.

Practice allows the individual to become familiar with the relevant patterns that apply to the various processing levels applicable to reading. These patterns include the feature combinations that define letters, the letter combinations that are allowable in the language, the letter combinations that specify words, the probability of occurrence of the words in the language, the likelihood that various words will appear in combination, the combination of words that are allowable in sentences, and so forth.

All of these levels of processing combine simultaneously in the act of reading. Readers do not first identify the letters in a word and then combine these letters to determine what the word is. Word recognition influences letter recognition just as letter recognition influences word recognition. This reciprocal influence is true of all other levels in reading processing.

What makes this interactive processing possible is familiarity with the patterns applicable to each level of reading processing. Skilled reading requires years of practice because it is fundamentally a skill that relies upon experience and familiarity.

The Interactive Model of Reading

The interactive model of reading assumes that letters are recognized, not only on the basis of the visual features that are present, but also on the basis of the word in which they are embedded (McClelland and Rumelhart, 1981). This notion is based on a number of very old and well-known findings.

Cattell (1886) presented arrays of letters to subjects for a very brief duration, 10 milliseconds. (Given that there exists a sensory memory of about 200 milliseconds, Cattell's subjects actually had about 210 milliseconds to process the displays.) He found that people could read about 3.5 unconnected letters under these conditions. Cattell then presented subjects with three-letter words for the same duration and found that they could read about two of them during this time span. This means that they could report the identity of the 6 letters that comprised the words even though they only had time to recognize 3.5 unrelated letters. Clearly, the words were not read by first identifying each of the letters.

Reicher (1969) presented brief displays of either a word (e.g., WORD), a non-word composed of the same letters (e.g., OWRD), or a single letter (e.g., D). After a brief presentation time of about 60 milliseconds, the stimulus was masked to erase the sensory memory, and the subjects were asked to choose which of two letters had been presented (e.g., D or K). Interestingly, the observers were more accurate when identifying the letter within a word (89%) than when it was presented in either a non-word (76%) or as a single letter (78%). A similar effect has been found where a word is more easily recognized when presented in the context of a sentence than when presented alone (Wheeler, 1970).

More generally, the average adult reads about 250 words per minute during normal reading, which corresponds to a reading rate of approximately four words per second (Crowder and Wagner, 1992). Thus, the average time to read a word is about 250 milliseconds. Given this rate and the assumption that the average word is about four to five letters long, the time to identify a letter is about 55 milliseconds. Under ideal laboratory conditions, skilled adult readers have been found to require about this amount of time to identify a letter (Sperling, 1960). Normal reading rates would be impossible if readers first had to recognize each letter since additional time would be required to determine the words, sentence structure, and meaning. Normal reading rates could not be achieved if letter and word recognition processes were independent.

The interactive model of reading was developed to account for such effects. Within this model, the visual system first extracts information about the features (lines, angles, curves, and so forth) that make up a letter. This information activates representations of those letters that could be composed by these features. In addition, words are activated by the activation of the letters that comprise them. However, before these processes reach completion, activation also flows in the opposite direction, from activated words to letter representations. Consider the partially obscured word that is presented in Figure 1 (adapted from McClelland, Rumelhart, and Hinton, 1988). The features that are visible for the final letter are consistent with either a K or an R. Since K is the only letter that allows the string to form a word, an interactive reading model will identify this letter as a K. In normal reading, it is assumed that similar processes take place. That is, the word, WORK, will become activated by the activation of its constituent letters and will, in turn, activate those letters. This reciprocal activation begins early in the reading process, prior to when all of the letters have been uniquely identified.

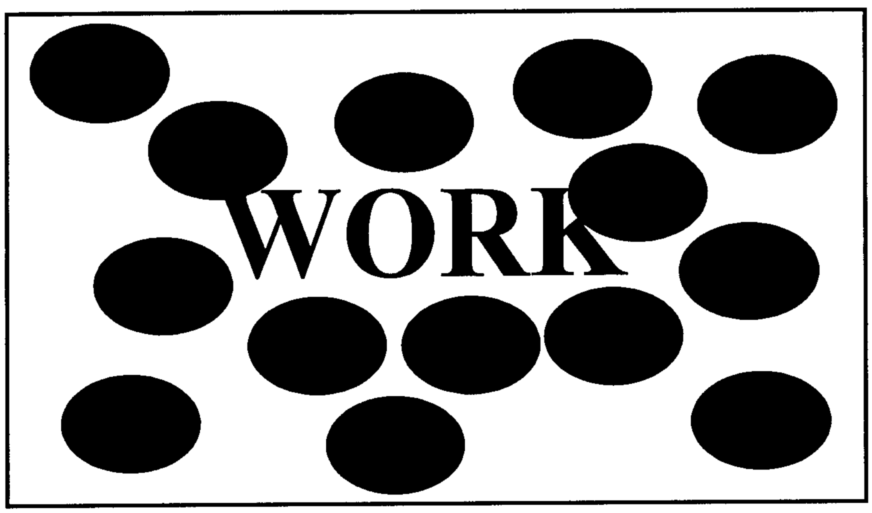

Figure 1. A partially obscured word. The final letter could be either a K or an R. K is chosen because it allows the four-letter string to comprise a word.

Such reciprocal activation is not limited to words and letters. Activating a word causes an activation of other words to which it is related. This is called semantic priming. In a typical experiment on this phenomenon, words (e.g., BREAD) and non-words (DRAEB) are presented and the subject's task is to indicate as quickly as possible whether the letter string is a word or not. The dependent measure is reaction time. If the word BREAD is followed by the word BUTTER on the next trial, then the time to indicate that BUTTER is a word will be significantly decreased relative to when it is preceded by an unrelated word. This is a general finding. Recognizing a word decreases the time required to process subsequent words to which it is related (Meyer, Schvaneveldt, and Ruddy, 1975). Other effects of this kind have been found involving syntax and context (Lesgold and Perfetti, 1981).

All of these reciprocal activation effects point to underlying mechanisms that have been trained through experience to exploit familiarity. Letters are easier to recognize when they are seen in a word because people are familiar with the word and know what letters comprise it. Moreover, the frequency with which a word appears in a language influences the time needed to read it; more frequently encountered words are easier to read (Sereno, Pacht, and Rayner, 1992). The rate and ease with which skilled readers read is based in large part upon their implicit appreciation for familiar patterns.

Mixed Versus Uppercase Letters

It is easier to read words presented with mixed or lowercase letters than with all capital letters (Healy and Cunningham, 1992; Reynolds, 1982). This is so for two reasons. First, readers normally encounter words in mixed or lowercase form, and thus, are most familiar with this style. Second, the ascenders (e.g., f) and descenders (e.g., y) in mixed and lowercase text allow readers to identify word shapes easily, which reduces the need to identify each letter. In Figure 2A,B, and C, the lowercase letters of the alphabet are organized into three groups: ascenders, compact, and descenders. In Figure 2D, a word shape is shown. It is quickly identified as the word *the* because *the* is the only word in the English language that has this shape and that is not a contraction. Familiarity is clearly at work here. In Figure 2E, the words *left* and *right* are shown as lowercase word shapes. Note how much more distinctive these shapes are than when the word shapes are shown for all capitals (Figure 2F). Finally, try to read the phrase shown in Figure 2G. Most people find this to be hard to do unless a context is provided such as the following: The phrase is the title of a book and a famous movie. This last example was provided to demonstrate how much information is in lowercase word shapes and also to emphasize the role of context and interactive processing in reading. In this last case, a knowledge of books and movies facilitated the recognition of the underspecified letters. (The title in Figure 2G is *gone with the wind.*)

Words presented in all capital letters appear as undifferentiated blocks and, thus, require additional processing. In fact, Healy and Cunningham showed that in a proofreading task, readers made fewer errors when the text was printed in mixed/lowercase than in all capitals. The only contexts in which all capital letters have been found to facilitate the processing of text is for familiar non-word strings, such as FBI and YMCA (Henderson, 1974), and when letters are presented in isolation (Kember and Varley, 1987).

Abbreviations

Abbreviations take between 800 to 1000 milliseconds to read (Rogers and Moeller, 1984). This is considerably slower than the 250 milliseconds per word rate of average reading.

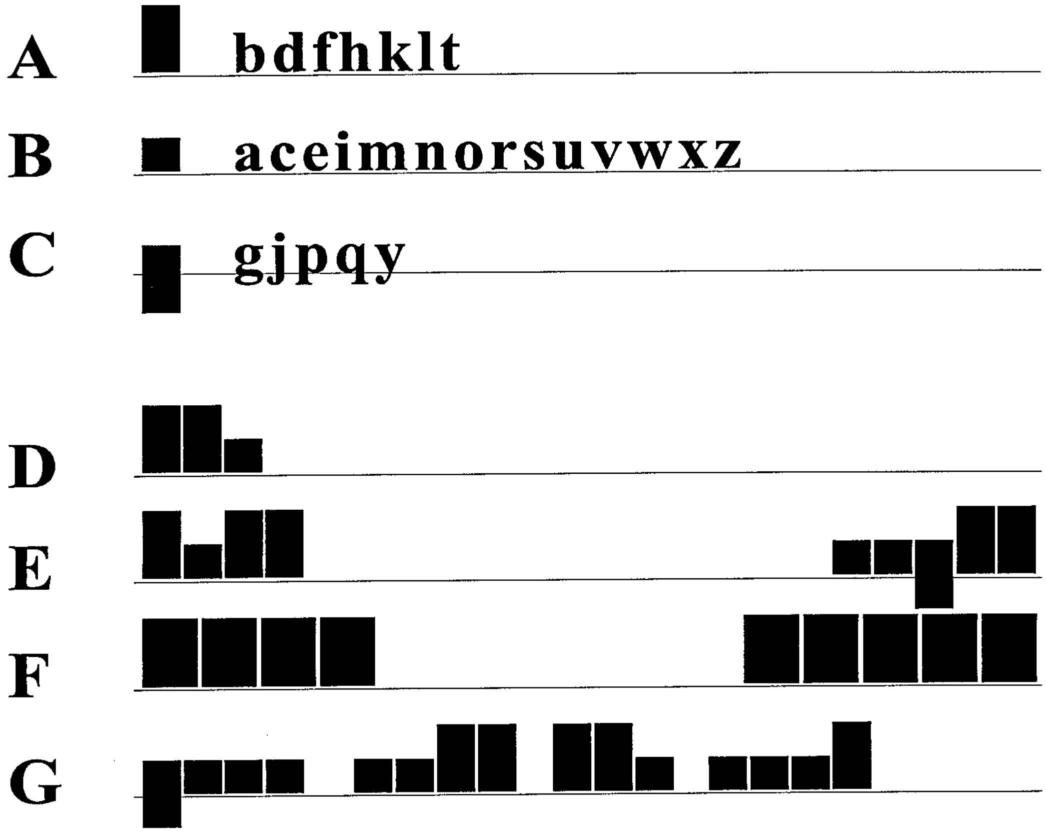

Figure 2. Panels A, B, and C depict the three shapes of lowercase letters. Panel D shows the lowercase word shape for *the*. Panels E and F show the word shapes for the words *left* and *right*, in lowercase and uppercase, respectively. Panel G shows the lowercase word shapes for a familiar phrase (see text).

Of course, abbreviations are used to shorten overly long words, so 250 milliseconds underestimates how long it would take to read the unabbreviated word. Be that as it may, abbreviations are clearly harder to read than non-abbreviated words of similar length.

Rogers and Moeller (1984) conducted a study comparing different abbreviation methods. Conventional methods of abbreviation are created by experts within a field and are based on the specific characteristics of each word (e.g., required = reqrd). Consequently, conventional abbreviations are sometimes equivalent to those created by other methods. Although such abbreviations are created by experts within a field, they are the result of subjective opinion and should be tested on the population to which they will be presented. Truncation methods of abbreviation cut the letters from the ends of words until the desired length is achieved (e.g., required = requi). Finally, contraction methods of abbreviation removes the vowels and the letters *h*, *w* and *y*, except for the first letter of a word and the first vowel. This is followed by simple truncation to achieve the desired word length (e.g., required = reqrd).

Sonar operators were asked to rate which method of abbreviation they preferred for various words. Truncated abbreviations were slightly more preferred than conventional abbreviations, with contraction abbreviations being the least preferred. In a second study investigating response time to decode words, only truncated and conventional abbreviations were used. When the participants were asked to identify the contracted words as quickly as possible, the error rates for conventional and truncated abbreviations were about equal. However, the response times were faster for truncated abbreviations. Further, the times to decode truncated abbreviations became faster with increasing trials, whereas the time to decode conventional abbreviations did not change significantly.

Implications

1. *If VMS messages are to be optimally effective, then they must maximize the familiarity of their content.* Reading is an interactive process in which high reading rates are afforded by the readers' familiarity with the words, phrases, and sentences that are presented.

2. *Familiarity would be promoted by standardization.* The same words, phrases, and sentences should be used to describe equivalent situations.

3. *Mixed case letters are preferable to all capitals.* Current flip-disk VMSs cannot display lowercase letters without an unacceptable reduction in the distance at which they are legible (Miller, Smith, Newman, and Demetsky, 1995). Although the use of mixed case letters will probably have to wait until VMS technology improves, administrators should take into consideration the potential of displaying mixed case text in selecting future VMS systems.

4. *Abbreviations should be avoided.* If it is deemed desirable to use an abbreviation—for example, because it allows a message to be presented on one VMS instead of two—then truncated abbreviations are preferable to those created by conventional and contraction methods.

Warning Signs

People respond differently to warning signs depending upon such factors as how familiar they are with the particular area and whether they construe the warning to signal a serious danger.

How People Respond to Warning Signs

When a driver encounters a VMS, its message must be attended to and comprehended, the information must be remembered until it is relevant, and the driver must be given enough time to prepare and execute the actions that are to be performed. There are many factors that contribute to the successful execution of these actions (Lehto and Papastavrou, 1993; Racicot and Wogalter, 1995).

In an extensive review of warning research, Lehto and Papastavrou (1993) stated that people's response to warning signs differs depending upon whether their response is skill based, rule based, knowledge based, or judgment based. Skill-based behaviors are well-learned, automatic actions as opposed to actions that are based upon conscious decisions. Skill-based behaviors promote fast and facile driving performance; however, they can cause a driver to overlook warning signs. For drivers who are familiar with a particular road, driving becomes a well-learned and practiced routine. As a result, they may not notice a new sign because, in general, they are not paying much attention to signs. In order to capture the attention of such drivers, a new sign needs to be more conspicuous (e.g., a flashing light on top of the sign).

When a VMS is introduced into an area, it is likely to be noticed by those who frequently drive past its location. However, if its message remains unchanged for some period of time, then it is likely that frequent commuters will fail to notice a change in the message should it occur. The sign needs to be made more conspicuous if it is to be noticed by these drivers. Once noticed, drivers' behavior becomes rule based.

Rule-based behavior is characterized as "reading to do" (Lehto and Papastavrou, 1993, p. 586). Because many drivers are trying to get from point A to point B in the least amount of time and with the fewest distractions, there is a likelihood that they will not read signs. Although these drivers may notice signs, they are more likely to read them if they require little effort. Brief text or symbol displays that are familiar and can be perceived and comprehended in a glance will be most effective for people who are in the "reading to do" state. In addition to being brief, warnings may be most effective when they state explicit actions instead of consequences or specific conditions. For example, it is often more effective to tell drivers to "Merge Left" rather than "Road Work Ahead . . . Merge Left." If orange cones and construction equipment are visible, then it is likely that drivers are aware that roadwork is being conducted. The function of the sign should be to inform drivers about how to change their actions, not to inform them about conditions about which they are already aware (Sanders and McCormick, 1987).

In contrast to rule-based behavior, knowledge-based behavior is described as "reading to learn" (Lehto and Papastavrou, 1993, p. 587). Drivers who engage in this sort of processing are unfamiliar with the particular setting. Such drivers actively seek out information. They are more likely to notice and read signs than someone familiar with the same area. For such a driver, it is important that signs be unambiguous. As discussed with rule-based behavior, an explicit, concrete message is better understood than a vague, abstract one. For example, "Icy road ahead!" is more concrete than "Dangerous road conditions ahead!"

The final influence on people's response to warning signs is their affective or emotional response to the situation. Being highly aroused leads to judgment-based behavior (Lehto and Papastavrou, 1993). People are more likely to comply with a warning sign's directive if they perceive there to be an immediate danger in failing to do so. The more hazardous a situation is perceived to be, the more likely it is that an affective reaction will be evoked. This arousal is a motivating factor in people's decision to follow a sign's directive.

Factors That Influence the Effectiveness of Signs

Overall, the research on perceiving traffic signs has indicated that symbolic signs are recognized better, more quickly, and from greater distances than are corresponding verbal signs, especially under degraded conditions (e.g., Childers, Heckler, and Houston, 1986; Edell and Staelin, 1983; Ells and Dewar, 1979; King, 1975; Kline and Fuchs, 1993; Kline, Ghali, Kline, and Brown, 1990). The following studies provide strong support for this conclusion.

Ells and Dewar (1979) investigated the rapid comprehension of verbal and symbolic traffic signs, in normal and degraded conditions. In all conditions, subjects were tested in a dark vision tunnel in which verbal and symbolic traffic signs were presented as slides on a projection screen at 0.57 degrees of visual angle. This visual angle was chosen because it corresponds to a regulation traffic sign presented at 59 m, which is the stopping distance required for the average car traveling 80 km/h. In the degraded conditions, the observers viewed the signs through non-corrective, uncolored glass lenses with plastic film over them. A combination of warning and regulatory signs were presented to the observers. Warning signs were diamond-shaped and yellow, with black text, and regulatory signs were rectangular-shaped and white, with black text. An example of a warning sign that was used is a "Winding Road" warning, and an example of a regulatory sign that was used is a "No U Turn" sign. Before presenting each slide, an experimenter read aloud a traffic message. A slide was then presented and the observer was asked to respond "yes" or "no" as to whether the symbolic or verbal sign corresponded to the message which was read aloud. The results showed that observers responded more quickly to symbolic than to verbal signs in both normal and degraded viewing conditions.

More recent research has shown that symbolic traffic signs are more visible and allow a greater response time than their verbal counterparts (Kline and Fuchs, 1993; Kline et al., 1990). Kline et al. evaluated the smallest size at which observers could identify black and white traffic signs in simulated daylight (65 cd/m^2) and dusk (10.5 cd/m^2) conditions. When identifying the signs, the observers were asked to describe the meaning of each sign as they would to someone that could not see it. Although presented in black and white, all of the signs were obtained from the U.S. Department of Transportation (1988). The minimum visibility height (cm) of each sign was recorded for each observer.

The average height at which the symbolic signs could be clearly identified was smaller than the average height for verbal signs in both daylight (3.87 cm vs. 7.32 cm) and dusk conditions (5.13 cm vs. 10.38 cm). An important aspect of these data was that the symbolic signs in the dusk conditions were identified at smaller presentation heights than were verbal signs in the daylight condition.

From the minimum visibility heights, Kline et al. (1990) calculated the corresponding distance threshold for these signs. When the visibility distances were calculated, the results showed that the symbolic signs were visible from almost twice as far as corresponding verbal signs in both daylight (150 m vs. 80 m) and dusk (110 m vs. 55 m) conditions. Furthermore, symbolic signs presented in the dusk condition were identified from 30 m farther away than the verbal signs presented in the daylight conditions. It is clear that using symbolic signs has a general advantage over using verbal signs.

Kline and Fuchs (1993) replicated these results with the same signs but presented in color. They found the same advantages for symbolic signs, and these advantages were even increased when the contour size and contour separation of the symbolic signs were maximized. Not only can symbolic signs be identified from longer distances than can verbal signs, but symbolic signs can be identified more accurately than verbal signs when presented at very short durations. Specifically, King (1975) showed that symbolic traffic signs were more accurately reported when presented tachistoscopically at 1/18 sec than were verbal signs, but that no difference in accuracy was found at 1/3 sec.

European road signs follow international traffic sign standards that were adopted by most continental nations in 1934/1935. Almost all of the signs are symbolic rather than verbal. The preference for symbolic signs is due in part to the diversity of languages spoken by European drivers. These signs can be viewed on the worldwide web: http://www.travlang.com/signs.

In conclusion, studies have shown that symbolic traffic signs are recognized more quickly, and from greater distances, than are corresponding verbal traffic signs, especially under degraded conditions. However, it should be noted that the intended meaning of symbolic signs is not always comprehended as well as that of verbal signs. Whereas literate drivers can usually comprehend a novel message conveyed by a verbal sign, they may only correctly comprehend about 70% of novel symbolic signs (e.g., Kline et al., 1990). In order to take advantage of the benefits of symbolic traffic signs, it is necessary to survey the comprehensibility of current and new symbolic signs and to educate drivers about their meanings. Moreover, because approximately one-fifth of American adults are functionally illiterate or weak readers (Kirsch et al., 1993) the importance of using symbolic traffic signs is further underscored. However, if verbal signs are used, careful consideration should be given to their text size.

The character size required to read single words or short messages is smaller than that needed to read longer ones. Staplin, Lococo, Sim, and Drapcho (1987) showed observers simulated regulatory, warning, and guide signs and asked them to report when they could detect any of the words in the message and then when they could detect the entire message. Regulatory signs displayed black text on a white background, warning signs displayed text on a yellow background, and guide signs displayed white text on a green background. The results showed that the character size (subtended minutes of visual angle, $\underline{M}$) necessary to detect an entire four to six word message was larger ($\underline{M} = 2.17$) than the character size necessary to detect a single word or only a part of the message ($\underline{M} = 1.47$). Also, elderly observers (ages 65 to 80 years) required significantly larger character sizes than young and middle-aged observers (ages 18 to 49 years) for detecting both the entire message ($\underline{M} = 3.02$) and a single word ($\underline{M} = 2.06$).

In addition, research has shown that commonly used signal words, such as DANGER, WARNING, and CAUTION, may not be interpreted as intended by the guidelines recommending their use (Lehto and Papastavrou, 1993; Wogalter and Silver, 1990). In addition, Ursic (1984) found that people's performance was unaffected when warning signs were prefaced by a signal word versus when they were not. Thus, it may be better to state a message immediately rather than prefacing it with an ambiguous signal word. Doing so is likely to save time and prevent confusion.

Implications

1. *VMSs must be distinctive if they are to attract the attention of commuters familiar with their site.* If the message on a VMS is changed without changing the sign's location, then many commuters will fail to read it unless the sign has consistently displayed changing useful information.

2. *VMS messages should be short and concise.* Whether a person is familiar or unfamiliar with a roadway, they will benefit most from messages that are unambiguous and that can be read quickly. Short messages can be read at a smaller size and/or greater distance.

3. *Symbolic messages are more effective than verbal ones.* They can be comprehended at a smaller size, a greater distance, and at shorter exposure durations.

4. *Motorists must be familiar with the meaning of symbolic messages.* Novel symbolic signs may be harder to comprehend than verbal messages.

5. *Signal words, such as CAUTION, are not effective.* People's behavior has not been shown to be influenced by signal words.

Placement of VMS Signs

It has been claimed that VMSs have an "unreadable distance" that corresponds to the distance at which the sign's angular displacement from the road's centerline becomes greater than 10 degrees (Dudek, 1991; King, 1970). This claim has not be empirically tested in any way but rather has been based solely on the notion that 10 degrees defines the drivers central vision and that any verbal message that falls outside of this range would be difficult to read. This would be true if drivers always looked straight ahead while they drove but, of course, this is not the case.

To get an idea of the extent of a 10 degree visual angle, fully extend your arm and look at your fist. The size of your fist will be about 10 degrees of visual angle. The interior rearview mirror is displaced by about 30 degrees relative to the straight ahead and drivers glance at it every few seconds.

Thus, the angle at which a VMS becomes unreadable is greatly underestimated by the 10 degree prescription. So long as a VMS is not obscured, drivers intent on reading its message will look at angles approaching 90 degrees.

On the other hand, there is an issue as to what is the optimal orientation of VMSs with respect to the road. The optimal viewing orientation for a sign is perpendicular to the line of sight. Since VMSs are oriented perpendicular to the road, they are at the optimal orientation only when the driver is infinitely far away, given a straight road. A more optimal orientation would be for the VMS to be rotated slightly toward the road.

To see why this is so, look at Figure 3. Panel A of the figure depicts a driver at some distance from a VMS. q is the angle between the driver's line of sight and the surface normal to the middle of the sign. The ideal angle would be 0 degrees; that is, ideally the sign would be perpendicular to the line of sight. However, for a straight road, this angle is realized only at an infinite distance. If we take 10 degrees to be the maximum angle at which the sign is readable (Dudek, 1991; King, 1970), then at this angle the sign is rotated 10 degrees away from the line of sight. Thus, the sign is never at an ideal viewing angle. At infinity it is normal to the line of sight but too far away to be read. As the driver approaches the VMS, the sign rotates away from the line of sight.

Figure 3B shows a VMS that has been rotated slightly to face the road. Again, if we take 10 degrees to be the maximum readable distance, then rotating the VMS by 5 degrees would cause its orientation with respect to the line of sight to deviate by no more than ±5 degrees over the readable distance. If as suggested above, the readable distance is not constrained by the 10-degree value, then the VMS should be rotated by a larger value. A 20-degree readability distance would argue for a 10-degree rotation of the VMS toward the road so that the maximum deviation of the line of sight to the sign was ±10 degrees.

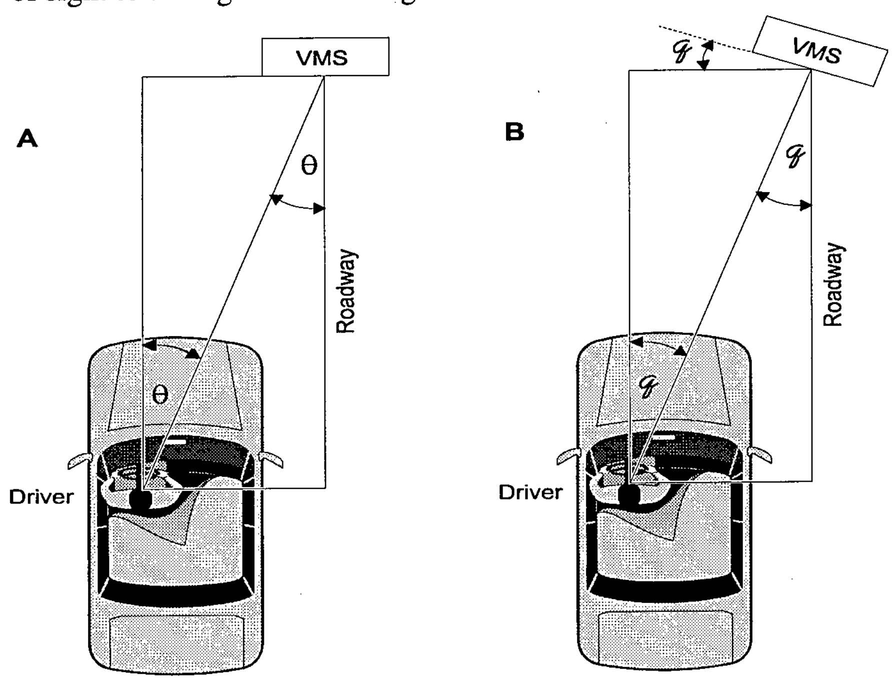

Figure 3. Panel B depicts a driver who is displaced by being angled from a VMS. Note that by the law of similar triangles, the sign is oriented away from the driver's line of sight by angle q. Panel B shows a VMS that has been rotated toward the road by a magnitude equivalent to the driver angular displacement from the sign. The sign is now at the ideal reading orientation, 90 degrees.

Implication

It may be desirable to rotate portable VMSs slightly by 5 to 10 degrees to face the road. This will increase the amount of time that they are at an optimal reading angle. This implication is based solely upon geometry. There is no research on how drivers spontaneously read VMSs that would allow a specification of the range of viewer-relative angles over which they are read. In addition, there are issues such as headlight glare that need to be taken into account.

CONCLUSIONS

Literacy

About 25% of Virginians age 16 and older are not skilled readers. These individuals have difficulty deciphering words, are slow readers, and are especially troubled by degraded or difficult to read text. In addition, these reading difficulties place greater demands upon their memory. All of these factors imply that these individuals are likely to encounter difficulties with novel VMS messages. Providing familiar standardized messages and employing symbols will help these low skill readers. Short messages that minimize memory requirements will also be helpful.

How People Read

Reading is an interactive process that derives much of its speed and accuracy from implicit knowledge acquired through familiarity. VMS effectiveness will be enhanced if drivers are familiar with their content. This argues strongly for standardization. The same verbal messages and symbols should be used to describe equivalent situations. In general, mixed case letters are preferable to all capitals and abbreviations should be avoided.

Warning Signs

In addition to being easier to read, short, concise messages are more likely to be read. Symbolic messages are more effective than verbal ones. They can be comprehended at a smaller size, at a greater distance, and at shorter exposure durations. Novel symbolic messages need to be assessed for their comprehensibility and some instruction may be required at their introduction. Signal words, such as CAUTION, are not effective.

Placement of VMS Signs

People will persist in attempting to read a VMS even after it becomes displaced by more than 10 degrees relative to the straight ahead. VMSs would be easier to read if they were rotated slightly to face the road so long as this does not introduce salient headlight glare.

LESSONS LEARNED AND FUTURE RESEARCH NEEDS

From this literature review, four key lessons and four broad areas for further research are evident.

Lessons Learned

1. *As many as a quarter of Virginians have low reading skills.* Using familiar words and phrases will improve reading time and comprehension for these persons. Since familiarity comes from exposure, the more often persons with low reading skills see the same words and phrases used in messages, the more likely they are to recognize the message quickly.

2. *Using words within a message that have the opposite meaning should be avoided.* For example, RIGHT LANE CLOSED-MERGE LEFT.

3. *Messages should be short and concise.* Signal words such as CAUTION should not be used. Descriptions of the conditions that motivate a warning or imperative, such as the presence of construction, should be minimized, especially if the driver can ascertain the conditions by other means.

4. *Administrators may desire to influence the capabilities of future VMSs.* Current limitations of VMSs adversely affect the presentation of symbols, mixed case fonts, and in the case of portable VMSs, phrases that do not fit conveniently within the normal 3 line 8 character per line message screen. Administrators may find, for example, that a slightly larger number of characters per line yields a tremendous increase in the flexibility of messages that can be accommodated by the VMS. Such a need can be identified by recording situations where VMS limitations prevented the dissemination of more effective messages.

Future Research Needs

1. *Standardization for commonly occurring situations.* As has been done in *the Virginia Work Area Protection Manual,* there may be some benefit to identifying situations that occur frequently and developing standard practices to address these situations. Such standardization would be affected not only by the VMS message purpose but by the layout of the relevant roadway elements such as intersections and interchanges, static sign convention,

visual cues, distance from the VMS to these features, and placement of the VMS. Application of the VMS within a system of roadway elements, rather than as an isolated text message medium, would thus need to be examined. It is possible that the Statewide Incident Management Committee may pursue this recommendation in conjunction with their plan to record VMS messages that are used in various situations.

2. *Symbols and abbreviations.* Symbols can have the potential for easy recognition, depending on motorist familiarity and the capabilities of the VMS. Yet symbols can also be confusing if they are not well recognized or if public education efforts have been inadequate. Similarly, the utility of abbreviations depends on their recognition, as well as their visibility. Knowledge of which abbreviations, and in the future which symbols, to use could be helpful in key situations. To indicate a left lane closure using a single line from an eight character VMS, for example, the question of "LEFT LN" versus "LFT LANE" could be addressed. It is suggested in a previous 1995 VTRC report (*Development of Manuals for the Effective Use of Variable Message Signs*) that research on the comprehension of abbreviations for VMSs was last conducted in 1981. In brief, therefore, symbols and abbreviations would each need to be examined in the areas of legibility and recognition.

3. *Mixed case legibility.* Mixed case messages may be easier to read but their legibility compared to uppercase messages needs to be considered. As VMS technology improves, field tests should be used to resolve this issue.

4. *Angling the VMS.* The MUTCD advises angling the VMS away from the roadway to reduce headlight glare, yet angling the VMS toward the roadway could be desirable for increasing readability. This last position depends on a host of factors, including the motorists field of view and assumptions about how willing the motorist is to turn their head. Theoretical research based on geometry and practical field tests with motorists is relevant.

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