

A Computer-Based Methodology for Evaluating the Content of Variable Message Signage

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Successful communication of traffic information to motorists via intelligent transportation systems (ITS) is critical for improved safety and traffic flow in high risk areas such as work zones. The conveyance of pertinent, real-time information through variable message signs (VMS) technology is integral to ITS. The content of messages presented on VMS is especially important given that drivers must detect, comprehend, and translate signage information while being occupied to some degree with the task of driving their vehicle. A simulation experiment was conducted, using a prototype dual-task methodology developed to examine message content of VMS in work zones and to assess the effect of message type, display type, sign content, and repeated exposure to the signs on message comprehension and translation. Twenty participants (mean age = 25 yrs) viewed a computer simulation of a section of road leading to a work zone site that had VMS along the road side. Signs were of two message types (speed vs. time signs), three display types (two inexpensive; one with full text wrap-around and one with partial wrap-around; and one expensive matrix of three lines by eight characters flashed twice), two similar message versions, and a complete repeat for reliability in a $2 \times 3 \times 2 \times 2$ repeated measures design. The primary task required attending to a grid line in the rearview mirror and remembering which signal had appeared. The concurrent, secondary task was reading the message content of VMS that were optically expanding at a rate comparable to traveling at 111 kilometers/hour (70 mph). Questions regarding the grid line signal and sign comprehension and interpretation followed. The results support this methodology's capacity to evaluate message content of VMS, especially in an ITS context. Message type significantly affected comprehension of sign content and translation of the consequences of the information conveyed, but display type did not influence responses to time or speed signs. This suggests a potential for substantial savings from the increased use of inexpensive displays instead of full-matrix units. Future research should involve assessment of the validity of the computer simulation, in addition to testing behavioral responses to message content either with a follow-up on-road and/or driving simulation study.

Keywords: intelligent transportation systems; variable (changeable) message signs; message content; work zone safety; mental workload; visual perception

INTRODUCTION

Traditional highway signage is relatively consistent and unchanging over time. The message is displayed in such a fashion that passing drivers are able to comprehend content and act appropriately. Unfortunately, the driving environment is not static and changes can take place over several temporal ranges — years, months, days, and even moments. Traditional, static signage is able to convey information for the longer ranges, but cannot reflect the daily or hourly changes in conditions. This situation is insufficiently flexible for future highways as envisaged under intelligent transportation systems (ITS). In response to these concerns, a number of different strategies have been proposed for more dynamic information presentation, including in-vehicle information services. However, one problem with such innovations pertains to drivers not equipped with such capabilities. An intermediate proposition is to develop driver information signs that can vary their content in real time in response to local conditions and changes. These are commonly known as variable message signs (VMS) or changeable message signs (CMS). Nowhere is such capability needed more than in work zones where operational conditions frequently change on a daily basis and can even alter according to momentary requirements. The goal of the present experiment was to examine the message content of proposed VMS intended for a work zone and to develop a computer based, dual-task methodology, replete with controlled exposure times, optically expanding VMS, and the capability of manipulating the difficulty levels of the primary task (driving) in order to assess the appropriateness of VMS content.

MAIN TEXT

Background

Highway work zone-related fatalities in the United States increased from 489 to 782 (60%) between 1982 and 1989 (Mervin, 1991). Future increase in traffic volume requires even more road construction with attendant dangers of increased fatalities, thus necessitating measures for increased safety. While many issues must be considered for improving safety in work zones, successful communication of traffic signs to motorists is critical. For this reason, in recent years, there has been a rapid development of advanced traffic management systems. In the United States, for example, Information for Motorists (INFORM) has been created to improve throughput along a highway corridor in New York. Variable (changeable) message signs (VMS) provide traffic congestion and transit delay information that allow drivers to make appropriate

route diversions and other navigational decisions (Smith, 1992). This signage system is also capable of delivering congestion warnings and speed advisories (Bolte, 1984). In Germany the Aichelberg Congestion Warning System was designed to optimize flow of traffic and reduce the number of rear-end collisions. Regardless of the type of traffic management systems, certain fundamental human factors issues must be addressed, *i.e.*, readability, comprehension, interpretation, and work load.

One common element of these systems is a reliance on the technology of programmable and fixed-bar VMS. Variable message signage is an improvement over conventional static road signs, especially because of its capability of providing real-time traffic information for regulations, diversions, and traffic state descriptors for any type of road. The freedom to express more informative messages is, however, constrained by the limitations of the human information processing system and possible interpretations of sign meaning. Thus, an abundance of human factors questions must be addressed when designing the message content for VMS systems (Dudek, 1978, 1979, 1984, 1991, 1992). To maximize the effectiveness of these signs in modifying drivers' behavior, optimal message content and wording must be identified. Given the limited length and duration of most displays, including signage and in-vehicle equipment, messages must nearly always be abbreviated or truncated. While the designers of these messages understand their notation, the messages are not always understood as intended by the drivers. Current message design is primarily based not on human factors or text comprehension principles, but solely on the programmer's opinion of what should work. Variable message signs can be used to provide pertinent real-time information. However, the choice of message should be empirically demonstrated as appropriate, given that drivers must detect, comprehend, and translate signage information while being occupied to some degree with the primary task of controlling the vehicle.

Optimizing throughput of traffic in a work zone, through the implementation of an ITS employing VMS, may be a starting point in the reduction of the hazards for both the motorists and construction workers in work areas. This may be accomplished with signage that successfully re-routes traffic before the work zone, in addition to reducing the speed and variability of traffic entering into the work zone. Acquisition and processing of traffic information, such as congestion and traffic speeds, via sensors and computers, is integral to any ITS. Equally important is research addressing human factors issues regarding message content of two types of VMS to be implemented in the work zone. The first VMS can be placed before the work zone and the final point of diversion. Its contents provide sufficient information for the driver to make a decision whether

of not to divert and thus avoid the work zone. The second VMS can be placed immediately before the work zone. It functions to reduce the speed and variability of traffic entering into the work zone. Note that while this study is concerned with comprehension and interpretation of message content of VMS, research suggests that VMS content does influence driving behavior (Alm & Nilsson, 1995), therefore, relevant research will be referenced in this review of the background literature.

Arguably, when motorists approach a traffic incident, such as road construction, they are most concerned with the immediate effects on their travel time. They need to know whether diversion from the incident is most prudent. How then should this information be presented? Should time be expressed in terms of delay, added travel time, extra travel time, or total travel time? While some messages may prove ambiguous in interpretation, still others require additional mental calculations; neither of these are conducive for effective communication of information.

Travel time is problematic because it can be easily discredited and motorists must mentally calculate additional travel time (Dudek, 1992). Huchingson and Dudek (1979) addressed interpretation of the sign 'DELAY X MINUTES'. The most popular interpretation expressed delay as extra travel time relative to normal travel time. Heathington, Worrall, and Hof (1970) studied motorist preference for traffic descriptors for levels of traffic congestion. 'EXTRA DELAY-10 TO 20 MINUTES/NEXT 3 MILES' (ranked 5th) and 'TRAVEL TIME 15-25 MINUTES/NEXT 3 MILES', (ranked 6th) were least preferred as descriptors for heavy congestion. Similarly, Beers (1974) found delay time ranked 4th and travel time 6th in a list of preferred traffic descriptors. These incident descriptors were outranked by information such as cause of congestion, traffic speed, or lane closure; information that most likely would be included in most intelligent work zone systems, in addition to delay or travel time information. Emerging from these two studies is a preference for delay information over travel time. The results of a driver simulation study suggest that drivers' diversion behavior varies in response to changing message content of VMS presenting traffic descriptors (Janssen & van der Horst, 1993). More specifically, participants' willingness to divert varied as a function of the traffic descriptors (delay *vs.* travel time *vs.* length of congestion) of the VMS, the reliability of the descriptor information (high *vs.* medium *vs.* low), and the content of the information.

Delay information may be considered unambiguous and more useful relative to travel time information. It should be noted, however, that travel time, in these contexts, refers to the total amount of time to traverse the work zone. It may prove beneficial to express travel time in terms of additional or extra time to travel through the work zone.

Traffic speed signs pose a variety of human factors questions for any intelligent highway system. Should these signs be speed advisories or real-time updates of traffic speed at various points in the work zone? Once this issue has been settled, a consensus of appropriate verbiage must be achieved. Numerous articles have employed or made reference to the message content of speed signs. Most, however, have looked at driving behavior measures without directly examining sign comprehension or the relationship between sign comprehension and driving behavior. Examples of the content of some speed signs include 'Max SPEED 45 MPH' and 'SLOW TO 45 MPH' (Hanscom, 1982) or 'MAINTAIN 15 IN FOG' (Wagner, 1978) or 'SLOW DOWN X' (Helliars-Symons & Wheeler, 1984). Richards, Wunderlich, Dudek, and Brackett (1985) and Richards and Dudek (1986) explored the effectiveness of four different types of speed controls in the work zone: flagging, law enforcement, variable message signs, and lane width reduction. The VMS were divided into two categories, those with wording such as 'DETOUR AHEAD' or 'ROAD WORK AHEAD' plus a speed advisory such as '35 MPH' or 'SLOW 45 MPH' and those VMS that contained speed advisory only. The VMS, however, produced only 'modest' speed reduction at urban arterial and freeway sites. Brannen (1990) manipulated the content of speed signs. Speed advisory signs that read 'IT'S THE LAW SPEED LIMIT 40 PAST CREW' in addition to 'WORK ZONE SPEED LIMIT', resulted in greatest reduction of speed and variability of traffic speeds before the work zone.

Significant speed reductions have occurred at the entrance of a work zone when a speed monitoring display, coupled with radar, displayed both the work zone speed and the speed of a given car entering the work zone (McCoy, Bonneson, & Kollbaum, 1995). Radar has also been employed to trigger a warning message on VMS when a motorist's speed is in excess of the traffic speed of the work zone (Garber & Patel, 1995). In this experiment, messages on VMS included 'HIGH SPEED SLOW DOWN', and 'REDUCE SPEED IN WORK ZONE'. These signs proved most effective in reducing traffic speeds in a work zone.

From reviewing the literature it is apparent that more experimental manipulation of message content of a variety of speed advisory signs and incident descriptor signs is greatly needed in addition to the design and implementation of more valid testing procedures. This requires testing the content of VMS in a context similar to the one in which they will be experienced on the road. Such a context would include all other signs, both VMS and static, to be used in the ITS, and an environment replete with optically expanding signs, controlled exposure rates, simulated travel, and secondary tasks for division of attention. Some examples of secondary tasks which have

been implemented in studies of driving behavior are reading and repeating random digits located on a dashboard display (Wierwille, Gutmann, Hicks, & Muto, 1977; Wierwille & Gutmann, 1978), detecting changes in consecutive 8-digit numbers (Brown, 1962), detecting an odd-even-odd sequence in an audibly-presented succession of numbers (Brown, 1965), and listening to 10 letters and remembering which letter was repeated twice (Brown, 1965). This study used a primary task that was somewhat analogous to monitoring traffic in a rearview mirror, a more natural source of divided attention during driving. Finally, any analysis of message comprehension should extend beyond reader preference and interpretation and include integration of the information with the goal of determining the effect it will have on the motorist's specific driving situations.

Method

Participants

Twenty participants (10 males and 10 females) were recruited from a sign-up sheet in the Psychology Department at the University of Minnesota. Average ages for males, females, and both were 25.4, 24.6, and 25.0 years, respectively. Average numbers of years driving with a license for males, females, and both were 9.3, 7.3, and 8.3, respectively. The self-reported, noncorrected and corrected (for the experiment) vision and the number of participants were as follows: 20/15 (1), 20/16 (1), 20/20 (13), and 20/50 (1). Four participants did not supply specific vision information, however, none of the participants stated any difficulties reading the signs on a 50 centimeter (20 inch) monitor, which was approximately 50 centimeters (20 inches) from their observation point. Participants were paid \$5.00 for their time.

Overview of Tasks

The participants viewed a computer simulation of travel down a section of road leading up to, but not including, a work zone (see Figure 1). On the side of the road was a series of optically expanding static signs and VMS. The primary task required attending to a grid line in the rearview mirror and remembering which signal had appeared. The concurrent, secondary task was reading the message content of the VMS. Questions regarding the grid line signal and sign comprehension and interpretation followed the passage of each VMS. This sequence of tasks was then repeated.

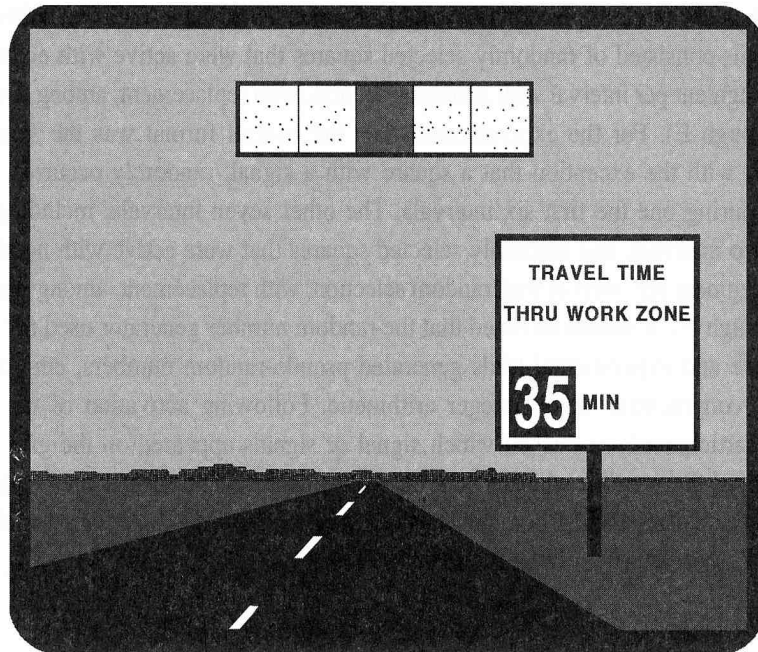


FIGURE 1 Sample of optically expanding 111 kilometer/hour (70 mph) hybrid variable message sign on the right of the roadway with a rear-view mirror grid line primary task.

Primary Task

Presented to the driver, in the location of the in-car center rear-view mirror, was a grid line that was divided into five, adjacent, white squares. Each square was either inactive, active, or active with a signal. When a square was inactive, it consisted of a single, white square. When the square was active, the white square was switched to a yellow square. When the square was active with a signal, the white square was replaced with a yellow square with a signal inside. The signal consisted of a black letter (either A, B, C, D, or E, depending on which of the five squares in the grid line was active). In order to group the squares of the grid line, a rearview mirror shaped box enclosed the entire grid line. This box was not significantly larger than the grid line it enclosed. A single, practice trial preceded the experimental trials. For the practice trial, during the eight seconds the letters on the VMS were visible on the opposite side of the road, one of the five squares in the grid line became either active, or active with a signal, in a random manner at a rate of one square per second (*i.e.*, exposure time = one second; inter-exposure interval = 0 second). In other words, the period over which the grid line was active consisted of eight, one second intervals. During two, randomly selected intervals throughout this period, two squares were active with their respective signals (one segment per interval with random

selection, without replacement, among squares A through E). The other six intervals consisted of randomly selected squares that were active with no signal (one segment per interval with random selection, with replacement, among squares A through E). For the experimental trials the overall format was the same as above, with the exception that a square with a signal, randomly occurred only once during one the first six intervals. The other seven intervals, including the last two intervals, had randomly selected squares that were active with no signal (one segment per interval with random selection, with replacement, among squares A through E). It should be noted that the random number generator used for both practice and experimental trials generated pseudo-random numbers, employing linear congruential 48 bit integer arithmetic. Following activation of the grid line, participants were asked which signal or signals appeared on the grid line. They had six possible choices (one of which never occurred and thus acted as an additional foil) and filled their answers out on multiple choice answer sheet, later to be read by an optical character reader.

Secondary Task

A Silicon Graphics IRIS-class mini-computer and a 50 centimeter (20 inch) SVGA monitor were used to simulate travel along a section of road leading to, but not including, a work zone (frame speed ≥ 20 frames/second). Static and variable message signs, which occupied the right side of the road, were produced on Designer's Workbench. This allowed continuous expansion of the visual angle of the sign to be correlated with simulated forward movement. This, coupled with a fixed distance between the participant and the monitor, resulted in constant optical expansion of VMS, both within and between subjects. A display time of eight seconds was chosen as a maximum readability time for the VMS, because the average VMS used by the Minnesota Department of Transportation (MNDOT) has 40 centimeter (16 inch) letters, with a readability rate of 6.1 meter/cm (50 feet/inch). It was expected that traffic should be able to read and comprehend signs when traveling at 111 kilometers/hour (70 miles/hour). Hence, readability time was approximately eight seconds. Questions preceding VMS were used to assess comprehension and interpretation of message content. In response to time signs, participants were asked to determine how late they would be for work. Answers were in multiple choice format, with nine time choices ranging from 5–50 minutes, incremented with five minute intervals. In response to speed signs, participants were asked to determine what type of sign it was. Answers, once again, were in multiple choice format with three possible responses, namely, that the sign was regulatory, advisor, or an update of speed of traffic ahead.

Miscellaneous

An auditory signal warned participants of the continuation of each driving sequence. A digital heads-up speedometer display appeared in the lower left corner of the monitor and always read 60 MPH. This value was chosen, despite above calculations of readability at 111 kilometers/hour (70 miles/hour), so mental calculations of time to get through the work zone could be easily calculated.

Design

Time Signs

This experiment employed two $2 \times 3 \times 2 \times 2$ repeated measures ANOVA designs with 24 conditions: one for time signs and one for speed signs. Time signs were either transit or delay signs. Transit signs described the total travel time through the work zone. Delay signs described the additional time required to travel through the work zone. The two types of time signs were then presented with three types of variable message signs: wrap-around black lettering (against white background) with green variable numeric digits (against black background) in the center of the signs (display type 1); nonwrap-around with black lettering (against white background) preceding green numeric digits (against black background) in the lower left portion of the sign (display type 2); sequential with all green lettering: two sequences with a sequencing rate of two seconds/sequence, three lines per sequence, and a maximum of eight characters per line (display type 3). Each of the three display types for both transit and delay signs was further divided into two choices or examples. Each example was further divided into one of two times. Trial 1 was the first time the sign was seen by the participant. Trial 2 was the second time the sign was seen by the participant. Thus 12 time signs were presented twice for a total of 24 cells (see Table I and Appendix A).

TABLE I Time sign design: note (D)isplay, (C)hoice, (T)rial (Wagner *et al.*)

Type	TIME SIGN											
	Transit						Delay					
	D1		D2		D3		D1		D2		D3	
Display	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2
Choice	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2
Trial	T	T	T	T	T	T	T	T	T	T	T	T
	1	2	1	2	1	2	1	2	1	2	1	2

Speed Signs

Speed signs were of two types: personal or ahead signs. Personal signs provided the advised speeds for entrance into the work zone. Ahead signs supplied average speeds of traffic at the beginning of the work zone. The two types of speed signs were then presented with three types of variable message signs that were identical to those used for the time signs (see description of three displays above). Each of the three display types for both personal and ahead signs was further divided into two choices or examples. Each choice was further divided into two trials. Once again, Trial 1 was the first time the sign was seen by the participant. Trial 2 was the second time the sign was seen by the participant. Thus 12 speed signs were presented twice for a total of 24 cells (see Table II and Appendix B).

TABLE II Time sign design: note (D)isplay, (C)hoice, (T)rial (Wagner *et al.*)

SPEED SIGNS												
Type	Personal						Ahead					
Display	D1		D2		D3		D1		D2		D3	
Choice	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2
Trial	T	T	T	T	T	T	T	T	T	T	T	T
	1	2	1	2	1	2	1	2	1	2	1	2

The experiment consisted of approaches to the work zone (one practice, 24 experimental). Each pass contained two static construction signs, followed by a time sign and a speed sign. Twelve combinations of both signs were randomly produced, with a random number table. These twelve combinations were randomly sequenced for the first twelve passes of an order. The mirror opposite of this order was used for the last 12 passes. The same twelve combinations of time and speed signs were used for both conditions.

Procedure

On a monitor participants viewed a computer simulation of a stretch of road leading up to a construction zone. After a moment of driving simulation, a static sign, CONSTRUCTION AHEAD, approached (loomed up) on the right side of the roadway. After another segment of road had been traveled, a second static message sign, CONSTRUCTION NEXT 10 MILES, appeared and passed on the right side of the road. Participants were instructed to pay attention to the message on each of these signs and be prepared to answer questions about the

third and fourth sign in the sequence. Participants were instructed beforehand as to the nature of the two types of signs and the questions they would be asked regarding both the primary and the secondary task. After another segment of road had been traveled, a VMS emerged from the horizon and passed on the right side of the road. This sign was a time sign. At approximately the same time the VMS was readable, the grid line became active. Once the time sign passed out of view eight seconds after becoming visible, the screen paused for 15 seconds. Two questions regarding the time sign and the grid line were presented to the participant. Following the pause, an auditory signal occurred and the simulation continued. After another segment of road had been traversed, a variable message sign approached on the right side of the road. This sign was a speed sign. At, approximately, the same time the variable message sign was readable the grid line once again became activated. Once the speed sign passed out of view, the screen paused (15 seconds). Two questions regarding the speed sign and the grid line were presented to the participant. After the pause and auditory signal occurred, another trial began. The entire scenario was repeated 25 times, with one practice pass and 24 experimental passes. The primary and secondary tasks, answer options for each, and the coding of answers on a standard optical character reader response form were designed to permit large screen projections and the testing of large numbers of participants, simultaneously (*e.g.* an entire large auditorium). The limit of participants tested at one time would be determined by the seating arrangement that insured the same visual angle for all participants.

Treatment of Data

A 5-way repeated measure ANOVA was run on dichotomous correct and incorrect responses to both time and speed Signs with CATMOD (from SAS 6.08; see also Lunney, 1968) conducted on significant and relevant contrasts.

Results

Primary Task

Participants monitored the grid pattern display with a high level of accuracy, the mean number of incorrect responses being 2.3 out of a possible 48 (*s.d.* = 2.1; range 0 to 7). Occasional errors did not appear systematic. Near perfect performance by most participants made further analyses unwarranted.

Secondary Task

Test-retest reliability: For speed signs no differences were found between first and second presentation, regardless of factors, except for what is, most likely, a spurious four-way interaction of type by display by choice by time ($F(2, 36) = 4.03$; $p = .0246$; Greenhouse-Geiser corrected $p = .0293$). However, for time signs the effect of a 4-way interaction of type by choice by time by condition ($F(1, 18) = 17.92$; $p = .0005$) revealed that participants were significantly more accurate on trial 2 than trial 1 ($F(1, 18) = 20.19$; $p = .0003$), likely due to the better understanding of the task at hand obtained from a complete reviewing of all signs in the study. Henceforth, all analyses are based only on trial 2 data, considering trial 1 data as practice.

Check of counterbalance: Although none of the interactions were significant for time sign trial 2 data, *i.e.*, no simple effects emerged, a main effect of type was found ($F(1, 18) = 18.24$; $p = .0005$). Counterbalances were then collapsed and a three-way repeated measures ANOVA was conducted. Once again only the main effect of type was significant ($F(1, 19) = 18.18$; $p = .0004$), with participants responding with greater accuracy on delay signs than transit signs (mean percent correct 95.0 and 46.7, respectively). A repeated measures ANOVA with the single factor of type using percent error from six responses for each type showed a main effect of type ($F(1, 19) = 18.8$; $p = .0004$), with a mean percent correct for delay and transit signs of 95.0 and 46.7, respectively (see Figure 2). Polygons, rather than histograms, are used to better illustrate potential interaction and trends in the data.

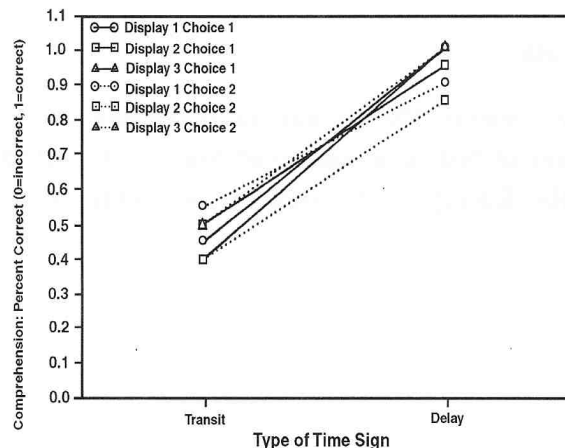


FIGURE 2 Percent correct on comprehension of time signs as a three-way interaction of type, display, and choice.

For speed sign trial 2 data, main effect of type ($F(1, 18) = 14.98$; $p = .0011$) and choice ($F(1, 18) = 36.73$; $p = .0001$) were found. Counterbalances were then

collapsed and a three-way repeated measures ANOVA was conducted. Once again main effects of type ($F_{1, 19} = 15.55$; $p = .0009$; Chi-squared = 16.36; $p = .0001$) and choice ($F_{1, 19} = 38.00$; $p = .0001$; Chi-squared = 40.00; $p < .00005$) were significant, with participants responding with great accuracy to update over advisory signs (mean percent correct 65.8 and 30.8, respectively) and choice 2 over choice 1 (mean percent correct 65.0 and 31.7, respectively). In addition, a two-way interaction of type by choice ($F_{1,19} = 4.41$; $p = .0493$; Chi-squared = 4.64; $p = .0312$) was significant (see Figure 3). Figure 4 provides interpretation percent correct as a function of display, choice, and type of speed sign.

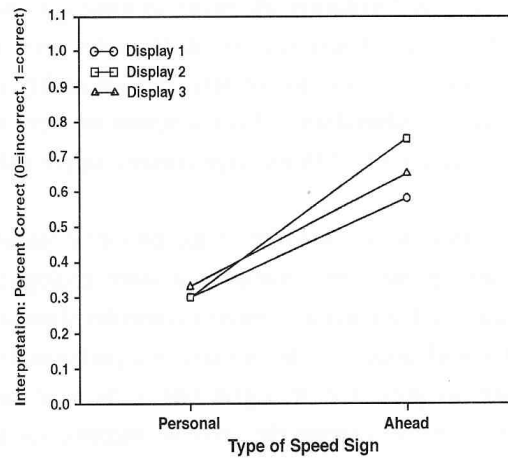


FIGURE 3 Percent correct on interpretation of speed signs as a two-way interaction of type and display. (Wagner *et al.*)

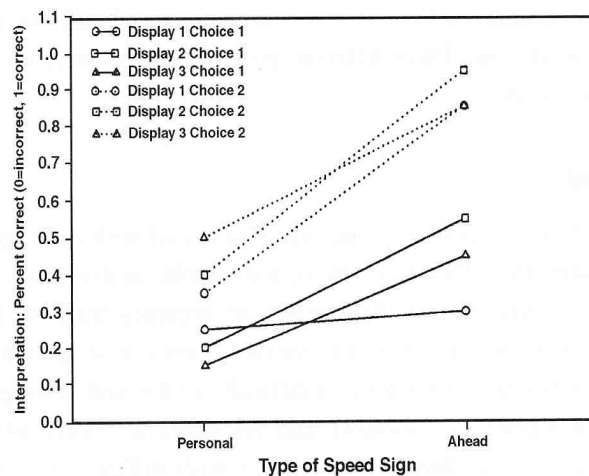


FIGURE 4 Percent correct on interpretation of speed signs as a three-way interaction of type, display, and choice. (Wagner *et al.*)

Discussion

The goal of this experiment was to develop a technology that could be employed to study the comprehension and interpretation of the content of variable message used in ITS, particularly, the work zone. Variable message signs provide real-time information to motorists and allow considerable flexibility in the type of information conveyed independently or in concert with existing technology found in intelligent highway systems. While much research, to date, has focused on physical and perceptual aspects of these signs (*e.g.* readability) considerably less attention has been given to other, more functional aspects of signage, like comprehension and interpretation. In some situations, message ambiguities may lead to slight confusion and irritation. However, in more extreme cases, misunderstandings could be fatal. Unfortunately, work zones tend to be a typical backdrop for such occasions, due to the size and variability of the speed of incoming traffic and the vulnerability of construction workers within the zone. Thoughtful experimentation of VMS message content might reduce the number of tragedies.

The dual-task methodology employed in the present experiment provides a means for easily testing message content in a more ecological manner than conventional procedures. Participants viewed a computer simulation of a section of road leading to a work zone. For the primary task participants monitored and remembered the signals presented on a grid line in the rear view mirror. This task was designed to loosely capture the level of attention required to monitor the lane position of traffic in the rearview mirror. The concurrent, secondary task involved viewing an approaching (optically expanding) VMS and answering questions based on sign content interpretation and comprehension. Variable message signs presented information about time or speed and how these factors related to the work zone. Three different typed of displays were also tested. The main findings follow.

Primary Task

During experimental trials, only one signal occurred with each approach of a variable message sign. This task proved too simple, as evidenced by the near ceiling levels of performance. As a result, an accuracy trade-off between the primary and secondary task was not assessed. Future research should involve systematic manipulation of the level of difficulty of this task, through increasing the number of signals to remember and the speed at which the signals are presented. It is important that the primary task loads sufficiently on the information processing capabilities of the driver so that resources for performing the secondary task are appropriately taxed.

Secondary Task

Time signs: Transit time signs conveyed the time necessary to traverse the work zone, while delay signs provided the additional amount of time to traverse the work zone. To respond correctly, participants had to determine the number of minutes they would be late for work. In the former situation, one needed to mentally calculate the amount of time it would have taken to travel along the same stretch of road, without the work zone and subtract this from the total amount of time to traverse the work zone. Given the time constraints on reading, interpreting and comprehending the consequences of such traffic signs, this was not a trivial task. It was correctly predicted, therefore, that people would perform less accurately on transit signs that did require mental calculation (Dudek, 1992) than signs such as delay signs that did not require this extra effort (Huchingson & Dudek, 1979). It is interesting to note that while drivers may be consistently accurate with their interpretation of such transit signs and even show preference for the information they convey, as evidenced in survey study conducted by the authors prior to this experiment, the ability to glean the most useful information from this type of sign, namely its effect on travel time, seemed to be lacking under the more valid conditions of this experiment. This would indicate that care must be taken when assessing signs based solely on driver preference out of the context within which comprehension will occur. Another interesting question lies in the message content of the two choices. Delay time signs were further broken divided into those which expressed additional time to travel the work zone, either in terms of extra time or delay. In addition to further testing comprehension of the consequences of delay, the present simulation experiment tried to determine whether additional time could be expressed in a seemingly less ambiguous manner, using the words 'extra time.' Both choices rendered high level of accuracy in responses and did not differ significantly from each other. Finally, the different display types of variable message signs did not appear to differ significantly in their effect on a person's comprehension of the consequences of messages expressing time information.

Speed sign: When drivers were asked to interpret speed signs used in this experiment as regulatory, advisory, or an update of the speed of traffic ahead, they generally misinterpreted the personal speed signs more often than ahead speed signs. People also tended to correctly interpret choice #2 signs more often than choice #1 (for a reminder, choice #1 and choice #2 represent two different ways of expressing the same type of information, *i.e.*, two ways of expressing speed advisory). There was also an interaction between the type and choice of speed signs due, largely, to a consistently high level of accuracy on choice #2

ahead speed signs. These signs were, most likely, interpreted correctly as update signs due to the unambiguous use of either the verb 'moving', the adjective 'ahead', or both. Choice #1 ahead speed signs, on the other hand, used the words speed in conjunction with the word traffic; the referent of traffic being either the person reading the sign or the cars ahead. Furthermore, the word 'speed' is quite often seen in the context of a regulatory or advisory speed sign. This combination could have lead to misinterpretation of a choice #1 ahead speed sign as one or the other. Personal speed signs resulted in the greatest number of misinterpretations. The messages on these signs, as is often the case of advisory signs, were phrased as commands, contrary to what their name implies. Consequently, it is not terribly surprising that participants tended to misinterpret them. Finally, the different types of variable message sign displays did not appear to differ significantly in their effect on a person's ability to interpret messages expressing speed information.

Findings of the present experiment indicate that the type of message on VMS does affect comprehension and interpretation. Motorist are more likely to glean relevant information when the message expresses additional amount of time to travel through the work zone, as opposed to the total amount of time. This information may have the effect of increasing the number of detours taken before the work zone; thus reducing some of the congestion preceding the work zone. If the sign expressed speed, messages in command form were likely to be interpreted as speed advisories, whereas speed signs that use the action verb 'moving' are more likely to be correctly interpreted as describing the speed of traffic ahead. The type of VMS did not appear to influence significantly either sign interpretation or comprehension of consequences. This suggests that the cost of constructing variable message signs might be reduced by creating hybrid signs that provide pertinent real time information. Future research into the secondary task should involve assessment of the validity of the computer simulation through testing and evaluating the proximity of the simulation parameters, *i.e.*, rate of optical expansion of the visual images (signs), refresh rates, and luminance, to real world experiences. In addition, it must be established that correct comprehension and interpretation of VMS leads to correct decisions making (braking, diverting, etc.) by conducting a follow-up on-road and/or driving simulation study.

CONCLUSIONS

The goal of this research was to develop a methodology for assessing the effectiveness of variable message signs used in intelligent work zones.

A computer simulation experiment was conducted, using dual tasks, to assess the correctness of interpretation of meaning and comprehension of the consequences of the information on variable message signs. Although participants performed with high levels of accuracy on the primary task, in general, the type of message found on the variable message signs significantly influenced the accuracy of interpretation of speed signs and the comprehension of consequences for the time signs. Even speed signs that shared a common meaning resulted in different interpretations. In further understanding the influence of divided attention on message comprehension in this context, manipulation of the levels of the primary task and examination of the resulting interactions between the primary and secondary task performance should prove informative.

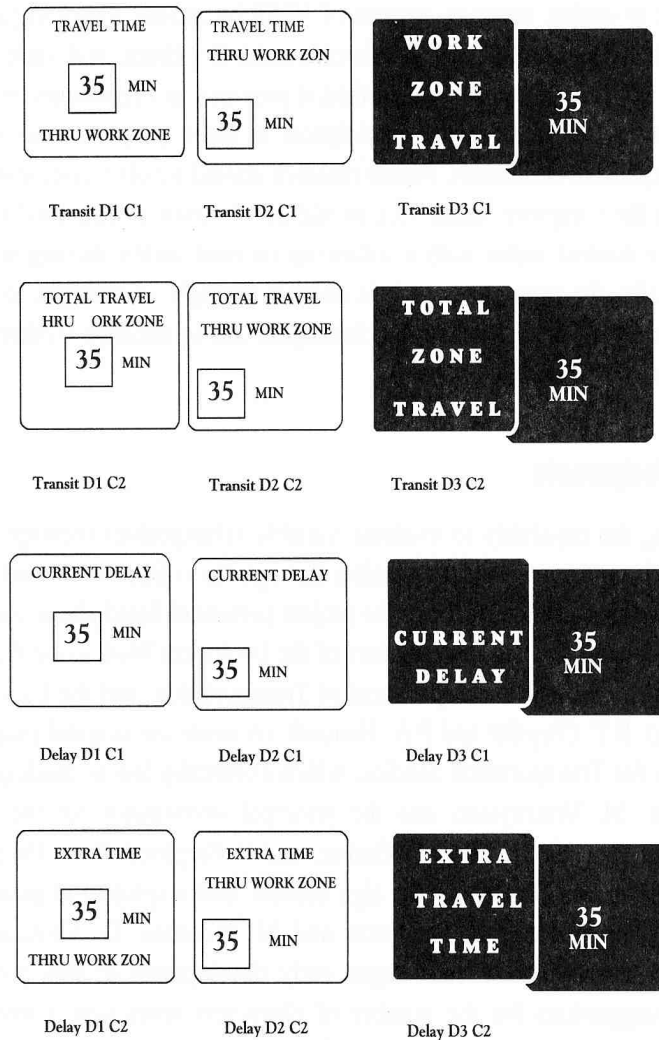
The computer-assisted methodology employed by this research provides a means for assessing message content of VMS by having visual expansion of VMS, in the context of a ITS, consistent readability times, and varied display types in a divided attention task. Further, it provides an opportunity to manipulate attentional demands of test participants in video projection environments without expensive simulators. Future research should involve assessment of the validity of the computer simulation, in addition to testing behavioral responses to message content either with a follow-up on-road and/or driving simulation study. Finally, the present research is another example of attempts to improve work zone safety procedures and technologies and to enhance worker training and motorist education.

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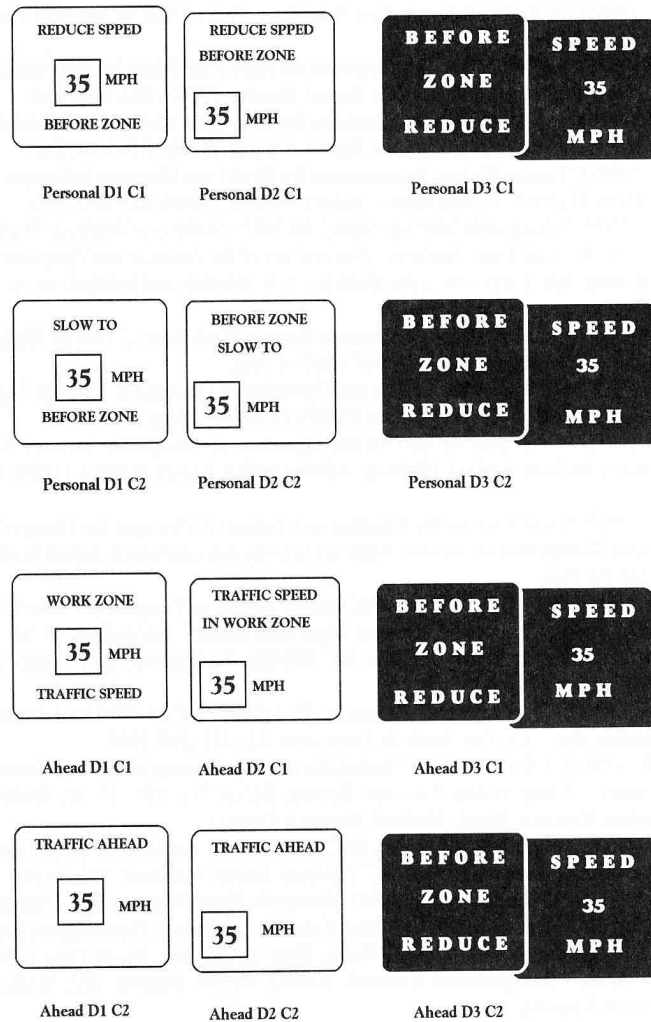
provided important perception and optical flow information to this research. M. Coyle provided computer programming for the simulation experiment. O. Olofinboba was technical coordinator and chief engineer for the simulation experiment. R. Stevens and G. Williams helped to create the signs in the computer simulation. W. Verwey provided key reports from VMS research in European laboratories. Two anonymous reviewers provided valuable comments during preparation of the final manuscript.

APPENDIX A



APPENDIX A Simulation experiment sign content: time signs. (Wagner *et al.*)

APPENDIX B

APPENDIX B Simulation experiment sign content: speed signs. (Wagner *et al.*)

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