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Contents

Part 3 —Highway Safety Research

Foreword

Three general themes are covered by the papers in this volume. In the section on human engineering of transportation systems, Smith et al. describe an experiment with experienced mariners using automated navigation systems while piloting "ships" at the CAORF simulation facility. A human-machine task allocation is proposed with a corresponding optimized high-speed train control display by Yin and Sheridan. The next five papers deal with various aspects of user information systems. The papers by Ullman et al. and Khattak et al. discuss the effects of different types of information on driver route diversion behavior. This work relates current and new technologies for providing drivers route information. The next four papers are on more traditional information system topics. What affects how drivers detect and recall traffic signs? Al-Gadhi et al. address this question for international warning and regulatory signs. Then Bonneson and McCoy surveyed drivers to determine understanding of protected and permitted left-turn signals. Literature and driver surveys were used by Fitzpatrick et al. to examine driver comprehension of exit lane drop signs and markings. The final papers look at other aspects of highway and traffic safety. Van der Horst and Hoekstra used a driving simulator to study a variety of means to reduce driver speed behavior, especially on rural roads. Lane width, rumble strips, and edge markings were varied and significant speed reductions were found. Freedman et al. evaluated drone radar operation at high crash risk locations. The enforcement patterns used in Hawaii to obtain one of the nation's highest seat belt use rates is studied by Kim et al. An emerging method for gathering and presenting evidence in highway tort liability cases is described in the final paper. The advantages, disadvantages, and methods for using videotaped evidence in highway tort liability trials are discussed by Turner.

PART 1

Human Engineering in Transportation Systems

Mariner's Use of Automated Navigation Systems

MYRIAM WITKIN SMITH, ROBIN AKERSTROM-HOFFMAN, CARMINE M. PIZZARIELLO, STEVEN I. SIEGEL, AND IRENE M. GONIN

As part of a recent United States Coast Guard evaluation of Electronic Chart Display and Information Systems (ECDIS), an experiment was conducted to examine the mariner's use of such systems in the controlled setting of a shiphandling simulator. Two ECDIS systems were interfaced with the simulator at MarineSafety International/Computer Aided Operations Research Facility in Kings Point, New York. On the simulator, experienced mariners each made multiple port arrivals and departures as a lone watchstander on the bridge: navigating a planned route, responding to the traffic of a busy harbor, and managing the preparations for the arrival or departure. During transits under baseline conditions, the conventional methods of navigation were available: plotting on the paper chart, radar/automated radar plotting aid (ARPA), and visual piloting. During the test conditions, one of the ECDIS systems was added to the bridge, with or without automatic updating of own ship's position, and with or without the integration of radar features. ECDIS increased safety, both by decreasing the cross-track distance of own ship from the planned route and by increasing the proportion of time that the mariner spent on look out and collision avoidance. ECDIS significantly decreased the mariner workload for navigation when automatic updating of position was available. The mariners expressed a preference for a relatively simple chart display for route monitoring, with the immediate availability of a larger set of chart information. No measurable effects of radar features on ECDIS were found, although the mariners believed that this would be a valuable addition.

In the past few years, the Electronic Chart Display and Information System (ECDIS) has emerged as a powerful addition to the modern bridge, offering the possibility of effecting major changes in the navigation process and improving the safety and efficiency of maritime operations. By superimposing an electronic chart, ship's position, and radar video on one display, ECDIS has the potential to improve the accuracy of navigation, increase awareness of dangerous conditions, and reduce the mariner's workload. This report describes an examination of these potential effects using the special capabilities of a full-mission ship's bridge simulator. As of this writing, a larger report is being revised (*1*).

The International Maritime Organization (IMO) is in the process of establishing a Performance Standard (PS) for ECDIS (*2,3*). The United States Coast Guard's primary purpose in sponsoring this simulator evaluation was to contribute to a 1993 report to IMO and to the U.S. position on PSs.

The objectives of the experiment were to examine several broad issues underlying the IMO PS, those for which the simulator was especially appropriate as a tool. The simulator makes it possible to examine the dynamic situation of route monitoring with a control that would be difficult or impossible at sea. Four issues, used as organizing concepts to plan the evaluation and to select the performance measures, follow.

- *Contribution of ECDIS to the Safety of Navigation.* ECDIS should enhance safety by affording the mariner a more timely and accurate knowledge of the ship's position and its relation to a planned route and to potential hazards than is possible with conventional bridge procedures and a paper chart.
- *Reduction of Navigational Workload by ECDIS.* ECDIS can integrate information from a number of sensors and can automate the primary, and generally time-consuming, navigation function of position fixing. This automation should reduce the mariner's workload. The experiment was designed to examine ECDIS's potential to reduce workload during relatively demanding transit conditions, assuming that a reduction would mean an increase in the mariner's ability to control the ship and, therefore, greater safety (*4,5*). This experiment did not consider low workload conditions and the possibility that ECDIS might reduce workload to the point of boredom and inattention.
- *Chart Features and Navigational Functions on ECDIS.* At this early point in the development of ECDIS technology, there is no industry consensus about which electronic chart features and which computer-based navigation functions will be needed by mariners. The simulator experiment allows observation of the mariners' actual selections of features and functions from the two sample systems under a variety of conditions.
- *Integration of Radar Features on ECDIS.* A highly integrated navigational system would combine two plan-view displays—the electronic navigation chart and radar/automated radar plotting aid (ARPA)—on one system. This integration would have positive effects on safety and workload.

METHODOLOGY

Shiphandling Simulator

The experiment was run at MarineSafety International/Computer Aided Operations Research Facility (MSI/CAORF) in Kings Point, New York. The simulator has a realistically equipped full-mission bridge and a considerable history of human factors and ship control research. MSI/CAORF's capabilities include sophisticated ship models, harbor data bases, observational and data collection methods, and an engineering and research staff able to adapt these capabilities to new operational problems. For this study, two commercial ECDIS systems were integrated with the simulator and were available to the watchstander as required by the experimental plan.

M. W. Smith and I. M. Gonin, U.S. Coast Guard Research and Development Center, 1082 Shennecossett Road, Groton, Conn. 06340-6096. R. Akerstrom-Hoffman and S. I. Siegel, MarineSafety International, National Maritime Research Center, USMMA, Kings Point, N.Y. 11024. C. M. Pizzariello, MarineSafety International; current affiliation: Simship Corp., 260 Main St., Northport, N.Y. 11768.

Commercial ECDIS Systems

The two systems selected were Offshore Systems Limited's (OSL) Precision Integrated Navigation System and Robertson Marine Systems Incorporated's Disc Navigation System.

The two systems used for this study differed from each other in a number of ways, most of which are summarized in Table 1. The differences most prominent in the experiment were display configurations, chart presentations, and radar integration. The OSL system had a single display screen that could be configured by the user to present several graphic and alphanumeric windows; the Robertson system had a display screen dedicated to the chart presentation and a separate liquid crystal display (LCD) to present alphanumeric information. The OSL had relatively simple stylized charts that could be viewed in separate windows at different scales; the Robertson had a more complex paper chart–like presentation on the single dedicated screen. The OSL presented complete radar video as an overlay to the chart and presented target range and bearing information in an alphanumeric window; the Robertson system presented only the targets acquired by the separate ARPA on the bridge and their vectors on the chart display and presented range, bearing, closest point of approach (CPA), and time to CPA on the separate alphanumeric LCD. The single screen, stylized chart, and radar video of the OSL system are illustrated in Figure 1. This figure is adapted from an OSL photo. The actual view shown did not appear in the experiment. Note that both systems are prototypes and not representative of the systems now available from the manufacturers.

Primary Experimental Manipulation

The primary experimental manipulation was in the methods of navigation available to the watchstander in a given scenario. In all scenarios the conventional choices for navigation were available: position fixing on the paper chart, radar/ARPA, and visual piloting. In two baseline scenarios, only these conventional methods were available. In the remaining scenarios, one of the commercial systems was added to the bridge in one of three modes:

- ECDIS with automatic position updating and radar features (positioning was to an accuracy of 5 m or better. Mariners were told that differential Global Positioning System was in use.),
- ECDIS with automatic position updating and no radar features, and
- ECDIS without automatic position updating (and with instructions to update manually).

Content of Experimental Scenarios

All the scenarios were transits through the Coastal and Harbor/Harbor Approach phases of navigation (*6*) in New York or San Francisco. As is frequently done in simulator research, the workload was increased beyond realistic levels on the assumption that a high but sustainable workload increases the sensitivity of the mariner to the experimental manipulations and, therefore, increases the sensitivity of the performance measures. To ensure a high workload, each participating mariner made port arrivals and departures as the one officer alone on the bridge. In addition, no pilot came on board when the ship passed the pilot station. To keep the workload sustainable, the equipment consoles were arranged for "centralized control" to minimize movement around the bridge. This arrangement is illustrated in Figure 2. Also indicated in the figure are video cameras (numbered as 1, etc.) and microphones (labeled as M1, etc.). A qualified helmsman was present in all scenarios.

As the single officer on the bridge, the subject mariner was responsible for navigation, collision avoidance, and bridge management activities. The scenarios were designed by MSI/CAORF mariners to be approximately equal to each other in their density of events representing each of these three categories of activities. The experimental approach requires any differences in observed performance among scenarios to be attributable to the primary experimental manipulation and not to differences in scenario background content. This scenario design is an example of the type of control that is possible on the simulator but not at sea.

Participating Mariners

Four masters and two mates each spent a week at MSI/CAORF. They all had extensive resumes, and simulator or computer experience, or both. The intention was to select mariners who could be expected to adapt to the new technology and provide good performance and meaningful reactions in a relatively short time. During

TABLE 1 Major Differences between Two Commercial Systems

	Offshore Systems Limited PINS -VME	Robertson Marine Disc Navigation
Computer	68030 @ 25 MHz	80386 @ 33 MHz
Screen	19 inch, 1024 x 788 pixels	25 inch, 1080 x 1040 pixels
Displays	configurable into windows, chart or text	chart on screen, text on LCD
Electronic chart	landmass, contours, channels, aids	complex, "chart-like"
Interface	touch screen and trackball	keyboard and trackball
Radar features	video overlay, some ARPA info	ARPA targets, some ARPA info
Own ship symbol	scaled outline	outline not to scale

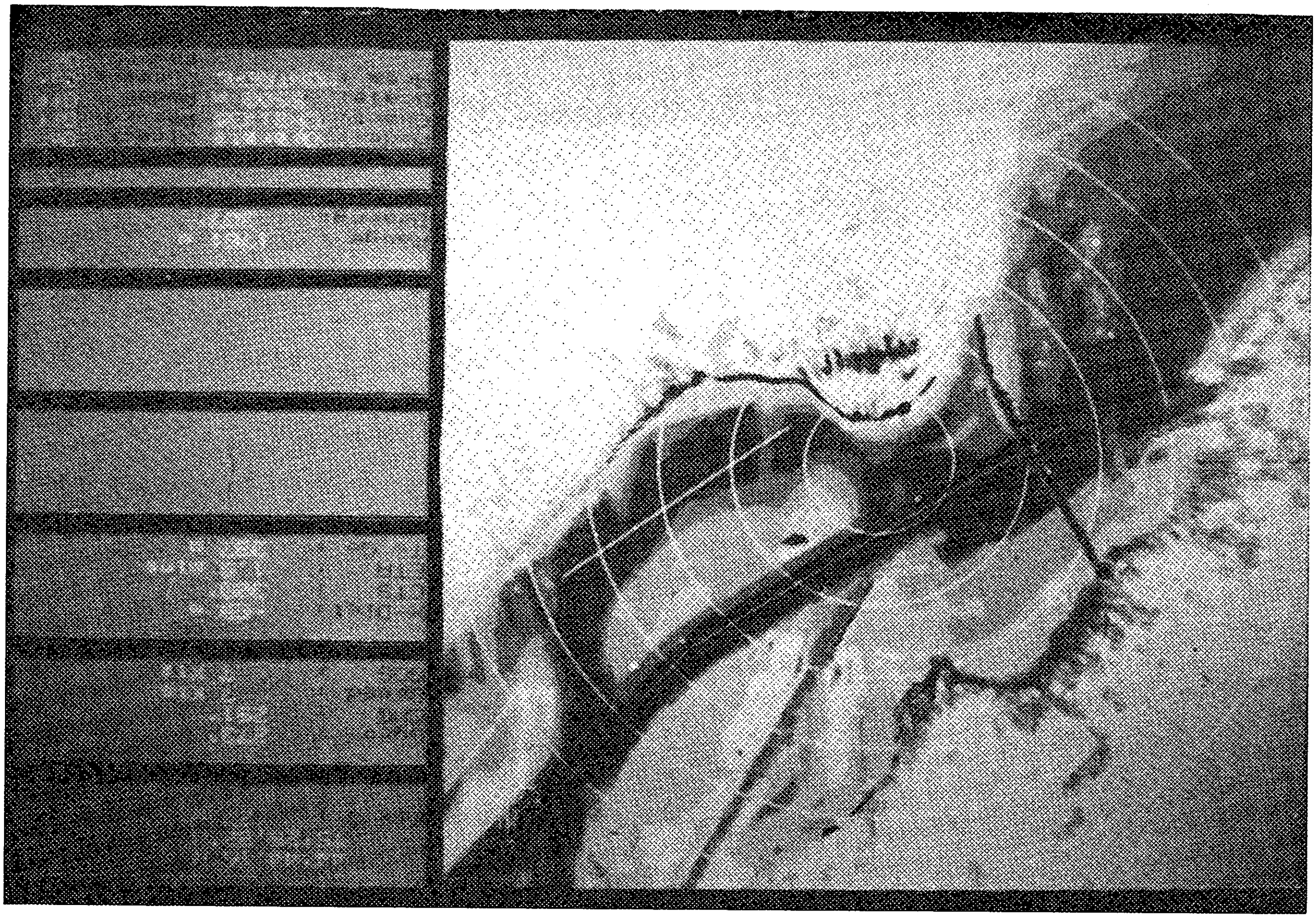

FIGURE 1 Offshore Systems Limited's PINS VME display screen.

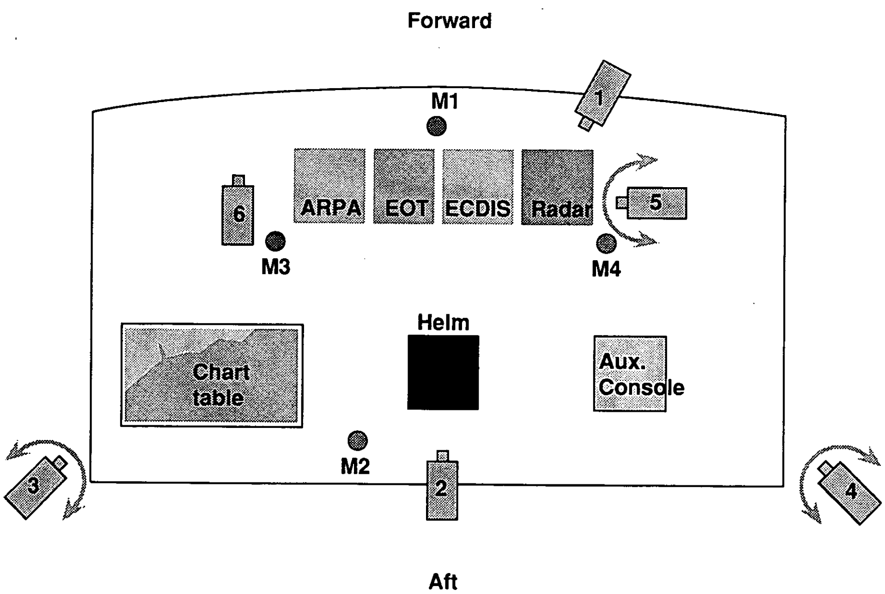

FIGURE 2 Shiphandling simulator's bridge arranged for centralized control.

each week, the mariner received brief formal training on each of the two ECDIS systems and ran through all the experimental scenarios in a different counter-balanced order.

Performance Measures and Data Analysis

A variety of ship control and human factors data was collected and analyzed. Those that proved the most productive in investigating each experimental objective are discussed in the section that follows. All measures based on mariners' reports were subjected to analyses of variance. Specific hypotheses were tested using single degree of freedom contrasts. Cross-track distance data were compared between scenarios by using *t*-tests. All effects discussed here were statistically significant ($p < 0.05$).

RESULTS

Primary Method of Navigation

Each mariner reported the primary method of navigation used for each identifiable segment of the transit after each scenario. The assumption was that the selection of method would reflect the mariner's view of the best combination of safety and workload for the conditions. The results are summarized in Table 2 for the Harbor/Harbor Approach phase of navigation, with its relatively high risk and high workload. With this high workload, plotting on the paper chart for position fixing was rarely used. Instead, in conventional bridge conditions, without ECDIS available, visual piloting and radar/ARPA were the methods reported. When ECDIS with automatic updating of position was available, it was reported to be the predominant method of navigation; however, without automatic updating of position and with the requirement for manual updates, ECDIS lost its preferred status.

Safety Measured by Accuracy of Trackkeeping

Safety of navigation has been measured in simulator research (*7,8*) and in sea trials (*9*) by cross-track distance from a planned trackline. Although no special instructions to keep the ship close to the line were given in this experiment, it was hypothesized that ECDIS would increase safety by reducing cross-track distance. At some critical points, such as approaches to bridges or to major turns, the availability of ECDIS with automatic positioning resulted in substantial reductions in mean cross-track distances. A notable example is illustrated in Figure 3. These figures are plots of the simulator's harbor data base with the actual tracks traced by own ship's center of gravity for each of the mariners superimposed on them. This treatment provides a composite track plot. The upper half of Figure 3 represents performance using ECDIS with automatic updating of position (Scenario 5); the lower half represents performance with the baseline conventional bridge (Scenario 9). Note that the tracks in the upper half, using ECDIS, are more tightly clustered than are the tracks in the lower half of the figure, using conventional methods. This difference is particularly obvious as the tracks pass under the Golden Gate Bridge and as they round the turns to the southeast of Alcatraz Island.

Summary data from the track plots in Figure 3 are presented in the top half of Table 3. The use of ECDIS decreased the mean cross-track distance to approximately one-third of what it was with conventional methods. The bottom half of the table shows the effect of the failure of automatic updating of position and the necessity of manually updating position: cross-track distance is increased and ECDIS loses its advantage in track-keeping accuracy.

Workload Measured by Time Spent and by Mariner's Ratings

Workload was measured by asking the mariner after each scenario what proportion of the time was spent on navigation, collision avoidance, and bridge management. The mariner was also asked to rate workload on each of these three categories of tasks separately, using the National Aeronautics and Space Administration's Task Load Index (*10,11*). This is a frequently used rating scale that yields a score from zero to 100 representing the perceived demand of a task. The hypothesis was that ECDIS would reduce the workload of navigation.

A summary of the findings are presented in Table 4. The availability of ECDIS with auto positioning decreased the mean workload for navigation and the mean reported proportion of time spent on navigation below that measured for conventional bridge procedures. The necessity of manually updating position increased the navigation workload and the proportion of time spent in navigation. Workload was increased over that for the conventional bridge and ECDIS with automatic positioning.

TABLE 2 Reported Primary Method of Navigation for Bridge Conditions (in Harbor/Harbor Approach)

Bridge Conditions	Proportion of Total Transit Segments for Which Method was Reported as Primary for Each Bridge Condition*				Total Transit Segments
	Plotting/ Paper Chart	Radar/ ARPA	Visual Piloting	ECDIS	
Conventional bridge	0.03	0.25	0.73	NA	40
ECDIS auto positioning	**0.00**	**0.15**	**0.18**	**0.67**	**79**
ECDIS no auto positioning	0.05	0.61	0.28	0.05	18

* Proportions do not sum to one due to rounding error.

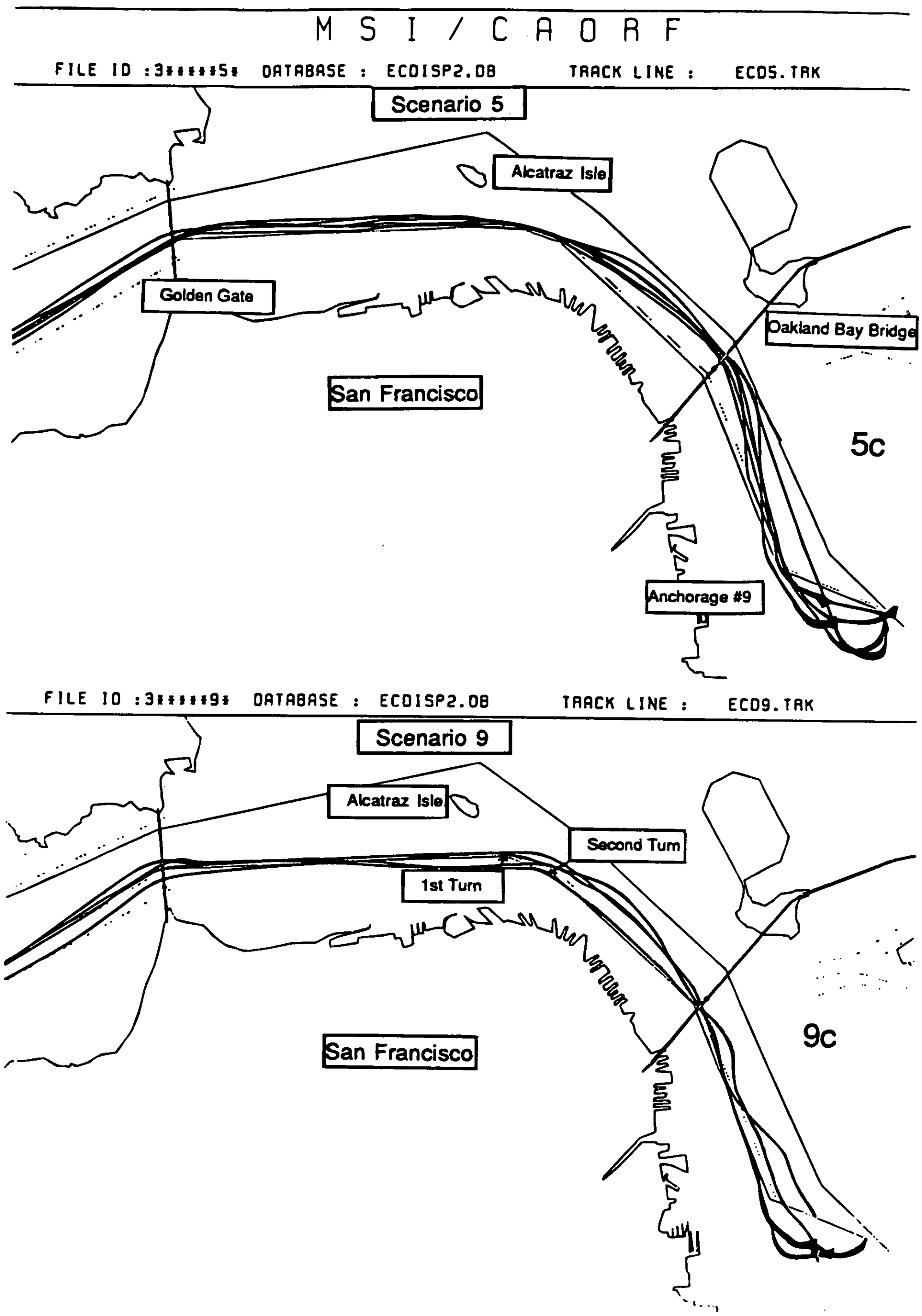

FIGURE 3 Track plots illustrating effect of ECDIS on track-keeping accuracy.

Time Spent on Navigation Versus Time Spent on Collision Avoidance

Table 4 also shows a reciprocity between navigation and collision avoidance. With the decrease in proportion of time spent on navigation using ECDIS with automatic positioning, there was a corresponding increase in the proportion of time spent on look out and on collision avoidance. The mariners indicated, both in spontaneous comments and in formal questioning, that in their view this shift represented an increase in safety. Navigation workload and the proportion of time spent on navigation were positively and significantly correlated with each other. Navigation workload and the proportion of time spent on collision avoidance were negatively and significantly correlated. ECDIS with no automatic

TABLE 3 Mean Cross-Track Distance at Selected Points in Transit for Bridge Conditions

Location	Mean Cross-track Distance (Meters*)		Probability
San Francisco	**ECDIS auto positn (Scenario 5)**	Convention bridge (Scenario 9)	
Golden Gate Bridg	**32**	117	0.05
Alcatraz 1st turn	**18**	100	0.09
Alcatraz 2nd turn	**29**	98	0.06
New York	**ECDIS auto positn (Scenario 1)**	ECDIS no auto (Scenario 3)	
Ambrose 1st turn	**41**	128	0.09
Ambrose 2nd turn	**59**	219	0.006
Verrazano Bridge	**18**	148	0.18

* 1 meter = 3.3 feet.

TABLE 4 Mean Navigation Workload and Reported Distribution of Mariner's Time for Bridge Conditions

Bridge Conditions	Navigation Workload	Proportion of Time on Task*		
		Navigation	Collision Avoidance	Bridge Management
Conventional bridge	52	0.46	0.33	0.21
ECDIS auto positioning	**36**	**0.37**	**0.41**	**0.21**
ECDIS no auto positioning	63	0.49	0.34	0.17

* Proportions do not sum to one due to rounding error.

updating of position again showed the most unfavorable results on all measures.

Feature and Function Use

The use of chart features and navigation functions on ECDIS was examined in a number of ways. Experimental observers watched on video monitors and tallied features and functions enabled on the ECDIS systems by the mariner, questionnaires after each scenario contained checklists for reports of what had been used and what was wanted, and a final questionnaire contained a checklist asking the mariner to recommend what should be available.

The results obtained with this final measure are summarized in Table 5. Only a few features were recommended by most mariners as "display always." The asterisks mark items selected as one of the three most important by most mariners. A much larger set was recommended by most to be available "at user's option."

Corresponding recommendations on the ECDIS-based navigation functions are summarized in Table 6. The mariners' use of such functions and their comments are further discussed in the larger report on this study (*1*).

Results on Use of Radar Overlay

No significant differences were found, either between ECDIS with and without radar features or between ECDIS with the complete radar video and ECDIS with targets only. Mariners believed that radar integration should be a valuable addition to ECDIS but that the examples that they saw were not satisfactory. The principal drawbacks mentioned were an overly cluttered screen and incomplete ARPA information that did not allow them to depend on that single system for both navigation and collision avoidance.

DISCUSSION AND CONCLUSIONS

Contribution to Safety of Navigation

The use of ECDIS during route monitoring has the potential to provide equivalent or greater safety than that provided by the paper chart and conventional procedures. Two mechanisms to provide this increased safety were identified: (a) decreased cross-track distance from the planned route and (b) an increased proportion of time spent

TABLE 5 Mariners' Recommendations of Charted Features

Charted Features	Display Always	At Users Option	Display Never
	(number of mariners of six)		
coastline/landmass	6	0	0
indication fixed aids to navigation	6*	0	0
indication floating aids to navigation	6*	0	0
federal channel lines	4	2	0
navigation lanes/fairways	4*	2	0
pilot areas	4	2	0
indication of isolated dangers	4	2	0
spot soundings	0	6	0
names-landmasses, islands, etc.	1	5	0
light / sound characteristics	1	5	0
cable/pipeline areas	1	5	0
details of isolated dangers	1	5	0
lat/long grid lines	1	5	0
bottom characteristics	0	5	1
details of cautionary notes	0	5	1
ENC edition date	0	5	0
anchorages	2	4	0
bottom contours	2	4	0
compass rose	2	4	0
physical classification (can/nun)	1	4	1
physical description (e.g. white tower)	1	4	1
magnetic variation	0	4	2
geodetic datum	0	4	2
prohibited and restricted areas	3	3	0
indication of cautionary notes	3	3	0
indication of units of depths/ heights	3	3	0
radio characteristics (RACON)	2	3	1
coastal topography	1	3	2
land feature/characteristics	1	3	2
visual and radar conspicuous features	2	2	2

* also rated as one of three most important features by majority of mariners

on look out and collision avoidance. These findings, that ECDIS supports more accurate ship control and allows more time to be spent on non-navigation tasks, support simulator evaluations of the use of automation for one-man bridge operations (*12*).

Effect on Workload

The use of ECDIS during route monitoring has the potential to reduce the navigation workload compared with using the paper chart and radar and visual piloting techniques. The major factor in the reduction in workload is the automation of position fixing that allows navigation at a glance. Automatic updating of position and a generally high level of display accuracy are critical to the effectiveness of ECDIS in the Harbor/Harbor Approach region. Refinements in the design of the system may also contribute to the reduction of workload.

Chart Features During Route Monitoring

A relatively simple display was recommended by the participating mariners during the dynamic situation of route monitoring to avoid a cluttered display. The consensus of features to display always corresponds approximately to the standard display of the IMO PS (*2,3*). The preference for a simple display for route monitoring is consistent with conclusions in other reports (*13–16*). At the same time, the participating mariners recommended immediate and easy reference to a much larger set of features.

It appears worthwhile to make a distinction between two functions of a navigational chart: a dynamic function for the route monitoring, which needs only the information used in ship control, and a static function as a geographic information system (GIS), which provides much more extensive information for reference. The mariners' preferences for features and functions were based on the route monitoring task they experienced. The use of ECDIS for the navigation task of passage planning was not addressed in this experiment.

ECDIS-Based Navigation Functions

Given the capability of a microprocessor, the functions that might be added to an ECDIS are limited only by the ingenuity of the manufacturers. The valid needs of the user should be met, but, at the same time, a system should not be overly complicated, cluttered, and confusing. A similar approach could be taken for navigation functions as has been taken for chart features (*2,3*). That is, there could be a base set provided in every mode on every model by every manufacturer. In addition, there could be additional functions to be

TABLE 6 Mariners' Recommendations of ECDIS Based Navigation Functions

ECDIS-Generated Information	Display Always	At Users Option	Display Never
	(number of mariners of six)		
navigation fault alarm (eg. GPS down)	**6***	0	0
own ship outline	**5**	1	0
display planned trackline	**5***	1	0
display waypoint /waypoint number	**4**	2	0
past track	1	**5**	0
vector of course /speed made good	1	**5**	0
display overlay of actual radar	1	**5**	0
set and drift	1	**5**	0
display range rings	0	**5**	1
vector of own ship heading and speed	2	**4**	0
display selected ARPA targets	2	**4**	0
display current vectors	1	**4**	1
ETA to waypoint	1	**4**	1
display dead reckoned position / time	1	**4**	0
scale bar	1	**4**	0
chart scale boundaries	1	**4**	0
display wheel over points/turn radius	3	3	0
grounding alarm	3	2	1
own ship's safety depth contour	3	1	1
zoom in/ out function	3	1	1
display chart north up and course up	2	3	0
off track alarm	2	3	1
display fix marker and time	1	3	0
course to steer (trackline)	1	3	2
provide method for manual fix taking	1	3	2
display visual limits of lights	1	2	3

* also rated as one of three most important features by majority of mariners

selected by the user. Finally, manufacturers could have the opportunity for product differentiation and innovations that do not interfere with the base set. According to the expressed needs of the mariners participating in this study, there should be sufficient standardization across systems that an experienced individual can make safe use of a different system. The marine pilot, who must board a strange ship and make immediate use of available equipment, would have even greater needs for standardization.

Radar Features During Route Monitoring

No definite conclusions are possible from this experiment on the issue of whether, or how, radar should be integrated with ECDIS. The mariners' understandable concerns with the use of ARPA for collision avoidance in harbor entrances and departures suggest a need for further studies on the use of integrated systems.

Integrated Navigation Systems

The U.S. Coast Guard is involved in several studies of integrated systems. In cooperation with the Canadian Hydrographic Service, a further study is in preparation at the Centre for Marine Simulation at the Marine Institute in St. John's, Newfoundland. This study will examine the contributions of an integration of ECDIS and radar to navigation and collision avoidance. No published report is available. The U.S. Coast Guard is also a co-sponsor, along with the Maritime Administration, of the Shipboard Piloting Expert System. This ambitious project is a real-time expert system that reasons about the available data and formulates recommendations to the mariner (*17*). Sea trials are planned.

ECDIS as Automation

Many of the ECDIS issues considered during this study—effects on workload, situational awareness, safety, need for special training, and so forth—are general to the use of automated systems. The consequences of the increased use of technology on ships and related changes in the mariner's role are of great interest in the marine industry at the present time. Many comments from the mariners who participated in this study suggest concern that the consequences might be negative as well as positive: junior officers might become over-confident or overly complacent, they might fail to keep proper look out or notice targets not acquired by ARPA, they might not learn or maintain the necessary skills to function in case of system failure, or they might not be aware of system inaccuracies or malfunction. Owners might take a person off the bridge for every ECDIS they put on it. Because of the broad implications of these types of issues for maritime safety, the U.S. Coast Guard has begun a major study of the effects of automation. As of this writing, a task to define the study methods is nearing completion (*18,19*).

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This study would not have been done or would not have been as effective without the contributions and guidance of Marc B. Mandler, Lee Alexander, Frank Seitz, and William R. Daniels.

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Optimal Driving Aid for Speed Control of High-Speed Trains

S. YIN AND T. B. SHERIDAN

Recent development in computer technology and in cab signal systems has made automatic train speed control technically feasible. However, completely automatic control on high-speed passenger trains may not be easily accepted for various political, safety, or economical reasons. Therefore, humans remain in the cabs of high-speed trains. The question is, then, which tasks in train operations should be entrusted to the human and which to the computer? In view of the weakness and strength of humans and computers, we seek some kind of human-machine cooperation that combines the strength of the two agents in the cab and overcomes their weaknesses. An optimal solution of speed and thrust-braking profiles can be developed under the assumption that the speed limits across the trip from one point (which could be a station or any known point) to the next are known a priori and that the track and the train characteristics are known. An integrated speed control display based on this optimal solution presents the human driver with the optimal speed and thrust-braking profiles and other information relevant to speed control. Four different options of train speed control based on the proposed display are: (*a*) simple manual control, (*b*) manual control with the display as an aid, (*c*) manual control with the display as an aid plus the automatic control option, and (*d*) fully automatic control with emergency-override options. Considerations that bear upon the choice among the alternatives include basic system features, experimental results, view of human role in automation, introduction of new tasks for the human driver accompanying the automation, public anxiety, and liability in case of an accident.

The primary task in train driving is speed control. To perform this task well, the driver, whether human or machine, must know the track properties (grades, curvatures, etc.), the train properties (length, weight, propulsive power, characteristics of resistance and tractive forces, etc.), and the operating rules (speed limits, emergency handling procedures, etc.). As measurement technology develops and computer capability improves, fully automatic speed control becomes technically possible.

The question is, then, how should the available information and control capability be used? At one end of the utilization spectrum is manual control, which currently dominates most locomotive operations. At the other is completely automatic control. The former is demanding on the driver and is likely to result in less-than-ideal performance. The latter may not be easily accepted by the public for various reasons even if technology permits and will surely fail when the input information is incorrect.

Assuming full automation, keeping the human operator in the cab without an opportunity to participate in the control during normal operations has its problems. On the one hand, the human operator may develop complacency, low job satisfaction and other human factors problems, and may not be able to cope with emergencies in the way in which he or she is expected. On the other hand, machines lack the flexibility that humans have in handling abnormal or emergency situations. Some kind of human-machine cooperation that combines the strength of the two agents in the cab and overcomes their weaknesses is sought.

Automatic speed control in high-speed trains (more than 200 km/hr or 125 mph) has been used at different levels in different countries, depending on the types of braking facilities used. In Germany, speed control frequently takes the form of cruise control with the cruising speeds indicated by a display. This form of speed control, which can be inefficient in terms of energy consumption, is affordable because of the regenerative braking capability of trains. In France, by contrast, trains are controlled manually by using a written specification on the most efficient coasting strategy. Cruise control is rarely used because of the energy loss resulting from rheostatic braking.

Studies have been made on automatic dispatching that involves pacing trains over a territory by a train dispatcher to ensure travel according to an optimal velocity profile to save fuel (*1,2*). However, the issues of how the driver uses the velocity profile (a combination of throttle and brake settings) in cab and how it might be used for fully automated speed control have not been addressed.

This paper addresses the issue of human-machine allocation of train control tasks by proposing a scheme of train speed control. First, an optimal solution of speed and thrust-braking profiles for a high-speed train is described. Second, an integrated speed control display based on the optimal solution of speed and control profiles is proposed. Third, various possibilities of using the display as a speed-control decision aid for the human driver are discussed. The paper concludes with a brief summary and the authors' outlook on future works.

OPTIMAL HIGH-SPEED TRAIN CONTROL SOLUTION

Technically, it is now quite feasible to automate train speed control to keep the train within speed limits, adhere to the schedule, and, under these constraints, minimize energy consumption. Automatic measurement of train position, velocity, thrust, braking, and other variables has steadily improved and advanced cab signal systems are becoming available. Modeling of train dynamic characteristics is more precise with the advent of new technologies. Computers are becoming faster, cheaper, and more reliable, which allows implementation of some computationally demanding algorithms that were not possible earlier. Therefore, once the current location, time, and the scheduled next stop location of a train is known, it is possible to obtain an optimal solution of the speed control for its whole trip—optimal in terms of energy consumption.

The problem of an optimal solution to train speed control can be stated as follows: a train is known to traverse the section of track

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from point A to point B in T hours. Terminal speeds at the two points are known. (Note that points A and B could be the two stations of a trip or any other known points along the trip, as long as the train speeds at the two points and the time to traverse the section between them are known). The speed limits, track grades, and curvatures of the track blocks are known a priori. Related train dynamic characteristics, such as mass, tractive effort, and resistance force on a flat track (i.e., resistance induced by aerodynamics and factors not related to curvatures and grades), as functions of speed are also assumed to be known a priori. This implies that the total resistance force experienced by a train at any moment is the sum of those induced by track grades and curvatures and that on a flat track. The question is to find the speed profile that minimizes the energy consumption of the trip from A to B in T hours. This is a constrained optimization problem that can be solved with dynamic programming techniques. Figure 1 depicts the function of a dynamic programming algorithm. (Detailed mathematical derivation can be obtained from the authors.)

In applying the above optimal solution of train speed control, some practical considerations deserve special attention. Ideally, if the track geometry were known perfectly and the train model were perfect, the optimal speed and thrust-braking profiles could be calculated. This implies that these profiles can be simply followed, and train positions and velocities would never have to be measured. Since this ideal situation is not true, the only reasonable approach is to update the optimization repeatedly during the transit from point A to point B.

The updating should take the current actual (measured) train position, velocity, and time as the initial condition and current speed limits, which may have been changed as a result of a breakdown of the train ahead, for example, to obtain a new set of speed and thrust-braking profiles for the rest of the transit. These updated profiles are then followed until the next update. Such updating would guarantee getting to the terminal point B nearly on time, but with slightly less than optimal energy cost. It is a matter of experimental test, however, to determine how accurately such a calculation can be made under the current capability of cab signal systems.

INTEGRATED DISPLAY FOR THE HUMAN DRIVER

Although automatic control can relieve the human operator from tedious repetitive manual tasks, it is not always readily accepted for various technical, safety, or political reasons. If automatic speed control is not acceptable, the optimal solution discussed in the previous section can serve as a decision aid for the driver instead. One design of such an aid is the integrated color display shown in Figure 2 in black and white.

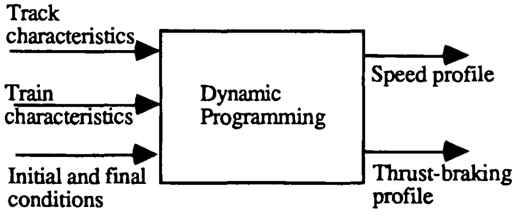

FIGURE 1 Function of dynamic programming algorithm.

This display integrates all relevant information on speed control. It provides the human driver with the optimal thrust-braking profile as a function of train position and tells the driver exactly what control action to take in order for the train to follow the speed profile that meets all the given speed limits, gets the train to the next station or a known terminal point on time, and minimizes energy consumption. The right-hand edge of the speedometer indicates the location of the train momentarily. Atop the speedometer, two horizontal bars might serve as a trip timer and a trip odometer, respectively. The display may also show the stopping distance momentarily. This may help the driver to make decisions on the type or amount of braking force to use in case of track obstruction.

In practice, it is unrealistic to expect a train to follow the optimal speed profile even if the driver follows the displayed optimal thrust-braking profile perfectly. A major reason is that the model used in calculating the optimal solution may not conform precisely to the reality. An example is that the resistance force in the model may not represent that induced by instantaneous wind gusts. One way of remedying this situation is by updating the optimal solution for the rest of the transit, as mentioned in the previous section. Using the deviation of the current speed from the optimal speed, the current time from the scheduled time, or both, as a cue, the driver may request the computer to update the optimal solution. As a result, the control is suboptimal in practice.

TO KEEP OR NOT TO KEEP THE HUMAN DRIVER?

Two contrasting ways of applying an energy-optimal solution to train speed control have been described. It is argued that, under the assumption of sufficiently accurate models of track geometry and train dynamics, and sufficiently accurate train state measurements, optimal automatic control of train speed is feasible. One design of such automatic control would be the direct implementation of the optimal thrust-braking profile described in this paper. Alternatively, the optimal profile can be used, not for automatic control, but as a display for a human driver. If the human, in manual control, followed precisely such a profile, better speed-control performance would be achieved than if that person had to perform various mental calculations during continuous decision making and control. This decision-making process can be quite demanding for a new driver. Thus there are four options:

- *Manual control, with traditional displays only.* Keep the human driver in charge and withhold the integrated display, because he or she might slavishly follow its recommendations and lose the ability to think for himself or herself.
- *Manual control, with the integrated display as an aid.* Keep the human driver in charge, provide the display, and expect the driver to use the display as a decision aid for controlling the train along with his or her expertise.
- *Manual control, with the integrated display as an aid, plus the automatic control option.* Keep the human driver in charge, provide the display, and make some form of optimal automatic control available. Leave the use of either mode of control at any time up to the human operator (much as cruise control is now used in trains and automobiles).
- *Fully automatic control with emergency-override options.* Automatic optimal speed control under normal conditions, but

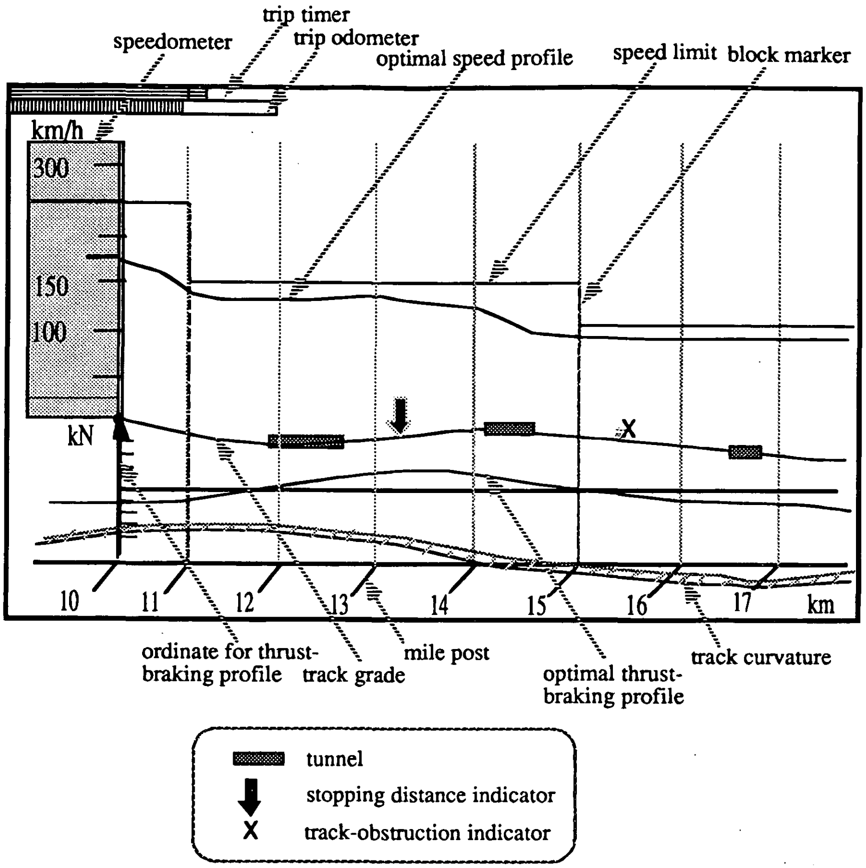

FIGURE 2 Integrated display as decision aid for train speed control.

allowing emergency override by (*a*) an operator in the cab who is there to perform other duties, (*b*) staff personnel elsewhere on the train who might take control from where they are or move to the cab as time allows, or (*c*) a dispatcher from the dispatching center, if the system allows.

Note that these options should include the automatic train protection capabilities with which a train is normally equipped (*3*).

In the fully automatic control mode, the display serves as a means for the computer to communicate with the human driver about the current states and future intentions of the automatic control system. Several considerations bear upon the choice among the speed control alternatives:

- *Basic system features.* System features, especially signal system capability and types of braking systems, strongly influence the appropriate level of cab automation and the role of the driver.
- *Experimental results.* Most important is the outcome of experimental tests and demonstrations of the proposed driver aid or of automation.
- *Proper view of human role in automation.* A prevalent position taken by engineers is that automatic control is essential for modern high-speed trains and there is simply nothing to debate. A high degree of automation is now widely accepted in aviation by pilots, airlines, and regulators, although human pilots remain in cockpits. However, accidents, for which pilots often blame automation, still occur.

With regard to automation, history has shown that we are not always as smart as we think we are. For example, Charles Stark Draper, the father of inertial guidance used to take the astronauts to the moon, proclaimed at the outset of the Apollo Program that the astronauts were to be passive passengers and that all the essential control activities were to be performed by automation. It turned out that he was wrong. Many routine sensing, pattern recognition, and control functions have to be performed by the astronauts, as do some critical emergency decisions.

- *Introduction of new tasks for the human driver accompanying the automation.* Since some tasks (such as planning ahead, replanning in case of emergency, voice communication with the dispatcher, etc.) may not be automated, a trained human operator may be required to remain in the cab, with little to do during normal operations. This may result in loss of vigilance and development of complacency. A natural remedy is to give the operator something more to do. More activity than now practiced in diagnosing various subsystems on the train, such as air conditioning, engine operating status, and the like, is one possibility. How such additional tasks interact with the speed control task is an issue to be investigated.
- *Public anxiety.* It is expected that there would be great public anxiety with driverless control in full-size high-speed trains. However, it is clear that some small-scale trains that operate in airports (e.g., in Dallas–Fort Worth, Atlanta, Orlando, and Chicago) or from airport to city center (e.g., the French VAL) are driverless. Therefore, reflex anxiety about driverless trains may be waning.

• *Liability in case of an accident.* The threat of litigation in case of any accident in an automated system gives developers pause.

The authors believe that development should pass from the current situation, fully manual control (the first control option listed at the beginning of this section), to manual control with integrated display as an aid (the second option listed), to manual control with an automatic control option (the third option), and perhaps finally to fully automatic control (the fourth option). This sequence would be the safest and most acceptable route for development and evaluation.

CONCLUDING REMARKS AND FUTURE WORK

An optimal solution to train speed control has been proposed. Potential uses of the optimal solution for automatic control or as a decision aid for human drivers have been discussed. The decision aid may take the form of the proposed integrated display. It is not the purpose of the paper to provide answers to the design of the cab, but instead to propose possible uses of the optimal speed and thrust-braking profiles and possible designs of a decision aid for the human driver. The authors are in the process of setting up human-in-the-loop simulation experiments to investigate the proposed options. The experiments are expected to provide insight on the issue of human-machine allocation of high-speed train operation tasks.

Although the research is primarily concerned with high-speed trains, the concept proposed in this paper is equally applicable to other types of trains.

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PART 2

Research on User Information Systems

Effect of Freeway Corridor Attributes on Motorist Diversion Responses to Travel Time Information

GERALD L. ULLMAN, CONRAD L. DUDEK, AND KEVIN N. BALKE

Two short telephone surveys were administered to a group of subjects who regularly travel the North Central Expressway in Dallas, Texas, for their daily home-to-work trip to the Dallas central business district. Subjects were presented with eight hypothetical traffic radio messages that varied three corridor attributes believed to affect motorist diversion decisions: the location where the traffic message recommended diverting from the expressway, the location where the traffic congestion on the expressway was said to exist (relative to the location where motorists were advised to divert), and the alternative route (a toll road or an arterial street) recommended in order to save time. Survey subjects were asked to indicate the time savings value that they would require to cause them to divert from the primary route. The results of the study suggested that motorist diversion decisions in response to a given time saved message vary dramatically, even for a group of motorists with the same origins and destinations making a morning work trip. Consequently, the widely differing attitudes and preferences of individual drivers concerning the characteristics of a corridor (i.e., what routes are available, where to divert, and the like) could not be systematically categorized on the basis of recommended route, diversion location, or congestion location.

As traffic demands in urban areas continue to grow, transportation agencies are looking for ways to better manage existing roadway facilities to minimize traffic congestion and maintain mobility within the region. One way agencies can better manage traffic is by providing motorists with information about current roadway conditions. Research indicates that motorists desire accurate and timely information about unusual roadway and traffic conditions and are willing to react to this information by altering their departure time, route, and, to a small degree, mode of travel (*1–3*).

Various technologies can be used to provide motorists with certain types of real-time information, including changeable message signs, highway advisory radio, telephone hotlines, and commercial radio and television traffic reports.

In the future, advanced traveler information systems, part of the intelligent vehicle-highway systems program, will provide drivers with traffic information and navigational assistance tailored to their needs.

Previous human factors research (*4,5*) has generated basic design guidelines for the traditional forms of real-time motorist information displays. This research has also shown that travel time information can have a significant influence on motorist diversion decisions. Real-time traffic information must be packaged and presented to motorists in the proper manner to facilitate quick, easy, and correct comprehension. Travel time information can be presented to motorists in a variety of formats, including the following:

- Absolute travel time value between points on a given route,
- Delay to be encountered between two points,
- Time to be saved between two points by diverting to a specified alternative route,
- Delay to be avoided between two points by diverting to an alternative route, and
- Presentation of travel times for both the given route and one or more specified alternative routes.

In 1979, human factors studies conducted by Huchingson and Dudek showed that motorists were more likely to consider diverting because of a time savings value than to an identical delay time value (*6*). A time savings value explicitly compares the primary travel time to the alternative route, whereas delay values require the motorist to estimate how much longer it will take to bypass congestion via an alternative route and whether the increased travel time on the alternative route is offset by the delay expected on the primary route. From this study, the 50th-percentile motorist considered diverting if a delay of 15 to 20 min or greater were indicated or if a time saved value of 5 to 10 min or greater was displayed.

Research indicates that motorists do not always perceive a given delay or time saved value identically in all situations. In a 1984 study conducted by Huchingson et al. (*7*), the 50th-percentile motorist considered diverting if a message indicated 5 to 10 min or more of delay was present (as compared to the 15 to 20 min found for the 50th-percentile motorist in the earlier study). Several differences in the way the two surveys were administered could account for some of the differences in the results. However, it is apparent that motorist sensitivity to travel time information may not be identical for all driving situations. As summarized elsewhere (*8*), the findings of other studies indicate that diversion decisions are influenced by various alternative route characteristics, type of trips being made, and possibly demographic and socioeconomic characteristics of the driving population. It would seem logical that these factors might interact with the travel time information in affecting diversion decisions as well. In other words, motorist diversion decisions based on travel time information might vary depending on the alternative routes available in the corridor, the type of trip being made, the time of day, and so forth. These potential interactions were the focus of the surveys described in the remainder of this paper.

STUDY PROCEDURES

Study Objectives

Three corridor attributes were examined in this study by determining motorists' time saved threshold values for each of several hypo-

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thetical traffic messages. A time saved threshold value represents the minimum amount of time savings a subject would require before considering diversion to the recommended alternative route. It was assumed that a subject would also consider diverting at any time saved value that was larger than the threshold value. Thus, the number of subjects that would consider diverting at a given time saved value would be the sum of those reporting that value as their threshold plus all subjects having a smaller threshold value. The objectives of this research were to

1. Determine whether motorist-reported time saved threshold values depend on the type of alternative route specified in a traffic message;
2. Determine whether the threshold values depend on the location in the corridor where motorists are told to divert; and
3. Determine whether the threshold values depend on how far upstream from the congestion on the primary route motorists are told to divert.

This study assumed that motorists would place confidence in the accuracy of the diversion messages presented. However, as will be seen in the results that follow, some study subjects were reluctant to assume total accuracy. Instead, they appeared to balance the magnitude and likelihood of the travel time benefits being promised in the message against the repercussions they might endure if the information were wrong.

Description of the Study

The study was accomplished through two short telephone surveys of a group of 44 subjects known to travel the North Central Expressway in Dallas, Texas, to and from work. These subjects were assumed to be familiar with the routes and traffic characteristics of that corridor. Subjects were recruited with assistance of two major employers located in the Dallas central business district (CBD). Subject selection was designed to yield employees who drove their own automobiles to work daily, lived in a specific region of the Dallas metropolitan area, and normally used the North Central Expressway for their home-to-work trip. In this way, it was possible to limit the study sample to those having a common trip purpose and nearly identical origin-destination characteristics.

With approval of each of the employers, subjects were contacted on two weekday mornings to participate in a 5- to 10-min survey administered over the telephone. Subjects were called at work in the morning in order to facilitate their recall of travel conditions on the North Central Expressway during a normal trip to work. On each day, subjects were read a series of four traffic messages in random order, and asked to envision themselves receiving these messages over the radio as a traffic advisory broadcast. The subjects were asked how much time they would need to save (i.e., promised in the traffic message) to cause them to consider diverting. Afterward, subjects were questioned about their responses to gain insight into the reasons for any differences in time saved threshold values provided from one message to the next. No monetary incentives were provided to subjects participating in this survey.

North Central Expressway Corridor

The North Central Expressway (US-75) extends from the eastern side of the Dallas CBD through north Dallas. The expressway borders the small cities of Highland Park and University Park and passes through the satellite communities of Richardson and Plano farther to the north (see Figure 1). Built in the 1940s, the four-lane divided highway currently carries approximately 130,000 vehicles per day and experiences severe congestion during much of the day over the 14.9 km (9.3 mi) between the Lyndon Baines Johnson (LBJ) Freeway (I-635) and the CBD. It is currently undergoing major reconstruction; however, no lane closures are allowed on the freeway during the peak periods.

Two major interchanges are located on the expressway within the study corridor. On the northern end of the section is a fully directional freeway-to-freeway interchange with I-635. The design of the interchange is insufficient to accommodate certain traffic demands, and it usually causes congestion on the expressway. Approximately midway between LBJ Freeway and the CBD, a second interchange provides cloverleaf connections between the expressway and Northwest Highway (Loop 12). In the vicinity of the expressway, Northwest Highway is a six-lane divided arterial street with closely spaced traffic signals. Frontage roads that parallel the expressway are not continuous after the I-635 or the Northwest Highway interchanges.

Several north-south arterials parallel the expressway in this part of Dallas. Of these, Greenville Avenue is the most highly used arterial in the corridor (*9*). Its close proximity and easy access to the east side of the expressway (less than one-block separation in some locations) also make it a prime alternative route for expressway motorists during incident conditions. To the west, the Dallas North Tollway (a controlled-access toll facility) is located approximately 4.0 to 4.8 km (2.5 to 3 mi) from the expressway, providing the fastest means of north-south travel in the corridor during peak periods (*9*). It is also a viable alternative route to the expressway for some motorists in the north Dallas area.

Table 1 summarizes the morning peak period and peak hour travel times on the expressway, the tollway, and Greenville Avenue between LBJ Freeway and the CBD. As can be seen, the tollway provides the quickest trip downtown (13 min on the tollway, 18 min on the expressway, and 22 min on Greenville Avenue during the peak hour). However, there is a fee for using the toll facility, which discourages some motorists from using it and preserves its higher speed operation.

Description of Traffic Messages Evaluated

Eight traffic messages that varied the three corridor attributes evaluated in this study were developed. The three attributes studied were as follows:

- Alternative route recommended in the message in order to save time,
- Location where motorists were told to divert from the expressway, and
- Location where the problem was said to exist on the expressway.

For example, Greenville Avenue was specified as the alternative route in one-half of the messages, whereas the Dallas North Tollway was recommended in the remaining messages. Likewise, subjects were told to divert either at the LBJ Freeway interchange, or at the interchange of the expressway with Northwest Highway. Finally, the location of congestion in the messages was specified as either immediately downstream of the location where diversion to the alternative route was recommended, at a cross-street approximately

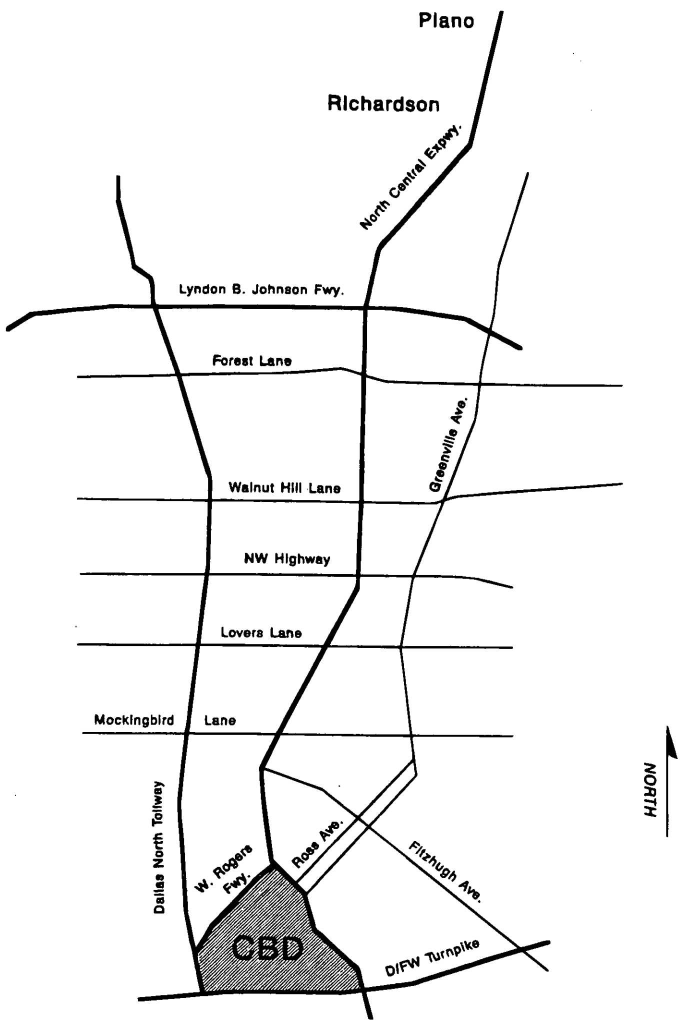

FIGURE 1 Schematic of North Central Expressway corridor in Dallas, Texas.

1.6 km (1 mi) downstream of the recommended point of diversion, or at a cross-street approximately 4.8 km (4 mi) downstream.

The remaining components of the traffic message were kept constant. The type of incident creating congestion was always specified as an accident. In addition, information about the length of congestion provided in the messages was kept constant at 1.6 km (1 mi), using major cross-streets as reference points. Table 2 summarizes the key features of each of the traffic messages used in the study. The study was conducted as two separate surveys on different days, with four messages evaluated on one day and the remaining four on the second day (it was believed that subjects would not have the time or motivation to provide high-quality evaluations of all eight messages during one study).

Data Collection Procedures

As part of each survey, researchers asked subjects to imagine themselves driving to work during their normal daily commute when they receive a traffic advisory alert over their automobile radio. The researcher would then recite one of the four traffic messages sched-

TABLE 1 North Central Expressway Corridor Travel Times (9)

Time Period	Average Travel Time from LBJ Freeway to Dallas CBD, Minutes		
	North Central Expressway	Dallas North Tollway	Greenville Avenue
AM Peak Period	14.3	12.5	21.4
AM Peak Hour	18.1	13.1	22.4

TABLE 2 Traffic Messages

Message Number	Corridor Characteristic			Message
	Alternative Route	Diversion Location	Congestion Location	
1	Greenville Avenue	LBJ Freeway	LBJ Freeway	ATTENTION SOUTHBOUND TRAFFIC ACCIDENT AT WALNUT HILL LANE CONGESTION BEGINS AT LBJ FREEWAY EXIT LBJ FREEWAY EASTBOUND TAKE GREENVILLE AVENUE TO DOWNTOWN SAVE -- MINUTES
2	Dallas North Tollway	LBJ Freeway	LBJ Freeway	ATTENTION SOUTHBOUND TRAFFIC ACCIDENT AT WALNUT HILL LANE CONGESTION BEGINS AT LBJ FREEWAY EXIT LBJ FREEWAY WESTBOUND TAKE DALLAS NORTH TOLLWAY TO DOWNTOWN SAVE -- MINUTES
3	Greenville Avenue	Northwest Highway	Northwest Highway	ATTENTION SOUTHBOUND TRAFFIC ACCIDENT AT FITZHUGH AVENUE CONGESTION BEGINS AT NORTHWEST HWY EXIT NORTHWEST HIGHWAY EASTBOUND TAKE GREENVILLE AVENUE TO DOWNTOWN SAVE -- MINUTES
4	Dallas North Tollway	Northwest Highway	Northwest Highway	ATTENTION SOUTHBOUND TRAFFIC ACCIDENT AT FITZHUGH AVENUE CONGESTION BEGINS AT NORTHWEST HWY EXIT NORTHWEST HIGHWAY WESTBOUND TAKE DALLAS NORTH TOLLWAY TO DOWNTOWN SAVE -- MINUTES
5	Dallas North Tollway	LBJ Freeway	Forest Lane	ATTENTION SOUTHBOUND TRAFFIC ACCIDENT AT NORTHWEST HWY CONGESTION BEGINS AT FOREST LANE EXIT LBJ FREEWAY WESTBOUND TAKE DALLAS NORTH TOLLWAY TO DOWNTOWN SAVE -- MINUTES
6	Greenville Avenue	LBJ Freeway	Forest Lane	ATTENTION SOUTHBOUND TRAFFIC ACCIDENT AT NORTHWEST HWY CONGESTION BEGINS AT FOREST LANE EXIT LBJ FREEWAY EASTBOUND TAKE GREENVILLE AVENUE TO DOWNTOWN SAVE -- MINUTES
7	Dallas North Tollway	LBJ Freeway	Northwest Highway	ATTENTION SOUTHBOUND TRAFFIC ACCIDENT AT FITZHUGH AVENUE CONGESTION BEGINS AT NORTHWEST HWY EXIT LBJ FREEWAY WESTBOUND TAKE DALLAS NORTH TOLLWAY TO DOWNTOWN SAVE -- MINUTES
8	Greenville Avenue	LBJ Freeway	Northwest Highway	ATTENTION SOUTHBOUND TRAFFIC ACCIDENT AT FITZHUGH AVENUE CONGESTION BEGINS AT NORTHWEST HWY EXIT LBJ FREEWAY EASTBOUND TAKE GREENVILLE AVENUE TO DOWNTOWN SAVE -- MINUTES

uled for that day (depending on the order required by the statistical design). At the end of the message, the researcher asked the subject whether he or she would consider diverting in response to the message if the amount of time saved was said to be 5 min. If the subject said yes, the researcher moved to the next message. If the subject responded negatively, the researcher repeated the last part of the question, asking the subject if he or she would divert if the time saved value was said to be 10 min. Each time the subject said no, the time saved value was increased. Once the subject said yes, the researcher recorded that particular time saved value as that individual's threshold value to that message, then moved to the next traffic message and repeated the sequence. Subjects generally had no difficulties in understanding the survey administrator's instructions or in responding to the questions at the end of each traffic message.

Once threshold values to the different messages were obtained, subjects were asked to explain any differences in values they gave for the various messages. Study personnel used an open-ended question format in this phase of the survey. At the conclusion of the second survey, data were collected regarding each subject's normal work trip travel habits. These data included an estimate of their normal arrival time at work, the time they are expected to be at work, the level of importance the subject placed on arriving at work on time, and average trip duration under normal conditions. No attempt was made to counterbalance any of these data in the study design.

Subject Demographics

Table 3 summarizes the basic demographic characteristics of the subjects participating in the study. Males were slightly overrepresented in the sample (57 percent). Most subjects (93 percent) were between the ages of 25 and 54 years. Only 2 percent were younger than 25, and only 5 percent were older than 55. It should be remembered that subject selection was based on origin-destination patterns and expressway usage; no attempt was made to balance the demographics of the subject groups.

Data on the subjects' normal home-to-work trips are also presented in Table 3. As shown in the table, the majority of the subjects normally arrive at work between 7:00 and 8:30 a.m. However, approximately one-third (32 percent) indicated that they arrived before 7:00 a.m. Although not asked of the subjects directly, it became apparent through the surveys that at least one employer maintained a flextime policy for its employees.

The distribution of arrival times over the morning peak period resulted in a wider range of travel times than had originally been hoped for in the subject selection process. Table 3 also shows the average reported travel times for subjects arriving at work before 7:30 a.m. and at 7:30 a.m. or later. For the former group, average travel times were less than 26 min, whereas they were almost 49 min for the latter group (even though both groups traveled the same approximate distances). Thus, although the selection process did yield subjects with homogenous origin-destination patterns, there were some differences as to when during the peak period these subjects traveled each day and the traffic conditions they normally encountered when traveling at those times.

RESULTS

Average Time Saved Threshold Values

Table 4 summarizes the average time saved threshold value for each of the eight traffic messages examined in this study. Also shown are the standard deviations of the threshold values. Average time saved thresholds ranged from a low of 10.2 min for Message 5 to a high of 17.6 min for Message 2. Furthermore, substantial variation was evident in the threshold values from one subject to the next, as evidenced by the large standard deviations obtained for the different messages.

The similar averages for the different messages does not mean that all subjects provided identical threshold values for all messages. By grouping the subjects according to the messages for which they provided different time saved threshold values, it was possible to confirm that many subjects did indeed have specific preferences regarding where they would divert, which routes they would use, and so forth. For example, by placing all subjects who selected a lower threshold value for the message recommending Greenville Avenue (as compared to the message recommending the Dallas North Tollway) into one subgroup and those having a lower threshold value when the tollway was recommended in another subgroup, substantial differences among the subgroups were evident.

Table 5 summarizes the average values of these subgroups. For the subgroup with lower threshold values when Greenville was recommended (Messages 1,3,6,8), an additional 7 min (19 min – 12 min), on the average, was needed to get them to use the tollway if it was recommended (Messages 2,4,5,7). Conversely, subjects selecting lower threshold values when the tollway was recommended would require an average of 12 more min (21 min – 9 min) of time saving before they would consider diverting to Greenville Avenue.

TABLE 3 Subject Demographics and Travel Characteristics

Category	Value (n=44)
Gender Distribution:	
males	57%
females	43%
Age Distribution:	
less than 25	2%
25 to 39	43%
40 to 54	50%
greater than 54	5%
Work Arrival Time Distribution:	
before 6:30 am	16%
6:30 - 6:59 am	16%
7:00 - 7:29 am	23%
7:30 - 7:59 am	23%
8:00 - 8:29 am	18%
8:30 am or later	2%
flextime	2%
Required Work Start Time Distribution:	
before 6:30 am	5%
6:30 - 6:59 am	2%
7:00 - 7:29 am	27%
7:30 - 7:59 am	14%
8:00 - 8:29 am	48%
8:30 am or later	2%
flextime	2%
Average Work Trip Travel Time:	
those travelling before 7:30 am	25.8 min.
those travelling after 7:30 am	48.6 min.
those on flextime	50.0 min.

TABLE 4 Time Saved Threshold Values by Message

Message Number	Corridor Characteristic: Alternative Route	Diversion Location	Congestion Location	Value, Minutes: Average	S. Deviation
1	Greenville Avenue	LBJ Freeway	LBJ Freeway	13.9	8.9
2	Dallas North Tollway	LBJ Freeway	LBJ Freeway	17.6	9.4
3	Greenville Avenue	Northwest Highway	Northwest Highway	14.5	5.8
4	Dallas North Tollway	Northwest Highway	Northwest Highway	15.5	7.5
5	Dallas North Tollway	LBJ Freeway	Forest Lane	10.2	8.2
6	Greenville Avenue	LBJ Freeway	Forest Lane	12.5	9.0
7	Dallas North Tollway	LBJ Freeway	Northwest Highway	12.6	12.6
8	Greenville Avenue	LBJ Freeway	Northwest Highway	17.4	10.0

TABLE 5 Average Time Saved Threshold Values by Subgroup

Traffic Messages	Average Time Saved Threshold Value, Minutes: Subgroup with Lower Values for Greenville	Subgroup with Lower Values for DNT
Messages Recommending Use of Greenville	12	21
Messages Recommending Use of DNT	19	9
	Subgroup with Lower Values for LBJ Fwy	Subgroup with Lower Values for Northwest Hwy
Messages Recommending Diverting at LBJ Fwy	13	18
Messages Recommending Diverting at Northwest Hwy	23	12

DNT = Dallas North Tollway
LBJ Fwy = Lyndon B. Johnson Freeway (I-635)

A similar distinction can be made about the location where diversion was recommended. The subgroup with lower thresholds for diverting at LBJ Freeway would require 10 more min (23 min – 13 min) of time savings before considering diverting at Northwest Highway, whereas those selecting a lower threshold to divert at Northwest Highway would require an additional 6 min (18 min – 12 min) before diversion at LBJ Freeway would be considered. Because most subjects gave identical threshold values for the different congestion locations examined in Experiment 2, averages subgrouped by this variable were not included in Table 5.

Statistical comparisons of the averages reported in Table 5 were not attempted because the time saved threshold distributions were found to be nonnormal. Instead, differences in the threshold values for the different messages were analyzed through comparison of the distributions of the time saved thresholds and through analysis-of-variance techniques. The results of those analyses are discussed in the following sections.

Cumulative Distributions of Time Saved Threshold Values

Figure 2 presents graphs showing the percent of subjects who would consider diverting when presented with time saved values ranging from 5 min to 2 hr. Also shown in the graphs are the results of the 1979 Huchingson and Dudek study of time saved messages (*6*). The top portion of Figure 2 illustrates subject responses when the messages instructed them to divert at the LBJ Freeway and to use Greenville Avenue or the Dallas North Tollway (Messages 1 and 2, respectively). The bottom portion of Figure 2 displays similar information when subjects were instructed to divert at Northwest Highway, again either to Greenville Avenue or to the Dallas North Tollway (Messages 3 and 4, respectively).

The percent of subjects indicating they would consider diverting to a given time saved value when Greenville Avenue was the recommended route was slightly greater than that when the Dallas North Tollway was recommended. Numerically, the lines diverge most at a time saved value of 15 min (by 17 to 19 percent). Because of the fairly small sample size available for this analysis, however, these differences were not statistically significant [based on a Kolmogorov-Smirnov goodness-of-fit test (*10*)]. Examination of the effect of the recommended diversion location for each of the recommended alternative routes (by comparing the Greenville and Dallas North Tollway lines from each graph) also showed no statistically significant effect.

The graphs in Figure 3 show the time saved distributions of subjects for Messages 5 through 8. In both graphs, the distributions again show that subjects tended to have slightly lower threshold values for Greenville Avenue as compared to the Dallas North Tollway, regardless of the reported location where congestion was

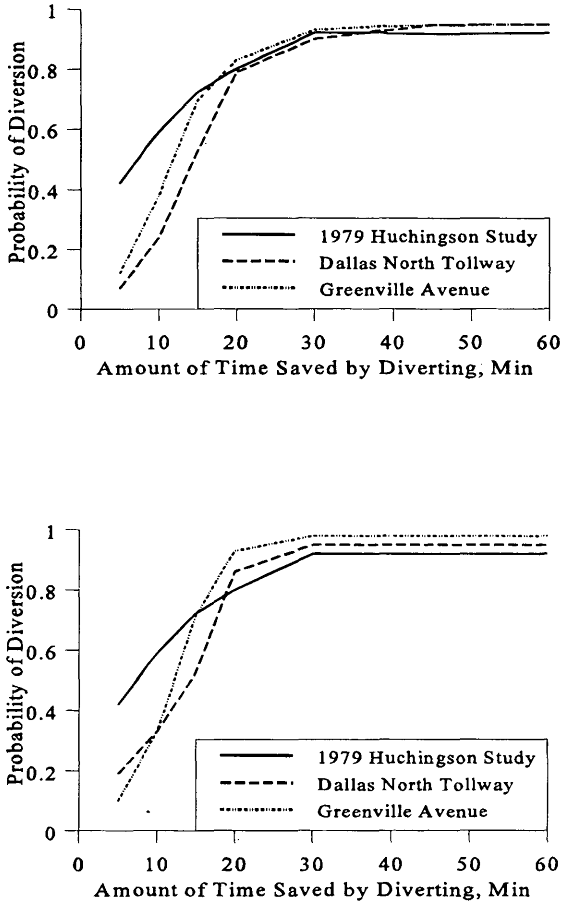

FIGURE 2 Effect of recommended route on percent of subjects considering diversion at a given time saved value for Messages 1 through 4.

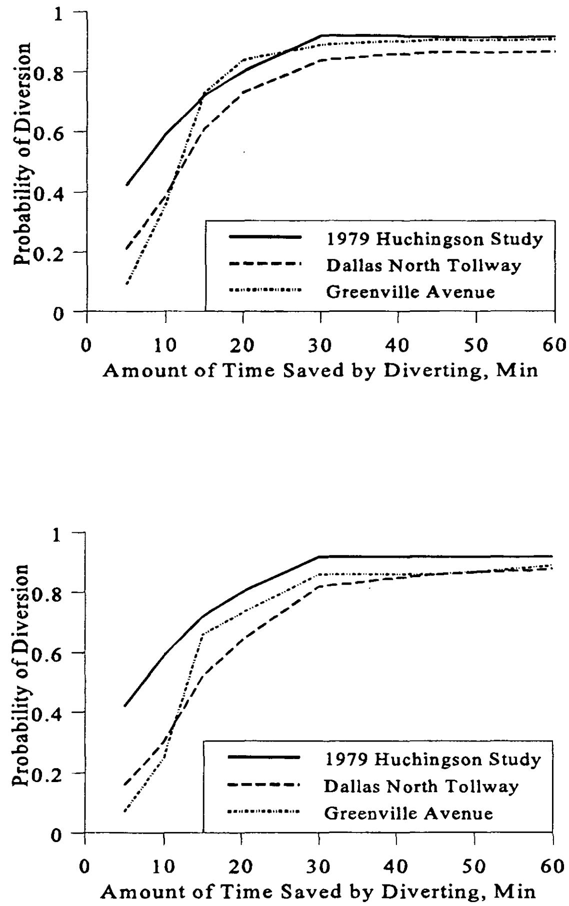

FIGURE 3 Effect of recommended route on percent of subjects considering diversion at a given time saved value for Messages 5 through 8.

said to begin (Forest Lane or Northwest Highway). However, the differences in distributions were not statistically significant. Likewise, comparing the Greenville Avenue and Dallas North Tollway distributions across the two graphs also suggested no significant difference due to the reported location of congestion.

Although the curves representing the current study data are not significantly different from each other, they are different from the results of the Huchingson and Dudek study (*6*). Subjects in the Huchingson study were sensitive to very small time saved values, with the 50th-percentile subject considering diversion when a time saved value between 5 and 10 min was presented. Conversely, data from the current study show that the 50th-percentile subject required 10 to 15 min of time savings before considering diversion. The results from this more recent study were statistically different from the previous Huchingson study, based on the Kolmogorov-Smirnov test at a 0.05 level of significance.

It should be noted that study techniques of the two studies were quite different. Huchingson brought subjects into a laboratory to participate, whereas the current study was conducted by telephone. Subjects in the Huchingson study were presented a driving scenario to a special event in a city in which they lived, but no attempts were made to control for how familiar subjects were with the specific roadways (both primary and alternative) used in the study, or how often they used these roadways. Conversely, the current study focused on peak period commuting trips by subjects who were presumed to be quite familiar with the roadways available in the freeway corridor. In fact, informal discussions with the subjects during this latest survey indicated that many actually experimented with the different routes in the corridor periodically.

Analysis-of-Variance Evaluation

Other research (*3*) has suggested that the numerous subgroups within the driving population can each have distinct attitudes, perceptions, and behavioral tendencies with respect to diversion. Despite the steps that were taken to select a uniform sample population for testing purposes, it was believed that the differences within the study sample with respect to age, gender, average travel time for the trip, and the like may have affected their sensitivity to travel time information in making diversion decisions. To investigate this possibility, the demographic and travel characteristic data collected from each subject were combined with the recommended route, diversion location, and point of congestion variables of the study design in an analysis-of-variance (ANOVA) evaluation. In this way, effects of the message variables on average time saved thresholds could be systematically assessed for different subgroups of the sample.

Because of the study design, separate ANOVA evaluations were performed on the data from each survey. Furthermore, because the study was not designed to completely counterbalance the subject demographic and travel characteristics, only one subject variable at a time was combined with the corridor characteristic variables in the analysis. Hence, the analysis for each experiment tested several three-factor models, all of which included (*a*) a subject variable (demographic or travel characteristic), (*b*) the recommended route variable, and (*c*) the recommended diversion location or the location of the beginning of congestion variable (representing Studies 1 or 2, respectively).

Subject variables explored in the ANOVA evaluations included the following:

- Age,
- Gender,
- Employer,
- Usual arrival time at work,
- Required work start time,
- Difference between the subject's reported time of arrival and required work start time (the arrival time cushion),
- Subject rating of the importance of arriving to work on time, and
- Normal home-to-work travel time.

Subject time saved thresholds values were modeled as a function of the recommended route, diversion location or congestion location, and one of the subject variables listed. Unfortunately, none of the models tested were found to be statistically significant at a 0.05 level of significance, and only two fell within a much less stringent 0.10 level of significance. Details concerning the ANOVA evaluation can be found elsewhere (*8,11*).

Reasons for Individual Differences in Time Saved Thresholds by Message

The reasons some subjects selected a higher time saved threshold value for one route or diversion location over the other are provided in Table 6. Several subjects cited anticipated congestion on the roadways used to access the Dallas North Tollway (via either LBJ Freeway or Northwest Highway) as a reason why they would require a greater time savings to divert to the tollway than to Greenville Avenue. Reasons that were originally expected to be significant in their decisions regarding the use of the tollway, such as the greater distance from the North Central Expressway or the cost for using it, were cited only a few times. On the other hand, the most common reason cited by those subjects requiring a greater time savings before diverting to Greenville was the presence of traffic lights and stop signs and poor past experiences with using that route. Judging from these reasons, it appears that the subjects were basing their time saved thresholds on how much they disliked one or the other of the recommended routes (and not on which route they preferred).

Conditions on the access roads to the alternative route were another factor that caused subject thresholds to differ depending the recommended diversion location. For those subjects selecting lower time saved thresholds to divert at LBJ Freeway, the reason cited most frequently was that they perceived access to either Greenville Avenue or the tollway to be more difficult via Northwest Highway. Another common reason cited was that the network south of Northwest Highway did not allow for an easy return to the expressway beyond the point of congestion. Thus, some subjects said they needed a bigger incentive before attempting to follow any recommended diversion advice at Northwest Highway.

For subjects selecting lower time saved thresholds for diverting at Northwest Highway, the most common reason was that in diverting so far away from their destination (at LBJ Freeway) they were more likely to encounter a problem on the alternative route and be delayed anyway. Another common reason cited was the poor travel conditions on LBJ Freeway, which made it difficult to access the alternative routes at that point.

Taken together, the various reasons cited for different time saved threshold values suggest a lack of confidence in the information provided in the traffic messages being tested. In essence, subjects balanced the benefits of diversion (as defined in the traffic message) against the risk of acting on inaccurate information.

TABLE 6 Reasons Given for Selecting Different Time Saved Threshold Values

Reasons	Percent[a]
For Higher Threshold Values to Divert to the DNT:	
• Roads accessing DNT (LBJ Freeway, Northwest Hwy) are too congested	75
• The Tollway is farther away from the Expressway	8
• It is difficult to return to the Expressway once at the Tollway	8
• The Tollway requires a fee to use	9
For Higher Threshold Values to Divert to Greenville:	
• Too many traffic lights, stop signs on Greenville	58
• Had poor experience with Greenville in the past	42
For Higher Threshold Values to Divert at LBJ Freeway:	
• Diverting farther away from destination increases risk of encountering problems	50
• Had poor experience with LBJ Freeway congestion in the past	31
For Higher Threshold Values to Divert at Northwest Hwy:	
• More difficult to access alternative routes at Northwest Hwy	36
• Hard to return to the Expressway from alternative route south of Northwest Hwy	14

[a] Some subjects gave multiple reasons, so percentages do not necessarily add to 100

SUMMARY

This paper has presented the results of telephone surveys conducted to assess the effects of selected corridor attributes on motorist time saved threshold values. The corridor attributes evaluated in this research were the type of recommended alternative route, the location where motorists were advised to divert to the recommended alternative route, and the location where congestion was said to begin relative to the location where motorists were advised to divert. The surveys used subjects who regularly drove on the North Central Expressway in Dallas, Texas, for their daily home-to-work trip to the Dallas CBD. The major results of the study are as follows:

- The cumulative distribution of subjects' time saved threshold values were not statistically significant as a function of the recommended route, diversion location, or location where congestion was said to begin. However, many subjects did select different threshold values for one or more messages.
- Although the cumulative percentages for the different messages were not found to differ significantly from one another, all were found to differ significantly from those obtained from Huchingson and Dudek in 1979. Whereas the 50th percentile subject in the Huchingson study considered diversion if the time saved value was between 5 and 10 min, the 50th percentile subject in this study required a nearly 15-min time savings before he or she would consider diverting.
- ANOVA procedures used to examine the effect of the corridor features on motorist time saved threshold values failed to detect any consistent differences in time saved thresholds for several different demographic or trip-related subgroups.
- Explanations provided by the subjects suggest that the different threshold values provided by subjects are generally due to an aversion to one or the other of the alternatives instead of any specific preference for one of the alternatives.

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Stated and Reported Route Diversion Behavior: Implications of Benefits of Advanced Traveler Information System

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Advanced Traveler Information System (ATIS) user benefits are estimated from a survey of commuting behavior undertaken in the San Francisco Bay Area in 1993. Reported and stated responses to unexpected congestion are used to determine the commuters who would directly benefit from qualitative, quantitative, predictive, and prescriptive ATIS information. Under incident conditions, ATIS quantitative delay information may induce about 40 percent of the commuters to change their route to work, mostly the people with greater diversion opportunities, knowledge of more alternative routes, and lower congestion levels on their best alternative route. The travel time savings achieved by ATIS-induced route diversion (with quantitative information) is calculated and translated into monetary benefits. The value of time used is a function of personal income and of the time savings. The frequency of annual diversion is estimated from the time elapsed since the last incident. The potential annual benefits from ATIS route diversion, applicable to about 40 percent of commuters in the Golden Gate Bridge corridor, range from $124 to $324 per person, depending on the weight assumed for delay.

Advanced Traveler Information Systems (ATIS) are intended to help people make more informed travel decisions. Computerized information systems could support pre-trip decisions, such as departure time, destination choice, and trip chaining sequence, as well as route selection and diversion while en route.

The successful introduction of ATIS in the market depends on the net benefits to users. Time savings achieved when a user changes routes to avoid incident-induced bottlenecks will probably be among the most tangible benefits of ATIS. This study intends to evaluate the extent of such benefits, using the results of a survey about commuting behavior. The survey is used to determine who would divert when prompted to do so by an ATIS device, how these people value their time, how much time they would save by diverting, and consequently, how much they would benefit from a route change.

CONCEPTUAL STRUCTURE AND SYNTHESIS OF LITERATURE

Benefits of ATIS

ATIS benefits can accrue to users and nonusers of the device, as well as to the transportation system as a whole.

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User Benefits

The main user benefits of ATIS will be travel time savings from fewer errors when driving in unfamiliar areas and from avoiding unexpected congestion by changing travel decisions such as destination, mode, departure time, route, en route diversion, parking, and trip chaining. There are also many less tangible, but important, benefits:

- Increased knowledge of travel options (e.g., yellow pages information),
- Reduced anxiety—even if travelers do not change their travel decisions,
- Greater likelihood of arriving on time at destination,
- Enhanced ability to avoid congestion,
- Improved ability to communicate during emergencies, and
- Reduced possibility of getting lost.

System Benefits

Transportation system benefits of ATIS may include reductions in trip time, air pollution, and energy consumption, as well as greater safety. System benefits are more than the aggregate of user benefits. Indeed, certain impacts, such as reduced energy consumption, less air pollution, and lower probability of accidents, might be too small to be perceived at the user level but become very important at the system scale.

This study focuses on the *user* benefits of route diversion. Although a wider definition of ATIS user benefits is possible, only time saving for people with access to ATIS devices is considered.

Propensity to Divert

The extent to which user and system benefits of ATIS can be achieved is a function of how travelers respond to information. Researchers have found that drivers are willing to divert in response to prescriptive and descriptive traffic information and that this propensity increases with delays and congestion (*1–7*). In addition, longer trips, fewer traffic stops on alternative routes, and familiarity with alternative routes encourage diversion. Drivers who are young, male, or unmarried are more likely than others to divert.

Studies on diversion behavior conducted so far are insightful, but there is a need to quantify the effect of the type of information provided on drivers' diversion behavior. Is descriptive information enough? Are drivers willing to follow prescriptive information?

Does information about future travel time increase the propensity to divert? These are some of the questions addressed in this paper.

SURVEY CONTEXT

This paper is based on a survey about commuting behavior undertaken in the San Francisco Bay Area in 1993 (*8*). The questionnaires were distributed to peak-period commuters crossing the Golden Gate Bridge during morning and afternoon rush hours. There might have been a self-selection bias among respondents, because they had to mail back the questionnaire. Money incentives for completing the survey were successful in achieving a good response rate: more than a third of the 9000 copies distributed were returned [see Khattak et al. (*8*) for details]. Half the questionnaires were concerned with en-route responses to unexpected congestion, and the other half looked at pre-trip response. The questionnaires inquired about normal travel patterns, unexpected congestion, willingness to pay for different ATIS features, and socioeconomics (*9*).

General Characteristics and Representativeness of Sample

Three-fifths (63 percent) of the 1492 respondents to the en-route questionnaire were male, and the average age of the sample was 43 years. Seventy-three percent of the respondents had at least a college degree; their major occupational fields were professional/technical (36 percent) and management (30 percent). The average annual personal income was $65,500, with 36 percent of the respondents earning more than $80,000 per year. Sixteen percent of the sample lived in one-person households, and 44 percent reported two-person households. Most respondents (57 percent) lived in Marin County and worked in San Francisco. The sample represents a middle-aged, well-educated, and wealthy segment of the population.

To evaluate the representativeness of the sample, it was compared with census data (*10*) and the Bay Area Travel Study (1990). Minor differences were found for the ratio of solo drivers to carpools, the average trip time to work, and the number of cars and persons per household (*11*). The differences were expected, given the method chosen to distribute the questionnaires. It was concluded that the sample, although it did not reflect the whole population of the area, provided a clear picture of the population commuting by car in the Golden Gate Bridge corridor.

Commuting Behavior of Respondents

Fifty-six percent of respondents stated that they selected their route to work before getting in the car; the remaining 44 percent chose it while on the road. A majority (97 percent) used at least some portion of a highway as their usual route. More than half of the respondents (53 percent) stated that they had at least one alternative route; for 37 percent of them, this route was an arterial. A third (33 percent) of those who had an alternative route did not use it in the past month, 19 percent used it once because of traffic congestion, 16 percent used it twice, and the remaining third (32 percent) used it three times or more.

Three-quarters (74 percent) of the respondents reported that they experienced unusual congestion on their usual route to work in the past three months; these people constitute the sample for the rest of this study. Information about the length and cause of delay, the weather at that time, and the way respondents learned about the congestion was obtained. Only 17 percent of the people could not give the cause of the delay. Forty-eight percent of the respondents learned about the incident by observing the congestion, and 11 percent learned through radio reports only. Twenty-four percent first observed the congestion and then received a confirmation from the radio, and 23 percent obtained the information in the opposite sequence. Respondents were asked how much they thought the congestion would add to their trip when they first learned about it (expected delay), and how much it actually added (experienced delay). On average, respondents expected a delay of 21.1 min but actually were delayed for 25.6 min. There is nevertheless a wide discrepancy between the expected and actual delay for a given respondent: the difference between the two values ranges from −70 to +75 min, and only 52 percent of the respondents were able to correctly estimate their delay within ±5 min. This suggests that an ATIS device giving accurate length of incident-related delays can fill a need.

Respondents were then asked about how they responded to this unexpected congestion while on the road; results are shown in Table 1, with the corresponding average delays. Only 21 percent of the respondents reported that they had an opportunity to divert. Most of those (78 percent) did divert.

Table 1 shows that about 9 percent of the total respondents modified their trip chaining sequence by adding or canceling some intermediate stops as a response to the unexpected congestion. Thus, a significant portion of commuters facing unexpected events responded by changing their activity sequencing. ATIS may be able to support such decisions by providing travelers with information about relevant activities (e.g., shopping places in the vicinity). For the remainder of this paper, respondents were simply divided into two basic categories: those who stayed on their usual route and those who diverted to the best alternative route.

REPORTED AND STATED PREFERENCES ABOUT DIVERSION PROPENSITY

The questionnaire was designed to use reported diversion behavior (a measure of the true behavior) as the basis of a sequence of stated

TABLE 1 Response to Unexpected Congestion on Usual Route and Corresponding Delays

Response	Proportion of Respondents[a]	Average Delay (min.) Expected	Experienced
Did not change travel plans	78.3%	20.3	24.9
Took alternate route	16.3%	22.8	24.4
Canceled intermediate stops	4.7%	18.8	26.5
Added unintended intermediate stops	4.0%	26.7	42.1[b]
Used public transportation after parking the vehicle	0.5%	20.0	28.0

[a]The numbers do not sum up to 100% because more than one answer is possible.
[b]Including the extra stops

preference questions about the propensity to divert with a future in-vehicle ATIS device. This methodology increases the validity of the stated preferences technique by relating the response to ATIS technology to a specific incident that was actually experienced by the respondent. The objective of the stated preference questions was to determine how incremental amounts of information provided by an ATIS device would influence the propensity to divert.

Travelers were asked to imagine starting once again, on the same day, the trip during which they experienced their most recent unexpected congestion. They were told not to be aware of any unexpected congestion before they got in their vehicle, until an in-vehicle ATIS device provided them with accurate traffic information. For each question, that is, for each level of information provided, respondents were asked whether they would divert to their best alternative route. They were asked to report this on a 1–4 scale, where 1 meant "I definitely take my usual route" and 4 meant "I definitely take my best alternative route." Respondents who answered either 3 or 4 were taken as showing a preference for diversion; results are shown in Table 2.

In the qualitative information question, the ATIS device does not provide more details than what was available to the driver when he or she first learned about the congestion. Qualitative traffic information equivalent to "unexpected congestion on your usual route" is available in the Bay Area; it is gathered by the commercial media and disseminated almost in real-time through radio traffic reports. Because the qualitative information context is comparable to the situation for which the behavior was reported, this question can be used to relate stated preferences to reported behavior (see Table 3). The sample size here is 895 because only respondents who faced unexpected congestion are included, and missing responses are eliminated on a listwise basis.

It appears that respondents overstated their propensity to divert when compared with reported behavior. One-fifth (22 percent) of the respondents stated that they would divert even though they reported not having diverted. On the other hand, only 5 percent of the people stated that they would not divert even though they actually diverted when they faced the unexpected delay. The correlation between the two variables is only 0.32. Some of the difference, however, might be explained, because respondents had more opportunities to divert in the stated preference questions, since they were asked to imagine that they were just starting their trip. Also, some respondents might have regretted not having diverted in the original trip; their expectation of the delay was later influenced by hindsight.

As seen in Table 2, the largest stated propensity to divert (69.3 percent of respondents) is obtained when the ATIS device also gives real-time information about traffic conditions on the alternative route. This result suggests that some respondents might be currently restrained from diverting by not knowing the conditions on their alternative route. When the complete picture is given, respondents might be more confident and consequently more inclined to divert.

TABLE 2 Route Diversion Behavior under ATIS

Type of information	Question	Proportion of Respondents Stating a Preference for Route Diversion
Current	Reported diversion behavior	16.3%
ATIS Qualitative	*The device knows your usual route and gives you the following message:* << Unexpected congestion on your usual route >> *but does not tell you how much of a delay this congestion is causing*	32.9%
ATIS Quantitative	Usual route, real-time *The device tells you the expected length of delay on your usual route at the present time (your initial estimate of delay)*	57.4%
	Usual route, forecast *The device tells you the length of delay at the present time, and accurately predicts the length of delay it will cause 15 to 30 minutes into the future*	61.6%
	Alternate route, real-time *The device tells you the length of delay at the present time, and provides information regarding present travel time on your best alternate route*	69.3%
ATIS Prescriptive	*The device tells you* << Unexpected congestion on your usual route >> *and suggests that you take your best alternate route*	67.5%

TABLE 3 Stated Preference versus Reported Behavior

		REPORTED BEHAVIOR		
		Does not divert	Diverts	Total
STATED PREFERENCE	Does not divert	**555**	**46**	**601**
		62.0%	5.1%	67.2%
	Diverts	**197**	**97**	**294**
		22.0%	10.8%	32.8%
	Total	**752**	**143**	**895**
		84.0%	16.0%	100%

A high proportion of respondents (67.5 percent) also stated that they would divert when provided with simple prescriptive information, that is, when the device suggests taking the best alternative route. Prescriptive information may be interpreted differently from other forms of information because it implies that the alternative route is the best option. Consequently, it may appear surprising that less diversion is obtained with this type of information (67.5 percent) than with detailed quantitative information (69.3 percent). This indicates that compliance rates may differ for prescriptive and quantitative information. Nevertheless, the relatively high diversion rate for prescriptive information indicates that, under incident conditions, some drivers are responsive to clear directions about the route to take (although they might still like to know details regarding the incident). Surprisingly, the decision to comply with prescriptive information does not appear to be influenced by the potential time savings. Indeed, people who stated they would comply to the prescriptive information were expecting to save, on average, as much time as those who did not.

The answers to the last four stated preference questions are closely correlated, indicating consistency in driver behavior. Indeed, people stating a preference either to divert or to stay on their usual route generally kept the same preference throughout the last four questions. However, the possible bias due to the ordering of the questions is recognized.

To explore further the correlation between reported behavior and stated preferences, a linear regression model relating the answers to each question was developed. The 1 to 4 scale of the stated preference questions was used. Reported diversion behavior was consequently recoded as 1 or 4 (no 2 or 3). All observations from the reported behavior and from the five stated preference questions were stacked in a single column vector, which thus contained six times the sample size. This vector was then related to a sequence of five dummy variables, flagging one when the observation was from the specific stated preference question. Reported preferences thus served as the base. The equation used is

$$DP = a_0 + \sum_{i=1}^{5} a_i SP_i$$

where:

DP = vector of observations on diversion propensity,
a_0 = constant,
a_i = coefficient to be determined by regression,
SP_i = 1 when the observation in DP is obtained from i and 0 otherwise.

The coefficients obtained reflect the influence of each stated preference variable in explaining the vector of observations and the increase in the probability of diversion given the additional information provided. The coefficients obtained are shown on Table 4; to account for correlation among responses of the same individual, the t-statistics should be reduced by a factor of 0.4. The constant reflects the base diversion propensity, that is, the reported diversion propensity. The value of a_1 corresponds to increased propensity of diversion with qualitative information. An even higher propensity of diversion is observed when drivers are provided quantitative information (a_2). However, additional details and prescriptive information do not induce significantly more diversion as reflected in the uniformity of coefficients a_2 to a_5.

TABLE 4 Coefficients of Stated Preferences Model

Coefficient	Value	t-stat. (p)
a_0 Constant term	1.36	44.6 (0.00)
a_1 Qualitative information	0.70	14.2 (0.00)
a_2 Quantitative information (usual route, real-time)	1.33	27.3 (0.00)
a_3 Quantitative information (usual route, forecast)	1.44	29.4 (0.00)
a_4 Quantitative information (alternate route, real-time)	1.58	31.6 (0.00)
a_5 Prescriptive information	1.56	32.1 (0.00)
Summary statistics:	$R^2 = 0.47$ Sample size = 1492	

WHO WOULD DIVERT UNDER ATIS?

The personal and contextual factors determining diversion propensity are explored and the consistency of the stated responses verified. Respondents were divided into four categories, according to their reported and stated diversion behavior (Table 5). The stated response was taken from the question generating the highest diversion rate, that is, when the device provides the most complete quantitative information, including travel times on the alternative route.

ATIS will benefit primarily the 54 percent of the sample who would change route when provided with the device. This figure applies only to the 74 percent of the sample who experienced unexpected delay; therefore, the proven percentage of commuters in the corridor who would change route with ATIS under unexpected congestion is actually around 40 percent.

To explore the characteristics distinguishing the first three groups (the fourth group is marginal and was ignored), discriminant analysis was performed by estimating two independent discriminant functions. These functions assign separate discriminant scores to each observation; both scores are then used to classify observations. The sample size here is only 376 respondents because missing cases are deleted on a listwise basis. The five variables best characterizing diversion behavior are presented in Table 6. The standardized coefficients assigned to each variable and their correlation with each function are indicated. Positive coefficients indicate a higher propensity to divert.

The existence of diversion opportunities is critical in determining diversion behavior. Furthermore, diversion propensity increases with the number of alternative routes known. Undivertable respondents know on average only 1.50 routes; those who could divert with ATIS, 1.73; those who currently divert, 1.94. The number of alternative routes known to travelers increases their possibilities of diversion; however, drivers also know more alternative routes because they tend to divert often. In this case, causality can actually work in both directions. Another important variable, the frequency of recreational trips, was found in previous research (*12,13*) to be a proxy measure of such personality characteristics as extroversion, achievement, and need for stimulus or adventure. The frequency of recreational trips does influence the propensity to divert with ATIS: nondiverting respondents travel on average 1.63 times per week for recreational purposes, and the people who could divert with ATIS do so 2.08 times per week. More diversion is also observed under bad weather conditions, as can be concluded from the sign of the weather coefficient. Finally, the presence of congestion on the alternative route acts as a deterrent to diversion. Nondiverting respondents have more congestion on their alternative route, using the

TABLE 5 Categories of Diversion Behavior

Category	Reported Diversion	Stated Diversion	Proportion of Respondents
1 Undivertable	NO	NO	29.3%
2 Could divert with ATIS	NO	YES	54.0%
3 Already diverts with current information	YES	YES	15.5%
4 No longer diverts with ATIS	YES	NO	1.3%

TABLE 6 Characteristics Determining Diversion Behavior

Variable	p value of F-statistic	Coeff. in 1st Function	Coeff. in 2nd Function	Corr. with 1st Function	Corr. with 2nd Function
Diversion opportunities (1 = yes, 0 = no)	0.00	**+1.00**	-0.02	**0.99**	0.00
Number of alternate routes known	0.00	+0.02	**0.69**	0.07	**0.71**
Frequency of recreational trips (times/week)	0.02	-0.08	**0.59**	-0.03	**0.62**
Weather (0 = good, 1 = bad (rain or fog))	0.01	0.01	**0.29**	-0.08	**0.23**
Congestion on best alternate route (1 = not congested, 2 = congested, 3 = heavily congested)	0.03	-0.11	**-0.24**	-0.07	**-0.32**
Summary statistics:					
Canonical correlation:		0.86	0.21		
% correctly classified: 65%					
Sample size: 376					

following scale: 1 = not congested, 2 = congested, 3 = heavily congested (their average congestion was 1.88), followed by the people who would divert with ATIS (1.72), and by the people who already divert (1.51). Although not significant at the 5 percent level, the number of stops on the usual route was also found to decrease with the propensity to divert: as expected, people constrained to stop on their usual route have less flexibility in changing route.

All these findings are consistent with what was expected and increase the confidence in the validity of the stated preference technique.

CALCULATION OF ATIS BENEFITS FROM ROUTE DIVERSION

Time Savings

The potential time-saving benefits achieved by diverting under ATIS are calculated here, using responses to the most complete quantitative information (highest stated diversion rate). The calculation applies to the 40 percent of respondents who would change their commuting behavior when provided with ATIS (N = 597). It does not include the potential time saving that other road users may experience or the extra delay that may occur on alternative routes once a larger number of vehicles are diverted.

The saving from route diversion is simply the delay minus the time difference between the alternative and usual routes. To account for the fact that time spent in a bottleneck is usually more onerous than normal in-vehicle travel time, a weight has been associated with delay. Because this weight is a subjective measure and has a direct influence on the final result, a sensitivity analysis was performed using weights ranging from 1.0 to 2.0.

Figure 1 presents the distribution of travel time savings that would accrue to people who stated they would divert to their alternative route. With a delay weight of one, 14 percent of the diverters would actually lose time by taking their best alternative route, 9 percent would see no change in their total travel time, and 77 percent would save some time. The average time savings is summarized in Table 7.

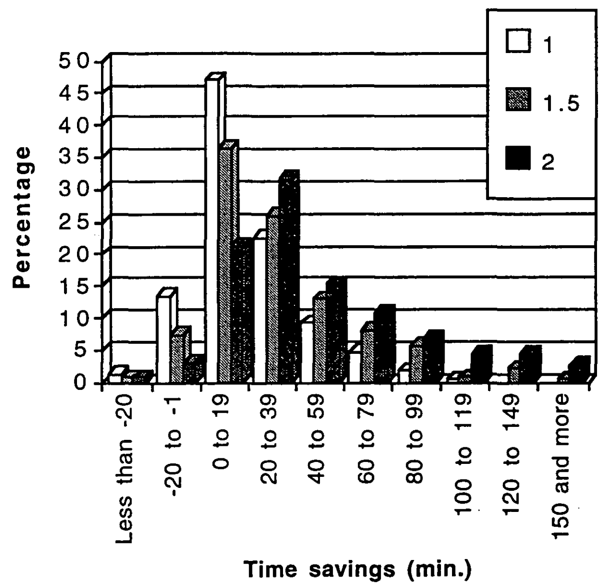

FIGURE 1 Distribution of travel time changes among people who stated they would divert to alternative route under ATIS, as a function of weight of delay.

TABLE 7 Route Diversion Benefits of ATIS under Incident Conditions

Weight of Delay Compared to Travel Time	Average Time Savings from Diversion (min.)	Proportion of People with Negative Savings	Monetary Savings per Trip with Diversion	Potential Annual Benefits of ATIS-induced Route Diversion
1.00	17	14.4%	$4.80	$124
1.25	24	12.9%	$6.60	$174
1.50	30	8.1%	$8.40	$224
1.75	37	6.3%	$10.20	$274
2.00	43	3.7%	$12.00	$324

Monetary Value of Time

To attach a monetary value to time saving, an estimate of the value of time for each respondent is needed. This value was taken as a fraction of the personal hourly income (*14*) to account for personal differences in the valuation of time. The value of travel time saving also depends on the amount of time freed for other purposes: a saving of a few minutes might not be important because it is too small to be used productively (*15*). Consequently, to avoid aggregating a large number of negligible time savings, the value of time was assumed to increase with greater time saving.

The function used is presented in Figure 2; it is adapted from a method presented by AASHTO (*15*). Travel time variations of ±5 min are valued at 10 percent of the personal hourly income. Those larger than 15 min are evaluated using a value of 50 percent of the hourly income. Negative time saving (increases in travel time) is valued similarly.

Money Benefits of Route Diversion

Figure 3 presents the distribution of monetary savings that would be achieved through route diversion under unexpected congestion. This was calculated by combining the time saving with the values of time for every respondent. The average savings for the sample is $4.80 per trip; this value includes the 14 percent of people who lose time by diverting. These people have been kept in the average to reflect that (a) any ATIS will not be perfectly accurate and might advise a small proportion of travelers to take routes that are actually longer and (b) some people are willing to lose travel time to avoid bottlenecks.

Annual Frequency of Route Diversion

The values presented in the previous section apply to a single trip with route diversion. To evaluate the annual benefits of such diversions, it is necessary to estimate how frequently they would occur. A precise measure of diversion frequency could be obtained using traffic and incident data in the corridor. For every origin-destination pair and time-of-day combination, it would be necessary to estimate how often an incident on the usual route would induce a route switch. However, all respondents differ in the minimum length of unexpected delay (threshold) that justifies a modification to the intended travel plans. The calculation would thus have to account for these different (and unknown) threshold values and for the fact that potential diverters are not on the road daily. All these obstacles make it difficult or impossible to know how often each respondent would divert to his or her best alternative route.

To overcome these difficulties, a proxy variable was used for the potential frequency of route diversion. When asked to report specifics of their recent unexpected congestion, respondents mentioned how long ago the incident occurred. If it is assumed that the occurrence of incidents follow a Poisson process, the time elapsed since the last incident is actually just the mathematical expectation of the time period between two incidents of at least the same size. The number of weeks between two incidents can then be translated into an annual frequency of incidents experienced, assuming that respondents work about 48 weeks a year. Table 8 presents the results and the corresponding frequencies of route diversion.

The weighted average frequency of diversion is 29 times a year. As seen from the table, the majority (77.4 percent) of respondents would divert between 8 and 32 times a year. About one sixth (15.7 percent) of respondents would divert as often as twice a week (out

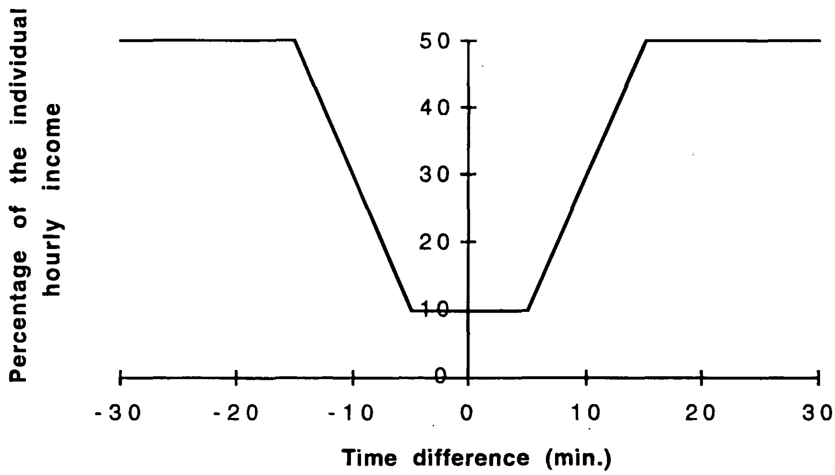

FIGURE 2 Function used for monetary value of time.

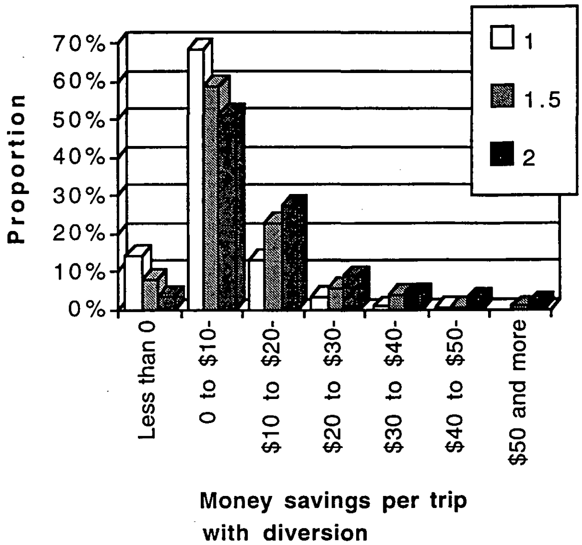

FIGURE 3 Distribution of monetary savings for people who stated they would divert to best alternative route, as a function of delay weight.

of 10 possible trips). These people might have a high variability in their route choice decision and are likely to divert as soon as traffic conditions deteriorate on their usual route.

The measure used for the frequency of route diversion might have a seasonal bias and is only approximate. Its correlation with the monthly frequency of diversion without ATIS is 0.14. However, it has two important advantages. First, it incorporates the threshold value of all respondents, because they are free to report the most recent unexpected delay they find worth mentioning. It is unlikely that smaller unexpected delays would be considered for route diversion. Respondents who faced their incident relatively longer ago apparently have larger threshold values, because they experienced longer delays (Table 8); they were accordingly assigned a smaller frequency of diversion. Second, commuters who are not on the road daily, because they also use transit or carpool, are less likely to face unexpected delays than others and are thus less likely to divert. The proxy measure used takes this into account by assigning these people a smaller annual frequency of diversion.

Annual Benefits of Route Diversion

By combining the annual frequency of unexpected delays and the monetary savings per trip, it is possible to calculate the annual benefits of route diversion under incident conditions (see Figure 4). The average annual benefit of ATIS-induced route diversion is $124 per year per diverter, when the weight of delay is one. Table 7 summarizes the results of the calculation for different weights of delay and shows the average time savings under each assumption. Note that the percentage of people with negative savings (i.e., with an alternative route longer than the travel time plus the delay on the usual route) dwindles as the weight attached to delay increases. This suggests that the apparently irrational behavior of longer diversion time could be partly explained by a high cost associated with queuing delays.

For our subset of the population, the annual benefits of route diversion through ATIS under incident conditions range from $124 to $324 per person, depending on the weight of delay. Recall that this value applies to about 40 percent of the automobile commuters in the corridor and that high values of time were used because of the large average income of the sample. It appears that the time-savings benefits of ATIS from route diversion under incident conditions are limited.

SUMMARY AND CONCLUSION

Three-quarters of the respondents reported that they faced unexpected congestion on their usual route to work at least once in the past 3 months. Twenty-one percent of them reported that they then had an opportunity to divert, and 16 percent did divert. Thirty-three percent stated they would divert if provided with ATIS qualitative information (roughly equivalent to currently available information) at the beginning of their trip. More diversion is obtained in the stated preference case, partly because respondents had the benefit of hindsight and had more opportunities to divert because they were starting their trip over. There might also be a tendency to overstate diversion behavior.

The stated preference questions showed that the more complete the travel information, the higher the proportion of commuters diverting under unexpected congestion. Almost 70 percent of the people stated they would divert when the device provided quantitative real-time information on their usual route plus travel times on their alternative route. Moreover, under incident conditions, prescriptive information might be sufficient to achieve high diversion rates. However, driver compliance with prescriptive information will be conditional on the effectiveness (reliability and accuracy) of ATIS in suggesting better routes.

Potential annual monetary benefits from ATIS-induced diversion in the Golden Gate Bridge corridor range from $124 to $324 per person, varying linearly with the weight assumed for delay. These figures apply to about 40 percent of the commuting population in the corridor.

The estimate of benefits is only preliminary, and a more reliable frequency of diversion under ATIS is needed from field operational

TABLE 8 Potential Frequency of Route Diversion Using Time Since Most Recent Incident

How long ago did the most recent unexpected congestion occur?	Correspond. Frequency of Incidents Experienced	Potential Annual Freq. of Route Diversion	Proportion of Potential Diverters	Average Expected Delay (min.)
Less than one week	Twice a week	96	15.7%	19
1-2 weeks	Every 1.5 week	32	22.6%	18
2+-4 weeks	Every 3 weeks	16	28.6%	22
1-2 months	Every 6 weeks	8	26.2%	24
More than 2 months	Every 12 weeks	4	6.9%	22

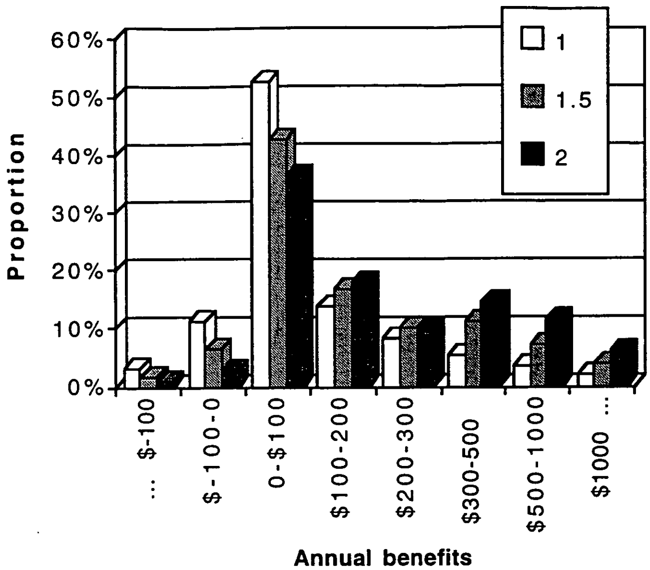

FIGURE 4 Annual monetary benefits of ATIS-induced route diversion, as a function of delay weight.

tests currently underway. Because the Golden Gate Bridge corridor offers limited route diversion opportunities and has a relatively high-income population, research should also be performed in other corridors to obtain more generalizable estimates.

This project has demonstrated that, even in a corridor with limited opportunities to divert, ATIS could bring about significant time savings to a certain portion of commuters by inducing route changes. Although the calculated benefits per driver may appear limited when translated into annual dollar figures, they account for only a subset of total ATIS benefits. Changes in other travel decisions such as departure time and mode may allow commuters to save time as well. Research is underway to estimate the extent of pre-trip ATIS benefits. Other less tangible benefits such as easier wayfinding, increased confidence in unfamiliar areas, increased ability to modify trip chaining, and the availability of general traveler information will also have to be summed up in the final analysis. Finally, greater benefits may be achieved by broadening the scope of ATIS through the development of an Advanced Activity and Travel Information System. Such a system is a logical extension, because it would provide information to support not only travel decisions but also activity participation.

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Driver Factors Affecting Traffic Sign Detection and Recall

SAAD A. AL-GADHI, SYED ABID NAQVI, AND ADEL S. ABDUL-JABBAR

Warning and regulatory traffic signs used in Saudi Arabia were evaluated. All of these signs are compatible with those of the 1968 U.N. Vienna Conference on Road Signs and Signals. The project was sponsored by the Saudi Arabian National Traffic Safety Committee and involved a large sample of subjects (10,137 drivers). Twenty-two regulatory and warning signs were used to test drivers for detection and recall. With the help of a police officer the vehicles were directed into a lane, where drivers were interviewed in a systematic way to evaluate the effect of age, experience, profession, education, language, sign type, and road condition on the detection and recall of signs. It was concluded that older drivers have poorer rates of detection and recall of traffic signs than younger drivers. The uneducated drivers have problems in recalling traffic signs. Retired people (>60 years of age) have trouble detecting traffic signs. Native language speakers detect signs more often and commit fewer errors in recall than nonnative language speakers.

Traffic safety has become a global issue in recent years because of the loss of lives and associated accident costs. The authorities responsible for traffic safety have taken extensive measures to achieve safety in many areas of the traffic system; however, more research in certain areas is greatly needed.

The sharp increase in the number of roads and vehicles and in the population in Saudi Arabia has resulted in increased automobile accidents. In 1953, there were only 239 km of paved roads in Saudi Arabia, but by the end of 1991 more than 122,000 km of roads had been constructed, of which 42,000 km were paved. The number of vehicles has increased as well. At the beginning of 1970s, there were approximately 100,000 vehicles in the country; in 1991 this number increased to 5 million, surpassing the vehicles per 1000 inhabitants mark for many European countries (*1*). The population of Saudi Arabia is on the rise, increasing from 10 million in 1973 to 17 million in 1993.

Several studies have been done on automobile accidents in Saudi Arabia (*2,3*). For example, a study (*2*) conducted in Riyadh presented the results of a questionnaire that covered various influential factors in traffic accidents. It was concluded that 57 percent of the accidents were because of traffic rule violations (e.g., improper overtaking, turning, and stopping), and traffic signal or sign violations. Moreover, most accidents were caused by driver error, and an in-depth analysis of various underlying human factor variables is warranted.

Several researchers have addressed the driver factor issues related to driving accidents (*4–7*). The major issues addressed involved accident proneness (*4,8*), psychological relationships (*5,6,9–11,17*), driver behavior (*12,13*), biorhythm theory (*7,14,15*), and risk taking (*16*). Most researchers agree that individual approaches, if considered alone, may prove to be misleading, and a common framework is needed to incorporate the interrelationships and interdependencies.

Another study (*18*) demonstrated that road sign systems do not function in their intended way, that drivers are sometimes blamed unnecessarily, and that signs are generally incompatible with human input systems. The study, which involved 1000 drivers, indicated that on average 47 percent of the drivers detected a road sign. Another study (*17*) reported that the overall probability of a road sign being noticed is less than 50 percent. Finally, a recent study (*19*) on the effect of road sign informational value on driver behavior suggests that the memory for signs is typically poor.

Saudi Arabia is a signee of the 1968 Vienna Road Traffic Convention and has built its traffic system within bounds of the convention. It has also developed appropriate manuals; one such document is Uniform Traffic Control Devices Manual developed by the Ministry of Transportation. The manual sets forth the basic principles relevant to traffic control devices.

This study on traffic signs was undertaken to identify relevant factors affecting the driver's ability to detect and recall traffic signs. Such a study was rarely done in Saudi Arabia and has not been seen in literature in the manner described previously.

This study examined the effect of driver's age, professional training (student, blue collar, white collar, driver, laborer, retired, other), education (illiterate, read and write; primary, intermediate, high school, vocational school, university, higher degrees, others); and language (Arabic, non-Arabic speakers) on the recall and detection of traffic signs. *Recall* is defined as the memory of what has been learned or experienced; whereas *detection* is the process of identifying the object as a sign.

METHODS AND PROCEDURES

Local and foreign literature relevant to traffic signs was searched and reviewed to develop background for the investigators. Proven methodologies in the study of traffic signs were used as presented in the literature with changes needed for the task. According to the field study protocol, 22 signs of the 84 regulatory and warning signs used in Saudi Arabia were selected from an earlier study by the investigators in a laboratory environment (*20*). These signs are shown in Figure 1. Four geographically different test locations were selected in Riyadh. The surveyors for field data collection were selected through an interview process with the criterion that they be proficient in Arabic and English, with any additional language a plus. The signs were allocated to each test location with emphasis on their relevance to the site. The data collection was carried out

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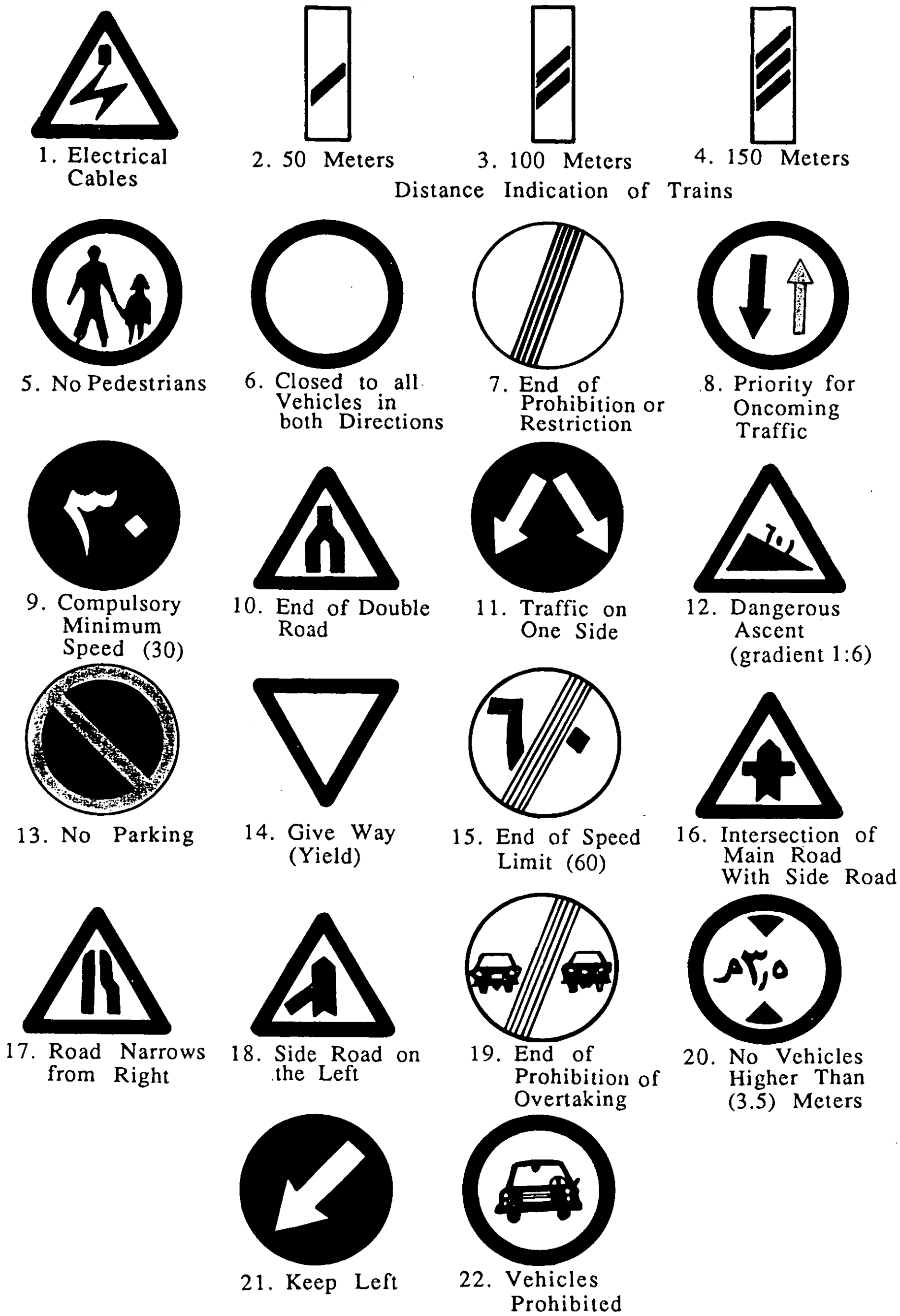

FIGURE 1 Traffic signs used in study.

during the day in two shifts, (9 to 12 a.m. and 3 to 5 p.m.). Surveyors were assigned to each location and were not rotated among sites. At each location, a test sign was placed according to current standards of sign posting used in Saudi Arabia. The sign was set up in such a way that it could be viewed by oncoming drivers from a distance of approximately 400 m (*18*). The test sign was posted so that it was the only sign a driver can see before passing it. The data collection site was set up beyond 200 m from the posted sign (*21*). It was also ensured that there were no other traffic signs in the 200 m span on either side of road. One sign per day was scheduled to be tested with about 400 data sets for each sign based on the experimental design, described later. A traffic police officer was assigned to stop the automobiles at each test site. The vehicles were directed into a lane on right side of the street formed by using cones and other safety devices. The vehicles were randomly stopped and drivers were evaluated on a first-come, first-served basis in the lane, which had the capacity of six automobiles with equal number of surveyors waiting.

As a driver arrived, the surveyor immediately asked, "What was the last road sign you passed?" If the response was incorrect or the driver did not see a sign, the surveyor proceeded to the next question.

Next the surveyor showed a card that displayed set of signs including the test sign and asked "Which one of these signs is the one you just passed?" The objective of this question was to double-check if there was any memory of the sign left. Various combinations of these questions and their results are given in Figure 2.

After initial questioning, information about the subject's age, driving experience, language, education level, and profession was recorded. The levels of each category can be seen in Table 1. The data were analyzed using SAS software on the IBM 3080 mainframe at King Saud University.

In this study there are data on two response variables—recall and detection—and seven explanatory variables (see Table 1). The sample size of approximately 400 for each sign was found statistically appropriate.

The study was conducted during the day. Roads were mostly dry (89.9 percent of time) and visibility was generally clear (99.2 percent of time). A total of 10,137 drivers were randomly stopped; 65.9 percent were native Arabic speakers and the rest were non-Arabic speakers. Other frequency distributions such as subject's age, driving experience, education level, and profession are not given here because of space limitations and can be found elsewhere (*20*).

ANALYSIS AND RESULTS

The response variables recall and detection are binary (taking a value of 0 or 1 only) and require a special technique called logistic regression (*22*). Logistic regression is a statistical method for analyzing the relationship between an observed proportion, or rate, and a set of explanatory variables.

Sign detection was found to be reasonable for this study (65.5 percent). Recall was only 12.16 percent. Table 2 summarizes mean detection and recall by sign. Other significant results are presented as follows.

Detection Model

For this model, five factors had a significant effect on the response variable (with significance level ≤ 10 percent). These factors were sign, age, profession, education, and language (Table 3). The full model involving all the above factors was significant at 1 percent level. Each of the factors, sign, age, education, and language, was highly significant. The significance level for profession was about 1.76 percent—also quite high.

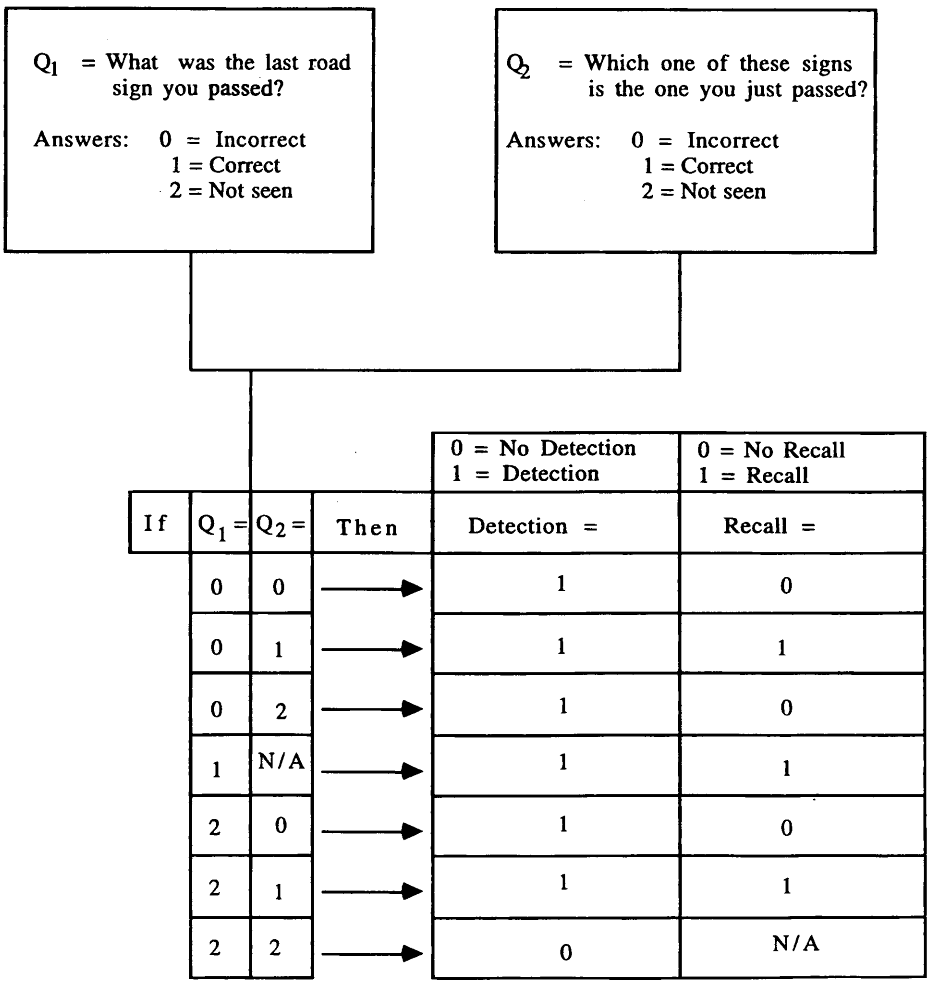

FIGURE 2 Memory logic diagram.

TABLE 1 Variables Used in Study

Independent Variables	
Sign No.	1 to 22
Age	Continuous Random Variable (years)
Road Condition	Wet, Medium, Dry
Experience	Continuous Random Variable (Years)
Profession	Student, Blue Collar (Skilled worker), White Collar (Office worker), Driver (Professional), Laborer (Unskilled worker), Retired, Other.
Education	Illiterate (No education & not literate), Read & Write, Primary (1-6), Intermediate (7-9), High School (10-12), Vocational, University (Bachelors level), Higher Degree (MS, Ph.D.) & Other.
Language	Arabic, Non-Arabic.
Independent Variables	
Detection Recall	

TABLE 2 Sign Detection and Recall Results

Sign No.$	Sample Size (N)	Mean@ Detection (%)	Mean@ Recall (%)
1	464	57.8	03.7
2	339	61.4	04.8
3	312	58.0	0.55
4	292	62.3	03.3
5	416	71.6	36.9
6	449	76.4	18.7
7	452	64.2	16.6
8	525	58.9	08.1
9	752	87.1	05.2
10	405	59.0	06.7
11	440	62.5	25.1
12	417	60.9	07.9
13	456	59.7	14.3
14	427	69.8	12.1
15	402	99.0	06.5
16	467	55.5	33.6
17	457	72.0	23.1
18	435	63.7	18.1
19	441	56.0	08.1
20	573	60.7	12.1
21	447	55.0	08.9
22	569	60.5	12.8
Total	10,115+		
Grand Average		65.5%	12.16%

$ See Fig. 1
+ 22 Missing
@ Rounded

TABLE 3 Detection Model (Model is Significant at α = 1 percent)

S. No.	Significant Variables*	P value	Parameter	Type
1.	Sign	.0001	+.0259	Discrete
2.	Age	.0001	-.0264	Continuous
3.	Profession	.0176	+.003	Discrete
4.	Education	.0001	+.383	Discrete
5.	Language	.0002	+1.433	Discrete

* significance level $\alpha = 10\%$

The regression parameter for age had a small negative value indicating that mean detection decreases with age but at a very slow rate. Because the factors profession and education were at several levels, a detailed analysis by Duncan's Multiple Range Test was performed. It was found in the profession category that mean detection was highest for students and it was significantly higher (at 5 percent level) than the mean of drivers, laborers, and retired people. However, it was not significantly different from blue and white collar people. The rate of detection among drivers and laborers was not significantly different. The rate of detection among retired subjects was significantly lower than all other profession categories. In addition, it was found that profession and education were not correlated (corr. coeff. = 0.05331, $p = 0.0001$).

The language factor was highly influential in determining detection. Arabic speakers had significantly greater mean detection than non-Arabic speakers.

The mean detection for the education variable was highest for vocationally trained followed by higher education, university, high school, intermediate, and primary. These levels were found not significantly different from one another; however, all the levels were significantly different from illiterate and read and write categories.

Table 2 presents the mean detection rate for various test signs. It can be seen that drivers had most difficulty in detecting Sign 21 followed by 16, 19, 1, and so on. The overall detection rate was 65.5 percent, a rate considered to be reasonable compared with European countries [47 percent (*18*), 50 percent (*17*)].

Recall Model

Only three factors, namely sign, age, and language, appeared to have significant impact on response variable (Table 4). The model involving the above three factors only was significant at 1 percent level. The regression parameter corresponding to age had a very small negative value indicating that the recall goes down with increasing age but at a very slow rate. Non-Arabic speakers committed significantly more errors in recall compared with Arabic speakers even through the Arabic speakers were not better educated. There was no correlation between education and language (corr. coeff. = 0.05024, $p = 0.0001$).

Table 2 presents the mean recall percentages for various test signs. It can be seen that the drivers had the most difficulty in recalling Sign 3 followed by 4, 1, and 2, with the recall percentage under 5 percent. The overall recall rate is also quite low (12.16 percent).

DISCUSSION AND CONCLUSIONS

The driver factors of age, profession, education, and language had a significant effect on detection. The increase in age resulted in decreased detection, and, in the profession category, retired people detected significantly at the lowest rate. This may be because of decrease of memory with age or related factors. Students detected the signs at a higher rate than all other professions. This may be attributed to their young age and better education level. The Arabic speaking drivers' detection rate was significantly higher than that of non-Arabic speaking drivers. This may be because of the presence of an Arabic inscription on some of the signs. These inscriptions may have helped many Arabic readers to detect the signs better. The poor rate of detection for non-Arabic speaking drivers may be because of inattention, lack of training, and so forth.

The overall detection rate (65.5 percent) may be higher than seen in some European countries but still should be better. The reason for not having a very high detection rate may be because of a diversified driver population, lack of driver training, inadequate traffic law enforcement, or sign characteristics (i.e., legibility, readability, conspicuity, location, or maintenance.)

The error in recalling a traffic sign was mainly affected by driver age and language. The decrease in recall for drivers with increasing age was significant. It is understandable because older people were expected to commit more errors as a result of reduced vision, attention, and information processing abilities. The overall increased error rate may have also been attributable to the sign itself and its understandability, as described earlier. The non-Arabic speaking drivers' recall of signs was significantly worse than that of Arabic speaking drivers. This may be because non-Arabic speaking drivers received different sign training in their home countries in addition to the other reasons mentioned earlier.

It can be concluded from this study that older drivers have a lower detection and recall of traffic signs when compared with younger drivers. Uneducated drivers will have problems understanding traffic signs. Retired people (> 60 years of age) have trouble detecting traffic signs. Native language speakers have better detection rates and commit fewer errors in recall compared with non–native-language speakers. It is recommended here that such studies be done in other countries and the findings of this and other relevant

TABLE 4 Recall Model (Model is Significant at α = 1 percent)

S. No.	Significant Variables*	P value	Parameter	Type
1.	Sign	.0001	-0.0085	Discrete
2.	Age	.0693	-0.037	Continuous
3.	Language	.0277	+0.6015	Discrete

* significance level $\alpha = 10\%$

past studies be used to revise or update the relevant road sign standards such as the 1968 Vienna Convention.

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Driver Understanding of Protected and Permitted Left-Turn Signal Displays

JAMES A. BONNESON AND PATRICK T. MCCOY

Driver comprehension of protected and permitted left-turn (PPLT) signal designs was evaluated by conducting a survey of 1,610 drivers. The survey included a perspective view of an intersection approach and its traffic signal display, followed by multiple-choice questions about the correct driving action. The survey questions were focused on four display indications in six different PPLT designs. The display indications included (*a*) permitted left-turn, (*b*) protected left-turn only, (*c*) overlapped left-turn and through, and (*d*) a modified form of the protected left-turn only indication. The modified indication deviates from the *Manual on Uniform Traffic Control Devices* guidelines for PPLT heads (which require both a green arrow and red ball) by displaying only the green arrow during the protected indication. The six PPLT designs varied in terms of the location of the signal head with respect to the lane line, the arrangement of the lenses in the signal head, and the inclusion of an auxiliary sign. The survey results indicate that drivers are better able to understand PPLT designs with any of the following characteristics: a modified protected indication, the PPLT head centered over the opposing left-turn lane, and no auxiliary sign.

The *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*) provides considerable latitude in the design of traffic signals on intersection approaches with protected and permitted left-turn (PPLT) control. It identifies several different combinations of left-turn and through movement signal lens arrangements or displays that can be used, some general guidelines for locating signal heads, and several choices in auxiliary signing messages. As a result of this latitude, a wide variety of traffic signal designs with PPLT displays is in current use. In this paper, the combination of PPLT and through movement displays, auxiliary signing, and display location with respect to the lane lines on an intersection approach will be referred to as a "PPLT traffic signal design."

The diversity of PPLT traffic signal designs may confuse drivers as they travel in various cities throughout a state and may lead to unsafe and inefficient operations. In fact, a recent survey of traffic engineers conducted by the Florida Section of ITE (*2*) indicated that many drivers do not understand or trust the protected portion of the phase and may hesitate when the green arrow is displayed.

The objective of this research was to determine if some PPLT signal designs cause more confusion and operational and safety problems for drivers than others. This objective was accomplished by conducting studies of driver behavior, understanding, and accident history. The research described in this paper focuses on a survey of driver understanding of PPLT designs. Findings from the studies of driver behavior and accident history are described in the final project report (*3*).

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COMMON DESIGN CONSIDERATIONS AND CONFIGURATIONS

Design Decisions

When designing the PPLT and through movement traffic signal arrangement, the traffic engineer is faced with several questions, including the following:

- What signal head arrangement should be used?
- Will the head be exclusive to one movement or shared by two or more movements?
- How far will the left-turn head be laterally offset from the lane lines and from the through signal heads?
- Is there a need for permanent or temporary auxiliary signing to better convey the meaning of the green ball to drivers making left turns?

These questions will be more fully examined in the following paragraphs. In all cases, it is assumed that an exclusive left-turn bay is provided for the PPLT movement.

Signal Head Lens Arrangements

In general, three PPLT signal head lens arrangements are being used in Nebraska. All three displays, shown in Figure 1, have five lenses arranged in a vertical, horizontal, or cluster pattern. The vertical display (MUTCD letter "m") has the advantage of being mountable on either mast arm or span wire and the disadvantage of being so tall that it requires a relatively high mounting to provide the minimum roadway clearance, unless it is mounted on or over a raised median.

The horizontal display ("n") has the advantages of being least sensitive to wind forces and requiring a minimum pole height to obtain the necessary roadway clearance. Its disadvantages are that it is unstable under moderate breezes when mounted on span wire, and that its lens arrangement may be confusing to some drivers. This latter disadvantage surfaces during the protected left-turn phase. During this phase, the green arrow is lit for the left-turn driver indicating that the left turn is protected; however, the red indication also remains lit because it is controlled by the coincident through phase (as required by MUTCD). In operation, this somewhat contradictory message rarely confuses motorists unless a horizontal display is used. In a horizontal display, the left-turn arrow is located to the right of the red ball and, during the protected left-turn phase, it points directly at the red ball. This orientation tends to amplify the contradiction of a green and red lens being lit at the same time and tends to confuse some motorists. In fact, a recent survey by Williams et al. (*4*) found that drivers were better able to interpret the intent of the

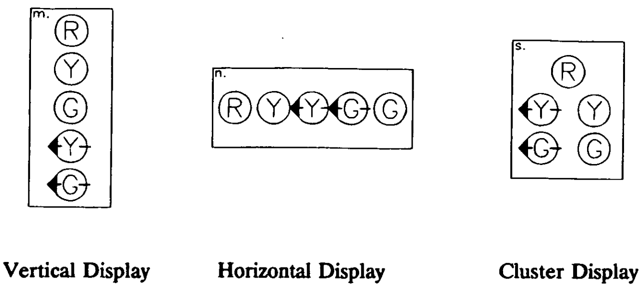


FIGURE 1 Protected/permitted left-turn signal displays (*1*).

green arrow when the red ball indication was off. Williams et al. recommended that a red ball and a green arrow should not be displayed simultaneously in a horizontal PPLT head.

The cluster display (MUTCD "s") has the advantage of being mountable on either span wire or mast arms. When the cluster head is used to control both through and left-turn movements in a shared arrangement, it has the additional advantage of displaying a logical relationship between the lenses and the traffic movements they control. More specifically, the left-turn arrow indications are located to the left of the solid ball indications just as the left-turn movement is located to the left of the through movement.

Number and Location of PPLT Heads

The minimal guidance provided by MUTCD permits many different PPLT signal designs. In fact, MUTCD states that an exclusive head is not required (*1*) for the left-turn movement. If an exclusive head is not provided, the guidelines imply that a shared head must be provided. One advantage of the shared-head arrangement is that the shared head can serve as one of the two required through movement heads, thereby minimizing the total number of heads and their associated costs. A disadvantage of the shared-head arrangement is that it may be less clear to the motorist which signal head is controlling his or her entrance to the intersection.

Auxiliary Signing

At some intersections, auxiliary signs have been mounted near the PPLT signal head to ensure that drivers understand the intended meaning of its signal indications. MUTCD (*1*) suggests that no information sign is necessary; however, if one is used it must be the R10-12 sign [Left Turn Yield On Green (symbolic green ball)]. A study of 30 intersections conducted by Agent (*5*) indicated that auxiliary signs made no difference in the number of left-turn accidents. Based on this finding, Agent recommended that auxiliary signing not be used. Similar recommendations were made by the Florida Section of ITE (*2*). Both groups indicated that appropriate driver education regarding PPLT signal displays would be more effective than auxiliary signing.

Protected and Permitted Signal Head Design Types

Because of the generality of MUTCD guidelines, many possible combinations of signal head lens arrangements (i.e., horizontal, vertical, or cluster) and lane location (i.e., shared or exclusive) may be used to define the signal head design. At present, five PPLT signal design types are used in Nebraska. A sixth type is being considered for some locations. A description of each follows:

- *Exclusive horizontal PPLT signal design.* This design, shown in Figure 2, has horizontal heads centered over each left and through lane.
- *Exclusive cluster and vertical PPLT signal design.* This design, shown in Figure 3, is an exclusive-head arrangement with vertical heads for the through movements and a cluster head for the PPLT movement.
- *Exclusive vertical PPLT signal design.* This design, shown in Figure 4, is similar to that shown in Figure 3 except that a vertical head is used to control the PPLT movement instead of the cluster head.
- *Shared cluster and vertical PPLT signal design.* For this design, shown in Figure 5, each signal head is placed over a lane line and used to control traffic in the lanes on either side of the line. This design is quite similar to that recommended by FHWA (*6*), the

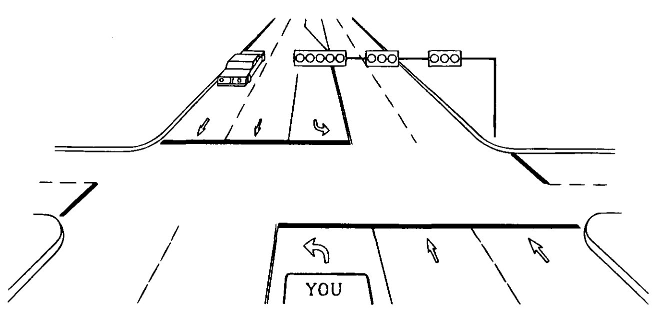


FIGURE 2 Exclusive horizontal PPLT signal design.

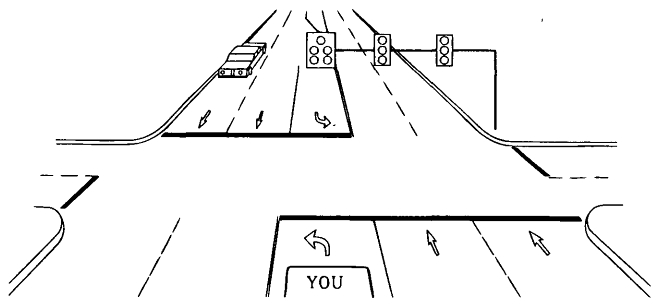


FIGURE 3 Exclusive cluster and vertical PPLT signal design.

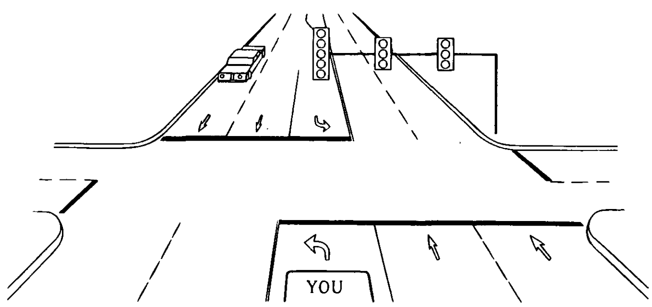


FIGURE 4 Exclusive vertical PPLT signal design.

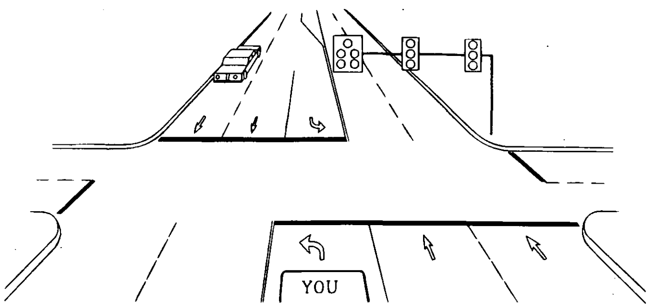


FIGURE 5 Shared cluster and vertical PPLT signal design.

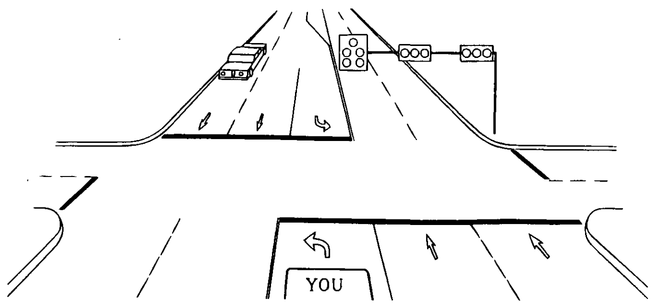


FIGURE 7 Shared cluster and horizontal PPLT signal design.

Florida Section of ITE (*2*), and Agent (*5*), although the latter two sources do not include a through movement signal head over the curb lane line.

- *Shared horizontal PPLT signal design.* This design, shown in Figure 6, has horizontal heads over each lane line.
- *Shared cluster horizontal PPLT signal design.* This design, shown in Figure 7, combines the cluster and horizontal head designs in a shared use arrangement.

As shown in Figures 2 through 7, the shared and exclusive designs use one PPLT head and two through movement heads. Three heads are commonly used in Nebraska but may not be common in other areas (i.e., some states use two heads in a shared design).

DRIVER SURVEY

The operational performance of a traffic control device is typically evaluated in terms of conspicuity, recognition, and comprehension. Comprehension is a measure of how well the motorist understands the meaning of the control device message as intended by its designer. The degree of comprehension of a device can be measured by the number of motorists that correctly understand its message. For this research, driver comprehension of the PPLT design was assessed with a survey of licensed drivers.

Survey Form

The survey design followed that used by Williams et al. (*4*), in which one perspective view of an intersection approach was shown at the top of the page and two multiple-choice questions asked the correct identification of a particular indication type. More specifically, a perspective view of an intersection approach was drawn from the viewpoint of the first-to-arrive left-turn driver. To reinforce the intended orientation of the respondent with respect to the intersection, the word "YOU" was drawn in the left-turn lane.

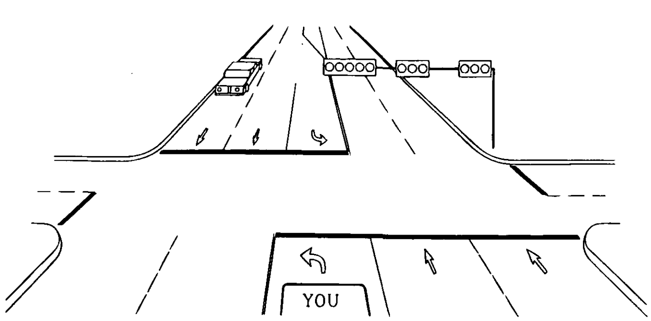


FIGURE 6 Shared horizontal PPLT signal design.

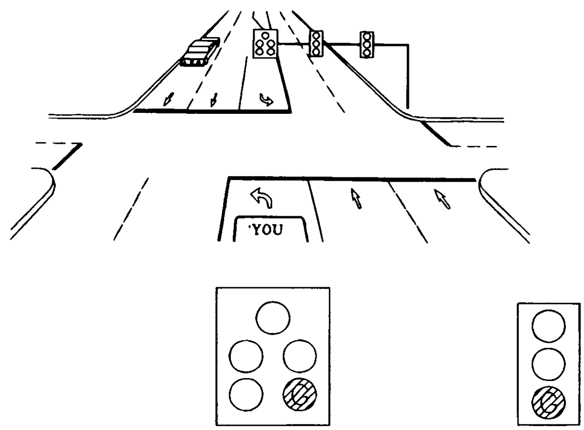
As the resolution of this perspective view was too low to indicate the signal indications clearly, an enlarged view of each head and its lighted indication was placed just below the perspective view. Below this enlarged view was a multiple-choice question with four possible responses regarding the appropriate driving action. To fully use space on the questionnaire, a second enlarged view (showing a different signal indication combination) and multiple-choice question were placed below the first question. A sample questionnaire is shown in Figure 8.

The survey contained questions about the six PPLT signal design types shown in Figures 2 through 7. An auxiliary sign was included in the survey for one PPLT design type. Although auxiliary signs of this kind are rarely used at intersections in Nebraska, there are a few locations that use these signs with the PPLT design shown in Figure 3. The sign is to the right of the PPLT head on the mast arm. The message on the sign is "Left-Turn Yield on Green (symbolic green ball)" (MUTCD R10-12).

Differences in driver understanding among the seven PPLT designs could be attributed to a combination of the PPLT signal design and the indication presented. Therefore, to test fully the effectiveness of the seven PPLT designs, the survey was designed to evaluate each PPLT design under each unique indication combination. The four different combinations considered include

- *Permitted* left-turn indication (green ball for both the left-turn and through movements);
- *Protected/MUTCD* left-turn-only indication (left-turn green arrow and through red ball), consistent with MUTCD specifications;
- *Overlap* left-turn and through indication (left-turn green arrow and through green ball); and
- *Protected/Modified* left-turn-only indication. The modified indication displayed only the green arrow in the PPLT head (i.e., without the red ball). This form is intended to overcome driver confusion from the simultaneous display of a green arrow and red ball in the same PPLT head.

The enlarged view of the signal heads was colored on the survey form to be consistent with the lit lens or lenses for each combination. Because only two questions appeared on each form, only two of the four indications were presented to each interviewee.



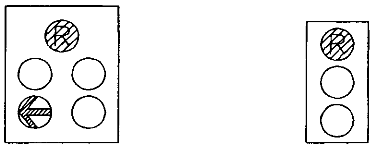
If you are waiting to turn left and see the above signal indication...
(please circle the letter corresponding to your response)

a. you are not allowed to turn left.

b. you are allowed to turn left; however, you must wait for a large enough opening in the oncoming traffic before doing so.

c. you are allowed to turn left since the oncoming traffic must stop.

d. you are not sure whether or not a left-turn is allowed.



If you are waiting to turn left and see the above signal indication...

a. you are not allowed to turn left.

b. you are allowed to turn left; however, you must wait for a large enough opening in the oncoming traffic before doing so.

c. you are allowed to turn left since the oncoming traffic must stop.

d. you are not sure whether or not a left-turn is allowed.

FIGURE 8 Sample survey form—driver understanding questions.

The back side of the questionnaire contained several demographic questions used to determine the age, driving experience, sex, rural or urban residence, and level of education of the respondent. The demographic portion of the questionnaire is shown in Figure 9.

Distribution Method

Several measures were taken to ensure a representative sample of the appropriate driving population in Nebraska. Since drivers in the urban areas of Nebraska have more exposure to PPLT signal designs than rural drivers, the questionnaire was administered in three of Nebraska's largest cities, Omaha, Lincoln, and Grand Island.

The survey was administered in person at the local Department of Motor Vehicles (DMV) driver's license testing facility in each city. Experience in conducting surveys at DMV testing facilities has revealed that it has several strong advantages over other places. One advantage is that it brings an unbiased sample of the driving population to the interviewer—unbiased in the sense that the people are at the facility on the basis of their birth date.

Another advantage is that the response rate tends to be high. Interviewees at the DMV are receptive to the survey because (*a*) they are mentally prepared to answer traffic-related questions, and (*b*) they have to wait for 5 or 10 min anyway. Filling out a ques-

Please provide us some general information about you to help us classify your response. This information is confidential, in fact, we do not need your name or address.

(please circle the letter corresponding to your response)

Age:

a. 25 or under
b. 26 to 35
c. 36 to 45
d. 46 to 55
e. 56 to 65
f. 66 to 75
g. 76 or over

Number of Years You Have Been Driving:

a. 5 or less
b. 6 to 10
c. 11 to 15
d. 16 to 20
e. 21 to 25
f. 26 to 30
g. 31 or more

Residence:

a. within city limits
b. outside city limits

Sex:

a. Female
b. Male

Education:

a. less than 12 years
b. high school diploma
c. some college work
d. college degree

Thank you for completing this survey. Your response will be used to help us determine the types of traffic signal indications that work best. We will be sharing this information with various state and city agencies in Nebraska.

FIGURE 9 Sample survey form—demographic questions.

tionnaire is not deemed to be an inconvenience. As a consequence of using the DMV, a 90 percent response rate was achieved.

Statistical Analysis Approach

The factors affecting driver response accuracy were identified using analysis of variance techniques. The analysis of variance was conducted using the Categorical Data Modeling (CATMOD) procedure in the SAS System (*7*). All statistical tests were conducted using a 95 percent level of confidence (i.e., $\alpha = 0.05$).

Potential bias from demographic diversity in the responses was controlled by including a wide range of demographic questions on the survey forms. Demographic factors found to be correlated with driver understanding were included in the statistical analyses, and all others were excluded. Bias associated with small sample size was minimized by using the maximum-likelihood analysis option available in CATMOD.

Analysis Results

Survey Demographics

In total, 1,610 completed questionnaires were obtained during a 3-week period in May 1992. Because each survey form contained two

PPLT design questions, 3,220 questions were considered in the analysis. A summary of the demographic characteristics of the survey sample is provided in Table 1.

At first glance, it may appear alarming that only 70 percent of the survey respondents correctly understand the meaning of the PPLT signal designs [a similar proportion of correct responses was found by Williams et al. (*4*)]. However, it must be remembered that the respondents were answering a questionnaire with a limited source of information (i.e., a black-and-white, two-dimensional perspective drawing with colored signal indications). It is likely that drivers receive other visual clues at intersections, which increase the likelihood of making the correct response. This hypothesis could be confirmed only by a detailed study of driver performance under real-world conditions. As noted by Williams et al. (*4*), however, each signal indication should, on its own merits, be understandable to drivers. The survey conducted for this research provides considerable insight in this regard.

Several trends apparent in Table 1 bear further discussion. In particular, there is a trend toward decreased understanding of the PPLT designs with increased age and driving experience. There is also a trend toward better understanding with more education. There does not appear to be strong differences between male and female drivers or between rural and urban drivers. These trends were considered in the analysis of driver response, as described in the next section.

Comparison of PPLT Designs

The principal focus of this survey was a comparison of driver understanding of the six PPLT designs shown in Figures 2 through 7. A seventh design was included to determine the effect of auxiliary signing. The proportion of correct responses is shown in Table 2.

Design Comparisons The analysis of the PPLT designs was based on the differences in responses for each signal display indication. In the fourth column in Table 2, the responses shown apply to the protected/MUTCD indication (i.e., green arrow with red ball) survey question. Differences between this indication and the protected/modified (i.e., green arrow, no red ball) are examined later.

As shown in the row total of Table 2 (right column), drivers appear to have the best understanding of the exclusive vertical PPLT design (Figure 4). The difference in results for this design and those for the least understood design is about 8 percent. A closer examination of the difference between each design pair indicates that none is significantly different. Although the differences shown in Table 2 suggest that some designs are better understood, a larger number of responses would be needed to confirm these trends.

With regard to differences in understanding the various indications, the column total in Table 2 indicates that the overlap indica-

TABLE 1 Summary of Survey Demographics

Demographic Factor	Level	Number of Respondants	Proportion of Correct Responses
Location	Grand Island	212	0.667
	Omaha	626	0.712
	Lincoln	772	0.716
Age	25 or under	594	0.743
	26 to 35	380	0.738
	36 to 45	329	0.676
	46 to 55	130	0.635
	56 to 65	76	0.671
	66 to 75	53	0.632
	76 or over	14	0.679
	not provided	34	0.559
Driving Experience	5 or less	382	0.716
	6 to 10	287	0.765
	11 to 15	204	0.733
	16 to 20	199	0.711
	21 to 25	161	0.677
	26 to 30	108	0.616
	31 or more	216	0.662
	not provided	53	0.708
Residence	Rural	233	0.721
	Urban	1341	0.709
	not provided	36	0.583
Sex	Female	756	0.695
	Male	720	0.729
	not provided	134	0.668
Education	less than 12 years	171	0.678
	high school diploma	334	0.659
	some college work	561	0.728
	college degree	515	0.732
	not provided	29	0.638

TABLE 2 Driver Understanding of Selected PPLT Designs

PPLT Design (Figure No.)	Display Indication[c]			Total
	Permitted	Overlap	Protected	
3 w/sign	0.824[a] <- high 119[b]	0.409 115	0.664 119	0.635 353
2	0.796 113	0.658 <- high 114	0.619 113	0.691 340
3 no sign	0.658 114	0.643 112	0.798 114	0.700 340
4	0.800 115	0.500 <- low 114	0.826 115	0.709 <- high 344
5	0.658 114	0.539 115	0.851 <- high 114	0.682 343
6	0.761 117	0.607 117	0.530 <- low 117	0.632 <- low 351
7	0.626 <- low 115	0.500 <- low 116	0.835 115	0.653 346
Total	0.732 807	0.550 803	0.731 807	0.671 2417

[a]Proportion of correct responses.
[b]Number of responses.
[c]This summary of responses includes the responses to only 3 of the 4 indication combinations: Permitted, Overlap, and Protected/MUTCD.

tion is least understood; only about one-half of the drivers surveyed answered this question correctly. Fortunately, a closer examination of the responses to this question indicates that most of the respondents who erred chose the safer course of action, which was to wait for a gap in oncoming traffic. Of course, in the context of the total intersection, driver understanding of the overlap indication is probably much higher than suggested by this survey. During the leading protected left-turn sequence (common in Nebraska), left-turn drivers become accustomed to the green arrow and the stopped opposing traffic. When the green ball subsequently joins the green arrow during the overlap phase, drivers are less likely to stop and yield incorrectly as suggested by the survey.

Demographic Effects The effects of the demographic factors listed in Table 1 were also considered in the analysis. On the basis of this analysis, it was determined that several factors had a statistically significant effect on driver understanding of a PPLT design. A closer examination of these factors indicated that driver age explained more of the variation in driver understanding than years of driving or education. Thus, age was kept in the analysis to the exclusion of the other two factors. In general, driver understanding decreased with increased driver age.

Comparison Among Signal Head Locations, Lens Arrangements, and Sign Use

A secondary focus of this survey was an examination of the effect of signal head location, lens arrangement, and sign use on driver understanding of the six PPLT designs shown in Figures 2 through 7. A seventh design was included to determine the effect of auxiliary signing. The proportion of correct responses to each of these factors is presented in Table 3.

Signal Head Location In the analysis of signal head location, the PPLT designs having the PPLT head centered over the left-turn lane (exclusive) were compared with those having the head over the lane line (shared). On the basis of this analysis, it was determined that more drivers understand the PPLT display when the PPLT head is centered in the left-turn lane. The difference in response rates indicates that about 4 to 5 percent more drivers are able to understand the exclusive head location than the shared head. This difference was found to be statistically significant ($p = 0.033$); however, it may be too small to have a practical significance.

Lens Arrangement The analysis of lens arrangement compared the cluster, horizontal, and vertical PPLT head displays (shown in Figure 1). This analysis indicated that the overall differences between the three arrangements were not significant ($p = 0.28$). There were, however, significant differences between the lens arrangements for the permitted and the protected indications. The survey results suggest that significantly more drivers understand the permitted indication in vertical and horizontal arrangements ($p = 0.001$) than in the cluster arrangement. The results also suggest that significantly more drivers understand the protected/MUTCD indication in the cluster and vertical arrangements ($p = 0.0001$) than in the horizontal arrangement.

Sign Use The analysis of sign use compared the exclusive cluster and vertical (Figure 3) with and without the use of an auxiliary sign (i.e., MUTCD R10–12). The results of this analysis indicate that a significantly higher correct response rate occurred with no sign ($p = 0.028$). This finding suggests that designs with no sign may be better understood than designs with a sign. However, this trend is not consistent among the signal indications. For the permitted indication, the sign appears to help driver understanding,

TABLE 3 Effect of Head Location, Lens Arrangement, and Sign Use on Driver Understanding

Factor	Levels	Display Indication[c]			Total
		Permitted	Overlap	Protected	
Head Location	Exclusive (Centered)	0.751[a] 342[b]	0.600 340	0.749 342	0.700 1024
	Shared (Lane Line)	0.682 346	0.549 348	0.734 346	0.656 1040
	Total	0.717 688	0.574 688	0.743 688	0.678 2064
Lens Arrangement	Cluster	0.658 228	0.590 227	0.825 228	0.691 683
	Horizontal	0.778 230	0.632 231	0.574 230	0.661 691
	Vertical	0.800 115	0.500 114	0.826 115	0.709 344
	Total	0.735 573	0.589 572	0.724 573	0.683 1718
Sign Use[d]	No Sign	0.658 114	0.643 112	0.798 114	0.700 340
	Sign	0.824 119	0.409 115	0.664 119	0.635 353
	Total	0.742 233	0.524 227	0.730 233	0.667 693

[a]Portion of correct responses.
[b]Number of responses.
[c]This summary of responses includes the responses to only 3 of the 4 indication combinations: Permitted, Overlap, and Protected/MUTCD.
[d]The analysis of Sign Use considered only the exclusive-cluster/vertical PPLT design (i.e., Figure 3) with and without an auxiliary left-turn sign. The sign used was a "Left-Turn Yield on Green (symbolic green ball)" (MUTCD R10-12).

whereas during the overlap and protected indications, it appears to confuse them. This finding is consistent with that of Hummer et al. (*8*), who found that slightly more drivers understood the permitted indication when it was accompanied by a sign, but many more drivers were confused by the sign during the protected and overlap indications.

Comparison of MUTCD and Modified Forms of Protected Signal Display Indication

Examination of the column totals in Table 4 suggests that the modified form of the protected indication is associated with greater driver understanding than the MUTCD indication. Overall, about 10 percent more drivers are able to determine the correct response to the modified indication. The analysis indicated that this difference is statistically significant ($p = 0.0003$).

Closer examination indicates that the greatest benefit of the modified display is realized by drivers faced with horizontal PPLT designs (Figures 2 and 6). For these two horizontal PPLT designs, it appears that about 25 percent more drivers are able to understand the protected indication when the red ball is *not* shown with the green arrow. Similarly, about 12 percent more drivers are able to understand the exclusive cluster and vertical PPLT design (Figure 3) when the modified display is used. Examination of the other designs indicates that the modified display increases driver understanding in every case.

CONCLUSIONS AND RECOMMENDATIONS

The survey of driver understanding indicated that the exclusive vertical PPLT design (Figure 4) is correctly understood by the highest proportion of drivers. Of the three indications considered (i.e., permitted, overlap, protected/modified), the overlap indication is understood by only about one-half of all drivers, the smallest number for any of the indications.

An analysis of the effects of PPLT signal head location and sign use on driver understanding revealed several interesting trends. The exclusive head location increased driver understanding by about 4 to 5 percent over the shared head location. The analysis of sign use compared the exclusive cluster and vertical (Figure 3) with and without a sign. The sign considered was the "Left-Turn on Yield on Green (symbolic green ball)" (MUTCD R10-12). This analysis indicated that designs with a sign decrease driver understanding by about 6.5 percent. It was found that the use of a sign tends to confuse more drivers during the overlap and protected phases than it helps during the permitted phase.

An examination of the differences between the MUTCD and modified form of the protected PPLT indication revealed that drivers understood the modified form (i.e., green arrow and no red ball) better. The most significant difference was found for the horizontal PPLT designs, which 25 percent more drivers understood. This difference is statistically significant and of sufficient magnitude to be of practical significance.

In recognition of the significance of the findings regarding the modified protected indication, a study of driver performance, under

TABLE 4 MUTCD versus Modified Form of Protected Signal Display Indications

PPLT Design (Figure No.)	Display Indication[c]		Total
	MUTCD	Modified	
2	0.619[a] 113[b]	0.877 114	0.749 227
3 no sign	0.798 114	0.911 112	0.854 226
4	0.826 115	0.851 114	0.838 229
5	0.851 114	0.852 115	0.852 229
6	0.530 117	0.778 117	0.654 234
7	0.835 115	0.836 116	0.836 231
Total	0.743 688	0.850 688	0.797 1376

[a]Proportion of correct responses.
[b]Number of responses.
[c]The PPLT design with the sign was excluded from this analysis.

either real world or simulated conditions, should be conducted to evaluate the level of confusion that apparently exists between it and the existing MUTCD version of the protected indication.

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Motorists' Comprehension of Exit Lane Drop Signs and Markings

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A literature review and two motorist surveys designed to investigate current motorist comprehension of exit lane drop signs and markings are presented. In the first motorist survey study, motorists viewed computer-generated scenes of a freeway with markings and signs appropriate for an exit lane drop situation. The types of markings varied among different alternatives. Motorists were asked to indicate the anticipated movement of traffic in different lanes. The first study also contained questions on the participants' preferences of signs at different locations along an exit lane drop. The second survey was a mail-out survey to driving instructors who were asked to provide their interpretations of their students' comprehension of exit lane drop signs and markings. The results of the research indicate that motorists have a high level of understanding of the yellow EXIT ONLY panel; however, they have a poor understanding of the meaning of the white arrow next to a yellow EXIT ONLY panel. Motorists have equal comprehension of the meaning of a solid white line and double white lines extending from the gore, but they have lower comprehension of lane drop markings (short wide lines or short gaps).

Lanes are often eliminated from the roadway in an effort to make the highway function more efficiently. This phenomenon is known as a lane drop. There are three basic types of lane drops: lane splits, lane terminations, and exit lane drops. A lane split refers to the division of a multilane highway into two separate roadways so that the level of service provided to either roadway is approximately equal. A lane termination denotes the ending of a lane, usually by tapering it into the adjoining lane. The exit lane drop refers to the departure of one or more lanes from the freeway through lanes in the form of an exit. The exit lane drop is the focus of this paper.

Exit lane drops can cause confusion if the driver does not expect the lane to exit but instead to continue with the freeway main lanes. Without proper notification of the impending exit, drivers can find themselves performing erratic maneuvers to prevent exiting at undesirable locations. For motorists to travel successfully through an exit lane drop area, they need knowledge of the presence of the lane drop and its location in sufficient time to perform the desired maneuver. The National and Texas Manuals on Uniform Traffic Control Devices (MUTCD and TxMUTCD) contain information on signs and markings available to warn motorists of upcoming lane drops (*1,2*).

BACKGROUND

Exit only signs and pavement markings are two treatments used to communicate an exit lane drop to the motorist. Signs are a required condition by MUTCD, but pavement markings are optional. Exit only sign treatments include diagrammatic signs, the modified diagrammatic signs, the use of the black-on-yellow EXIT ONLY panel on conventional signs, and others. Pavement markings include larger lane striping [203 mm (8 in.) wide by 0.92 m (3 ft) long white stripes separated by 3.66-m (12-ft) gaps beginning approximately 0.81 km (0.5 mi) in advance of the theoretical gore point] and a solid white channelizing line [203 mm (8 in.) wide extending approximately 91.5 m (300 ft) upstream from the theoretical gore point].

The 1971 edition of MUTCD was the first edition to present information on the EXIT ONLY sign panel. It stated that the panel shall have a yellow background with black legend and may be used, but is not required, on the lower edge or lowest line of overhead gore, exit direction, or advance guide signs on roadways approaching an interchange where there is a reduction in the number of available lanes for through traffic (*3*). It was not until the 1978 edition of the national MUTCD that the EXIT ONLY panel became a requirement at all interchange lane drops (*4*).

Between 1970 and 1972, operational reviews of metropolitan freeways were conducted in California, and the need for a special treatment at exit lane drops was found. The striping was approved in 1975 by the California Traffic Control Devices Committee and included in its traffic manual. In a letter written in 1978 to the National Advisory Committee at FHWA, California recommended the special pavement markings for inclusion in the national MUTCD.

OBJECTIVES

The intent of this project was to determine how motorists interpret the meaning of sign and pavement marking alternatives they may or may not have experienced before. Specific objectives included the following:

- To determine driver interpretation and comprehension of existing pavement markings and signs currently used at exit lane drops,
- To determine driver interpretation of alternative pavement markings that could be used at exit lane drops, and
- To determine driver preferences of pavement markings and signs to be used at exit lane drops.

PREVIOUS RESEARCH ON EXIT LANE DROPS

Exit Only Signs

Black-on-Yellow Panels

A 1976 study by Lunenfeld and Alexander (*5*) evaluated the EXIT ONLY panel and other variations. The study recommended the use

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of the EXIT ONLY panel when route continuity is maintained or, in conjunction with diagrammatic signs, at exits. Roberts and Klipple (*6*) reported in 1976 on an exit lane drop signing experiment that compared four different exit panel messages and one panel with directional arrows and no word messages. The experiment supported the conclusion that the MUST EXIT and EXIT ONLY panel messages were most helpful in correctly influencing driver expectations and that the difference between these signs is so small that either one is recommended for use; however, only one should be used in the interest of improving the accuracy of driver expectations.

Diagrammatic Signs

Several studies have investigated the use of diagrammatic signs versus conventional signs, especially at lane drops. Brainard et al. (*7*) in 1961 investigated the interpretability of diagrammatic signs, whether sign preferences existed, and whether these sign preferences are similar to typical diagrammatic signs found in Europe. The study concluded that pictorial signs were the most easily interpreted. MacDonald and Hoffmann (*8*) found that diagrammatic signs better communicate information to the driver in terms of initial perception time than do verbal signs. Another study, by Lunenfeld and Alexander (*5*), investigated the use of diagrammatic signs at lane drops with different geometric characteristics and recommended that diagrammatic signs be used at exits with route discontinuities.

A 1971 study by Roberts (*9*) investigated the effectiveness of diagrammatic signs at a single location in New Jersey and evaluated the use of these signs by conducting a before and after study. Roberts observed the occurrences of erratic maneuvers (stopping, crossing lane lines, or backing) in a 61-m (200-ft) zone ending at the gore to evaluate traffic characteristics before and after the installation of the signs. Roberts found that there were significantly fewer erratic maneuvers after the diagrammatic signs were installed. After six months, however, it was found that there was a significant increase in the number of erratic maneuvers. The increase was attributed to the two data sets being collected in unlike seasons.

A study of diagrammatic signs by Roberts and Klipple (*10*) investigated the effect of current signing and variations of current signing on driver expectancy violations, such as at lane drops. The study concluded that diagrammatic signs, with or without exit verbiage, influenced driver expectancy favorably.

Pavement Markings

The earliest study identified concerning pavement markings at exit and entrance ramps was conducted in 1966 by Roth and DeRose (*11*). This study investigated the effectiveness of a color coded system consisting of edgemarking, delineation, and signing. Pavement markings consisted of white lines for through traffic, blue for exit ramps, and yellow for entrance ramps. The study reported a significant reduction in erratic maneuvers around two exit and two entrance ramps as a result of the new pavement markings. The erratic maneuvers included two-lane lane changes (within the approximate 610-m (2000-ft) study sections), stopping, backing, and radical movements across the gore. In addition, driver interviews revealed that 85 to 90 percent of the drivers believed the system was beneficial.

Another study related to color coding of pavement markings was conducted in 1976 by Cornette (*12*). Cornette specifically tested 127-mm (5-in.) wide yellow edgelining and 0.61-m (2-ft) wide yellow gore striping at various lane drop situations, including exit lane drops. In addition, Cornette tested the effectiveness of double amber reflectors on both sides of the roadway with decreased spacing approaching the gore area. Seven lane drop sites were chosen, including two single-lane exit lane drops. At both sites, the combination of amber delineators and yellow striping was most effective in reducing erratic movements and brake light applications, although this combination was not necessarily found effective in other lane drop situations.

In 1975, Pigman and Agent (*13*) investigated the effectiveness of raised pavement markers at lane drops. The study collected before and after data at five lane drop sites, including two exit lane drops. The raised pavement markers, although effective during day and night, were found to be much more effective in reducing erratic maneuvers during nighttime conditions.

In the late 1980s, Texas sponsored a study that investigated signing or pavement markings, or both, that could provide additional information to motorists regarding impending exit lane drops (*14*). The use of a series of short white dashes followed by a double white stripe before the gore area and a DO NOT CROSS DOUBLE WHITE LINES sign were selected for investigation. The pavement markings were installed at three sites in the Houston area. All erratic maneuvers between the mandatory exit lane and the adjacent through lane from the gore to a point between 152.5–213.5 m (500–700 ft) before the gore were recorded before and after the markings were installed. Comparisons were made on a matched 15-min interval basis. Because of geometric configurations at the sites, one location received the pavement markings and the sign treatment, and the remaining sites received variations on the pavement markings treatment only. One location showed improvement in operations during all peak periods, another location (Braeswood Exit) showed improvement in operations for peak periods except the p.m. period, and the last site had mixed results with some improvements in lane changes and some increases in lane changes. In the case of the last site, most of the deteriorating operations were attributed to the difficult geometrics of the site.

Approximately 1 year after the special markings were installed at the Braeswood Exit, additional lane change data were collected. The data from this effort were compared with the data in the preceding effort. The results showed a continual decrease in erratic lane changes over time. In addition, total and peak hour volumes were collected for all three study periods. The volumes showed a continual growth over time, demonstrating that even with increased volumes, the erratic lane changes decreased as a result of the pavement striping (*15*).

Other Studies

Geometric Considerations

Cornette (*12*) conducted a study in 1972 comparing the operational characteristics of four different types of lane drops (single lane exit with refuge area after the drop, single lane exit without refuge area, a lane termination, and a single-lane, lane split). Conflict surveys (erratic movements and brake light applications), spot speed measurements, and lane volume counts were collected at the four sites before and after various traffic control devices were implemented at the sites. Cornette found that the single lane exit without refuge area had the lowest conflict rates. In addition, the study concluded that lane drops associated with poor geometrics, such as high rates of curvature and sight distance restrictions, had higher conflict rates than those with more optimal geometric features. As a result, it was concluded that traffic control devices are not as effective in reducing conflicts as are proper site geometrics. Goodwin and Goodwin (*16*), in 1972, and Goodwin (*17*) later in 1976 developed a set of principles on which lane drops should be designed, most of which are applicable to exit lane drops. Information needed to successfully and safely travel though an exit lane drop area included: (*a*) knowledge of the impending lane drop, (*b*) location of the lane drop, (*c*) choice of an appropriate maneuver, and (*d*) time to execute that maneuver.

Operational Effects

In 1971 Goodwin and Lawrence (*18*) conducted a study in which they determined from field data the effectiveness of existing freeway mainline lane drops with regard to traffic operations. For the exit lane drop, the results of data analysis showed that only 10 percent of the vehicles on the freeway were traveling in the exit only lane at the beginning of the test section (approximately 305 m (1000 ft) before the gore). Most of these vehicles not exiting performed the lane change well before the end of the lane. A few vehicles, however, did make their maneuvers in the last 15.3 m (50 ft) before the gore.

STUDY METHOD

Several options are available to the traffic engineer to communicate to motorists an approaching exit lane drop. Some of the options, such as the yellow panel on the green guide sign, have been used for several years. Other options, such as pavement markings, are reasonable ideas; however, they have not been used on a consistent basis. To test the effectiveness of several different types of pavement markings in the field would require a significant outlay of personnel effort and funds. A survey technique can obtain drivers' reactions to different types of pavement markings without the sizable monetary commitment. Two types of surveys were selected for this project: a survey of motorists at an automobile show and a mail-out survey of driving instructors.

MOTORIST SURVEY—AUTOMOBILE SHOW

Development of Survey

Initial efforts on developing the automobile show survey included several meetings of the research team to determine the survey's goals and to develop appropriate questions. Two goals for the questionnaire were to determine driver interpretation of alternative marking and sign techniques and, to determine driver preference of exit only signs.

The type of participant was also considered during the survey preparation efforts. Because these participants were attending a recreational event and were unpaid volunteers, simplicity and brevity were two qualities emphasized during the development of the questions. A survey length of 10 to 12 min was estimated to be the maximum time that a participant would be willing to contribute. Because this survey was testing alternative markings that may or may not be in current use, computer generated colored art work was used, instead of pictures of existing sites.

Once the survey questions were selected, the survey was pretested to ensure that the questions were understandable. More than 30 respondents representing different gender and age groups were used to evaluate the questions. The pretest resulted in only minor changes.

Experimental Plan

To overcome any learning curve within the survey, the research team decided that the participants would be asked questions on only one type of marking. Four alternative versions of the questionnaire would be used during the survey period, with each alternative containing the same questions but with different pavement markings.

The four pavement marking alternatives selected for testing were

- I—typical white lane lines (3.05-m stripe with a 9.15-m gap) (10-ft stripe with a 30-ft gap),
- II—double white lines (each 101.6 mm wide, set 101.6 mm apart) (each 4 in. wide, set 4 in. apart),
- III—short lines and short spaces known as "lane drop markings" (203.2 mm wide, 0.92 m long, 3.66-m gaps) (8 in. wide, 3 ft long, 12-ft gaps), and
- IV—wide white line (203.2 to 304.8 mm wide) (8 to 12 in. wide).

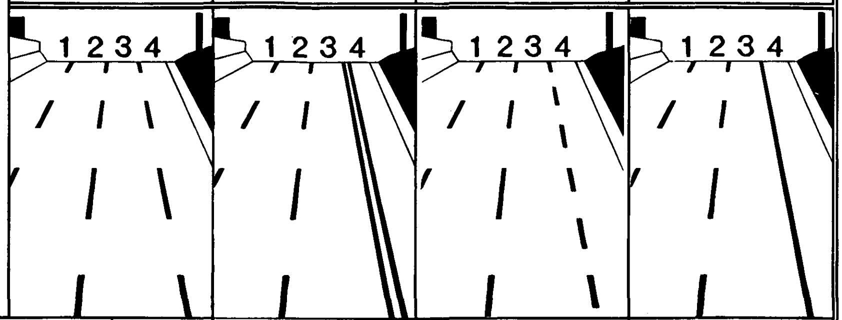
The typical white lane lines (Alternative I) were tested to serve as a baseline for comparison. The questions for each of the four alternatives were assembled into a separate three-ring binder for use during the automobile show. A participant would be asked questions from only one of the four three-ring binders. The use of each three-ring binder would be rotated so that a similar number of participants would answer the questions for each alternative.

Several types of questions were asked within each alternative. For example, the initial questions dealt with driver actions when only the markings were visible, and later questions covered driver actions when both markings and signs with an EXIT ONLY panel were visible. Only the visual presented to the participant (i.e., the type of pavement markings) changed for each alternative; the questions remained the same. The questions dealt with the following conditions for each alternative:

- Questions 1 to 3 dealt with markings only,
- Questions 4 and 5 dealt with markings and the appropriate sign for a one lane, lane drop exit,
- Questions 6 and 7 dealt with markings and the appropriate sign for a two lane, lane drop exit with an option lane and an exit only lane,
- Questions 8 to 10 dealt with markings and the appropriate sign for a two lane, lane drop exit where the alternative markings were placed between one set of lanes (Lanes 2 and 3), and
- Questions 11 to 13 dealt with markings and the appropriate sign for a two lane exit only where the alternative markings were placed between two sets of lanes (Lanes 2 and 3 and Lanes 3 and 4).

The initial set of questions (Questions 1 to 3) was critical to the survey, because it relayed the driver's understanding of the pavement markings without additional visual clues of the approaching mandatory exit (see Figure 1). The next set of questions (Questions 4 and 5) used the same markings and added a green guide sign with a yellow EXIT ONLY panel.

In addition to investigating driver opinion on alternative pavement markings, the survey contained questions about driver preference for the different types and locations of exit only signs. The signs tested included



QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
1 4 Must continue on freeway	2%	7%	8%	4%
1 4 Must exit	8%	73%	52%	72%
1 4 May either exit or continue	82%	13%	31%	19%
1 4 Not sure	8%	7%	9%	5%
2 3 Must continue on freeway	NA	67%	61%	55%
2 3 Must exit		3%	1%	3%
2 3 May either exit or continue		27%	37%	37%
2 3 Not sure		3%	1%	5%
3 L-4 must exit	NA	27%	42%	41%
3 L-3 may exit or continue		14%	35%	16%
3 May not cross marking		57%	9%	37%
3 Not sure		2%	14%	6%
Number of Respondents	132	148	124	124
Number of Responses for Question 3		175	153	157

FIGURE 1 Responses to markings only questions.

- The conventional green guide sign with a yellow EXIT ONLY panel (with a black down arrow on the panel or a white arrow on the green guide sign),
- A diagrammatic sign, and
- A green guide sign with a yellow EXIT ONLY panel and a black upward sloping arrow.

Conduct of Survey

The survey was conducted during the 1992 Houston Automobile Show. A total of 528 individuals participated, or an average of 130 per alternative. The participants in the survey were provided state and local maps and other literature from the Texas Department of Transportation in appreciation for their participation in the survey. No unusual conditions were experienced while administering the survey that would affect the survey results. Although the illustrations presented in this paper were modified to black and white for reproduction purposes, the actual drawings viewed by the participants were in color.

Findings

Demographics

The results from the demographic questions for the survey participants were compared with the distribution of licensed drivers in the United States (*19*). As in past automobile shows, most of the survey participants (approximately 66 percent) were white males; males represent 52 percent of licensed drivers. More than 80 percent of the respondents were less than 40 years old, with roughly half of these respondents in the less than 25 years age group and the other half in the 25 to 39 year age group. Approximately 53 percent of licensed drivers were less than 40 years old. Because the survey participants were younger than the licensed driving population, the survey captured drivers with less driving experience. This condition is assumed not to have an adverse effect on the findings of the study. Most respondents had high school degrees or equivalent, with approximately one-third of the participants having college degrees.

Markings Only Questions

The objective for the initial set of questions was to determine the driver's interpretation of pavement markings without any other visual clues. Figure 1 shows a summary of the responses from the four alternatives. For Alternative I, 8 percent of the participants said that if they were driving in Lane 4, they must exit from the freeway. Responses from Alternative III revealed 52 percent of the participants stated they must exit if they are in Lane 4. The other two alternatives pertaining to the solid white line markings resulted in approximately 72 percent of the participants stating that they must exit if in Lane 4. The solid white lines, even without additional visual clues such as the approach to the exit or a yellow panel sign, indicated best to the motorists that they will be required to exit if they continue in the lane.

Question 3 of the survey was similar to Question 1 but presented in a different manner to obtain additional understanding of motorists' interpretation of the markings. Although the participants were informed that they could choose more than one response, most participants selected only one response, with the type of response varying among alternatives. For example, in Alternative II, respondents tended to focus on whether they could cross the markings, but in Alternative IV the participants chose almost equally the Lane 4 "must exit" and the "may not cross markings" answers. The response distribution for Alternative IV was expected. The pattern of responses in Alternative II may be a reflection of the Houston district's using two solid white lines on some freeway exit ramps merging with a frontage road in conjunction with the sign that says DO NOT CROSS DOUBLE WHITE LINES. The results of Question 3 in Alternative III indicated that participants interpreted the lane drop lines as permissive. A higher percentage of respondents for Alternative III than Alternatives II or IV indicated that the vehicles in Lane 4 may either exit or continue.

Comments received from participants were informative. Some participants indicated that they had never seen some of the types of markings being tested (i.e., the double white lines or the lane drop markings). Several participants stated that they wanted a sign to provide the information about whether to exit instead of just basing their decisions on the pavement markings. These comments served as a reminder of the need to provide a secondary source of information until drivers are familiar with the new markings.

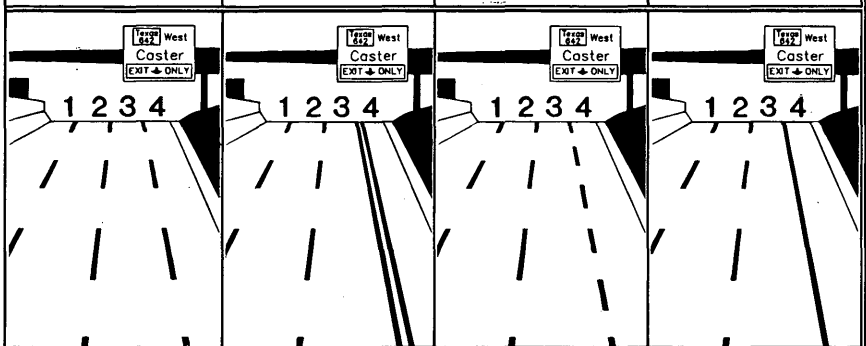
One-Lane, Lane Drop Exit Questions

The objective for the one-lane, lane drop exit questions was to determine whether the combination of signs and markings improves driver understanding of the approaching mandatory exit. Figure 2 illustrates the graphics as well as the findings from the survey. Driver comprehension of the markings increased noticeably with the addition of the EXIT ONLY sign. More than 91 percent of the respondents for each alternative indicated that Lane 4 must exit to Caster. For Alternative I, when no sign was used with the standard lane markings, 8 percent of the participants indicated that they must exit. When the sign was added, however, the must exit response increased to 92 percent.

Although the percentage of respondents choosing must exit to Caster for Lane 4 for the four alternatives was fairly consistent (91 to 98 percent), the percentage choosing "must continue" on freeway for Lane 3 was not as uniform. The lane drop markings alternative (Alternative III) had the lowest number of participants selecting the "must continue" option (60 percent). Most remaining participants selected the "may either exit or continue" selection. More than 80 percent of the participants of Alternative II selected the "must continue" option. This high percentage may be a reflection of the use of double solid white lines in some areas of Houston where some freeway exit ramps meet the frontage road.

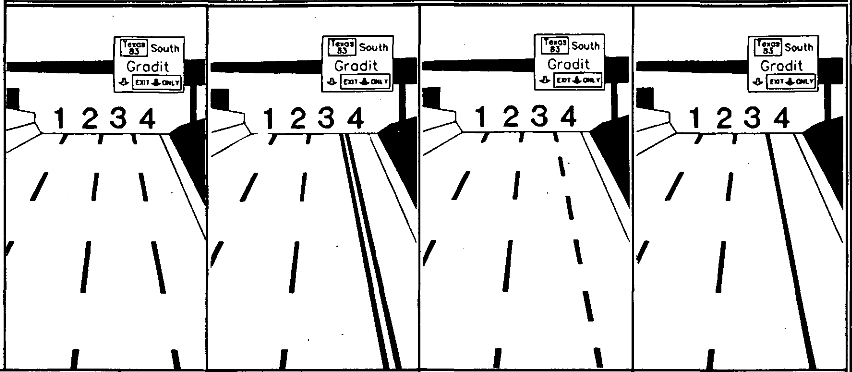
Two-Lane Exit with an Option Lane and an Exit Only Lane Questions

The objective of these questions was to determine whether the combination of signs and markings improves driver understanding that the approaching exit is a two-lane exit with one optional exit lane and one exit only lane (see Figure 3). More than 90 percent of the participants recognized that Lane 4 must exit. Between 67 and 79 percent of the participants selected the "may exit or continue on the freeway" option for Lane 3, which is the correct answer. A sub-



QUESTION	LANE	RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
4	4	Must continue on freeway	2%	1%	2%	0%
4	4	Must exit to Caster	92%	95%	91%	98%
4	4	May either exit or continue	6%	3%	5%	2%
4	4	Not sure	0%	1%	2%	0%
5	3	Must continue on freeway	NA	82%	60%	72%
5	3	Must exit to Caster		2%	2%	2%
5	3	May either exit or continue		15%	35%	23%
5	3	Not sure		1%	3%	3%
Number of Respondents			132	148	124	124

FIGURE 2 Responses to one-lane, lane drop exit questions.



QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
6 4 Must continue on freeway	1%	5%	5%	5%
6 4 Must exit to Gradit	92%	90%	89%	91%
6 4 May either exit or continue	7%	5%	4%	4%
6 4 Not sure	0%	0%	2%	0%
7 3 Must continue on freeway	28%	30%	18%	21%
7 3 Must exit to Gradit	4%	3%	2%	2%
7 3 May either exit or continue	67%	66%	79%	76%
7 3 Not sure	1%	1%	1%	1%
Number of Respondents	132	148	124	124

FIGURE 3 Responses to two-lane exit with option lane and exit only lane question.

stantial portion of the respondents, between 17 and 30 percent, selected the "must continue on freeway" answer for Lane 3. This indicates that several participants did not interpret the white down arrow (that is, outside the yellow EXIT ONLY panel) to mean that the drivers in the third lane can exit or stay on the freeway. Few participants (less than 5 of the 130 participants per alternative) selected the "must exit" answer.

Two-Lane, Lane Drop Exit with Markings Between One Set of Lanes Questions

The objective of these questions was to determine whether the combination of signs and markings improves driver knowledge of an approaching two-lane mandatory exit. Over 94 percent of the participants correctly selected the "must exit" answer for Lane 4, but only 82 to 90 percent of the participants correctly selected the "must exit" answer for Lane 3 (see Figure 4). Between 80 and 91 percent correctly selected the "must continue" option for Lane 2. Alternative III (lane drop markings), elicited the highest number of incorrect answers, primarily the "may either exit or continue on the freeway" answer. Respondents interpreted the permissive nature of the broken lane lines as allowing them to change lanes.

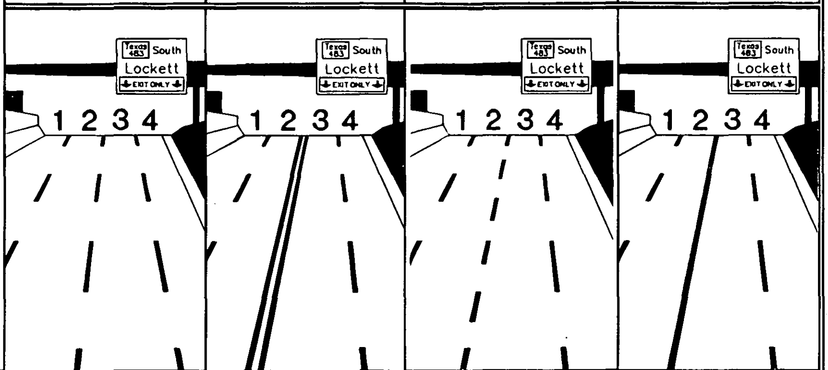
Two-Lane, Lane Drop Exit with Markings Between Two Sets of Lanes Questions

The objective of these questions was to determine whether the change in marking alters driver knowledge of the approaching two-lane mandatory exit. Figure 5 shows the results from the questions. The findings for this group of questions were similar to the previous group of questions. Between 93 and 99 percent (compared with 94 to 96 percent) of the participants correctly selected the "must exit" answer for Lane 4, and only 81 to 90 percent (compared with 82) of the participants correctly selected the "must exit" answer for Lane 3. Between 71 and 92 percent (compared with 81 to 91 percent) correctly selected the "must continue" answer for Lane 2. Alternative III (lane drop markings) again offered the highest number of incorrect answers, with those individuals selecting the "may either exit or continue" answer.

Several participants appeared surprised when viewing the graphics for Alternatives II to IV for this group of questions. They said that they had never seen a situation in which the markings are used between two sets of lanes. Several stated that Lane 3 should continue somewhere other than the direction of Lane 4 and that the sign is misleading because both lanes are going to Boulder. They thought that one lane should go to one destination and the other lane should go to another with this type of pavement marking.

Driver Preference Questions

Two objectives were selected for the driver preference questions. They were (*a*) to determine whether drivers understood the difference between an advanced guide sign and an exit direction sign and (*b*) to determine driver preference among different exit only signs. The participants were shown an exit only lane drop with three sign post locations. They were asked to indicate which of two signs they would prefer at each location (the choices were different for each sign location). The two primary findings were that diagrammatic



QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
8 4 Must continue on freeway	0%	2%	2%	2%
8 4 Must exit to Lockett	94%	96%	94%	94%
8 4 May either exit or continue	5%	1%	4%	4%
8 4 Not sure	1%	1%	0%	0%
9 3 Must continue on freeway	4%	4%	3%	2%
9 3 Must exit to Lockett	84%	89%	83%	90%
9 3 May either exit or continue	11%	7%	14%	8%
9 3 Not sure	1%	0%	0%	0%
10 2 Must continue on freeway	87%	91%	80%	88%
10 2 Must exit to Lockett	3%	2%	2%	1%
10 2 May either exit or continue	9%	6%	18%	9%
10 2 Not sure	1%	1%	0%	2%
Number of Respondents	132	148	124	124

FIGURE 4 Responses to two-lane, lane drop exit with markings between one set of lanes questions.

signs were chosen most often for the first sign but less often for later use and that drivers prefer the down arrow for the first sign use.

Interpretation of Findings

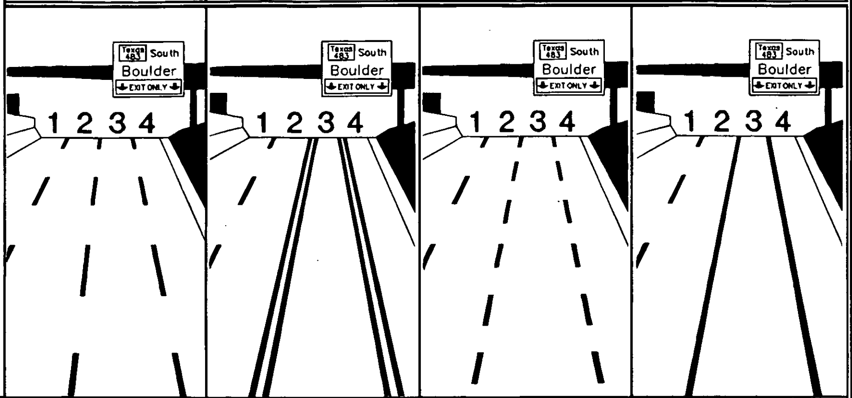
The motorist survey indicated a high level of understanding of the exit only signs. Only the sign for the two lane exit with one lane mandatory and one lane optional had correct comprehension of less than 80 percent. The white down arrow next to the yellow EXIT ONLY panel was correctly interpreted by only between 66 and 79 percent of respondents, depending upon the type of markings shown on the figure (see Figure 5). Note that the visuals represented only a specific location along a freeway. Drivers can encounter other visual clues, such as the approaching geometrics and other signs, to aid them in their driving decisions. In those cases in which a driver failed to observe a preceding sign, or the driver entered the freeway after preceding signs, most drivers correctly selected the appropriate response.

A noticeable difference occurred between the lane drop markings (short lines and short gap treatment) and the solid lane line markings. Drivers correctly interpreted the broken line markings as permissive and the solid lines as a restrictive. For example, when only the markings (no signs) were shown, more than 70 percent of the respondents indicated that the right-hand lane must exit. Only 52 percent of the respondents selected the "must exit" choice for the special markings alternative (see Figure 1).

DRIVING INSTRUCTOR SURVEY—MAIL-OUT SURVEY

The goal of the second survey was to obtain an indication of the comprehension of signs and pavement markings for freeway exit only lanes by inexperienced or new drivers. Driver instructors were requested to provide an assessment of their students' understanding of signs and pavement markings used at freeway exit only lanes. Of the 164 surveys mailed to driver instructors in large urban areas in Texas 44 were returned. Instructors indicated that their students had an above-average comprehension of current signing and pavement markings and a below-average comprehension of the difference between an up and a down arrow on an exit guide sign. In other questions instructors' responses revealed their belief that students had a good understanding of the meaning of the solid white line and a poor understanding of the meaning of the dashed white line (lane drop markings). When asked whether a diagrammatic sign better communicates that a lane must exit than the yellow EXIT ONLY panel, instructors responded overwhelmingly in favor of a diagrammatic sign. The survey indicated that the solid white line and the yellow EXIT ONLY panel are devices well understood by inexperienced drivers in Texas. This finding indicates the value of using pavement markings with signs to communicate information to motorists.

Instructors also made several suggestions for other traffic control devices at exit lane drops. Pavement treatments included pavement arrows, exit only signs, rough buttons lining the exit lane, and



QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
11 4 Must continue on freeway		2%	2%	0%
11 4 Must exit to Boulder	NA	96%	93%	99%
11 4 May either exit or continue		1%	3%	4%
11 4 Not sure		1%	2%	1%
12 3 Must continue on freeway		5%	5%	2%
12 3 Must exit to Boulder	NA	86%	80%	91%
12 3 May either exit or continue		7%	14%	6%
12 3 Not sure		2%	1%	1%
13 2 Must continue on freeway		89%	72%	92%
13 2 Must exit to Boulder	NA	3%	2%	0%
13 2 May either exit or continue		8%	25%	6%
13 2 Not sure		0%	1%	2%
Number of Respondents	132	148	124	124

FIGURE 5 Responses to two-lane, lane drop exit with markings between two sets of lanes questions.

beginning the solid white line at the first exit only guide sign. Sign suggestions included using diagrammatic signs in conjunction with the yellow EXIT ONLY panel, changing the colors of the signs, and adding RIGHT LANE or LEFT LANE to the yellow panel.

SUMMARY AND CONCLUSIONS

This paper presented findings from a literature review and two surveys on motorist comprehension of exit lane drop signs and markings. Studies of the black on yellow panels conducted in the early 1970s supported the use of the panels. The panels were required at interchange lane drops beginning with the 1978 edition of MUTCD. Early and recent studies on diagrammatic signs also support their use at exit lane drops. The results from both surveys conducted during this research support the findings from the literature. Motorists have a high level of understanding of the yellow EXIT ONLY panel, but they do not understand the use of the white arrow next to a yellow EXIT ONLY panel (see Figure 3). More than a third of the participants incorrectly interpreted the meaning of the white arrows. Motorists preferred the use of diagrammatic signs as the first of several signs indicating an approaching lane drop and the use of the conventional black on yellow panel (instead of the diagrammatic sign) close to the exit lane drop.

Pavement markings for exit only lane drops were first included in MUTCD in 1984 at the suggestion of California transportation engineers. They had several years of positive experience with the markings when they made the recommendation. Several of the previous research studies on pavement markings examined the use of markings at lane drops instead of exit only lane drops. A study in the late 1980s examined the effectiveness of markings at exit only lane drops. It found mixed results: at one location improvement in operations occurred during all peak periods, at the second location improvement occurred except during the afternoon peak, and the third location had some decrease and some increase in lane changes during the times observed.

The motorist surveys conducted for this research indicated that drivers showed equal comprehension of the meaning of the solid extra wide white line and the double white lines. Participants' responses also indicated that they knew the broken line markings are permissive and the solid lines are restrictive. The participants did not demonstrate as high a level of understanding of the meaning of the broken lines as of the solid line. The use of a solid line before an exit only lane drop is more prevalent than the use of the broken line.

RECOMMENDATIONS FOR FUTURE RESEARCH

Although surveys can obtain drivers' reactions and opinions to different types of pavement markings, field studies can measure actual driver behavior in response to a change. Studies that measure driver behaviors, such as lane changes and erratic maneuvers, before a treatment is installed and after a treatment is installed would indicate how drivers behave in response to a treatment. A control site study where two similar sites are identified and only one of the two sites receives a change in signs or markings could also be used. On the basis of findings from the surveys, testing the lane drop markings in the field would determine whether driver behavior is different with that type of marking than with standard white lane lines. Another area for research is the use of two sets of markings with a two lane exit (for example, see Figure 5). Several individuals during the automobile show commented that those markings would be appropriate when each lane is for a different destination.

Several studies, including this project, found that the meaning of the white arrow next to a yellow EXIT ONLY panel is not well understood by motorists. Research into alternative signs for two-lane exits with an option lane and an exit only lane would identify better techniques for communicating to motorists the downstream geometric exit configuration. The research could also examine whether different types of signs used at different locations would improve driver comprehension. For example, in this project, motorists indicated that they prefer the use of a diagrammatic sign as the first of several signs and the use of the EXIT ONLY panel close to the exit lane drop.

Additional research could also investigate the need for uniformity between signs and markings used for lane drops on freeways and on arterial streets (e.g., the use of the words EXIT ONLY on freeways and MUST EXIT on arterial streets). The research should include an appraisal of whether the status quo, although inconsistent, is better than modifying signs that have been used successfully for several decades.

ACKNOWLEDGMENT

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PART 3

Highway Safety Research

Testing Speed Reduction Designs for 80 Kilometer per Hour Roads with Simulator

RICHARD VAN DER HORST AND WYTZE HOEKSTRA

Reduction of driving speeds offers an important opportunity to improve traffic safety on rural 80 km/hr roads. An experimental project in Drenthe was aimed at developing measures to reduce speed effectively without significantly reducing driving comfort at speeds up to 80 km/hr. Some variants of proposed infrastructure measures were tested in a driving simulator before actual application. Experimental conditions consisted of two lane widths (2.75 and 2.25 m) and three experimental layouts of edge strips: one with a continuous profiled road marking, one with small lateral rumble strips every 5 m, and one every 10 m. On entering this edge strip (the 2.75-m lane had a strip of 0.20 m and the 2.25-m lane one of 0.70 m) auditive feedback by means of sound and steering wheel vibration was generated. A conventional 80 km/hr road (lane width 2.75 m) with standard road delineation served as control condition. Some subjects were instructed to drive in a relaxed manner, and the others were instructed to drive as if under time pressure. The results show that the narrow lane width (2.25 m with a 0.70 m edge strip) reduces speed the most and is fairly resistant to effects of adaptation. Moreover, the narrow lane width especially reduces the speeds of drivers under time pressure, implying that in practice speed variance may be reduced. The different layouts of the edge strips reveal relatively small differences in driving behavior. It is concluded that the basic design elements as developed in this project offer a good prospect for reducing driving speeds in practice.

In the Netherlands, rural 80 km/hr roads have the highest accident rates. In general, high speed contributes substantially to these accidents, and, reduction of driving speed may improve traffic safety on 80 km/hr roads. The experimental project Speed Reducing Measures on 80 km/hr roads in Drenthe—Drenthe is one of the 12 provinces in the Netherlands—was started in 1990 for the development and testing of measures that effectively reduce driving speed without significantly reducing driving comfort up to speeds of 80 km/hr. At speeds above 80 km/hr an increasing discomfort is aimed for. Measures to change the road and road environment that result in a natural lower speed choice by the motorist and reduced speed variation among cars will be explored. Measures of this type are well in line with recent developments of sustainable road safety and self-explaining roads (*1,2*).

The basic design elements for 80 km/hr roads were identified and compiled with the help of representatives from the local, regional and national government, research institutes, consultancies, and police (*3*). The design elements were used in a pre-evaluation of some variants of the proposed measures with respect to driving behavior by a driving simulator study. Apart from this study, the pre-evaluation included computer simulations of the effects of some road surface unevenness patterns on vehicle comfort and tire-road contact and a limited testing of the experimental road surface by instrumented vehicles on a road closed to other traffic (*4–6*).

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SPEED-REDUCING MEASURES

The literature on determining factors of speed choice was reviewed. Tenkink (*7*) distinguishes several behavioral models, of which the utility model is the most general: speed will be reduced when the risk or discomfort caused by high speed increases. In weighing the pros and cons of high speed, probability and the size of the consequences are important. For example, Tenkink (*8*) found that there was a reduction in speed when a narrow road width was combined with threatening obstacles along the road. Perceptual speed adaptation, uncertainty, and task demand also may play a significant role in drivers' speed choices. Negative consequences of high speed (discomfort, threat) may be effective if they are consistent, real, and if the involved risk is detectable, recognizable, and verifiable. Although an increasing threat, uncertainty, or workload may reduce speed, traffic safety may not necessarily improve (*9*). For each measure to reduce speed, the probability and the consequences of accidents must be assessed as well. Because drivers may react differently to given measures, with a possible increase in speed variance, measures must promote uniform behavior to the greatest extent possible. Furthermore, on a narrow road the visual guidance may be better than on a wide road, resulting in an increase in speed. These considerations resulted in a basic design for 80 km/hr roads (*3*) that consists of four main elements: lane width, edge marking, center marking, and verge reminders.

Lane Width

An important basic assumption in the design is that the net available lane width for drivers is reduced as much as possible. It takes some manoeuvering to make use of the so-called smooth asphalt part of the lane. Deviations from the right course must result in discomfort at speeds above 80 km/hr, but not in unsafe situations. Another constraint is to ensure that heavy vehicles (trucks, buses) are not impeded at speeds up to 80 km/hr. To meet both requirements, a net lane width of smooth asphalt between 2.25 and 2.75 m was proposed, together with a profiled edge marking that makes up a total road width of 6.20 m.

Edge Marking

A second assumption of the basic design is that no excessive visual guidance should be present. Therefore, it was proposed not to implement visual edge markings by delineation, but instead to use a tangible one in combination with the additional width needed for heavy vehicles. This edge marking must be designed in such a way that drivers of heavy vehicles do not notice much discomfort, but drivers of passenger cars experience discomfort that increases with speed.

Center Marking

Reducing the visual guidance of the edge markings requires drivers to get their information on the course of the road primarily from the center markings. The center marking must be clearly visible, even during darkness and bad weather, and must represent a unique code for 80 km/hr roads. Therefore, a 0.30-m center line, instead of 0.10 m, with 3-m-long white lines at 9-m spacing is proposed, preferably with a tangible component.

Verge Reminders

In the Netherlands, post-mounted reflectors at a height of 0.60 m every 40 m usually provide visual guidance. To reduce the visual guidance, these roadside reflectors are removed and replaced by so-called verge reminders that are uniquely designed for 80 km/hr roads at 500-m intervals.

In the simulator study, these four basic elements in the road design of 80 km/hr roads are included.

METHOD

Experimental Design

The aim of the simulator study is to gain insight in the functioning of the proposed measures in terms of driving behavior before they are implemented on the road. In general, results from simulator studies with respect to speed choice are well in line with real-world results (*9–10*), and the relative validity is acceptable. However, absolute speed levels should be interpreted with caution because one tends to drive faster in a driving simulator than in the real world.

The independent variables of the simulator-experiment included: instruction, road type, lane width, and edge-stripe configuration. Instruction and road type were varied between subjects, and lane width and edge-stripe configuration within subjects. A standard rural road with conventional delineation, a lane width of 2.75 m, and post-mounted reflectors every 40 m (see Figure 1) served as a control condition.

Instruction

In a previous simulator study on the effects of speed-reducing measures (*10*) two different driving instructions were used:

- *Relaxed*—Subjects are instructed to drive in a relaxed manner as they normally do when they are not in an hurry.
- *Time-pressure*—Subjects are instructed to drive as quickly as the conditions allow without jeopardizing traffic safety, as if they had left late for an important meeting.

A measure has the greatest effect when the speed of faster-driving motorists is reduced. An effect of instruction will clarify this.

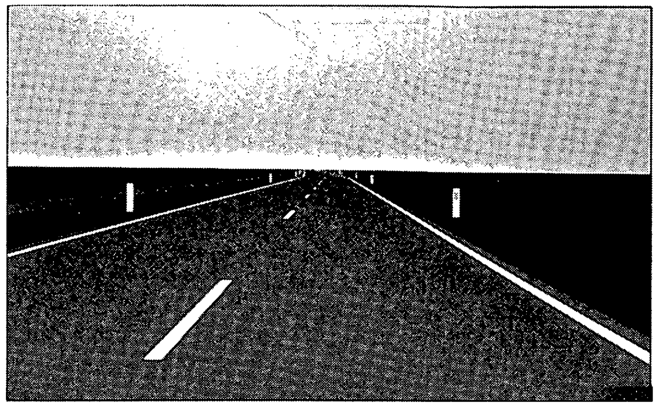

FIGURE 1 Road scene of control 80 km/hr road with conventional delineation in TNO driving simulator.

Road Type

In the experiment two types of rural roads were included:

- *Type A*—A road with long straight sections in an open environment with only a few vertical elements near the road.
- *Type B*—A more winding road through a varied landscape.

Both road types as implemented in the simulator were about 5.5 km long.

Lane Width

Because lane width is an important design element, two lane widths were chosen for the experimental roads: 2.25 m (narrow) and 2.75 m (wide). In all conditions the total road width remained the same, 6.2 m. The narrow lane always had a 0.70 m edge strip to provide enough space for heavy vehicles. All wide lane conditions had an edge strip of 0.20 m. Figure 2 shows the three lane configurations used in this study: the standard 80 km/hr road as a control condition, the narrow lane of 2.25 m, and the wide lane of 2.75 m.

Edge strips

Three experimental edge strip configurations were investigated:

- A continuously profiled marking strip (in the following indicated by profiled). As soon as the right front wheel hits this strip, the driver receives auditive feedback via a loud sound in the vehicle and a vibration in the steering wheel.
- Small cross rumble strips every 5 m. Driving over these rumble strips gives a pulsating sound and vibration in the steering wheel, depending on driving speed (5-m rumble).
- Small cross rumble strips every 10 m (10-m rumble).

These experimental configurations were applied on both edge strip widths (i.e. 0.20 and 0.70 m), resulting in the six experimental conditions shown in Figure 3. The center line of the experimental roads consisted of a 0.30 m-continuous profiled marking, with a series of three white blocks 0.80 × 0.30 m at a mutual distance of 0.30 m every 12 m. Entering the center marking with one of the

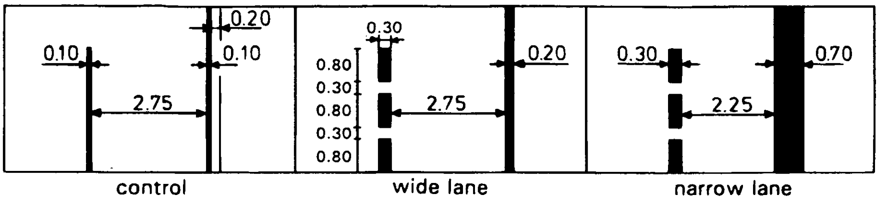

FIGURE 2 Cross section of control road (lane width 2.75 m) and experimental roads with wide (width 2.75 m) and narrow (width 2.25 m) lanes.

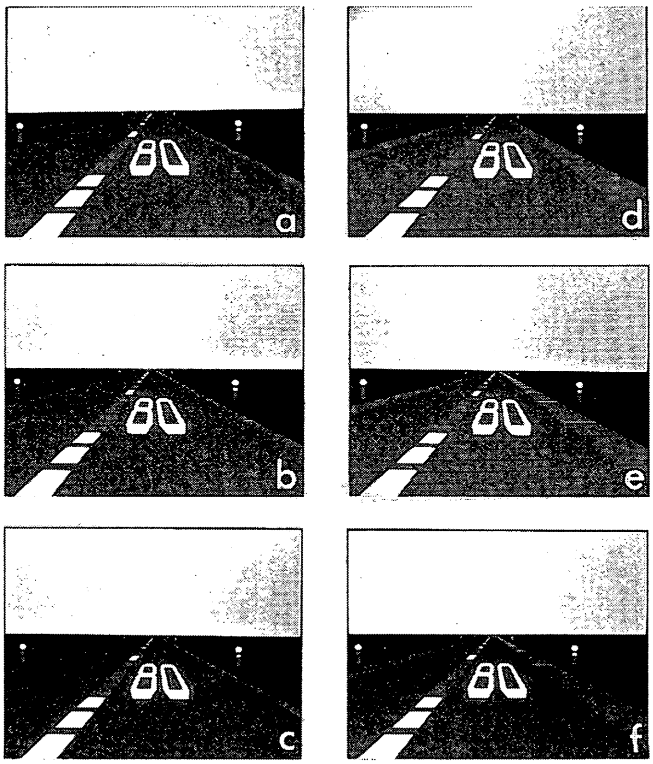

FIGURE 3 Road scenes of six experimental roads with two lane widths (a,b,c wide lane; d,e,f narrow lane) and three edge strip configurations (a and d profiled, b and e 5-m rumble, and c and f 10-m rumble).

wheels results in an auditive feedback to the driver as well. At the beginning of each experimental road the symbol "80" was painted on the road surface (see Figure 3).

To make the control condition comparable with the experimental conditions with respect to the post-mounted reflectors every 40 m, it was decided to have verge reminders every 40 m instead of every 500 m. The verge reminders consisted of red posts with yellow round plates.

Subjects

A total of 32 male subjects participated in the experiment; divided into four (2 × 2: instruction × road type) groups of eight subjects each. They were randomly recruited from the traffic subject records of the TNO Institute for Human Factors (TNO) by driving experience (having a driving license for at least 3 years and driving at least 10,000 km per year), and earlier experience with driving the TNO driving simulator. The ages varied between 21 and 53 years with the average age being 35.5. Subjects were paid for their participation.

TNO Driving Simulator

The experiment was conducted in the fixed-base driving simulator of the TNO. At the time of the experiment, this simulator had a MEGATEK 944 CGI system that generates the visual scene (1024 × 1024 pixels) at a refresh rate of 30 Hz. These images were displayed on a large screen in front of the vehicle mock-up (a Volvo 240) by a high resolution projector BARCOGRAPHICS 800 (*12*). The horizontal visual angle of the projected image was about 50 angular degrees. Recently, the TNO driving simulator has been equipped with a new CGI system and a three channel Evans & Sutherland ESIG 2000 system, which enables a horizontal visual angle of 120 degrees.

Procedure

Before driving in the simulator, subjects got either the relaxed or the time-pressure instruction in written form. Then a test run of about 5 min on a normal 80 km/hr road was begun to get the driver used to driving in the simulator again. In total each subject drove about for 2 hr in the simulator, subdivided into six (2 × 3: lane width × repetition) blocks of about 20 min each. Within each block a subject encountered four roads (control and 3 experimental ones), each road separated from the other by a roundabout at which the driver had to continue straight on. During each block the subject encountered 20 oncoming vehicles at speeds of 80 km/hr. After the experiment subjects completed a brief questionnaire. After a block was finished, a subject alternated with another subject and rested for about 20 min.

Analysis of Driving Behavior

During each run driving speed and lateral position were stored at a sampling rate of 5 Hz. At a sampling rate of 60 Hz where and how long either the center marking or the edge marking was entered by either one of the wheels were stored. Driving behavior on straight road sections and on curves (100 m before and 100 m after the curve included) was analyzed separately. The first and last 500 m of each road were excluded from the analysis. Separate analyses of variance (ANOVAs) were conducted on the dependent variables: speed, standard deviation of speed, lateral position, and standard deviation of lateral position. The number and duration of left and right lane exceedances, as well as the answers on the questionnaire, were analyzed but are reported elsewhere (*13*). The independent variables were instruction (two levels), road type (two), lane width (two), edge configuration (four), and repetition (three). If applicable, only the three experimental edge configurations were included in the ANOVAs.

RESULTS

Speed

The proposed measures aimed at reducing speed. Figure 4 shows the speed, averaged over subject, road type, and repetition, as a function of instruction, lane width ("smooth" asphalt), and the three experimental configurations of the edge strip. The results of the control condition with the conventional 80 km/hr road are added as a reference.

The absolute speed levels appear to be often rather high in a driving simulator. Also in this study, even for the instruction for relaxed driving the absolute speed values are well over 80 km/hr. ANOVA results reveal that differences between subjects contribute most to the variance (56 percent of explained variance). As illustrated in Figure 4, instruction has an important effect on speed. Subjects under time pressure drive about 15 km/hr faster on the straight road sections [113 versus 98 km/hr, $F(1,228) = 15.0$, $p < 0.001$, 17.3 percent of explained variance] and 14 km/hr faster in curves [110 versus 96 km/hr, $F(1,28) = 10.9$, $p < 0.005$, 14.3 percent explained variance]. The main effect of lane width does not reach significance [$F(1,28) = 3.6$, $p < 0.07$]. It appears that under time pressure the speed on the narrow lanes is significantly lower than on the wide lanes (*t*-test, $t = 3.4$, $p < 0.002$). A narrow lane especially reduces the speed of the drivers in a hurry. The three edge strip configurations differ only for the narrow lane width [interaction width × configuration $F(2,56) = 7.5$, $p < 0.002$]. Combined with the narrow lane width, the configuration with the continuous profiled marking reduces speed somewhat more than the two other configurations. So, the configuration with the most direct feedback to the driver has the most effect on speed. Repetition appears to have a main effect on speed [$F(2,56) = 38.3$, $p < 0.0001$, 3.1 percent of explained variance]. Speed increases with repetition, but the speed on the narrow lanes increases relatively the least [interaction lane width × repetition $F(2,56) = 7.5$, $p < 0.002$]. To compensate for this effect of repetition, for each run the difference between the speed on an experimental road and the speed on the control road within the same block has been calculated. Figure 5 gives the results.

An ANOVA reveals a main effect of lane width [$F(1,28) = 40.2$, $P < 0.0001$, 15 percent of explained variance]. The narrow lane gives the highest speed reduction. Combined with the narrow lane, the edge strip configuration with the continuous profiled marking reduces speed more than the 5 or 10 m rumble [interaction lane width × configuration $F(2,56) = 7.5$, $p < 0.002$].

To get an idea of the speed variations along a road, for each subject and each road the standard deviation of the speed has been computed separately for straight and curved road sections. Both reveal only main effects of instruction [relaxed 3.23 km/hr versus time pressure 5.54 km/hr, $F(1,28) = 22.5$, $p < 0.0002$] and repetition [$F(2,56) = 11.2$, $p < 0.0002$].

Lateral Positioning

For each subject the average lateral position relative to the center of the road has been calculated for straight and curved road sections.

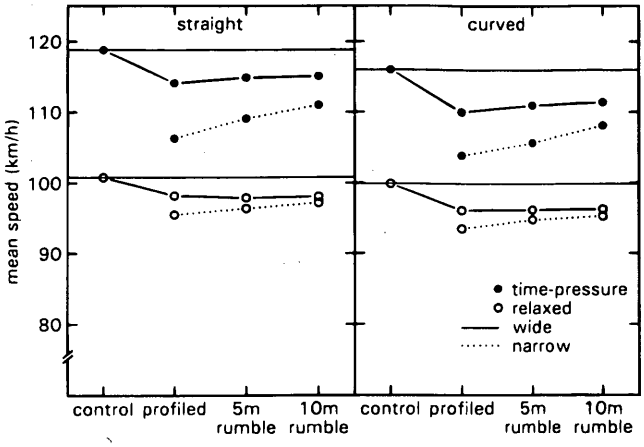

FIGURE 4 Mean speed on straight and curved road sections as function of instruction, lane width, and edge strip configuration.

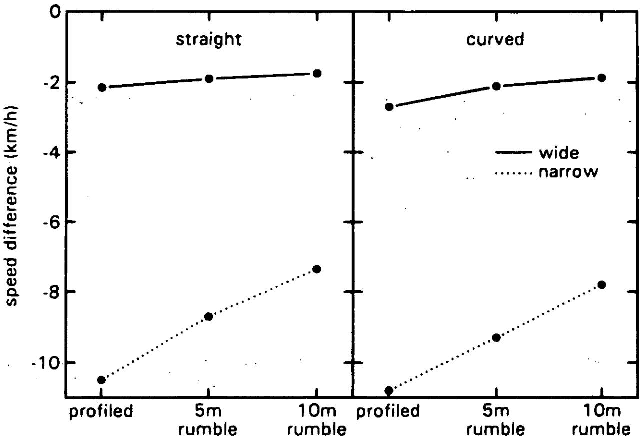

FIGURE 5 Mean difference in speed between experimental and control roads within each block as function of lane width and edge strip configuration on straight and curved road sections.

ANOVAs reveal that neither repetition, instruction, nor edge strip configuration has an effect on lateral position. As can be expected, lane width has far the greatest effect on lateral position [$F(1,28) = 509$, $p < 0.0001$, 72.9 percent of explained variance]. In the wide lane one drives 1.22 m from the middle of the road, whereas the narrow lane results in a lateral position of 0.99 m (straight road sections). The lane keeping behavior for both lane widths differs significantly from that in the control condition (mean lateral position 1.18 m) (wide lane versus control, $t = 4.04$, $p < 0.001$; narrow lane versus control, $t = 2.58$, $p < 0.02$). The resulting margins left and right of the vehicle relative to the road markings are shown in Figure 6.

With respect to the relative position of the driver within the center and edge strip, the three lanes differ little. On average, the driver chooses a position a little left from the middle of the lane (left 38 percent, right 62 percent).

The standard deviation of lateral position is independent of repetition, instruction, and edge strip configuration. Compared with the

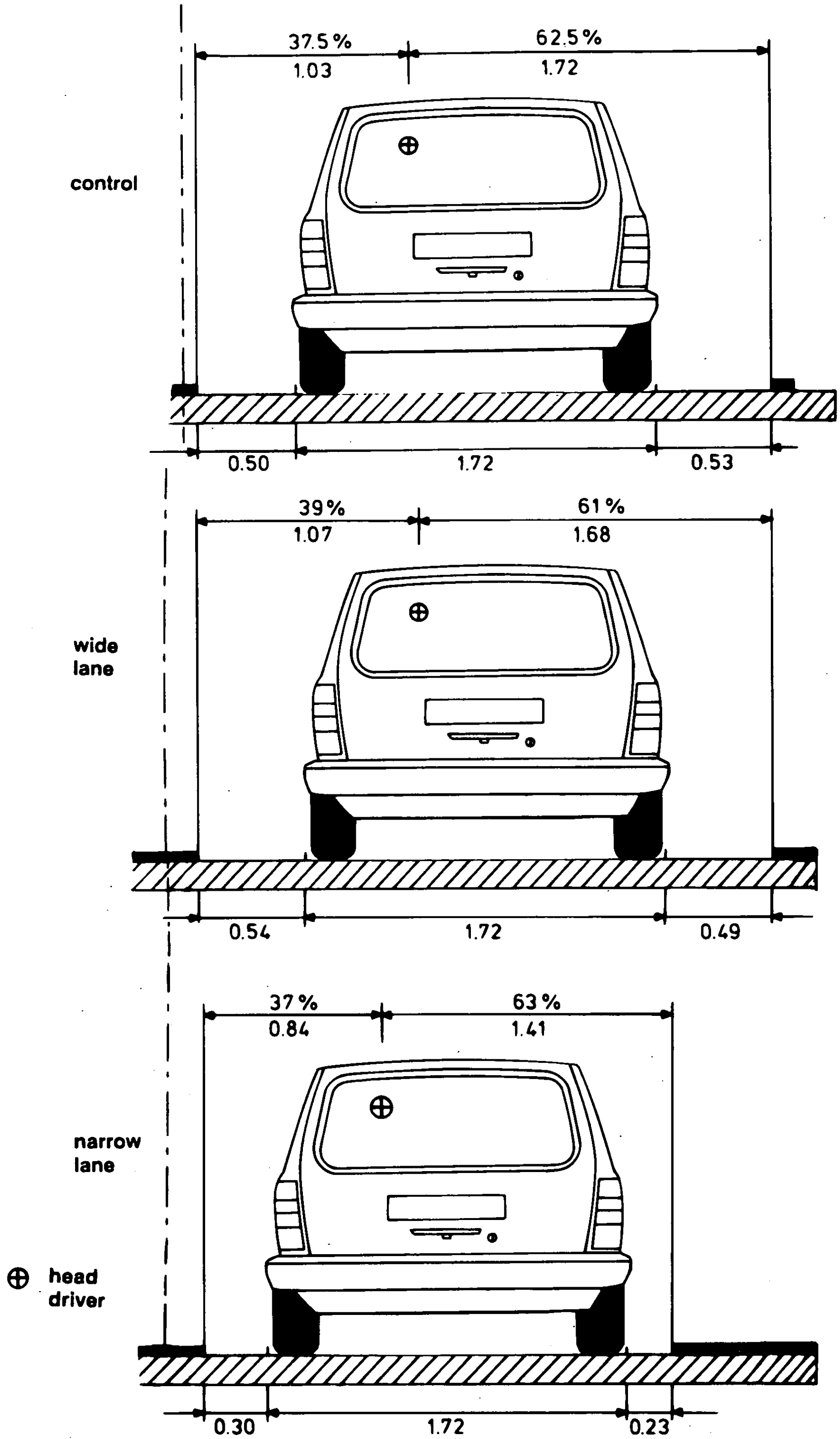

FIGURE 6 Mean lateral position of vehicle and driver within the traffic lane of the control, wide lane, and narrow lane condition.

control condition, the experimental lanes reduce the standard deviation of lateral position [$F(3,84) = 52.4$, $p < 0.0001$, 18.2 percent of explained variance] with the narrow lane having the strongest effect (standard deviation lateral position on straight road sections on control, wide lane and narrow lane 0.18, 0.15, and 0.12 m, respectively).

DISCUSSION AND CONCLUSIONS

An important question in simulator research is always to what extent the results found in a driving simulator have sufficient validity for actual driving behavior. As indicated before, in general, differences between experimental conditions appear to be comparable with real-world results in terms of relative validity. Absolute speed levels have to be interpreted with caution. This study also makes it clear that drivers drive fast in the simulator. Even with the relaxed driving instruction the driving speeds are well over 80 km/hr. Speed measurements on 80 km/hr roads reveal that the average speed (all vehicles included) is about 77 km/hr (*14*). Two aspects may partly bridge the gap between simulator and real-world results, but certainly not completely. First, about 28 percent of the total number of vehicles on 80 km/hr roads fall into a category of vehicles (vans, trucks, buses) that drive about 10 percent slower than passenger cars. Second, in the current study only free-riding cars were involved, not those influenced by a slower vehicle in front. Bakker and van der Horst (*15*) found that the average speed of free moving vehicles on 80 km/hr roads is about 9 km/hr higher than the average speed of all vehicles. In the current study the authors concentrated on the differences between conditions and especially the effects of the proposed speed reducing measures relative to the behavior on conventional 80 km/hr roads. The experimental configurations with the narrow lane of smooth asphalt of 2.25 m with an edge strip of 0.70 m result in the largest speed reduction relative to the control condition: on average, one drives 9 km/hr slower. With a lane width of 2.75 m (wide lane) only a small speed reduction can be expected. This lane width apparently provides even fast drivers enough space for staying in their lane comfortably. An important result is that the narrow lane especially reduces the speed of the drivers under time pressure. This may imply that in practice speed variance is considerably reduced with positive effects on traffic safety. Moreover, the narrow lane appears to be relatively resistant to effects of adaptation.

Edge strip configuration only has a small effect on speed in the narrow lane conditions. The continuous profiled marking with the most direct feedback to the driver and the greatest discomfort (vibration in the steering wheel and sound) gives the best results. This configuration in practice provides the driver with sufficient feedback. The study of the physical characteristics of different layouts by computer simulations (*4*) shows that the detailed design of the edge strip with the constraint—the discomfort of road users who inevitably have to use the edge strip (heavy trucks, buses) at speeds till 80 km/hr—is only marginal.

The lateral position of the driver within the lane does not differ much among the conditions and is in line with real-world findings of a 40:60 proportion relative to center line and edge line, respectively (*15,16*). In the wide lane condition, the 0.30-m center line with an acoustic warning shifts the driver 0.14 m to the right relative to the standard road profile, resulting in a reduction in the number of center line crossings. In the narrow lane drivers have to choose a lateral position more to the middle of the road, but the number of center line crossings does not increase relative to the control condition. The standard deviation in lateral position decreases for the experimental road designs, the most for the narrow lane and the result of a more accurate steering behavior by the drivers.

In summary, the basic design elements as proposed in this project offer a good prospect for reducing driving speeds in practice successfully. A narrow lane width of smooth asphalt 2.25 m wide, an edge strip of 0.70 m, and a center marking of 0.30 m, with acoustic feedback to the driver when crossing, appear to be effective measures to reduce speed. The final design details of the edge strip have to be based on the evaluation of the physical characteristics by computer simulation (*4*).

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Effect of Radar Drone Operation on Speeds At High Crash Risk Locations

MARK FREEDMAN, NANCY TEED, AND JAMES MIGLETZ

At highway construction and maintenance work zones and other locations where roadway alinement, road surface, and traffic flow conditions have contributed to high crash rates, crash risk may be reduced by lower and more uniform speeds. The use of unattended (drone) radar has been found to reduce the mean speed of vehicles and the number traveling at very high speeds. Drivers using radar detectors to warn of police speed enforcement activities respond to the warning and slow down, as do drivers of nearby vehicles. Speeds were measured with and without radar drones in operation at 12 construction and maintenance work zones and high crash locations in Missouri. It was found that mean speeds were moderately lower when radar was operating, and this effect was slightly greater for tractor-trailers than for passenger vehicles, although not significantly so at most locations. However, moderate reductions in mean speed were associated with more meaningful reductions in the number of vehicles exceeding the speed limit by more than 10 mph (17 kph), especially among tractor-trailers.

At hazardous highway locations where excessive speed contributes to crashes, reducing speeds is likely to be an effective countermeasure. Crash damage and injury severity have been found to increase with the square of velocity (*1*), and the risk of death in a crash has been shown to increase with the fourth power of the change in velocity (or the square of the energy dissipated) in a crash (*2*). Energy increases with the square of speed, and greater speed reduces the time and distance available to execute a crash avoidance maneuver and increases the distance needed to stop. In a study of crashes in Kentucky, speed was identified as a factor in almost 9 percent of all crashes and 37 percent of fatal crashes (*3*).

Highway construction and maintenance work zones are known to be especially hazardous locations where excessive speeds and driver inattention or distraction may contribute to crashes. Unanticipated changes in traffic speed, lane closures, and altered roadway alinement create conditions that increase the likelihood of a crash. Construction equipment and worker activities may distract a driver's attention, and temporary or absent road markings can render the proper path difficult to discern. Construction barricades and other traffic channeling devices may themselves become roadway hazards. In 1991 602 crashes caused 680 deaths at construction and maintenance work zones (*4*). FHWA guidelines stress that traffic movement in construction and maintenance work zones should be inhibited as little as practicable and that reduced speed zoning should be avoided as much as possible (*5*). However, preventing excessive speeds and large speed differences between vehicles helps alleviate some of the conditions that may lead to a crash. The characteristics of work zones where speed reductions are appropriate and the extent to which speeds should be reduced have been investigated previously (*6*). It was recommended that speed limits be reduced only where careful analysis indicated they were warranted, that maximum speed reductions be chosen according to roadway design and operating characteristics, and that active speed control (such as visible enforcement) be used where drivers are unwilling or unable to comply with posted work-zone speed limits.

Lower and more uniform speeds may also reduce the crash risk at other locations where roadway alinement, road surface, and traffic flow conditions have contributed to high crash rates. Although speed limits have been shown to affect speeds on freeways, many drivers exceed posted speed limits (*7*). Visible or perceived police enforcement tends to reduce speeds, especially in the immediate vicinity of those enforcement activities (*8*). Police radar is a widespread and effective speed enforcement tool.

To evade speeding citations, many drivers, especially tractor-trailer drivers, use radar detectors and slow down before being apprehended. Users of radar detectors have been found to drive faster than nonusers (*9–11*), to be more likely to be involved in crashes (*12*), and to slow down when they encounter police radar (*13,14*). Manned and unmanned (or drone) radar have been used to slow users of radar detectors. When radar detector–equipped vehicles slow down, other nearby vehicles also slow down. Research has revealed that about 15 percent of drivers of vehicles not equipped with radar detectors claim to adjust their vehicles' speed to that of a nearby radar detector–equipped vehicle (*15*). Drone radar has been found to effectively reduce the number of vehicles traveling at excessive speeds on roads with high crash rates, and especially to reduce mean speeds of the fastest vehicles approaching and within work zones (*8,16*). NHTSA has recognized the use of such drone radar operations as a speed deterrent and issued guidelines for their use (*4*).

The Federal Communications Commission (FCC), which regulates radar-emitting devices, requires them to conform to certain design and performance specifications. Some of the requirements are for unattended radar devices to be capable of transmitting and receiving a radar signal and to use the return signal to count vehicles or trigger a light or some sort of speed display. Low-power devices of this type are referred to as field disturbance sensors; full-power police radar units may also be used. Unattended radar units that do not use the return signal have been prohibited by the FCC.

In the present study, speeds were measured at roadways in Missouri that were identified by police and traffic engineering officials as having traffic speeds too high for safe operations. Drone radar units were deployed at these sites. The study sought to determine the effect of the radar drones on speeds in the vicinity of four types of hazardous locations: rural Interstate construction zones, rural and urban temporary work zones, rural Interstate high crash locations, and urban Interstate high crash locations.

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METHOD

Site Selection and Characteristics

The 12 study sites were selected from a list of candidate high crash locations and work zones provided by the Missouri Highway and Transportation Department Construction Division, the Missouri State Highway Patrol, and the Kansas City Maintenance Department. These were long-term construction zones on 65 mph (105 kph) rural Interstates [posted at 45 mph (72 kph) in the work zone], short-term maintenance zones on 55 mph (88 kph) urban and rural highways [posted at 45 mph (72 kph) in the work zone], high crash frequency locations on rural 65 mph (105 kph) Interstates, and high crash frequency locations on urban 55 mph (88 kph) Interstates. The normal speed limit for trucks on rural Interstates in Missouri is 60 mph (96 kph). Police accident reports were reviewed to ensure that excessive speed was a contributing factor at each candidate high crash site. Study sites were selected from candidates with relatively level terrain and adequate sight distances so that road geometry (such as sharp curves or steep grades) was not likely to have been a factor in the crashes or to influence speeds. Eleven sites had two lanes of traffic in each direction; one had three lanes. Average daily traffic (both directions combined) ranged from 20,000 to 70,000 vehicles per day. Sites were located according to the county's roadway records using the county road log milepoints. Site locations and characteristics are summarized in Table 1.

At each site, speed data for one direction of traffic were collected at two stations, as shown in Figure 1. One station was situated where a speed reduction was desired. The drone radar was also placed at this station, emitting radar in the upstream direction. For long-term construction zones, the radar drone station coincided with the beginning of the lane closure taper. At temporary work zones, the drone radar was at the first 45 mph (72 kph) reduced speed limit sign, located about 0.4 mi (0.6 km) upstream of the lane closure. At high crash locations, this station was near the county road milepost identified on the police accident report. The downstream station (out of range of the radar drone) was located well beyond where an initial speed reduction should have occurred but where reduced speeds are still important. At long-term construction zones, this was within the work zone, 0.2 to 0.8 mi (0.3 to 1.3 km) downstream of the drone radar. At short-term work zones, it was also within the work zone, 0.2 to 0.6 mi (0.3 to 1.0 km) downstream of the drone radar, near the beginning of the temporary lane closure. At high crash locations, the downstream measurement station was 0.4 to 0.8 mi (0.6 to 1.3 km) beyond the drone radar. The site types are shown in Figure 1.

Speed data were also collected at a third station, located at least 0.4 mi (0.6 km) upstream of the drone radar, where it was expected that vehicles would have been beyond the range of (and therefore uninfluenced by) the radar. These observations were intended to provide baseline speed data. It was later discovered that, because of variations in radar operating characteristics and radar detector sensitivity, vehicles at some of these upstream stations may have been within the radar's range. Because it was unclear whether these data were influenced by radar, they were not analyzed further.

Three different manufacturers' drone radar units were used in this study. Each type of drone unit was deployed at one long-term construction zone, one temporary work zone, and two high crash locations. Drones were mounted approximately 8 ft (2.4 m) above the pavement at the roadway edge at each site, with the mounting assembly (but not the drone) painted with camouflage colors to make it less conspicuous. Drones were operated on a 1-hr-on,

TABLE 1 Radar Drone Data Collection Site Characteristics

Site No.	Route	County	Urban or Rural	Speed Limit (mph)	Average Daily Traffic*** (veh/day)	County Road Log Milepoints: Drone	County Road Log Milepoints: Down-stream
Rural Interstate Construction Zones							
1	I-70 (W)	Cooper	Rural	65	20,880	10.2	10.0
2	I-70 (W)	Callaway	Rural	65	22,645	24.1	23.4
3	I-29 (N)	Platte	Rural	65	20,040	18.4**	19.2**
Rural/Urban Temporary Work Zones							
4	US-71 (S)	Cass	Rural	55	22,480	17.3	17.7
5	I-435 (S)	Jackson	Urban	55	70,370	58.3**	58.8**
6	I-470 (W)	Jackson	Urban	55	42,110	5.6**	5.4**
Rural/Interstate High Crash Locations*							
7	I-70 (E)	Montgomery	Rural	65	21,640	1.1	1.5
8	I-70 (W)	Callaway	Rural	65	23,670	11.4	10.9
9	I-70 (W)	Boone	Rural	65	27,075	7.7	7.0
10	I-70 (W)	Jackson	Rural	65	35,510	25.1	24.7
Urban Interstate High Crash Locations*							
11	I-35 (S)	Clay	Urban	55	46,590	18.4	19.2
12	I-35 (S)	Clay	Urban	55	41,865	20.1	19.4

* 60 mph (100 kph) for heavy trucks on rural interstates.
**Interstate mile post.
***1992, both directions.

1 mph = 1.6 kph; 1.6 km

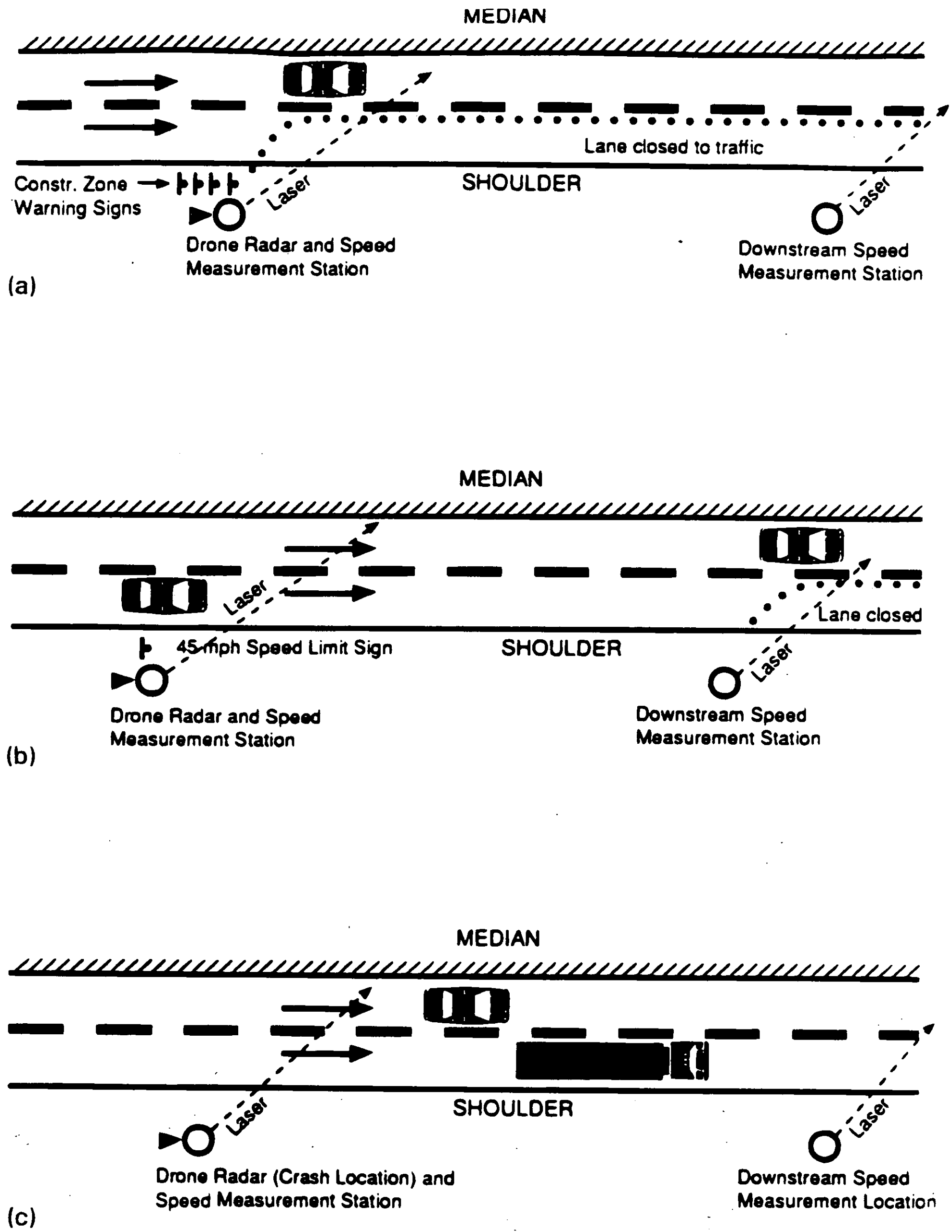

FIGURE 1 Schematic of study sites: (*a*) long-term construction zone layout, (*b*) temporary work-zone layout, and (*c*) high crash location layout.

1-hr-off basis throughout the data collection period, instead of on a longer-term before and after schedule. This was done to increase the likelihood that periodic changes in traffic flow characteristics not related to the drones (e.g., reduced speeds because of rain one day but fair weather and higher speeds on other days) would be equally represented in the two conditions, thus allowing comparison of the effects of drones on speeds.

Data Collection

Speeds of a random sample of vehicles were measured from 9:00 a.m. to 5:00 p.m. on a single day at each site. Data were collected during the full 8-hr period at each long-term construction work zone and high crash location; at temporary, maintenance work zones, speeds were measured while the work zone was in place (4 to 6 hr within the 9:00 a.m. to 5:00 p.m. period). Data were not collected during periods when precipitation may have affected speed.

Speeds were measured by using a commercially available laser speed measurement system, which determines speed by measuring the time of flight of very short pulses of infrared light. Lasers of this type are not detectable by radar detectors. Although laser detectors are commercially available, they are not widely used and have been found to be relatively ineffective in field testing on a closed course

(*17*). Lasers are used for speed enforcement by a growing number of police departments.

Speeds were sampled during the first 45 min of each hour. Vehicles were systematically sampled by selecting the next vehicle, in any of the studied lanes that crossed the laser's line of sight after the previously sampled vehicle's speed was recorded. At each site, data were simultaneously collected at each of the measurement stations. An observer located beyond the right shoulder measured speeds of vehicles with the laser aimed 500 to 1,000 ft (150 to 300 m) downstream of the observer's station. Traffic volume was counted each hour for 10 min following each speed data collection period. Observers also recorded the time, location, and nature of unusual events, such as vehicle breakdowns, that could have influenced traffic speeds. By monitoring drivers' comments on citizen-band radios, observers confirmed that the radar drone's signal had been detected by users of radar detectors.

Analysis

Measured speeds were divided by the cosine of the angle between a vehicle's heading and the laser's line of sight to compensate for cosine error. Frequency counts of speed observations, mean speeds, and percentages of vehicles exceeding the speed limits by various amounts were computed by vehicle type (passenger car, pickup, van, utility vehicle, tractor-semitrailer, tractor–double trailer, straight truck, bus, towed vehicle, and others), measurement station (upstream or downstream), and drone condition (off or on) for each site. The main effects and interactions of the drone radar condition and vehicle type on speed were determined separately for each measurement station and site with the SAS General Linear Model procedure (*18*). The effects of drone radar on the distribution of the fastest vehicles [those exceeding the speed limit by more than 10 mph (16 kph)] were determined by using the chi-square statistic.

RESULTS

A total of 20,516 observations of vehicle speeds were made at the speed reduction and drone radar and downstream measurement stations. As shown in Table 2, approximately three-fourths were of passenger cars, pickups, vans, and utility vehicles, and nearly one-fifth were tractor-semitrailer and double trailer combinations. The remainder (straight trucks, buses, towed vehicles, and others) made up less than one-twentieth of the sample. Because the operating characteristics and radar detector use among the vehicles in this latter group typically vary widely (*9,10*) and because the number of observations at each station at each site was small, these observations were not included in further analyses of speeds.

Mean speeds and percentages exceeding the speed limits by more than 10 mph (16 kph) with the radar drones on and off are shown in Table 3 for each station at each site for the combined group of passenger cars, pickups, vans, and utility vehicles and in Table 4 for the combined group of tractor-trailers (tractor-semitrailer and double trailer trucks).

Overall, speeds of all vehicle types were higher than the posted or reduced speed limits. Passenger vehicle speeds tended to be higher than truck speeds. Speeds were generally lower when the radar drones were on. The effect of radar drones on speeds was slightly greater for trucks than for passenger vehicles but was significantly so ($\alpha < 0.05$) at only two sites: the downstream location at Site 11, an urban Interstate high crash location, and the drone location at Site 4, a rural/urban temporary work zone.

The following sections discuss the effects of drones at each site type.

TABLE 2 Number of Observations by Vehicle and Site Type

	Site Type				
Type	Long-term Construction	Short-term Work Zone	Rural High Crash	Urban High Crash	Total
Passenger Vehicles					
Passenger cars	2,478	1,651	4,058	2,101	10,288
Pickups, vans, utility vehicles	1,111	1,147	1,825	1,274	5,357
Tractor-Trailers					
Tractor-semi-trailer trucks	376	1,477	1,385	521	3,759
Tractor-double trailer trucks	64	18	107	14	203
Other Vehicles					
Straight trucks delivery trucks	87	94	165	94	440
Other (bobtail, tractor, bus, towed vehicle, etc.)	133	68	210	58	469
Total	**5,386**	**3,318**	**7,750**	**4,062**	**20,516**

TABLE 3 Measured Speeds of Passenger Cars, Pickups, Vans, and Utility Vehicles (mph)

		Measurement Location					
		Drone			Downstream		
Site	Drone	No.	Mean	Percent High Speed**	No.	Mean	Percent High Speed**
Rural Interstate Construction Zones							
2	off	289	55.6	55	255	48.3	18
	on	212	55.1	50	261	47.0	12
3	off	364	65.3	93	277	57.8	68
	on	346	62.9	90	270	56.4	57
13	off	348	62.4	88	309	55.3	49
	on	329	61.5	87	365	53.7	38
Rural/Urban Temporary Work Zones							
9	off	209	60.3	85	211	57.7	66
	on	234	59.9	85	208	57.6	66
10	off	323	60.7	82	285	57.5	60
	on	227	57.3	66	256	54.4	44
14	off	181	56.5	62	174	53.8	40
	on	202	57.1	60	252	54.4	41
Rural Interstate High Crash Locations							
4	off	299	68.8	8	350	69.0	8
	on	294	67.1	2	295	67.2	4
5	off	369	67.0	5	310	66.9	6
	on	388	66.2	3	362	66.2	6
6	off	354	66.2	6	456	66.2	4
	on	438	66.3	4	414	67.0	4
12	off	363	66.1	2	367	66.0	3
	on	430	65.9	2	394	64.9	2
Urban Interstate High Crash Locations							
8	off	416	61.0	18	462	63.0	29
	on	411	60.3	16	475	62.9	30
11	off	374	61.2	22	408	60.8	20
	on	400	60.4	15	429	60.8	20

1 mph = 1.6 kph
** Exceeding speed limit by more than 10 mph (16 kph).

Rural Interstate Long-term Construction Zones

At Sites 1, 2, and 3, the usual posted 65 mph (105 kph) speed limit was reduced to a posted speed limit of 45 mph (72 kph). Although mean speeds for passenger vehicles were generally at or below 65 mph (105 kph), they exceeded the 45 mph (72 kph) limit by 10 to 20 mph (16 to 32 kph) at the drone stations and by a least 10 mph (16 kph) at two downstream stations with drone radar off or on. Tractor-trailers exceeded the reduced speed limit by up to 15 mph (24 kph) at the drone stations and by nearly 10 mph (16 kph) at two of the downstream stations with the radar off or on.

Regardless of the drone radar operating condition, mean speeds of passenger vehicles were higher than those for trucks at all measurement stations, as shown in Figure 2.

Mean speeds of passenger vehicles were 0.5 to 2.4 mph (0.8 to 3.9 kph) lower and of tractor-trailers were 0.6 to 3.6 mph (1.0 to

TABLE 4 Measured Speeds of Tractor-Trailers (mph)

		Measurement Location					
		Drone			Downstream		
Site	Drone	No.	Mean	Percent High Speed**	No.	Mean	Percent High Speed**
Rural Interstate Construction Zones							
2	off	145	51.3	31	136	47.5	12
	on	138	49.5	15	152	46.0	7
3	off	120	60.2	84	170	54.6	46
	on	150	56.6	59	153	52.3	30
13	off	78	57.7	69	103	53.2	33
	on	89	56.7	64	107	52.6	32
Rural/Urban Temporary Work Zones							
9	off	40	59.5	82	44	54.0	39
	on	59	56.0	52	52	52.0	33
10	off	42	54.6	48	36	52.3	31
	on	32	53.7	34	35	50.1	11
14	off	16	53.4	38	10	50.5	20
	on	15	52.0	40	13	52.4	23
Rural Interstate High Crash Locations* **							
4	off	121	63.2	10	116	63.6	9
	on	140	61.4	0	113	61.9	4
5	off	103	62.2	4	106	57.9	2
	on	70	60.4	3	88	56.8	0
6	off	81	63.1	4	71	62.0	3
	on	95	62.3	3	60	63.1	3
12	off	90	61.8	3	64	60.1	0
	on	90	60.3	1	84	59.9	0
Urban Interstate High Crash Locations							
8	off	86	59.2	9	73	62.6	23
	on	77	57.2	15	63	60.7	18
11	off	52	60.5	21	59	58.5	8
	on	58	59.5	10	67	57.4	6

1 mph = 1.6 kph
** Exceeding speed limit by more than 10 mph (16 kph).
*** 60 mph (97 kph) speed limit for trucks.

5.8 kph) lower when drone radar was on than when it was off. The differences were significant for two of three drone radar stations (the third was nearly significant) and for all downstream stations within the work zone. The effect of the drones was not statistically different for passenger vehicles and trucks.

The proportion of very fast vehicles was lower with radar on in every case, as shown in Figure 3. Proportions of passenger vehicles exceeding the speed limit by more than 10 mph (16 kph) were significantly (chi-square $p < 0.05$) lower at the downstream location at Sites 2 and 3. Excessive speeding was significantly reduced among tractor-trailers at drone stations at Sites 1 and 2 and at Site 3 downstream, and the differences were nearly significant at Site 1 downstream for passenger vehicles and trucks.

Rural and Urban Freeway Temporary Work Zones

A temporary speed limit of 45 mph (72 kph) was in force at Sites 4, 5, and 6, which were normally posted at 55 mph (88 kph). Mean speeds of passenger vehicles and trucks are shown in Figure 4. In

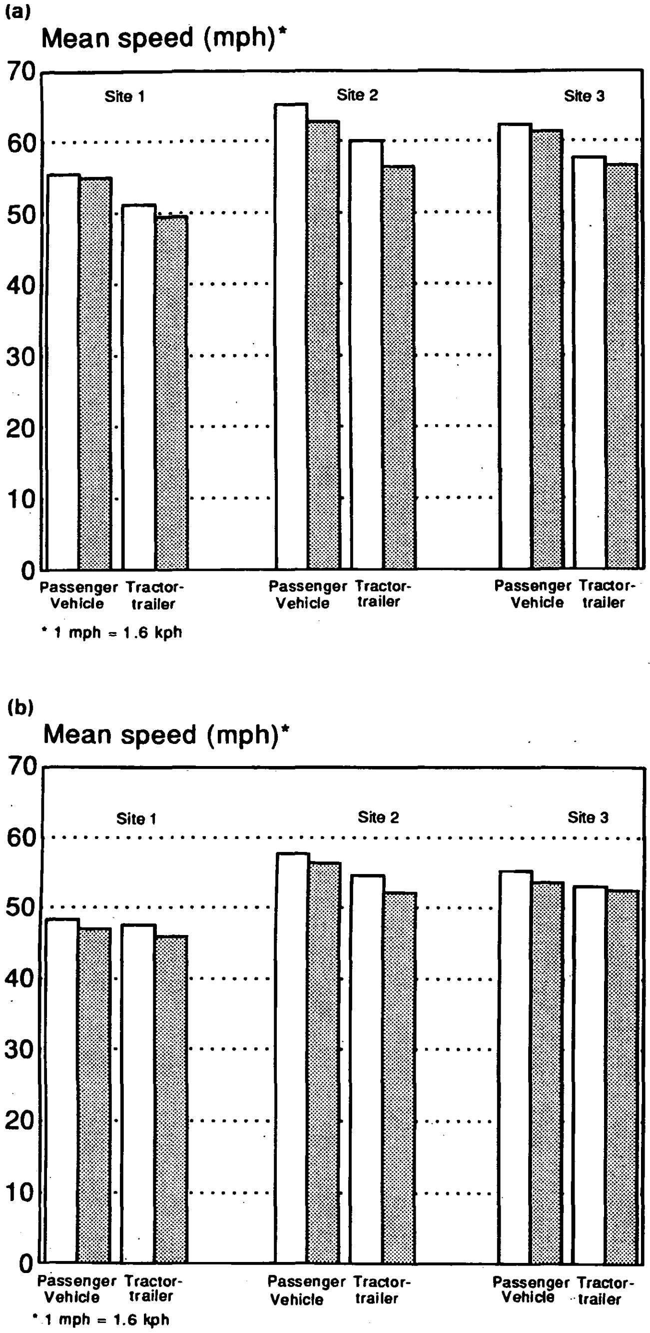

FIGURE 2 Mean speeds for passenger vehicles and tractor-trailers at long-term rural construction zones: (*a*) drone location and (*b*) downstream location (shaded bar, radar on; white bar, radar off).

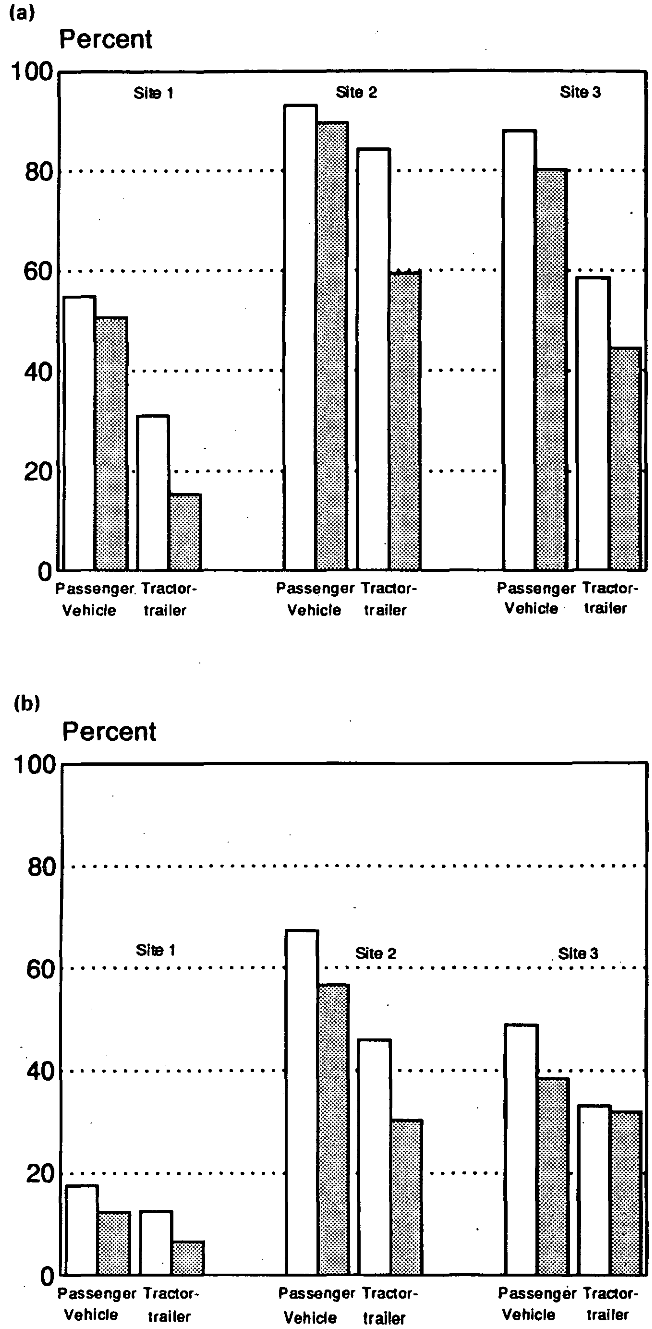

FIGURE 3 Percentage over speed limit by more than 10 mph (16 kph) for passenger vehicles and tractor trailers at long-term rural construction zones: (*a*) drone location and (*b*) downstream location (shaded bar, radar on; white bar, radar off).

most cases, the mean speed of passenger vehicles exceeded the normal speed limit at upstream and downstream stations, and in all cases, passenger vehicle and heavy truck mean speeds exceeded the reduced speed limit, regardless of whether drone radar was off or on.

Passenger vehicle mean speeds were significantly higher than truck mean speeds at upstream and downstream stations at each of the three temporary work zones, with drone radar either off or on.

Although passenger vehicle mean speeds were lower when the radar drones were on at the upstream and downstream stations at Sites 4 and 5, they were higher at Site 6. Mean speeds were also lower for heavy trucks at the upstream stations at Sites 4, 5, and 6 and at the downstream locations at Sites 4 and 5, but were higher at downstream Site 6. The differences (for both vehicle types combined) were significant at only Sites 4 and 5 upstream and Site 5 downstream.

The proportions of vehicles exceeding the speed limit by more than 10 mph (16 kph) were more often lower when radar was on, as shown in Figure 5. The differences were significant for passenger

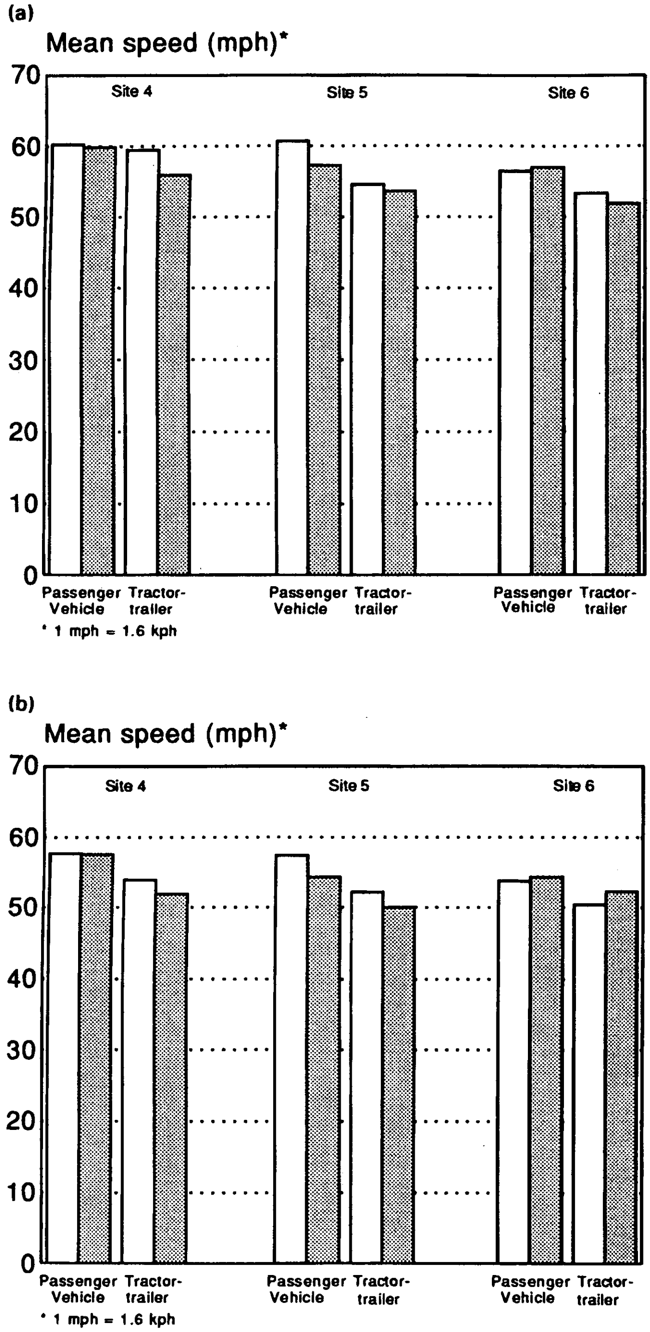

FIGURE 4 Mean speeds for passenger vehicles and tractor trailers at rural/urban temporary work zones: (*a*) drone location and (*b*) downstream location (shaded bar, radar on; white bar, radar off).

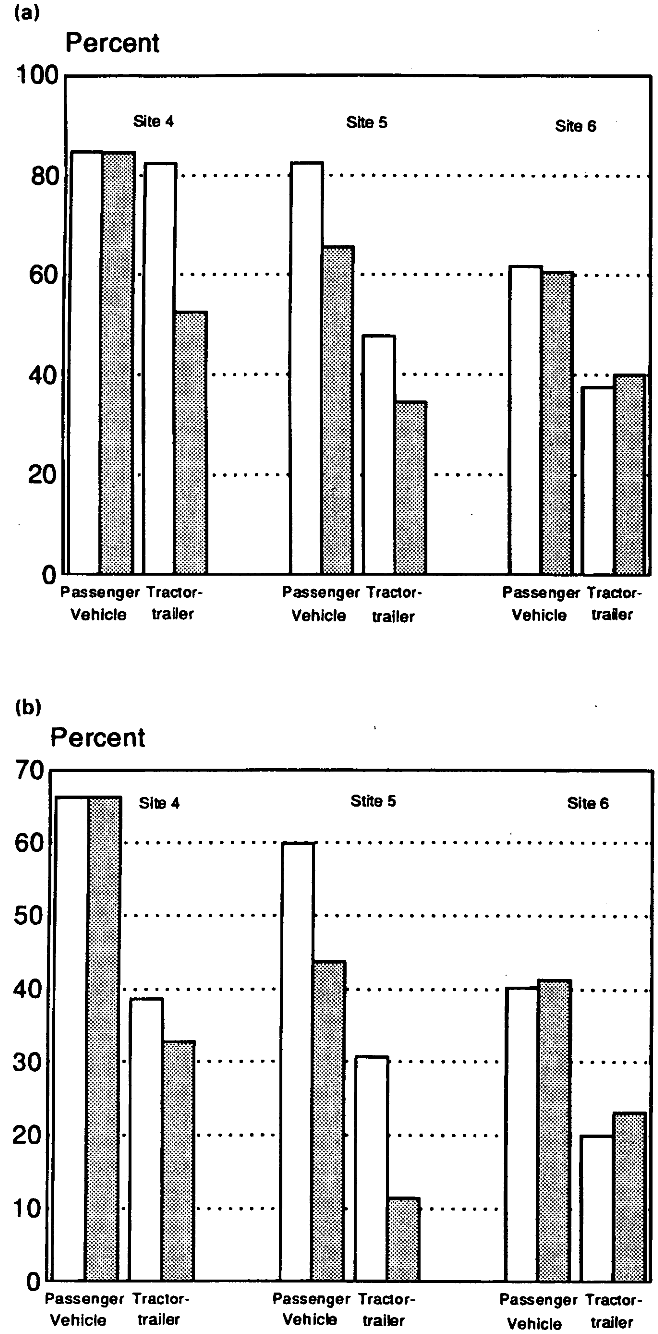

FIGURE 5 Percentage over speed limit by more than 10 mph (16 kph) for passenger vehicles and tractor-trailers at rural/urban temporary work zones: (*a*) drone location and (*b*) downstream location (shaded bar, radar on; white bar, radar off).

vehicles at the drone and downstream locations at Site 5 and for trucks at the drone location at Site 4 and the downstream location at Site 5.

Rural Interstate High Crash Locations

Passenger vehicle mean speeds were at or slightly above the posted 65 mph (105 kph) speed limit at Sites 7, 8, 9, and 10, regardless of whether the drone radar was on or off. Tractor-trailer mean speeds were more than the 60 mph (97 kph) truck speed limit at all drone stations and most downstream stations by up to 3.6 mph (5.8 kph). Tractor-trailer speeds were significantly lower than passenger vehicle speeds at the upstream and downstream stations at all four sites. When the radar was on, mean speeds were 0.2 to 1.8 mph (0.3 to 2.9 kph) lower among passenger vehicles at Sites 7, 8, and 10; however, speeds were 0.1 to 0.8 mph (0.2 to 1.3 kph) higher at Site 9. Among tractor-trailers, mean speeds were 0.2 to 1.8 mph (0.3 to

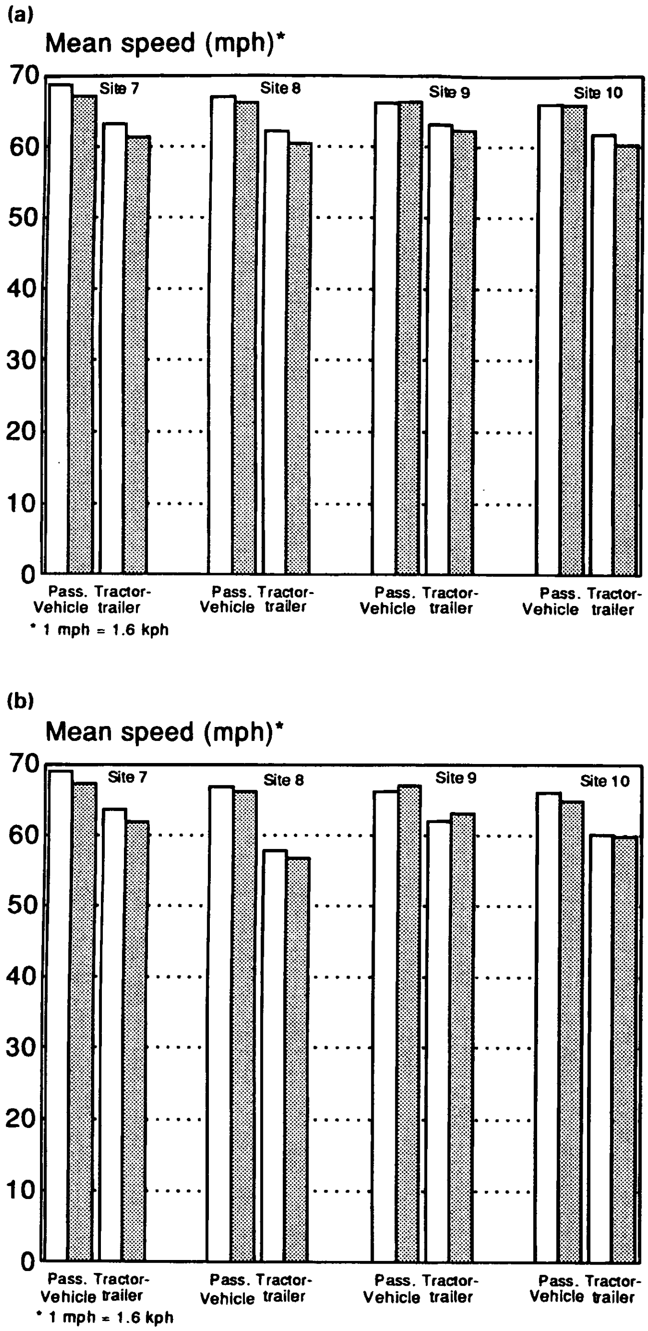

FIGURE 6 Mean speeds for passenger vehicles and tractor-trailers at rural Interstate high crash sites: *(a)* drone location and *(b)* downstream location (shaded bar, radar on; white bar, radar off).

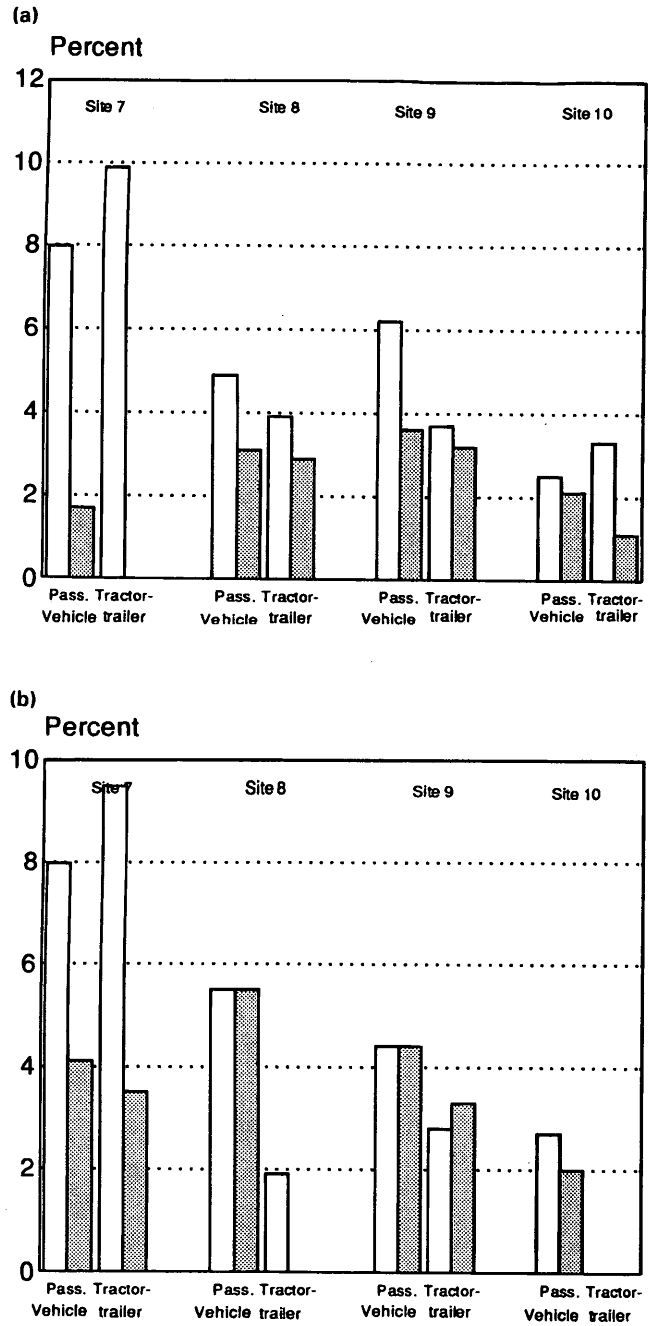

FIGURE 7 Percentage over speed limit by more than 10 mph (16 kph) for passenger vehicles and tractor-trailers at rural Interstate high crash sites: *(a)* drone location and *(b)* downstream location (shaded bar, radar on; white bar, radar off).

2.9 kph) lower at both stations at all four sites with the radar on. The speeds were significantly different for all vehicles combined at upstream stations at Sites 7, 8, and 10, at the downstream station at Site 7, and nearly significant downstream at Sites 8 and 9 (Figure 6).

The proportion of high-speed passenger vehicles was in all but two cases lower when radar drones were on, significantly so at the drone and downstream locations at Site 7, as shown in Figure 7. The proportion of high-speed tractor-trailers was reduced at most measurement stations, significantly so at the drone location (and nearly so at the downstream station) at Site 7.

Urban Interstate High Crash Locations

Passenger vehicle and tractor-trailer mean speeds exceeded the 55 mph (88 kph) speed limit at the drone and downstream stations with drone radar off or on at Sites 11 and 12. Unlike at other sites, speeds at Site 11 increased markedly [about 3 mph (5 kph)] from the upstream to the downstream location, regardless of whether drone radar was off or on. Passenger vehicle speeds, which averaged 6 to 8 mph (10 to 13 kph) above the speed limit, were in all cases higher than the mean speed of trucks. The differences were significant at the drone and downstream stations at Site 11 and at the downstream station at Site 12. With radar on, mean passenger vehicle speeds were only slightly lower than with radar off at all but one station, where the mean speeds were the same. Mean truck speeds were 1.0 to 2.0 mph (1.6 to 3.2 kph) lower at all locations with radar on. However, the effect of radar was associated with significantly different speeds for all vehicles only at Site 11 (Figure 8).

At drone locations, the proportion of passenger vehicles traveling more than 10 mph (16 kph) over the speed limit was lower with radar on, but was significantly lower only at Site 12, as shown in Figure 9. Conversely, the proportion of high-speed passenger vehicles was slightly but not significantly higher with radar on at downstream locations. High-speed tractor-trailers were in most cases less evident with radar on, but the differences were not significant.

DISCUSSION OF RESULTS

The results of this study indicate that the operation of drone radar can somewhat reduce the speeds of passenger vehicles (cars, pickups, utility vehicles, and vans) and tractor-trailer combinations at many long- and short-term construction and maintenance work zones and high crash locations on urban and rural freeways. These effects on speed were generally evident at the specific locations where a speed reduction was deemed necessary and were also found to exist at least 0.2 to 0.8 mi (0.3 to 1.3 km) downstream at long-term construction zones and 0.2 to 0.5 mi (0.3 to 0.8 km) downstream at temporary work zones. At urban and rural high crash locations, speeds generally remained lower for at least 0.4 to 0.8 mi (0.6 to 1.3 km) downstream when radar drones were activated. However, mean speeds were far above the speed limit, even when the drone radar was operating.

Tractor-trailer mean speeds were generally reduced much more than speeds of passenger vehicles, but this was not always the case and was statistically significant at only two sites. The greater influence on truck speeds is likely because of the more frequent use of radar detectors among heavy trucks. Radar detectors are used in about 4 to 7 percent of cars and light trucks and in 30 to 69 percent of tractor-trailers (*9–11*). It is therefore likely that a much larger proportion of tractor-trailers would slow near drone radar, influencing the mean speeds of those vehicles by a greater amount.

The magnitude of the reductions in mean speed were found to be moderate, at most. Passenger vehicle mean speeds were reduced by no more than 3.4 mph (5.5 kph) at work zones and by a maximum of 1.8 mph (2.9 kph) at high crash locations, but they were found to increase up to 0.8 mph (1.3 kph) at Sites 6 and 9. Tractor-trailer speeds were reduced by up to 3.6 mph (5.8 kph) at work zones and 2.0 mph (3.2 kph) at high crash locations, but they increased at just one measurement station (Site 6, downstream). However, moderate reductions in mean speed were associated with more meaningful reductions in the proportion of vehicles exceeding the speed limit, especially among the fastest vehicles. Radar detector use has been found to be associated with higher travel speeds (*9,10*). Consequently, drone radar is likely to affect fastest vehicles more, slowing them more than vehicles traveling at slower speeds. In the present

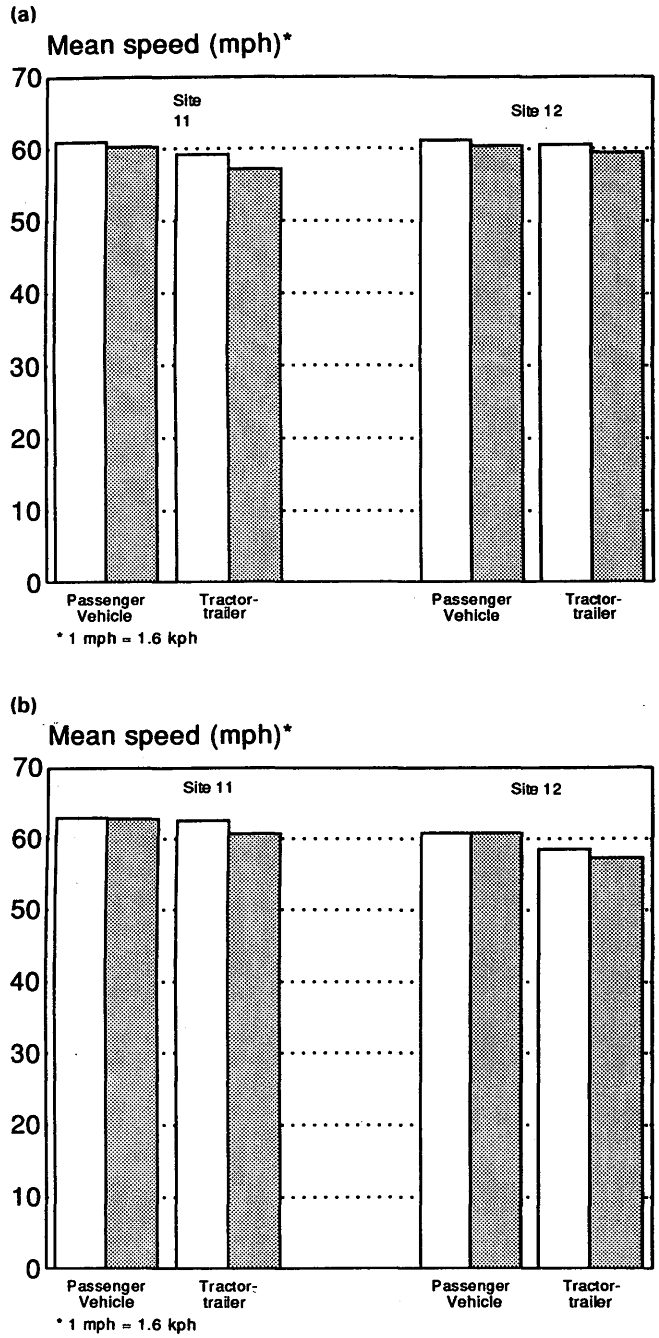

FIGURE 8 Mean speeds for passenger vehicles and tractor-trailers at urban Interstate high crash sites: (*a*) drone location and (*b*) downstream location (shaded bar, radar on; white bar, radar off).

study, proportions of excessive speeders were often (significantly) reduced by one-third to one-half when radar drones were on.

In most locations, especially construction and maintenance work zones, speeds decreased as vehicles went from upstream to downstream stations and speeds were lower with radar on than with radar off. However, at Site 9, a rural high crash location, and at Site 6, an urban short-term work zone, tractor-trailer speeds increased from upstream to downstream and were higher at the downstream loca-

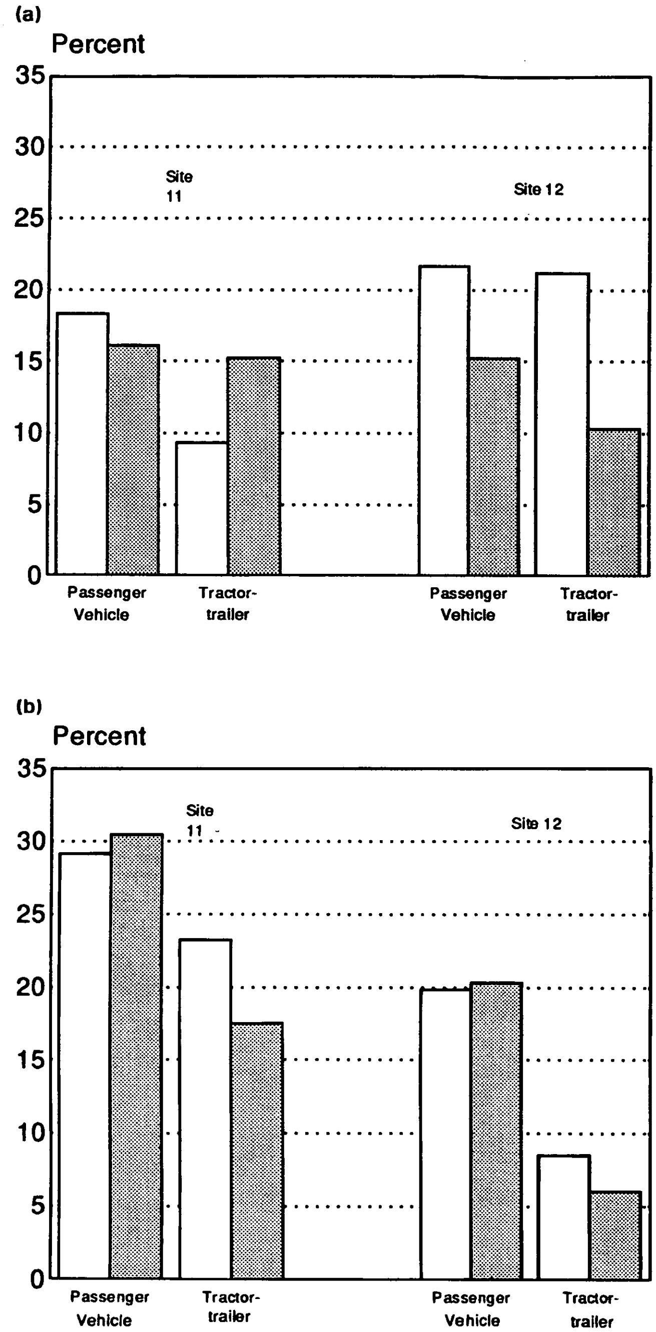

FIGURE 9 Percentage over speed limit by more than 10 mph (16 kph) for passenger vehicles and tractor-trailers at urban Interstate high crash sites: *(a)* drone location and *(b)* downstream location (shaded bar, radar on; white bar, radar off).

tion when the drone radar was on. The speed difference at the downstream station was significant at Site 6. It is possible that this unexpected outcome may have been because the radar drone was observed and reported over two-way citizen-band radios by truck drivers, who then accelerated as they left the study areas. If this undesirable behavior was because drivers realized that the radar signal was produced by a drone device, then more care must be taken to camouflage the drone radar units and active enforcement must be periodically used to heighten the credibility of the radar signal.

The unusual pattern of increasing speed from the upstream to the downstream stations at Site 11, an urban high crash location, could have been caused by normal traffic behavior in that area or an upstream disturbance in traffic flow. Such a disturbance could have slowed vehicles at first, then permitted them to accelerate downstream from it. Even in such a situation, the use of drone radar was associated with significantly lower speeds, especially among tractor-trailers.

Agencies that consider using unattended radar to reduce speeds at hazardous roadway locations should be aware of the FCC regulations prohibiting the use of unattended radar that does not use the return signal in some way, such as triggering a light, counter, or speed warning device. An effect of this restriction, however, is that drone radar units are more expensive than they need to be for their intended purpose, which will likely limit their use.

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Hawaii's Mandatory Seat Belt Law: Patterns of Enforcement

KARL KIM, RICHARD KIRSHENBAUM, AND GEORGE NABESHIMA

Hawaii is known for having one of the highest seat belt use rates in the nation and for having an aggressive enforcement program. Data on seat belt citations, driver licenses, police-reported crashes, and observed seat belt use studies reveal the following: (*a*) cited drivers are more likely to be young and male, (*b*) there are spatial and temporal patterns associated with enforcement, (*c*) a higher proportion of out-of-state drivers are cited than are involved in traffic collisions, (*d*) most seat belt citations issued in Hawaii are stand-alone violations, (*e*) the most common type of other citation issued with a seat belt violation is for speeding, and (*f*) repeat offenders tend to be male and young. These findings may have relevance for other states considering stepped-up levels of enforcement. The results suggest a need for more scrutiny of the associations between seat belt use, enforcement, and crash involvement, perhaps over a long time period.

Hawaii was the tenth state in the nation to adopt a mandatory seat belt use law, which took effect on December 16, 1985. The law covers front-seat passengers and gives police the power of primary enforcement. The four police departments in the state have vigorously enforced the law. More than 150,000 citations have been issued since the law took effect (see Table 1). These enforcement efforts have contributed to Hawaii's high rate of compliance with the law. Hawaii has consistently led the United States in seat belt use. Recent surveys show a use rate among front-seat occupants of more than 85 percent. An earlier study demonstrated the strong correlation between seat belt use and enforcement levels in Hawaii (*1*). In this article patterns of enforcement in Hawaii, characteristics of motorists who violate the seat belt law, patterns of repeat offense, and relationships between seat belt violations and other traffic offenses are described.

BACKGROUND

Over the years, various studies have examined the relationship between enforcement and seat belt use (*1–3*). Previous research also has examined the relationship between enforcement levels and the reduction of injuries or fatalities (*4,5*). These studies have helped to make enforcement of mandatory use laws a priority at the national and local levels. Enforcement has been adopted because of its effectiveness and relative ease of implementation. Seat belt use campaigns that attempt appeal to motorists' intellect (e.g., "seat belts save lives" or "seat belt citations will cost you dollars") are less effective than citing those people violating the law. With most public education and media efforts, it is often difficult to determine whether the targeted audience has been reached. This study examines the nature and pattern of enforcement in Hawaii, a state with an aggressive enforcement program.

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A deeper understanding of the seat belt citation data provides feedback about who violates the seat belt law, at least in terms of data administered by the judicial system. Given these findings, what sort of new strategies and programs, including improved enforcement, are justified? This study, combined with other data, helps in understanding some of the differences between the people who do not use seat belts and those who are cited.

Using citation data has several advantages over using observational data on seat belt use. Citation data provide more accurate information on age, gender, place of residence, and other personal characteristics than observational data. Moreover, some uncertainties associated with observing and recording seat belt use are reduced. Police officers apprehending violators and writing tickets are more reliable than the best trained observers. The observational studies in Hawaii, for example, involved posting graduate students who conducted surveys of moving and stopped traffic at fixed locations throughout the state. Approximately 3,000 observations were made per study period. The citation data base contains a similar number of records for most years. Citation data are also more accurate than telephone or mail surveys, which ask respondents to report whether they use restraints, because actual behavior is observed. Research in Hawaii has demonstrated that there are significant differences between observed and self-reported behavior (*6*).

At the same time, citation data may reflect enforcement instead of actual patterns of seat belt use. Police may be more inclined to stop and cite certain motorists than others. Many factors affect enforcement, which is but one of numerous duties that police officers must carry out. There is a need to examine the overall relationships between seat belt enforcement, traffic enforcement, and general law enforcement activities.

Circumstances in Hawaii offer advantages for this type of investigation. Measuring the impacts of an intervention such as the mandatory seat belt law is easier in an island state, isolated from other jurisdictions. There are only four counties and four police departments in the entire state corresponding to the major inhabited islands (Oahu, Maui, Hawaii, and Kauai). As such, it is also feasible to establish uniform enforcement programs and to make necessary changes in the enforcement regime. The data on citations, licensing, and crashes are centralized. Because the enforcement levels are so high, enforcement is more even than in other more fragmented jurisdictions. The lessons learned in Hawaii are transferable to other states interested in increasing enforcement activities.

DATA AND METHODS

In this study, data from different sources were compiled. The State of Hawaii Judiciary, which is responsible for administering records on traffic violations, provided a data tape with all seat belt citations

TABLE 1 Number of Citations Issued per Year—1985 to 1991*

YEAR	CITATIONS
1985**	219
1986	16,607
1987	24,587
1988	31,773
1989	34,625
1990	32,277
1991	19,437
TOTAL	159,525

*partial year --1/1/91 to 6/30/91
**month of December only for 1985

Source: Dept. of Transportation; State of Hawaii.

for a 12-month period. The city and county of Honolulu, Department of Data Systems, provided data on licensed drivers in the state. The State Department of Transportation provided data on motor vehicle crashes. In addition, data on observed seat belt use collected by the University of Hawaii, Department of Urban and Regional Planning, were also incorporated in this investigation. The analysis was performed on a dedicated Sun Sparc 10 workstation using SAS (version 6.09). Following a summary of the key findings, some of the implications of the results for Hawaii and other places interested in increasing enforcement levels are discussed.

FINDINGS

The results of this study answer the following questions: (*a*) Who is cited for violation of the seat belt law? (*b*) When are most citations issued? (*c*) What other citations are issued with seat belt violations? (*d*) What are the characteristics of repeat offenders?

Who is Cited for Violation?

Table 1 shows that more than 159,000 persons have been cited for violating the seat belt law in Hawaii since it became mandatory. Between 1986 and 1990, the full years for which there are data, the average number of citations issued per year was 27,973, or an average of 76.6 citations per day. Actual enforcement levels per day over a 12-month period beginning in 1990 varied from a few days when there were ten or fewer citations to some days when more than 350 citations were issued. This enforcement effort needs to be viewed also in terms of the state's geography and patterns of development. In terms of land area, Hawaii is the fourth smallest in the nation. With just over 4,000 mi of roads, it has the smallest amount of roadway of all states. Moreover, development has concentrated in certain key nodes, such as Waikiki, along the southern coast of most islands in a linear pattern, making it easier for police to establish a strong presence, compared with urban areas that are more sprawling.

TABLE 2 Citations by County*

COUNTY	NUMBER OF CITATIONS	PERCENT	NUMBER LICENSED	PERCENT LICENSED DRIVERS CITED BY COUNTY
HONOLULU	18,457	50.24%	537,127	3.44%
MAUI	7,617	20.73%	76,638	1.31%
HAWAII	5,642	15.36%	89,471	6.31%
KAUAI	5,025	13.68%	39,718	12.65%
STATE TOTAL	36,741	100.00%	742,954	4.95%

Frequency missing of cited driver = 3
* 7/1/90 to 6/30/91

Source: Judiciary; State of Hawaii and Dept. of Data System; City and County of Honolulu.

TABLE 3 Seat Belt Citations by Age Group*

AGE	NUMBER OF CITATIONS	PERCENT	NUMBER OF DRIVERS	CITATIONS PER AGE GROUP
15-18	2,666	7.38%	40,788	6.54%
19-25	9,035	25.01%	118,659	7.61%
26-35	10,832	29.98%	206,971	5.23%
36-55	10,392	28.76%	279,549	3.72%
56-64	1,749	4.84%	70,185	2.49%
65+	1,457	4.03%	78,329	1.86%

	CITATION	DRIVERS LICENSE
MEAN	34.71	39.87
MEDIAN	31.00	36.00
MODE	21.00	29.00
STD. DEV.	13.73	16.06

*7/1/90 to 6/30/91

Source: Judiciary; State of Hawaii and Dept. of Data Systems; Systems; City and County of Honolulu.

As Table 2 indicates, more than half of the seat belt citations are issued in Honolulu, the largest county in the state. More than three-quarters of the state's total population resides in this county. It is the most urbanized of the four counties. However, a higher proportion of the drivers have been cited in the counties of Kauai and Hawaii, also known as the Big Island.

Table 3 shows seat belt citations by various age categories. When grouped according to age cohorts, in terms of absolute numbers of citations, those in the 26 to 35 year old age group received the most citations. The number of citations decreased for the older age groups. However, in terms of the percentage of licensed drivers cited for seat belt violations, a different picture emerged. More than 7.6 percent of the 19 to 25 year olds and 6.54 percent of the 15 to 18 year olds received citations in a 12-month period, but less than 2 percent of those 65 and older were cited. This table also shows that the mean age for seat belt citations was 34.7 years and the mode was 21 years. The mean age of all registered drivers, however, was 39.87 and the modal age was 29.

Table 4 shows that proportionately more males than females were cited for seat belt violations. Approximately 72.3 percent of those cited were males; 27.6 percent were females. According to license data, 54.7 percent of drivers were male. Although more than 6 percent of the male drivers were cited for violation of the seat belt law, only 2.8 percent of all female drivers received citations.

Approximately one-fifth of the citations issued in Hawaii were to people with out-of-state licenses. This is not surprising, given the large number of tourists and military in Hawaii. In 1990, more than 6 million tourists came to Hawaii. Table 5 shows the home state of those with out-of-state licenses cited for seat belt violations in Hawaii. California drivers led all states outside of Hawaii. Because

TABLE 4 Seat Belt Citations by Gender*

SEX	NUMBER OF CITATIONS	PERCENT	REGISTERED DRIVERS	PERCENT	PERCENT OF REGISTERED DRIVERS CITED BY SEX
MALE	26,030	72.32%	423,094	54.67%	6.15%
FEMALE	9,960	27.68%	350,846	45.33%	2.84%
TOTAL	35,990	100.00%	773,940	100.00%	4.65%

Frequency missing of cited drivers = 754
* 7/1/90 to 6/30/91

Source: Judiciary; State of Hawaii and Dept. of Data Systems; City and County of Honolulu.

TABLE 5 States with Highest Number of Citations Issued in Hawaii*

STATE	CITATION	PERCENT
HAWAII	29,356	81.05%
CALIFORNIA	2,525	6.97%
WASHINGTON	388	0.83%
TEXAS	302	0.83%
ILLINOIS	265	0.73%
FLORIDA	248	0.68%
NEW YORK	213	0.59%
COLORADO	189	0.52%
OREGON	167	0.46%
ARIZONA	160	0.44%
TOTAL	33,813	93.36%

* 7/1/90 to 6/30/91

Source: Judiciary; State of Hawaii and Dept. of Data Systems; City and County of Honolulu.

TABLE 6 Frequency of Citations by Day of Week*

WEEKDAY	NUMBER	PERCENT
MONDAY	5,029	13.69%
TUESDAY	5,545	15.09%
WEDNESDAY	6,050	16.47%
THURSDAY	5,816	15.83%
FRIDAY	5,913	16.09%
SATURDAY	4,890	13.31%
SUNDAY	3,501	9.53%
TOTAL	36,744	100.00%

* 7/1/90 TO 6/30/90

Source: Judiciary; State of Hawaii.

TABLE 7 Frequency of Citations by Month*

MONTH	NUMBER	PERCENT
JULY	3,772	10.27%
AUGUST	5,511	15.00%
SEPTEMBER	2,923	7.96%
OCTOBER	2,033	5.53%
NOVEMBER	1,662	4.52%
DECEMBER	1,668	4.54%
JANUARY	2,480	6.75%
FEBRUARY	3,740	10.18%
MARCH	3,562	9.69%
APRIL	3,529	9.60%
MAY	3,155	8.59%
JUNE	2,709	7.37%
TOTAL	36,744	100.00%

* 7/1/90 to 6/30/91

Source: Judiciary; State of Hawaii and Dept. of Data Systems; City and County of Honolulu.

TABLE 8 Other Violation Issued*

TYPE OF CITATION ISSUED	NUMBER	PERCENT
SEAT BELT - NO OTHER VIOLATION	29,974	88.96%
SEAL BELT W/ SPEEDING	3,201	9.50%
SEAL BELT W/EQUIPMENT VIOLATION	261	0.77%
SEAL BELT W/DUI/DRUG	237	0.70%
SEAL BELT W/RECKLESS/INATTENTION	19	0.00%

* 7/1/90 to 6/30/91

Source: Judiciary; State of Hawaii.

of the large proportion of visitors from California and the large number of people who migrate from the West Coast, these results are not surprising.

When Are Most Citations Issued?

Table 6 shows that Wednesdays, Fridays, and Thursdays were the days with the most citations. The fewest citations were issued on Sundays, followed by Saturdays. The finding that weekends tended to be lower than weekdays suggests that some groups that drive more on weekends, such as youth or recreational drivers, may be at a lower risk of being cited.

Table 7 shows that the highest number of citations occurred in August, and the lowest occurred in November and December. The high citation rate in August correlates with a number of enforcement campaigns. Other seasonal factors that may correlate with the number of citations issued include peak tourist months, which occur in spring and summer.

What Other Citations are Issued with Seat Belt Citations?

Table 8 shows that approximately 89 percent of the seat belt citations were stand-alone violations. This is an important finding for states considering adoption of a primary enforcement law. Most seat belt violators were not in violation of any other traffic law. Primary enforcement enables police to target nonusers more effectively. A surprisingly small proportion (less than 1 percent) of the seat belt violators had equipment violations or were driving under the influence of alcohol or drugs. Motorists cited for noncompliance were more likely to be cited for speeding than for any other violation. Almost 10 percent of those who received a seat belt citation also received a speeding ticket.

What are the Characteristics of Repeat Offenders?

Statistics were compiled on repeat offenders during the period 1990 to 1991 by matching driver's license numbers. A total of 1,970 persons had more than one citation in 1 year (Table 9). Most of these repeat offenders, 89 percent, had two citations. Approximately 8.7 percent had three citations and 2.4 percent had four or more citations in 1 year. The mean age for repeat offenders (31.0 years) was lower than the mean age for all violators (34.7 years). The modal age for repeat offenders was 19, compared with 21 for the total population of those cited.

A higher proportion of the repeat offenders were male, 78 percent, compared with 21 percent who were female (Table 10). Males made up a slightly higher percentage of the population in the repeat offender category than in the general population of seat belt law violators (Table 4, 72 percent).

DISCUSSION

A summary of the key findings can be found in Table 11. It displays similarities between drivers cited for violation of the seat belt law and drivers who are involved in crashes. Age is a key characteristic

TABLE 9 Citations Received by Same Driver—1990 to 1991

NUMBER OF CITATIONS	NUMBER OF DRIVERS	PERCENT
1	26,607	93.49%
2	1,644	5.78%
3	165	0.58%
4	37	0.01%
5	7	0.00%
6	1	0.00%

Source: Judiciary; State of Hawaii.

TABLE 10 Gender of Repeat Offenders*

SEX	NUMBER OF DRIVERS	PERCENT
MALE	1,437	78.87%
FEMALE	385	21.13%
TOTAL	1,822	100.00%

* 7/1/90 to 6/30/91

Source: Judiciary; State of Hawaii.

TABLE 11 Summary of Results, 1990

	LICENSED DRIVERS	CITED DRIVERS	CRASH INVOLVED DRIVERS	SEAT BELT USE RATE
MEAN DRIVER AGE	39.87 yrs	34.71 yrs	35.57 yrs	UNAVAIL.
STD. DEV. OF AGE	16.06 yrs	13.73 yrs	15.25 yrs	UNAVAIL.
% MALE	54.67%	72.32%	65.50%	UNAVAIL.
% MALE AGES 18 - 25 YRS.	16.50%	20.07%	16.78%	UNAVAIL.
% URBAN (HONOLULU CNTY)	72.30%	50.00%	75.60%	84.20%
RURAL (ALL OTHER COUNTIES)	27.70%	50.00%	24.40%	78.82%
% OUT OF STATE DRIVERS	NA	18.87%	13.64	NA
% ALCOHOL RELATED	NA	0.70%	2.55%	NA
% SPEEDING	NA	9.50%	5.75%	NA
% INJURED OR KILLED	NA	NA	20.83%	NA
SEAT BELT USE RATE OF DRIVERS	NA	NA	UNAVAIL.	82.60%

Source: Judiciary; State of Hawaii, Dept. of Data Systems; City and County of Honolulu, Dept. of Transportation; State of Hawaii and University of Hawaii's Seat Belt Observational Studies.

in common. The average age of those cited is 34.7 years, which is very close to the mean age of drivers in the involved crash population, 35.5. Another similarity is the percentage distribution of males ages 18 to 25 who appear in the citation data base and crash file. Younger male drivers make up a large proportion of the population in both of these files. A smaller proportion of out-of-state drivers are involved in crashes than are cited for violation of the seat belt law. Two important differences noted in Table 11 are the differences between the citation population and the crash population when speed and alcohol were factors. Although these factors have been found to be significant when associated with crashes, their frequencies in both files are rather small.

This investigation indicates that enforcement of the seat belt law in Hawaii is related to certain driver characteristics (age, sex, state of license, etc.), spatial (urbanization, size of county, etc.), and temporal (time, day, month) factors. Hawaii has managed to implement an extensive enforcement program. Assuming that 80 percent of Hawaii's drivers are in compliance with the law, then approximately 20 percent, or 135,525 drivers, are potential violators. Given that more than 150,000 citations have been issued since enactment of the law and only a small percentage have gone to the same driver, one can begin to comprehend the magnitude of Hawaii's enforcement efforts. Although the effects are diluted by Hawaii's large tourist population, evident in that 20 percent of those cited have out-of-state licenses, clearly Hawaii's lasting rate of compliance is because of its strong enforcement efforts. More research is needed to determine whether the 80 percent level of compliance represents a saturated effect, or whether higher levels can be achieved. Future research will focus on the remaining 20 percent of nonusers to determine more about the underlying motivation of these individuals and on a deeper understanding of what sort of policies can be instituted, at what expense, to change their behavior.

Those cited for violation of the seat belt law tend to be male, young, and driving in more urbanized areas of the state. The mean age of those cited for violation of the seat belt law is much lower than the mean age of all drivers, but very close to the mean age of the crash-involved driver population. On the other hand, a disproportionately large number of males are cited for violation of the seat belt law, in comparison to their numbers in the general driver population and in terms of their representation in crashes.

Although out-of-state drivers make up only 13.6 percent of the drivers involved in collision in Hawaii, they make up almost 19 percent of those cited. These results can be attributed to the comparatively lower use rates among drivers in other states and the effectiveness of enforcement efforts in Hawaii.

The relationship between seat belt citations and other traffic violations showed that almost 90 percent of the seat belt citations given in Hawaii were stand-alone citations. This is an important finding for places considering the adoption of primary enforcement laws and for those interested in the relationship between different types of traffic violations. Speeding tickets were given in over 9 percent of the cases, but citations for driving under the influence of alcohol were issued in less than 1 percent of the cases. In examining patterns of repeat offense, it was found that the typical repeat offender tended to be male and younger than the general population of those cited for violation of Hawaii's mandatory use law.

This largely descriptive investigation calls for further analysis. More sophisticated modeling techniques might produce predictions about personal characteristics or other factors. Moreover, additional analysis of the behaviors and motivations of persistent seat belt law violators in a state with such a strong enforcement program is needed. Future investigations might consider targeting these repeat violators for more detailed scrutiny.

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Video Evidence for Highway Tort Trials

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The hand-held video camera provides an easy way to obtain evidence for use in highway tort trials. The simple advantages and disadvantages of using video evidence is discussed. Several differences in how the human eye gathers information and how the process is performed by a video camera are reviewed. Simple hints are given for improving the quality of video evidence. Example cases involving video evidence are used to introduce the wide range of applications.

The primary purpose of this paper is to encourage the use of videotape as evidence for highway tort cases. Examples of good and bad practices are discussed, and introductory advice on shooting video for highway tort is offered. The author hopes that this article will inspire others to expand this topic to include detailed advice and case citations so that an effective library can be assembled on this emerging tool.

SAMPLE USES OF VIDEO EVIDENCE

Almost all state highway agencies now have extensive videologs showing features along their roadways. Videologs are good sources of information, especially for the preliminary investigation of a site involved in a highway tort suit. The videolog may be reviewed to identify the general character of the roadway, geometric information such as the presence of curves, types, and locations of traffic control devices, the condition of shoulders, and similar information. The investigator must remember that conditions may have changed between the date of the videolog and the date of the traffic accident.

Another good use of videotape is to preserve evidence during an investigative visit to an accident site. Videotape can capture the types and locations of skidmarks, crushed vegetation, shoulder conditions, damage to vehicles, traffic control devices, and other features. The video may be reviewed later as needed to determine facts about the scene as the investigation proceeds.

The site of an accident may also be videotaped for use in court when the jury cannot travel to the scene for a firsthand observation. This provides the jurors with an overall perspective of the site and may aid greatly in their deliberations.

A video camera may be located in a vehicle to replicate what a driver saw as he or she drove toward the point of impact of a traffic accident. Such perspective may be especially important in determining whether the traffic control devices provided appropriate and adequate messages to the driver.

Another excellent use of videotape is to document construction zone work activities. Some highway agencies now make it standard practice to videotape an entire construction zone on a weekly or monthly basis. The tapes document the contractor's progress over time and may be used as evidence in tort claims actions.

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Law enforcement officials have made excellent use of videotape in driving-under-the-influence cases. A tape showing the appearance and state of mind of the defendant at the time of arrest can be compelling evidence. This use does not involve highway tort, but it illustrates videotape's acceptance in court.

These are only a few of the possible ways to use videotape as evidence. They represent examples of good uses of a good tool, which will become even better as video technology improves.

SHOOTING VIDEO

The quality of a videotape may be the most important factor in persuading a jury to accept it as compelling evidence in a case. Hiring a professional camera operator is a good investment. For the novice attorney or investigator planning to shoot video for the first time, several hints are offered from experiences.

Shooting tape at an accident site can be improved by the use of a tripod or other support. A tripod reduces bounce and vibration and produces a higher-quality and more satisfactory picture. Newer cameras with anti-bounce controls can help reduce the problem, especially if the camera is inside a moving vehicle.

In panning from one location to another, the camera operator must move slowly and smoothly so that the scene does not appear blurred or rushed to the observer. A camera mounted on a tripod is much easier to pan than a hand-held camera. An autofocus feature may have trouble keeping focused if the operator swings too quickly to the next view.

It is usually best to start each new scene with a broad view of the accident site or of the horizon, then slowly move to details of the site. This allows the viewer to become oriented to the site before examining the detail of the particular scene. This approach replicates the way a human eye works in becoming oriented to the whole scene before focusing on a detail; however, the eye and brain perform this process much more naturally and rapidly than a video camera.

Auto focus and auto exposure features make it easy to operate a video camera. However, manual operation may be better for moving the camera from light to dark areas or between objects at varying distances from the camera. This is particularly true for shots into the sun, items of drastically different color from the background, or moving objects. With a little training and some practice, manual operation can produce better video in these situations. When color is important, the camera should be "white balanced" before each use to provide truer and more consistent colors.

Care must be used when a scene is shot with the camera pointed into the sun. Important features will show up as silhouettes unless the camera operator compensates the exposure. Signs and signals shot into the sun may be difficult to read because they appear darker than in real life. Jurors may be led to believe that the sign or signal is always dark and hard to read. With careful planning, it may be possible to select the time of day or the camera location to minimize the adverse effect of silhouettes, overexposure, glare, or obtrusive shadows. The presence of shadows becomes especially important when shooting shoulder drop-offs, pot holes, or steep side slopes. Shadows exaggerate heights and slopes.

A professional camera operator will be familiar with the effects of sun angle and will know how to exaggerate or minimize the effects of distance and slope through the video camera lens. The quality of the tape is enhanced by a professional operator, and the attorney may save the cost of a second trip to the site to reshoot a tape of inferior quality.

Zoom lenses are handy, but they may change the perspective. The apparent closeness of objects and the relationship between objects can be drastically altered by zooming. If a zoom lens is used, the camera operator should be prepared to testify about the extent and effect.

Narration may be helpful or harmful. If well done, it might describe the location of the scene and provide useful background information. On the other hand, wind noise, vehicle noise, or poor enunciation could diminish the quality of the tape. Some judges routinely require that narration be removed before admission into evidence. The basis for this decision is that videotape, like a photograph, should speak for itself if it fairly and accurately depicts a scene. If additional explanation is desired, it may be given at trial by a properly qualified expert.

For some uses of video, a proper foundation is necessary before it can admitted. If so, the attorney should treat the videotape as a photograph or other piece of evidence. If it is material and relevant and is not likely to mislead or confuse a jury, a tape is generally admissible. A video may be easy to admit into evidence if it duplicates the essential conditions of the scene, or qualification may be necessary only for those aspects that do not replicate the accident site. Another option is to use the video only as demonstrative evidence.

DRIVER'S VIEW

It is frequently important to indicate what a driver saw while approaching a collision site. If so, the camera should be located toward the windshield and away from the rearview mirror. This removes obstructions from the video and encourages the viewer to concentrate on events in the center of the video. In some instances the exact view of the driver must be replicated. If so, the camera should be placed at the position and height of the driver's eyes, and the vehicle should be located laterally within the traffic lane at the same place as the vehicle involved in the collision. To provide foundation for admission of the evidence, the camera operator may have to testify about eye height measurement of the driver sitting in the vehicle and how this was replicated with the camera position. Testimony that the speed and type of vehicle were the same as involved in the collision may also be appropriate. Although such detail is rarely necessary, there are instances when it is essential. For example, eye height may be crucial in determining how far a driver could see over the crest of a vertical curve. A second example is that the camera's lateral and vertical placement inside the vehicle would be important in determining the adequacy of viewing angles for traffic control devices.

If possible, the video should be shot at the same time of day as the accident. For some positions of the sun, this may produce shadows or glares similar to those seen by a driver. The video camera does not necessarily treat this glare in the same manner as the human eye does. It is helpful to cover the dashboard with a black cloth during shooting to reduce reflection and glare.

Water or dust on the windshield, particles in the air, fog, or other substances may cause poor focus or blurry pictures. It may be necessary to shoot the scene several times to produce a tape that reasonably depicts the scene. If so, the court may require that all of the tapes be admitted. Opposing counsel may point out to the jury that the very worst tape might represent actual conditions during the collision.

The human eye can dart quickly toward a point of interest and then dart back to another location. Typically the eye requires 0.25 to 0.67 sec to move and focus. Additional time is then spent as the eye absorbs the new information. This speed cannot be achieved with the video camera without producing a blur on the TV screen. Another limitation is that the camera cannot see over the horizon or around a curve or glance quickly at signs on the side of the roadway. The human eye normally sees a wide periphery. The video camera cannot duplicate this; a portion of the top, bottom, and sides of the scene will be lost through the video camera. The video observer in the courtroom will have a limited view of the site. Because of this, the effects of speed, horizontal curves, and hills are usually exaggerated on a videotape. What the video camera operator may have thought was a casual drive along the road can appear jerky, rapid, or disconcerting on videotape.

The human eye judges distance through stereo vision. The brain measures the minute angles between the right and left eyes as they focus on a distant object. This angular measurement is converted into an estimate of distance by the brain. This concept is illustrated in Figure 1. This calculation is not possible when viewing videotape. The plane of focus is always that of the video screen or monitor, no matter what object the eyes are focused on. Therefore, calculations based on observed angles will yield the same distance between the eyes and the screen (see Figure 2). The brain can some-

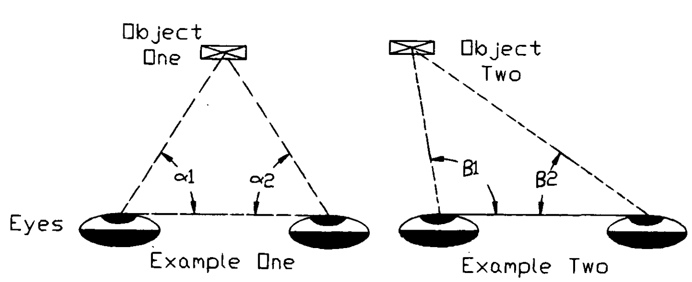

FIGURE 1 How eyes measure angles to objects so brain can "calculate" objects' location and distance.

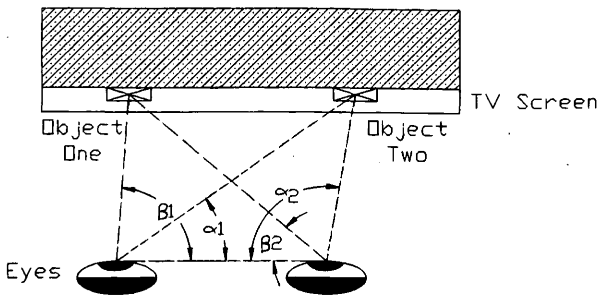

FIGURE 2 All objects on video screen are same distance from eyes, making them appear equal distances from viewer.

times overcome this limitation and obtain clues about distances by comparing object sizes, through perspective by watching lane stripes come together in the distance, or by noting that buildings get smaller toward the horizon. Because of the difficulty in establishing perspective, videotapes or photographs may not be good for estimating distances.

In a video picture the focus is normally very good in the center of the screen and less clear at the periphery. When a video is shot from a moving vehicle, objects near the edge of the screen will not be in focus. They also appear to pass very quickly while those in the center move more slowly. Consequently, reading signs or determining the condition of traffic control devices along the periphery is difficult. A 35 mm photograph of a traffic sign may more accurately depict color and condition than a videotape.

The human eye can distinguish contrast better than a video camera can. This is important in night video and in trying to read signs from a passing vehicle. Black and white contrast is much sharper on a videotape than are some other colors. Even with these limitations there are times when videotape evidence is very effective in the courtroom. The examples discussed later provide useful illustrations.

PITFALLS OF USING VIDEOTAPE AS EVIDENCE

The attorney may have to work hard to have the tape admitted into evidence. The camera operator may have to testify about how the tape was shot, the capabilities of the camera, and whether the tape replicated what the human eye saw at the scene. The court may also require the testimony of others who assisted in the planning, shooting, or editing of the tape.

The court may rule that all tapes shot at the site must be admitted into evidence. The initial tape of a site may not be of good quality or may not emphasize the items the attorney sought. When this happens, a second tape is often made. If the judge rules that both tapes must be admitted, the jury may have trouble deciding which tape to believe.

There have also been instances in which the court refused to admit a tape that had been edited to remove pieces of information the attorney wished to withhold from the jury. If an edited tape is admitted, the jury may be entitled to know what material was removed and why. If the opposing attorney can extract this information, it may cloud the usefulness of the edited tape.

It is often appropriate to practice shooting the videotape before actually going to the site of the accident. This should be done at a scene similar to the one where the collision occurred. If the practice tape is of poor quality, it does not have to be admitted because it was not shot at the collision scene.

It is difficult and time consuming to shoot night video that replicates what the eye saw. Any lights pointed at the camera can produce glare, halos, spots, and streaks that move within the camera lens barrel. The video camera cannot distinguish contrast as well as the human eye can, especially at night. Things that can be seen by the eye may not be discernable on videotape. On the other hand, traffic signs that were not visible at a scene can reflect enough light to produce glare on the videotape and sometimes can become unreadable. The tape may have to be shot several times at different light exposure levels to obtain a version close to what the observer saw.

EXAMPLE VIDEOS

Several videotapes used in highway tort cases will be discussed as examples of good and bad practices. Because most of the example cases were settled before trial, there were no judge's rulings on admissibility or other issues. The examples do, however, illustrate some of the grounds for objecting to use of video.

Example One—Construction Zone Signing

This case centered on the adequacy of a detour and construction zone traffic control devices. An accident occurred on a short two-lane detour that connected a four-lane bypass to a two-lane roadway. The plaintiff crossed over the center line in a reverse curve at the end of the detour and was involved in a head-on collision. A passenger in the plaintiff's vehicle died later, allegedly from complications resulting from the accident.

A videotape was prepared by the plaintiff's investigator 2 weeks after the collision, to illustrate the difficulty in using the detour. The investigator drove through the site several times, at 32 km/hr (20 mph) and then at 56 km/hr (35 mph). The exact speeds of the vehicles involved in the collision sequence were unknown, but the speed limit was 32 km/hr (20 mph) and the investigating officer estimated the speed of both vehicles to be 56 km/hr (35 mph). Additional footage was shot at the accident site to show roadway geometrics, visibility, traffic control devices, and other details.

It was raining when the collision occurred. In the first sequence on the videotape, the plaintiff's investigator simulated this by sprinkling water on the windshield. In later sequences, the vehicle's windshield wipers were operated as water was periodically sprayed on the windshield. For reasons discussed later, neither method replicated the effects of rain. In addition, with little water on the windshield, the wipers produced a grating sound that probably would have been distracting and irritating to a jury.

Several types and colors of signs were posted throughout the work zone. It was obvious that some sign colors offered higher contrast and more visibility than others. For example, a black-and-white speed limit sign was much easier to read at the edge of the screen than an orange-and-black construction zone sign was.

The final sequence on this tape illustrated one of the differences between the eye and the video camera. As the vehicle drove through the site, the camera was turned toward one sign, pointed at it for several seconds, then turned back to view the roadway. When the camera was pointed directly toward this sign, it was crisp, clear, and easy to read. The contrast between the orange background and the black wording was much sharper than when the camera pointed straight ahead and the sign was on the periphery.

Positive Effects

The video documented the traffic control devices and locations for the day of the videotaping. The state's expert used the videotape to estimate the distance between signs by using a stopwatch to measure elapsed time at given speeds. It was also possible to draw preliminary conclusions about the size, color, lateral clearance, spacing, clarity, and other aspects of each sign from the video.

Negative Aspects

The video was intended to represent the driver's view of the construction zone signs, but the location of the camera within the vehicle did not correspond to the driver's eye location. The camera was mounted to the right of the driver. It was aimed too low and sometimes showed major portions of the dashboard but only a partial view of the site through the lower part of the windshield. This did not correspond to the view of the driver. The camera was pointed straight ahead and focused at infinity. As the vehicle passed a sign, the sign was at the edge of the picture and out of focus. This lack of focus made it very difficult to read the sign from the video screen and would not have represented the driver's ability to read the sign.

Because the camera was not in the same position as the driver's eyes, it was not possible for the observer to experience the view from the driver's perspective. Depth perception, alignment of barrels, and visibility of signs were all affected by improper location of the camera. These were important issues because the adequacy of the detour and control devices was under dispute.

An attorney could have raised several objections against the admission of this tape. The location of the camera within the vehicle would serve as grounds for an objection. In addition, the water sprayed on the windshield did not replicate the effects of rain—for example, the pavement was not wet. Visibility of pavement markings would be much different during rain. A second difference is that sunlight shining through water on the windshield produced a glare and interfered with the driver's vision, but the sun was probably not shining during the rain at the time of the collision. It is hard to believe that the essential conditions affecting the driver's vision were accurately replicated by squirting water on the windshield.

Example Two—Visibility Of Pedestrian At Dusk

In this case, the plaintiff received debilitating injuries as a pedestrian. Issues in doubt included the exact time of the evening when the collision occurred, the amount of daylight available to an oncoming driver, the design of the intersection, and the presence of a phantom vehicle that blinded the oncoming driver with its lights.

Short video segments were shot at time intervals on the first anniversary of the accident. These video segments showed the light available to an oncoming driver at the time in question.

The plaintiff's brother wore the same clothes the plaintiff wore on the evening of the collision. The brother was approximately the same size as the plaintiff and stood in the roadway at dusk at the approximate location of the collision.

The video camera's internal clock was set at the same time as the U.S. Naval Observatory. An automobile entered the roadway from a side drive and turned directly toward the camera, in the same sequence as a phantom vehicle that was alleged to have blinded the oncoming driver. The intent was to show the range of visibility over a 30-min period at dusk and to document the effects of headlights.

Positive Effects

The video provided a good overview of the scene of the collision. Jurors could have obtained an impression of whether an oncoming driver should have seen a pedestrian on or near the roadway. The video also illustrated that light was available even after the official time of sunset. The video did a good job of imparting to viewers a perspective of how headlights might have blinded an approaching motorist and how long this blindness might have lasted.

Overall, the video served its purpose well. It provided evidence that could not have been obtained through the testimony of witnesses or through photographs.

Negative Effects

This example illustrates the advantages of practicing the video session at another site before the actual taping. During the taping, time passed very quickly and it was difficult to reset the automobile and the pedestrian for succeeding shots. If a practice session had been made the night before the taping, procedures could have been worked out for smoother shooting, and a better camera could have been used to minimize stray beams of light from bouncing into the camera barrel. As it was, glowing dots and tracers of light moved around the picture as the vehicle entered from the side road and turned toward the camera.

The difference between the automobile's high beam and low beam lights was dramatic on the videotape. A practice session would have provided knowledge of this difference, and the scene could have been shot with high and low beams during each of the planned time periods.

The video could have been improved if the camera had been mounted on a tripod instead of held by hand. Annoying jolts and bounces of the picture could have been prevented and the quality of the presentation would have been enhanced.

There was a major difficulty with using this videotape. The tape included a drive through of the accident scene. Because the camera would be pointed into the sun during part of the time, the camera operator elected to use manual focus and manual exposure instead of autofocus to minimize the silhouette effect when the camera pointed into the sun. The camera operator also sat outside the vehicle instead of inside, so that the dashboard, windshield wipers, and hood would not dominate the shot. Unfortunately, the operator did not have a secure seat on the vehicle and slipped back and forth on the hood during the drive through. Consequently, the picture was often overexposed and it bounced and swayed. As a result, this portion of the videotape resembled a bad ride on a roller coaster and imparted a negative effect to the viewer. The failure to secure proper exposure during this portion of the videotape cast doubts about whether the exposure at dusk was accurate.

Possible objections to the video were that (*a*) it was not shot from the height and location of the driver's eyes as the vehicle approached the pedestrian; (*b*) the camera might not have replicated the actual light conditions during dusk; (*c*) the phantom vehicle's position and orientation on the roadway were never documented, and the video may not have accurately demonstrated how its lights shone toward the approaching driver; and (*d*) the camera was stationary during the sequence in which the approaching driver (which the video was trying to replicate) traveled a great distance down the roadway.

Example Three—Vehicle Leaving Roadway

The third example video was used to show the scene of an accident that occurred in a southwestern state. The accident involved a pickup truck that failed to negotiate a low-water crossing when it hit a bump 23 m (75 ft) before the low point of the crossing. The driver lost control, the truck overturned, and an occupant was killed. The speed limit was 72 km/hr (45 mph), but the crossing was posted with a 32 km/hr (20 mph) warning sign. The plaintiff's witness testified that the pickup truck became airborne when it hit the bump at low speed, but the state contended that the speed was more like 96 km/hr (60 mph). The videotape was shot to provide a view through the windshield of a similar pickup as the vehicle navigated the low water crossing and of vehicles proceeding through the crossing at various speeds.

The video camera was set up on a tripod beside the road to record a small pickup truck, similar to that driven by the plaintiff, moving through the crossing. The speed was varied in 8 km/hr (5 mph) increments to show the effect of the low-water crossing and a slight bump over a culvert as the truck passed through the scene. The plaintiff alleged that at 40 km/hr (25 mph) the truck became airborne and produced a fatal collision. The videotape illustrated complete control of the truck at this speed with no hint of difficulty. The scene provided an excellent overview of the site and allowed the observer to draw conclusions about the circumstances surrounding the accident.

Shooting sites like the one in this case requires care not to exaggerate slopes or distances with the use of a zoom lens. The person shooting the video may be asked to testify about the use of zoom lenses to ensure that the appearance of the video matched that observed in real life.

The first sequence on this tape showed the state's expert driving through the site in a pickup truck similar to the one driven by the plaintiff. The sequence shot through the windshield illustrated the peril of video work. The camera was too low and focused on the windshield wiper instead of the outside scene. The roadway and surroundings were out of focus. Signs could not be read easily. A viewer could not draw conclusions about the suitability of the roadway, the signs, or the traffic control devices.

Viewers are particularly sensitive to windshield shots of curves and hills shot by means of hand-held video photography. This site was in rolling terrain with hills and curves. The tape suggested that a driver could not see around the curves or over the hills, and jurors viewing the tape might have been led to believe that the road was hazardous.

Positive Aspects

This video included a detailed examination of the accident site and showed the perspective from both approaches. It also contained a narrated close-up examination of the roadway edge, the low-water crossing, and other features that might have contributed to the collision.

The most positive aspect of this video was the taping of the pickup truck moving through the low-water crossing at various speeds. It would be difficult for a viewer of the tape to conclude that a 40 km/hr (25 mph) trip through the crossing would result in an accident if the driver was operating the vehicle properly.

Negative Aspects

Major portions of this tape were shot by the daughter of the state's expert. Most of the tape featured the expert and daughter driving toward the accident scene, describing the approach road. Unfortunately, the video camera was aimed directly at the windshield wiper. The autofocus feature of the camera caused the windshield wiper to stay in sharp focus and all else to be out of focus. Important signs beside the roadway were visible only briefly and were out of focus. The camera operator bounced as the truck hit bumps. Unfortunately, she lost control of the camera completely as the truck passed over the low-water crossing. This loss of control and the resulting wild swinging of the camera substantially offset any positive effects the video might have had.

Example Four—Computer Animation Prepared From Photographs

Another good use of video involves computer animation of accident sequences. Better software has become available, making it easier to make these videos, improving their capabilities, and enhancing their quality. As a consequence, the price of production has fallen and their use in court has become more frequent. Typically, a professional laboratory produces the animation from maps, measurements, and photographs of the site. For example, the laboratory may digitize aerial photographs to create a three-dimensional computer database. The database yields animated versions of the sites, which can be viewed from any perspective desired by the observer. This technique produces high-quality, convincing evidence.

Animation allows a realistic view of the sequence of events in an accident, which can seldom be obtained through other methods. Certain events may be difficult for a juror to understand from looking at scattered drawings. In particular, the juror may not grasp the intermediate events between drawings. One example case involved an accident that was animated to show the driver's view of a vehicle moving through a roadway construction zone, then striking a tree. Another accident was computer animated to show two vehicles hitting a third vehicle in the roadway. The camera then zoomed in on a front seat passenger in the first vehicle, to show what happened in the separate impacts with the two other vehicles.

Example Five—Modeling a Train Collision

Another example video involved a scale model duplication of vehicle movements in a train-car collision. The basic data for the video were gathered by a reconstructionist who had the train crew return to the site. With the locomotive stopped at various spots on the approach, a vehicle was driven down the highway and through the grade crossing until train crew members could independently identify the approximate speed of the vehicle involved in the collision. The train was moved to several locations and the vehicle's speeds were established at each point. With these data, the reconstructionist calculated the appropriate speeds and angles of vision.

A table top model was constructed on the basis of measurements taken at the site. Scale models of the train and the car were fitted to the model. They were configured to move up and down the track and road by means of fine wires strung through pulleys. With positions calculated from the field observations, testimony, and measurements, the model train and model car were aligned at starting points and one frame of videotape was shot. Next, the wires were moved in small increments to relocate the train and car to the exact scale distance they would have traveled in one-thirtieth of a second, then another single frame of videotape was shot. This process was repeated until the collision sequence was completed.

The collision sequence was repeated several times and taped from various camera locations, even from a platform moving alongside the model car. The method produced reasonable reproductions of what happened during typical scenarios related to the accident. The resulting video gave the jury an excellent idea of the relative speeds of the vehicles and how the collision could have happened.

SUMMARY

This paper was prepared to encourage the use of videotape as evidence in highway tort trials and to encourage the documentation of such uses. Discussions about the differences in how the eye and the video camera gather information, hints on improving the quality of video, and good and bad uses of video were included. Example videos from actual cases were discussed to illustrate the main points of the paper.

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