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Driver Performance, Passenger Safety Devices, and the Bicyclist

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Contents

Alcohol-Impairment Tests for DWI Arrests

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A study undertaken to develop an improved battery of field tests of driver sobriety is discussed. In most states, 0.10 percent is the blood alcohol concentration at which a driver is presumed to be driving while intoxicated, but the mean blood alcohol concentration of arrested drivers is closer to 0.17 percent. This reflects the difficulty of the police officer's task. Tests for determining whether a motorist is driving while intoxicated and whether an arrest should be made must be sensitive to alcohol impairment and meet the severe constraints imposed by limited time and the characteristics of the roadside environment. Six types of tests were selected for evaluation based on the literature, field observations, and pilot studies. In a laboratory study, 10 police officers administered the tests to 238 participants at 0-0.15 percent levels of blood alcohol concentration. Based on analysis of the data, a battery of three tests was selected: one-leg stand, walk and turn, and alcohol gaze nystagmus. By using the police officers' scores for these three tests, it was possible to correctly classify 83 percent of the participants as above or below 0.10 percent blood alcohol concentration.

In spite of a variety of efforts aimed at reducing and controlling the problem of drinking drivers, nationwide traffic accident statistics still show a high proportion of alcohol-related fatalities and injuries. Currently, the major approach to dealing with the alcohol-impaired driver is deterrence, a process that begins with the police officer in the field.

It appears that traffic-enforcement officers have difficulty detecting and arresting drinking drivers [commonly referred to as driving while intoxicated (DWI) or driving under the influence (DUI)]. Evidence abounds that only a small proportion of alcohol-impaired drivers are detected and arrested by the police. Estimates of the probability of being arrested while driving under the influence of alcohol vary from 1 in 200 to 1 in 2000.

Additional evidence of problems in the execution of this police function can be found in the blood alcohol concentration or blood alcohol content (BAC) distribution of DWIs. In the United States, the mean BAC of individuals arrested for driving while under the influence is approximately 0.17 percent. Yet in most states the BAC at which a driver is presumed to be alcohol impaired is 0.10 percent. This problem is also reflected in the discrepancy between the BAC distribution of persons on the road and those arrested for driving while intoxicated. A California roadside survey found that, even though 67 percent of all drivers whose BAC was 0.10 percent or higher had a BAC between 0.10 and 0.14 percent (1), only 26 percent of the drivers arrested as DWIs had BĀCs in that range. Thus, although the BACs of a majority of alcohol-impaired drivers are below 0.15 percent, 73 percent of arrested DWIs were at or above that BAC level.

The low probability of arrest for drinking drivers and the alcohol levels at which they actually are arrested reflect at least two areas of difficulty. First, police officers on traffic patrol must detect drinking drivers by observing traffic and noting vehicle-handling errors that may or may not be the effect of alcohol. Then they must assess the stopped driver at the roadside. Is the person impaired by alcohol? What is the probable BAC? Should the driver be arrested or released? Usually, police officers are reluctant to arrest unless they are very sure that a chemical test will produce a BAC reading of 0.10 percent or higher. It is a waste of time and effort to transport and test a suspect who cannot be booked, and law-enforcement personnel generally prefer to avoid practices that may bring charges of harassment and generate poor police-community relations.

Typically, the conditions for roadside evaluation of alcohol impairment are less than optimal. The officer must make a decision within a short period of time in an environment that may complicate the evaluation. Conditions such as lighting, noise, space, terrain, and onlookers vary widely, and the officer's assessment process must be adapted accordingly. Further, the driver's degree of alcohol impairment may be masked or confounded by drinking history, physical condition, age, and other variables about which there may be little or no immediate information. The consequence of these various areas of difficulty is that a large proportion of drivers who have BACs in the 0.10-0.15 percent range are not detected or are not arrested. The result is an underrepresentation of low BACs among arrested drivers.

The study described here was undertaken to examine and improve procedures for behavioral testing at the roadside after a driver has been stopped. It is believed that the police officer's use of improved behavioral tests of sobriety to assist in making a decision to arrest or release the DWI suspect will result in both an increased arrest rate and a BAC distribution for those arrested that more closely corresponds to the on-the-road BAC distribution.

In states that have a "per se" law, the BAC test provides sufficient evidence for a DWI conviction. Most states, however, are operating under a "presumptive" law; that is, a measured BAC of 0.10 percent or higher is presumptive only, and the arresting officer is required to give additional evidence of impairment, from both observed driving performance and behavioral tests. The most extensively used types of behavioral tests examine balance, coordination, and speech, but the specific tests and the procedures for administering them vary widely among law-enforcement agencies and individual officers.

The objective of this study was to develop and standardize an improved battery of behavioral tests for use by police officers in assessing DWI suspects at the roadside and providing behavioral evidence of impairment for court proceedings.

SELECTION OF TESTS

Roadside tests of alcohol impairment must discriminate between levels of impairment under a wide variety of circumstances. The first effort in this study was to locate tests that appeared to be potentially suitable.

An important criterion for the candidate tests was that the performance results be quantifiable. It was also considered essential that test variance be small in relation to the alcohol effect so that differences in individual performance would not obscure alcohol-related impairment. Tests were sought that would be sensitive to alcohol beginning at 0.05 percent BAC and would yield scores that correlate well with BACs of 0.05-0.30 percent. The tests should be short and easy to administer without specialized apparatus or equipment. In addition, the standardized administration and scoring methods to be developed should not be so complex that it would require difficult or lengthy training of police officers to use the tests in the field. Another important criterion in the selection process was that the test battery should be credible and acceptable to DWI suspects, law-enforcement personnel, and the judiciary.

A literature search was undertaken to locate potentially suitable behavioral measures. In addition, the application of currently used tests was observed by individuals who rode along with city and state police officers and sheriff's deputies in the cities and rural areas of five states. The 16 types of tests described below were selected for evaluation:

1. Alcohol gaze nystagmus (AGN)—The DWI suspect is asked to cover one eye and follow the movement of a small light or object with the other eye without changing the position of the head. The light is moved slowly to points that require 30° and 40° lateral deviation of the open eye. The eye is observed for a jerking movement that occurs in the presence of alcohol. The test is repeated with the other eye. The deviation required of the eye should not exceed approximately 40°. More extreme angles of deviation can result in the jerking movement even in the absence of alcohol (2).

2. Coin pickup—Three coins (or chips or matches) are placed on the floor. The individual is instructed to stand in one location, pick up the coins one at a time, and hand them to the examiner.

3. Color naming (attention diagnostic method, modified)—A card presents the numbers 10-59, in random order, in four colors, by row. The suspect is instructed to find a sequence of 10 numbers, beginning with some designated number, and to report the color of each. The verbal response, for example, might be, "10-blue, 11-white, 12-yellow, 13-red" and so on. The response measure is the time it takes the individual to report the colors of 10 numbers.

4. Finger count—The DWI suspect is instructed to touch each finger in succession, counting aloud. The examiner demonstrates: "Watch what I do. 1-2-3-4-5-5-4-3-2-1."

5. Finger to nose—The suspect stands erect with eyes closed, arms extended horizontally. Instructions are to touch the nose with the index finger, alternating right and left hands as instructed. A demonstration is given by the examiner.

6. Grip strength—The individual is instructed to squeeze as hard as possible a dynamometer of the type shaped like a pistol grip with grooves for each finger. This instrument measures the force exerted in isometric contraction.

7. Letter cancellation—The suspect is required to cancel a given letter every time it appears in a paragraph of text. The test lasts 30 s.

8. One-leg stand—The suspect is instructed to stand for 30 s with one leg held straight, slightly above the floor, in a forward direction. The eyes are to remain open.

9. Romberg (balance)—The suspect is instructed to stand with feet together, head tipped back, eyes closed, and arms at side. The position is demonstrated. The examiner observes anterior-posterior sway during a 45-s trial.

10. Serial performance—The device for the serial-performance test consists of a small box on the face of which are mounted five toggle switches and a small red light bulb. The box is presented to the individual with all switches in the center position. The instructions are to move the switches to locate the correct sequence of up-down positions. The red bulb lights up when the problem is solved. The response measure is the time to solution.

11. Subtraction, addition, counting backwards—The suspect is instructed to subtract 3 from 102 and to repeat the subtraction until the result equals some specified number (or to add 3 continuously in the same manner). The same general instructions may be given for counting backwards.

12. Tapping rate—The suspect is instructed to tap a telegraph key as rapidly as possible. The number of taps are recorded by electronic counter during a 10-s trial.

13. Tongue twisters—The suspect is asked to repeat as rapidly as possible such words as "methodist", "episcopal", and "sophisticated statistics".

14. Two-point tactile discrimination—The forearm or back of hand of the suspect is touched lightly and simultaneously with two pinpoints. The suspect's eyes are closed. The test begins with no separation between the two points, and the suspect is asked, "How many places am I touching your arm?" Trials are repeated with increasing separation between the pinpoints. The response measure is the first separation to which the person responds, "Two."

15. Tracing—The suspect is required to trace a pathway (maze) on a piece of paper. Three 20-s trials are given.

16. Walk and turn, heel to toe—The suspect is instructed to walk a straight line, touching heel to toe each step for nine steps, and then to turn and return along the same line in the same manner. A demonstration is given.

FIRST LABORATORY EVALUATION

The 16 tests listed above were evaluated in the laboratory by using nine pilot subjects and BACs ranging from 0 to 0.10 percent. Ten of the tests were identified as being unsuitable for roadside sobriety testing. The primary reasons for discarding tests were that (a) the results showed great variability among individuals and could not be interpreted in the single case without individual baseline data or (b) the test required special devices and conditions that could not be adapted for roadside use.

The following six tests appeared to merit further study: AGN, finger count, finger to nose, one-leg stand, tracing, and walk and turn.

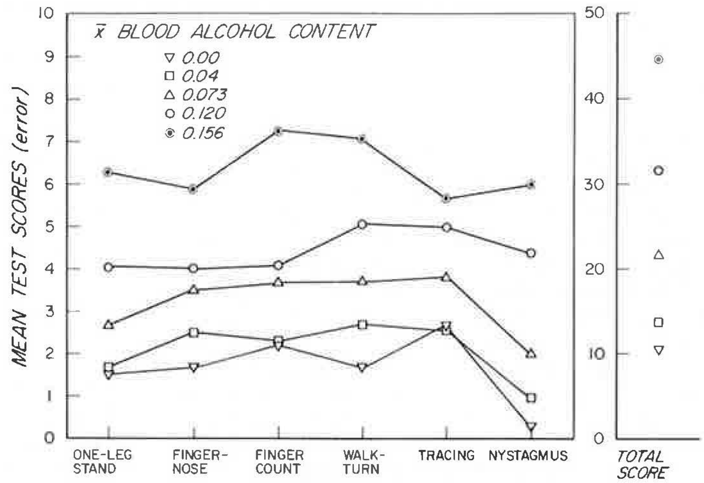
SECOND LABORATORY EVALUATION

A large-scale laboratory study was undertaken to evaluate the six tests chosen for further research. Procedures for administering the tests, including instructions, demonstrations, and scoring, were established. To evaluate the tests and procedures as they would be used by law-enforcement personnel, 10 officers were recruited from city police, sheriff's office, and highway patrol personnel. These officer-examiners administered the test battery and made "arrest-or-release" decisions about test subjects in laboratory sessions.

Some of the officers who participated in the study had been assigned to specialized DWI units and had made thousands of DWI arrests; others had only minimal experience with drunk drivers. Before serving as examiners, all officers attended training sessions in which they learned how to administer the test battery in a standardized manner, including giving instructions and demonstrations as well as scoring and interpreting the driver's performance.

The 238 participating subjects—168 men and 70 women—were recruited through employment offices and newspaper advertisements. Their ages ranged from 20 to 71 years and averaged 26.5 years. They reported drinking habits that characterized 62 of them as light

Figure 1. Mean test scores of study participants by BAC.



drinkers, 86 as moderate drinkers, and 90 as heavy drinkers (3). These subjects were given three drinks of vodka and orange juice over a 1.5-h period, in doses based on body weight, to produce BACs from 0 to 0.15 percent. The distribution of participants by drinking category and measured BAC is given below:

BAC (%)	Light Drinkers	Moderate Drinkers	Heavy Drinkers
0	26	27	26
0.05	36	16	3
0.075		6	7
0.10		37	13
0.15			41
Total	62	86	90

BACs were measured by taking breath samples with a gas chromatograph intoximeter. Neither the participants nor the examiners knew the amount of alcohol or the measured BAC for any individual. The examiners had no contact with the participants prior to testing; their observations of an individual's general behavior, appearance, and speech were roughly equivalent to such observations at roadside. Typical interrogation and interaction with the laboratory "DWI suspect" was permitted. The examiner administered the test battery and scored the individual's performance of each test on a 1-10 scale—the score increasing as a function of error and poor performance—and then recorded a decision as to whether the individual should be arrested or released.

RESULTS AND DISCUSSION

The police officers' scores showed all of the tests to be sensitive to the impairing effects of alcohol. The participants' scores correlated closely with BAC ($p < 0.01$). As Figure 1 shows, there was a consistent increase in mean error score with increase in mean BAC. However, the important question for the objectives of the study was whether the test results help the police officer in deciding the individual case. That is, do the tests discriminate between alcohol-impaired individuals and those who have not consumed alcohol and thus facilitate the DWI arrest decision?

The question of primary interest, then, is whether the officers were able to make the correct arrest-or-release decisions. The data show that the officers did correctly decide to arrest 84 percent of the persons who had BACs higher than 0.10 percent and to release 73 percent of those who had BACs lower than 0.10 percent. It is important to note that, although the officers were instructed to score test performance on the scale of 1-10 error points, no particular score or cutoff was designated as a criterion. The arrest decisions were based solely on the examiners' own interpretations and judgments of test scores and performance. Overall, the arrest-or-release decisions were correct for 76 percent of the participants, based on an arrest criterion of 0.10 percent BAC.

The officers indicated that they would have arrested 47 participants whose BACs were lower than 0.10 percent. It is believed that, since police officers are usually reluctant to make false arrests, this high "false-alarm" rate was an artifact of the laboratory setting, in which the officers were less conservative about making arrests than they would be in the field.

Further analysis of the scoring records revealed a related and particularly interesting phenomenon. It appears that the officers made arrest decisions "as though" 0.08 percent, and not 0.10 percent, were the legal BAC limit. It is not suggested that the officers consciously shifted the arrest criterion to the lower BAC. Rather, we believe that they consistently observed impairment at 0.08 percent and in their decision-making process simply equated observed impairment with arrest. Obviously, if the BAC criterion is 0.10 percent, this results in a high rate of false arrests. In states that have a 0.08 percent criterion, such as Utah, or in Europe, these cases would not be false arrests.

SELECTION OF FINAL TEST BATTERY

The police officer in the field is confronted with the individual driver and must make a decision to arrest or release. If the officer arrests, he or she may later be required to present as evidence in court proceedings a report of the driver behavior that led to the decision to arrest. The battery of sobriety tests has value for the officer only if it (a) facilitates the immediate decision to arrest or release and (b) enables him or her to give credible and convincing testimony in court.

The laboratory evaluation described here demonstrated that the six chosen tests were useful to the police officers in determining the individual's level of intoxication. The officers' scoring of the tests correlated with BAC as follows:

Test	Correlation with BAC
Nystagmus	0.67
Finger to nose	0.47
Finger count	0.31
One-leg stand	0.48

Test	Correlation with BAC
Tracing	0.44
Walk and turn	0.55

However, since administration and scoring of a six-test battery can require as much as 15 min, a longer time than that usually allotted for a roadside examination, it was necessary to select some subset of the tests as a final test battery that would meet real-world time constraints. This was done by using stepwise discriminant analysis. The discriminant model derives linear functions of the test-battery scores and makes the maximum separation of the BAC groups.

The analysis was carried out by using the BMDP7M analysis program from BioMedical Computer Programs (4). This program computes the set of linear classification functions by choosing variables in a stepwise manner. At each step the variable with the highest standard F-statistic is chosen. By using specified prior probabilities and pooled within-group variances, group classification functions are obtained.

The discriminant analysis led to the selection of three tests: AGN, one-leg stand, and walk and turn. The total score derived from these three measures appears to be the best predictor of BAC. By using the officers' scores for these three tests alone, more than 83 percent of the participants in the laboratory evaluation were correctly classified. Note that, although the officers had administered six tests and had made their own observations of general behavior, appearance, and speech, their decisions were correct for only 76 percent of the participants. This indicates that using the criterion scores from the analysis would greatly improve the rate of correct arrest-or-release decisions.

It is of considerable interest to examine the cases that were incorrectly classified by the discriminant analysis. Eight misclassifications involved participants whose BACs were lower than 0.08 percent but whose test scores placed them in the >0.10 percent group. Six of these individuals were light drinkers, and it can be reasonably assumed that the misclassification demonstrates their lack of tolerance for alcohol. On the other hand, 10 people who had BACs greater than 0.12 percent were classified in the <0.10 percent group. As might be expected, all were heavy drinkers whose drinking practices appear to have led to the development of a chronic, partial tolerance to some of the impairing effects of alcohol. It appears that the tests are measuring true impairment, which varies for a given BAC as a result of the tolerance or lack of tolerance to alcohol produced by the individual's drinking practices.

The discriminant analysis confirms that a few individuals may perform in a manner that is not congruent with their BAC level but is usually explainable in terms of a tolerance effect. Long-term, heavy drinkers are likely to be less behaviorally impaired than the individual who is a light to moderate consumer of alcohol. An infrequent or inexperienced drinker may show impairment at relatively low levels of alcohol. These persons can present a problem for sobriety testing, as do drivers whose BACs fall within a narrow ±0.02 percent range around 0.10 percent. It is hoped, however, that the experienced officer has developed observation skills that enable him or her to use such factors as age, appearance, and locale as additional clues to the suspect's drinking habits. The three-test battery, together with the information derived from observation and interrogation, will serve to minimize the number of incorrect arrest-or-release decisions made at the roadside.

CONCLUSIONS

The laboratory evaluation of behavioral tests of alcohol impairment led to the selection and recommendation of three tests for a sobriety test battery: the one-leg stand, walk and turn, and AGN. The data indicate that, if balance and walking are examined and the eyes are checked for the jerking nystagmus movement, and if these tests are administered and the results observed and evaluated by a police officer trained for the task, the officer will have as much information as can be obtained routinely and quickly from behavioral tests at the roadside.

These conclusions are in close agreement with those of the only other known study of similar scope and methodology (5, 6). Based on the examination records of 495 Finnish drivers, Pentillä and others concluded that an optimal test battery should include measures of walking, balance, and nystagmus. Their longer battery also included counting and picking up small objects.

Note that both groups of investigators found nystagmus to be a particularly sensitive and valuable measure. Further study of AGN is in progress at Southern California Research Institute.

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Effects of Roadway Delineation and Visibility Conditions on Driver Steering Performance

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Visual input provides drivers with the primary cues for vehicle steering control. An empirically based model for analyzing the effects of the visibility of roadway delineation on driver steering performance in terms of lateral lane deviations and probability of lane exceedance is described. The model is based on experimental data collected in both an interactive driving simulator and an instrumented vehicle on the open highway.

Drivers receive their primary cues for vehicle steering control visually. A variety of elements, including road boundaries and roadside obstacles, can serve to indicate the desired path. Early programs (1) demonstrated the value of roadway markings, or delineation, for providing positive guidance to the driver, and delineation is now universally applied and accepted. The effectiveness of delineation is determined by its visibility, which in turn is determined by the physical characteristics of the markings, lighting factors, and atmospheric conditions. New delineation under daylight conditions can be optimal, whereas worn delineation under night and/or fog conditions might be marginal or inadequate.

A basic theory for the use of delineation that takes into account physical conditions and driver psychophysical and perceptual motor properties has been presented (2). This work was based on driver steering and speed-control performance measured in an interactive driving simulator. More recently, the effects of delineation visibility on the steering-control behavior of drivers (using control theory models) have been presented (3).

In this paper, simulator experiments in the use of delineation are compared with related experiments conducted in an instrumented vehicle on the open highway. The comparison is made by using a model of delineation visibility, which is analyzed to demonstrate the effects of various factors on the use of roadway delineation, such as road-marking contrast and configuration (mark and gap sizes), atmospheric conditions, and headlighting characteristics.

EXPERIMENTS IN DRIVER STEERING PERFORMANCE

Simulator

A fixed-base but otherwise fully interactive driving simulator was used to test drivers under a wide variety of visibility and delineation-configuration conditions. The simulator had a high-quality, wide-angle video projection display of roadway markings. Display perspective and motion were correctly represented with respect to driver eye position, and the electronic display generator was designed to control delineation and visibility. Apparent road motion relative to the cab was controlled by driver steering, acceleration, and braking actions through equations of motion mechanized on an analog computer. The simulator is described in detail elsewhere (4).

The simulator tests involved a range of visibility distances, delineation configurations, and driving speeds. Desired visibility distances for each run were adjusted according to the driver's subjective impression of the point at which the displayed delineation disappeared. This procedure controlled for variations in the equipment and differences in the visual characteristics of the subjects. Lane deviations measured on a simulated winding road were used in the analysis described here.

Field Test

Open-highway tests were conducted in a specially instrumented van that included an electro-optical device for measuring lateral lane position relative to the delineation of the left edge (5, Appendix C). Tests were conducted at night over a winding 64-km (40-mile) section of I-80 in the Sierra Nevada mountains. The primary tests were conducted under two conditions: (a) after the highway delineation markings were freshly painted in 16-km (10-mile) segments (a different glass-bead-to-paint ratio was used for each segment to obtain variations in delineation brightness) and (b) after the spring thaw and prior to repainting, when snowplows and tire chains had severely degraded the delineation. Lane-position data were tape recorded as the subjects drove both directions over the highway circuit, and these data were then reduced on a digital computer to give the standard deviation of lateral lane position.

The delineation contrast was determined from photometer measurements made under night headlight conditions from the driver's eye position in the instrumented vehicle. In this paper, contrast is defined as the differential luminance between delineation (L_D) and roadway background (L_B) divided by background luminance [$C = (L_D - L_B)/L_B$]. This reproduced the exact photometric conditions observed by the driver subjects. Photometer measurements were obtained at several points in each highway segment.

COMPARISON BETWEEN SIMULATOR RESULTS AND FIELD TEST

The results of the simulation led to an empirical relation among lateral lane deviation, speed, and delineation visibility and configuration (2). Ignoring speed effects, this relation can be expressed as

$$y = b_1 + a_2 C_v \quad (1)$$

where b_1 accounts for both speed and threshold effects, a_2 accounts for road geometry, and C_v includes visibility and configuration factors, as previously defined (2). C_v can be partitioned into configuration (e.g., dash and gap length) and visibility components, as follows:

$$C_v = b_2/x_v \quad (2)$$

where b_2 contains all the delineation-configuration factors and x_v is the visual range of delineation cues. In the simulation study, one of the main independent variables was the visual range x_v; in the field study, measured delineation contrast quantified the experimental treatment. Thus, to compare these data sets, visual range must be expressed as a function of delineation contrast, as described below.

The visibility of a given target is defined by its size and contrast. Well-known data of Blackwell and Taylor (6) give the contrast required (i.e., the threshold) for a target to be detectable. These thresholds are functions of target size, background luminance, and target contrast. If the apparent size of delineation marks as a function of distance down the road is combined with Blackwell threshold contrast characteristics, then the dependence of contrast threshold on visual range can be roughly approximated by a straight-line relation (5), as follows:

$$\log C_T = \log C_{T_0} + c_1 x_v \quad (3)$$

where the parameter c_1 is determined by target size and background luminance and the parameter C_{T_0} defines the vertical location or zero-distance intercept of the threshold characteristics and thus includes the effects of multiplying field factors applied to the Blackwell data on contrast threshold.

We can now combine Equations 1, 2, and 3 to obtain an analytical relation between threshold contrast and performance:

$$y = b_1 + \{a_2 b_2 c_1 / [\log (C_T + C') - \log C_{T_0}]\} \quad (4)$$

where the residual contrast C' has been added to account for other road cues that would provide some guidance in the absence of delineation.

Figure 1. Comparison of field-test data and simulation performance model.

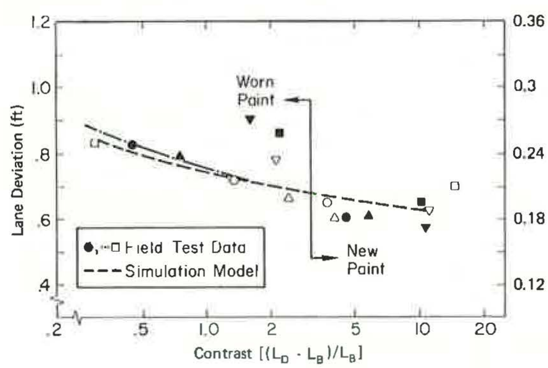


Figure 1 shows field-test data on lane deviation, averaged for six subjects, as a function of delineation contrast measured on a clear night under headlights. The measurements for contrast values higher than 3 were obtained under new-paint conditions, and the data at contrasts below 3 were obtained under worn-paint conditions. The different symbols in Figure 1 for field data correspond to different sections of the experimental highway circuit, and some of the variability in the data can be explained by variations in curvature among the sections. Even so, there is a clear trend in Figure 1 between driver performance in keeping to the lane and measured delineation contrast.

The prediction of the simulator performance model is also shown in Figure 1. It can be seen that the model response as a function of contrast is in fairly good agreement with the field data. As a result of accounting for the absence of an edge line, the current model predictions plotted in Figure 1 are different from and much better than previously published results (5).

PERFORMANCE MODEL SUMMARY

A summary of the model of delineation visibility and driver performance developed in this paper is shown in Figure 2 in the form of a block diagram. The basic model of driver steering performance is given by Equation 4. This relation was derived from the simulation tests and validated in open-highway field trials. Steering performance, as given by Equation 4, is basically a function of delineation configuration and driver contrast threshold at a given visual range.

The visual range of delineation targets is a function of the characteristics of the driver's visual contrast threshold and the apparent contrast of the target. Apparent target contrast decreases with range, and visual contrast threshold increases with range; the point at which target contrast becomes less than the driver's visual threshold then defines the driver's maximum visual range.

Apparent target contrast can be affected by atmospheric conditions and light-source characteristics. Under adverse climatic conditions such as fog, snow, dust, and rain, light is scattered as it passes through the atmosphere to the driver's eye. Under daylight conditions, contrast decreases with range and particle density according to the simple Koschmieder law (7). Under nighttime conditions, apparent contrast drops off even more rapidly because of headlight scattering, which attenuates the light reaching and returning from the target, and also because of the veiling luminance created by backscattered light.

Visual contrast thresholds are a function of background luminance and apparent target size. Apparent

Figure 2. Block diagram of steering-performance model.

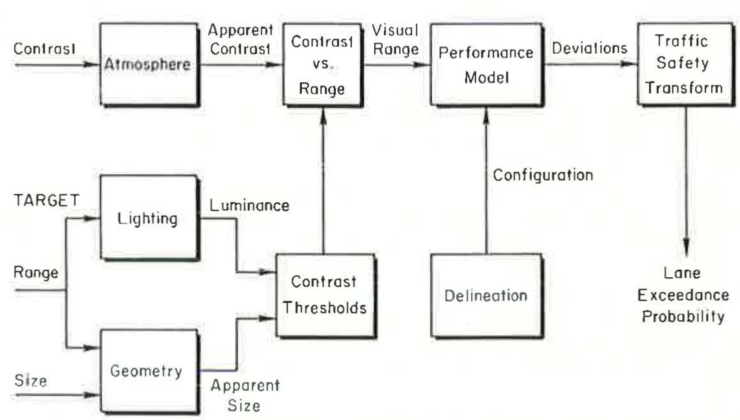
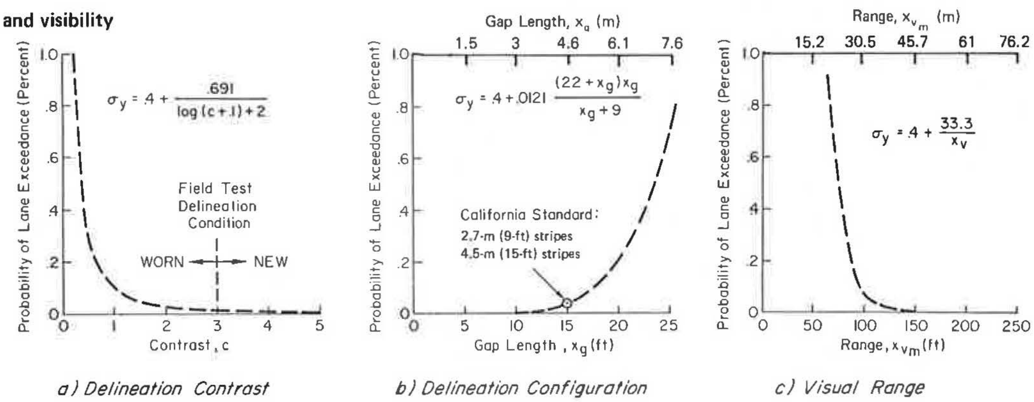


Figure 3. Analysis of delineation and visibility effects by steering-performance model.



target size and background luminance can be specified as a function of range, which then allows contrast thresholds to be specified as a function of visual range (Equation 3).

Lateral lane deviations provide a useful measure of intermediate performance, but it is desirable to obtain a measure that is as closely related to traffic safety as possible. Small lane deviations are of little consequence, but as lane deviations increase, the probability of interference with other traffic increases. A useful measure for quantifying this effect is the probability of exceeding the lane boundaries. If we assume that lane deviations are Gaussianly distributed, then a useful standard approximation for the area of the tails of Gaussian distribution is given by

$$P(y > w) = \sqrt{2/\pi} \cdot (\sigma_y/w) \exp(-w^2/2\sigma_y^2) \qquad (5)$$

where 2w is the difference between lane width and vehicle width and σ_y is the standard deviation of lateral lane deviations.

We now have three measures by which to evaluate delineation utilization: As Figure 2 shows, the first is maximum visual range; the second is steering performance σ_y, which takes into account delineation-configuration factors that might be considered a measure of delineation "quality"; finally, the probability of lane-edge exceedances is used as a traffic safety measure, which tends to weight large lane deviations more heavily than small values.

MODEL APPLICATION

Delineation Contrast

By using Equation 5, the probability of lane exceedance can be computed as a function of delineation contrast, as shown in Figure 3a. The figure shows a knee in the curve in the 1-2 contrast range. Although the probabilities in this region are small (approximately 0.004-0.01 percent), the simulator study showed that drivers attempt to keep lane deviations below 0.3 m (1 ft) (2), and the field-test lane deviations in the 1-2 contrast region were approximately 21-27 cm (0.7-0.9 ft). The knee of the curve in Figure 3a is also consistent with the demarcation point between the fresh-paint and worn-paint conditions in the field study (Figure 2).

Delineation Configuration

Let us now consider the effect on steering performance of the length of gaps between delineation marks. Equation 4 was evaluated for single-sided delineation with 2.7-m (9-ft) long marks and an apparent low contrast value (0.5) that might be typical of worn paint and some atmospheric scattering. The probability of lane exceedance is shown in Figure 3b for the range of gap values. Note that, as the length of gaps between delineation marks extends beyond the standard length of gaps in California, the probability of lane exceedance increases dramatically.

Visual Range

Among the conditions that might affect visual range are atmospheric scattering (e.g., fog) and headlight pattern. A combination of conditions determine visual range; here we consider the basic effect of variations of visual range. The probability of lane exceedance is plotted as a function of visibility range in Figure 3c for one-sided delineation that consists of 2.7-m (9-ft) long marks and 4.5-m (15-ft) gaps. Here we see performance deteriorating to a visual range of less than 45 m (150 ft) and deteriorating rapidly below 30.0 m (100 ft). This result may have implications for the design of headlight beam patterns.

CONCLUSIONS

The effects of delineation visibility on driver performance have been reviewed in two experimental situations: a driving simulation and open-highway vehicle tests. The results have shown reasonable consistency when related through a visibility model that includes characteristics of visual contrast threshold.

The results and the model would be useful in various analysis applications. Driver performance or probability of lane exceedance can be used as a figure of merit in comparing delineation treatments and headlight patterns. The model can also be incorporated in cost-benefit analyses by using probability of lane exceedance as an indication of potential accident rate.

Further development of the model might be useful. Computerization would make it possible to include contrast-threshold and background-luminance distributions more precisely. Other delineators, such as retroreflectors, might also be accounted for. Finally, some of the previously identified dynamic aspects of delineation perception as a function of vehicle speed (3) might be included.

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Use of Child-Passenger Safety Devices in Tennessee

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The combined impact of a Tennessee law on child-passenger safety and a promotional campaign for child-restraint devices on the rates of use of such devices is evaluated, and characteristics of users and nonusers are compared. A basic statewide public information and education (PI&E) program called for distribution of brochures and posters through such facilities as pediatricians' offices and hospitals. The comprehensive PI&E program consisted of an extensive mass-media campaign in addition to the basic program. Six target areas, including the five major metropolitan areas of the state, were chosen for the evaluation. The major findings are that the combination of the law and the basic PI&E program is effective in increasing the rates at which child-restraint devices are used, and the comprehensive program ensures an even higher rate of use. Cross tabulations of such use with other variables reveal that use of child-restraint devices is associated with (a) the age of the child, (b) all socioeconomic variables such as family income and education level, (c) other demographic and vehicle data, and (d) the wearing of safety belts. A market segmentation strategy for future PI&E programs is proposed.

Mandatory passenger-safety requirements have an uneven record in terms of public acceptance. For example, safety-belt interlock systems were rescinded by law after the public outcry against them, and, although the presence of safety belts has been accepted, their use has not. Recent legislation on child-passenger protection in Tennessee has created an opportunity to study the public reaction to a more limited passenger-safety law designed to protect children under four years of age.

After an extensive promotion campaign led by pediatrician Robert Sanders (1), the legislation was passed in 1977 and became effective on January 1, 1978, the first such state law in the nation. It requires in part that

> Every parent or legal guardian of a child under the age of four (4) years residing in this state shall be responsible, when transporting his child in a motor vehicle owned by that parent or guardian operated on the roadways, streets, or highways of this state, for providing for the protection of his child and properly using a child passenger restraint system meeting federal motor vehicle safety standards or assuring that such child is held in the arms of an older person riding as a passenger in the motor vehicle.

Since mere passage of the law does not ensure a reduction in the number of traffic deaths and injuries to Tennessee children, the National Highway Traffic Safety Administration (NHTSA) and the Tennessee Governor's Highway Safety Program jointly established the Child Passenger Safety Program in Tennessee. The purpose of this program is to publicize the law, educate the people of the state about the importance of child-restraint devices, and evaluate the effectiveness of these efforts. The project was implemented 3 months before the law went into effect so that baseline data on the use of child-restraint devices (CRDs) could be collected and public information and education (PI&E) programs could be designed and developed. The project began on October 1, 1977, and will continue for a 36-month period.

This paper is restricted to describing a portion of the results from the first nine months of the Child Passenger Safety Program; this comprises the three-month baseline period and the first six months of the PI&E program that began with the inception of the law. The descriptions of the sampling plan and the PI&E program have been limited to what is germane to the reported results. The purposes of this paper are to

1. Review the literature on the effectiveness and use of CRDs and on the efficacy of past PI&E programs,
2. Describe the characteristics of CRD user and nonuser groups,
3. Evaluate the effectiveness of PI&E programs in conjunction with the law, and
4. Suggest marketing strategies to improve the impact of PI&E on the rate of CRD use.

REVIEW OF LITERATURE

According to National Safety Council reports (2), children four years old and under sustained 1600 motor-vehicle-related deaths and injuries in 1976. Furthermore, the reports indicate that automobile accidents are the leading cause of death among children over one year of age. In Tennessee, 18 children under the age of five lost their lives in automobile accidents in 1976. During the same period, 1229 injuries to children under five years of age were reported in the state by the Tennessee Department of Safety (3). It is believed that these reported cases underestimate the actual number of children adversely affected by automobile accidents.

Effectiveness of Restraint Devices

An unpublished Washington state safety-belt (and CRD) study conducted from 1970 to 1973 indicated that, if all children under the age of five were restrained at the time of an accident, fatalities could be reduced by 91 percent and injuries by 78 percent. A follow-up report to that study documented even higher protection rates. However, safety belts, if used alone, do not provide adequate protection for small children. Shelness and Charles (4) have pointed out that small children need to wear special CRDs. They cite reports that lap-type safety belts could slip on the child's abdomen and cause internal injury during a crash. They also note that children (especially infants), because of their proportionally short legs and large, heavy heads, are far more likely than adults to be thrown about in a vehicle in a collision.

An example of the ineffectiveness of safety belts for small children is the Australian experience. Since 1971, Australia has required the use of safety belts for all passengers in motor vehicles. During the period from 1972 to 1974, a 25 percent reduction in fatalities and a 20 percent reduction in injuries were reported in most categories. There were no significant reductions, however, in fatalities and injuries to small children (5).

Several effectiveness studies have addressed the adult-restraint component of the automobile safety system. An NHTSA report published in August 1976 (6) summarized the results of eight safety-belt studies and estimated that lap belts are 40 percent effective in reducing the number of occupant fatalities whereas lap-shoulder safety-belt systems are 60 percent effective.

The National Highway Safety Needs Report (7) concludes the following:

> In reviewing programs of crash prevention and injury reduction, one countermeasure stands out clearly superior to all other countermeasures, and is perhaps superior to a combination of several other leading candidates. This is the effectiveness of occupant restraint systems in preventing death once an automobile crash occurs.

More than 19 countries have recognized the public health benefits of safety belts by requiring some level of use by their citizens (8). Sweden is one example. A document of the Nordic Road Safety Council (9) attests to the efficacy of safety belts in saving lives and reducing the number and severity of injuries.

Use of Restraint Systems

Do people use passenger-restraining systems? Research on this and related questions has been intense.

In 1976, the Insurance Institute for Highway Safety reported that 93 percent of children under 10 years of age ride as passengers in vehicles without any type of restraint (10). That study, which observed child passengers traveling in automobiles to and from amusement areas and shopping centers in Maryland, Massachusetts, and Virginia, also shows that, of the children under 4 years of age who were riding in child-restraint devices, only 27 percent were properly restrained against death or injury. Thus, even people who are aware of the benefits of using child-restraint devices need education in their proper use.

Estimated rates of safety-belt use range from a high of 75 percent among occupants of 1974- and early-1975-model automobiles with starter interlocks to 22 percent during 1975 (11).

Evaluations of regulations compelling the use of safety belts have been reported from countries around the world. All of these studies found a substantial increase in rates of safety-belt use after the regulations went into effect (8). However, research reported by the Insurance Institute for Highway Safety (12) indicates that in Ontario, where a safety-belt regulation was enacted, the initial dramatic rise in safety-belt use was followed by a decline. The decline put the gain in the rate of use at about 25 percent rather than the 50 percent initially experienced. A similar pattern has been observed in Puerto Rico (13).

Effectiveness of Public Information and Education

Given the probability of a peak-decline pattern in rates of restraint-device use after the enactment of regulations that make the use of such devices mandatory, how can these rates of use be increased and maintained? A number of countries that compel the use of restraint devices have recognized this problem and operate some type of PI&E program as a countermeasure (8). Farr's research in England (14) indicates a gradual increase in the use of restraint devices since 1964 and a marked increase in 1973 that coincided with a large national advertising campaign. Based on an unpublished report by Scherz, all countries that have PI&E programs experience a 10-20 percent increase in usage. There are not enough data available, however, to differentiate between the various types of public information programs. On the negative side, PI&E campaigns for passenger safety are often ineffective, particularly those that use "scare tactics" (15, 16).

The obvious variation in the effectiveness of PI&E programs highlights the need for a better understanding of the driving population and of driving conditions as factors in the use of restraint devices. Williams (17) has investigated some of these factors and reported that parents' use of safety belts and level of education were important factors in the use of restraint devices by ninth-grade students. Education was an important factor in the parents' own report of use of such devices. Williams concludes that the use of restraint devices is associated with a variety of preventive health behaviors (17). The research of Neumann and others (18) supports this viewpoint. They reported that children most likely to be using appropriate CRDs had parents who used safety belts, who had completed high school, and who indicated an ability to control what happens to them in life. This California study also found that these children were over six months old and had parents who were white, married, and born in the United States (18). Additional research concerning use of and attitudes toward CRDs is currently being conducted in Australia (7).

Lonero and others (19) report that parents of children who participated in an elementary school program on safety-belt use were observed using their safety belts more frequently than other parents. These studies seem to suggest a reciprocal "safety socialization" effect between parents and children. It is not particularly surprising that parents may have this effect on children, but it is important to note the potential impact of children on parental behavior.

Health professionals have been extremely active in alerting others to the importance of CRD use. Many recommendations for increasing such use have focused on physicians as an information delivery system. Kanthor (20) studied the effect of prenatal counseling on 35 women and found that 69 percent of counseled women and 42 percent of uncounseled women were using a safe CRD at the six-week checkup visit.

Pless and others (21) asked people in a telephone survey to report on sources from which they obtained information on child-passenger accident prevention. Only 46 percent of the respondents reported receiving such information from any source. Fifty percent of the respondents who indicated that they had received advice cited the news media as the source. Another 13 percent cited friends as their source of information, and 12 percent cited relatives. It is somewhat surprising that none of the respondents cited physicians until they were prompted by the interviewers.

Allen and Bergman (22) investigated the effects of three different educational approaches to increasing ownership of CRDs. They based their education efforts on social learning theory and found that CRDs were purchased by 54 percent of those parents who only received descriptive literature, by 71 percent who received literature and saw a film, and by 60 percent who received literature, saw a film, and saw a CRD demonstration.

In a similar study by Arnberg in Sweden (23), parental acceptance of rearward-facing CRDs was studied. Arnberg reported that parental acceptance of such devices increased with actual experience in using them.

Christopherson (24) has conducted research on the improvement of children's behavior through CRD use. His results indicate that children's behavior improves dramatically when they are introduced to CRDs and begin to use them.

Generalizations

Several generalizations seem to emerge from the literature review:

1. Properly used safety belts and CRDs are effective in reducing death and injury.
2. Automobile occupants are more likely to use appropriate restraint systems when there are regulations that compel such usage and some type of PI&E program exists.
3. The use of safety belts by adults is correlated with the use of restraint devices by child passengers.
4. Further investigation of the influence of various PI&E programs and other factors associated with the use of restraint devices is necessary for the development and maintenance of high rates of proper usage.

RESEARCH METHODOLOGY

A data collection plan was devised to obtain information on use of CRDs before and after enactment of the Tennessee law. The data collection involved a complex collection system, with two data collection intervals six months apart at each of six selected target areas. These areas include five major urban centers (Memphis, Nashville, Chattanooga, Knoxville, and the Tri-Cities) and one "rural" area (composed of merged data from Dyersburg, Columbia, and Morristown). The baseline data collected at the end of 1977 provided information such as the number of people using safety belts, the use of child-restraint devices, demographic characteristics of the population surveyed, and other data vital for evaluating the impact of the PI&E program. To make the estimates of CRD use, two data collection "tiers" were used. The first tier was observational; the second included a second observation, a personal interview, and a self-administered questionnaire.

The tier 1 instrument was designed to record essential observed data in a matter of seconds. The observations were performed at entrances to shopping centers, public health centers, and children's hospitals—locations to which small children might be transported by their parents or guardians. The data collected included the position of the child passenger in the vehicle, use or nonuse of safety belts by the driver, and the license plate number of the vehicle for identification purposes. The tier 1 instrument was designed to record data for vehicles in which there were children estimated by the observer to be younger than four years of age. License plate numbers were recorded for those vehicles and, where possible, matched with the next tier level. About 50 percent of the observations recorded at tier 1 were also recorded at tier 2.

Tier 2 was designed to gather specific information about the child, the driver, the other passengers, and the vehicle and to verify CRD and safety-belt use. Tier 2 information was collected by using a combination of observation, an interview by a trained interviewer, and a self-administered questionnaire. The self-administered portion of tier 2 was designed to collect demographic data on drivers who were transporting children younger than four years of age. The tier 2 data from the baseline period provided a profile of CRD users and nonusers.

The procedures for data collection included the use of two-way radios by observers and interviewers to track vehicles with small children. Field workers were trained in observation and interviewing techniques, two-way radio communication procedures, and specific problem areas. Observers were trained to collect tier 1 data, and interviewers were trained to collect tier 2 information.

Except for the data interval in Nashville after the introduction of a comprehensive PI&E plan, for which a minimum sample size of 500 was selected, a minimum combined tier 1 and tier 2 sample size of 400 per target area was established.

The PI&E program consisted of two levels: (a) a basic state program (BSP), which included statewide distribution of brochures and posters, and (b) the comprehensive program (CP), which consisted of an intensive mass-media campaign and other promotional activities in the Nashville area. The comprehensive program incorporated the basic state program and added the use of public service announcements and interviews on television and radio, newspaper articles, outdoor advertising, displays, and contacts with special-interest groups.

The initial measure of effectiveness for either level of the PI&E program is the change in the rate of use of CRDs. Based on Scherz's unpublished study, it is expected that significantly increased use will also bring about a reduction in death and injury rates. It is recognized that CRD use and proper use are not the same thing. However, even if the rate of proper use remains near 30 percent, an increase in the rate of use will bring about a corresponding increase in the number of properly used restraint devices.

The outline of the PI&E implementation and evaluation plan, and the comparisons that can be made, are shown in Figure 1. These comparisons require careful estimation of rates of CRD use. Each rate for a given target area within a data interval is calculated by using a weighted combination of nonoverlapping data from two sources. The first data set consists of those vehicles whose licenses were observed at tier 1 but for which no tier 2 data were recorded; the second set consists of the matched tier 1 and tier 2 data along with some tier 2 observations for which there are no matching tier 1 license numbers. Estimates from the second data set are based solely on the tier 2 information. Estimates

Figure 1. PI&E implementation and evaluation plan.

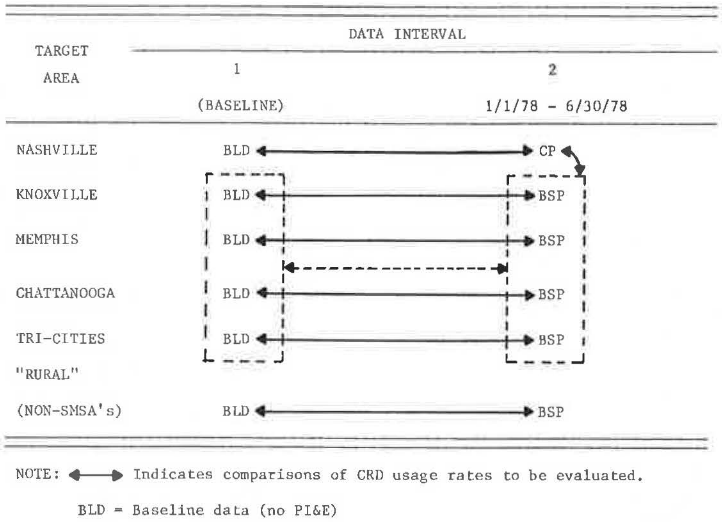

Table 1. Rate of CRD use by data group.

Group	Category	CRD Use[a] (%)	Level of Significance
Characteristics of child passenger			
Age	≤1 year	24.6	
	1-2 years	18.8	
	2-3 years	8.1	<0.001
	3-4 years	5.5	
Sex	Male	13.7	NS
	Female	14.2	
Socioeconomic status			
Annual family income	$0-$4999	8.7	
	$5000-$9999	9.4	
	$10 000-$14 999	14.7	
	$15 000-$19 999	18.6	<0.001
	$20 000-$24 999	19.4	
	$25 000-$29 999	20.9	
	>$30 000	31.0	
Education	Less than high school degree	5.4	
	High school or G.E.D. degree	10.4	
	Vocational or technical school degree	14.9	
	Some college	17.4	<0.001
	College degree	25.0	
	Graduate degree	27.0	
Employment status of couples	Both employed	12.2	
	One employed, one unemployed	14.9	
	One employed, one homemaker	18.5	<0.025
	One employed, one student	13.9	
	Both unemployed	5.3	
Owner of observed vehicle	Yes	15.5	<0.001
	No	6.6	
Number of automobiles owned	One	10.7	
	Two	17.0	<0.001
	Three or more	13.4	

Group	Category	CRD Use[a] (%)	Level of Significance
Other demographics			
Sex of driver	Male	12.6	<0.05
	Female	15.6	
Driver's relation to child	Parent	15.1	<0.001
	Not parent	3.3	
Marital status of respondent	Married or living with mate	15.0	<0.025
	Other	8.4	
Number of children younger than age 4 in vehicle	One	12.8	
	Two	20.7	<0.001
	Three or more	27.3	
Use of safety belts			
Driver	Yes	40.6	<0.001
	No	11.6	
Driver and all passengers over age 4	None	9.1	
	Some	24.9	<0.001
	All	34.8	
Vehicle data			
Size of automobile	Subcompact	15.2	
	Compact	12.9	NS
	Full-sized	15.4	
Automobile manufacturer	American Motors	9.7	
	Chrysler	16.5	
	Ford	12.3	NS
	General Motors	14.7	
	Foreign	17.6	
Year of vehicle	1973 or older	12.6	<0.05
	1974-1978	15.8	
Body style	Station wagon	19.6	<0.05
	Other	13.9	

[a] In this context, the rate of use is for the most-restrained child under four years of age. More than 87 percent of vehicles contained just one child, so the figures are close estimates of overall CRD use.

from the first data set are calculated from the tier 1 observations but are adjusted for "over-age observations" (based on the proportion of over-age children encountered at tier 2). The results from both data sets are then pooled to obtain the reported rate of use of CRDs.

RESULTS

Characteristics of CRD Users and Nonusers

The tier 2 data collected during the baseline period were used to obtain a profile of CRD users and nonusers. The data from all six target areas were combined (for a total of 2504 tier 2 observations), and cross tabulations of CRD use versus the other items on the questionnaire were performed. These gave usage rates for the various subgroups and provided chi-square tests of significance. The results of these analyses are given in Table 1. For discussion purposes, the questionnaire items have been arranged in five groups: characteristics of the child, socioeconomic-status variables, other demographics of the occupants, use of safety belts, and vehicle data.

The characteristics of the child have contrasting effects on the rate of CRD use. The age of the child is a major factor in the use of CRDs. The data given in Table 1 show that the usage rate declines markedly with increasing age of the child, from 24.6 percent for infants to 5.5 percent for three- to four-year-olds. In general, infants not only appear more vulnerable but also are usually more compliant than older children and in any event must be carried in some device or by another person. Apparently, a CRD satisfies the protective instincts of the person in charge of the child as well as any other infant-carrying device. The sex of the child appears to have no significant effect on the rate of CRD use.

Demographic variables that are primarily measures of socioeconomic status are all significantly related to CRD use. There is a steady increase in the rate of CRD use as family income level increases. Exactly the same phenomenon is apparent for the education variable. Similar patterns have emerged before in studies of safety-belt use (17, 25) and were expected to carry over to CRD use. It seems reasonable that those who have more education and more discretionary income are more likely to purchase and use CRDs.

Rates of CRD use for another socioeconomic variable, the employment status of couples, show differences that may have other sociological implications. On the one hand, when neither mate is gainfully employed, the usage rate is low, as one would expect on the basis of the family-income variable. But the highest rate of CRD use occurs when one mate has paid employment and the other is a full-time homemaker. These results may be tied in with income, since it is possible that a large proportion of those who stay home with their young children are members of more affluent families.

The next socioeconomic variables involve automobile ownership. People who use a vehicle that they own show a higher rate of CRD use than those who use a borrowed vehicle. This is to be expected because (a) the law does not apply to borrowed vehicles, (b) it is not easy to transfer a CRD from one vehicle to another, (c) respondents who do not own a motor vehicle are unlikely to own a CRD, and (d) not owning a vehicle may indicate low socioeconomic status.

The use of CRDs is also a function of the number of vehicles owned. People who own two motor vehicles are more likely to use CRDs than either those who own just one vehicle or those who own three or more. The low usage rate for this last group was unexpected, but it may be a reflection of the difficulty of transferring a CRD from automobile to automobile. It can be conjectured that some people who own one automobile are financially disadvantaged and that the low rate of use for one-automobile owners is connected with the low-income effect.

Other demographic measurements are also related to CRD use. A significant difference in rates of CRD use was found among male and female drivers. Female drivers were more likely to be using CRDs than male drivers. This may be attributable to the fact that more female drivers transport children who are younger than four years of age without other adults in the vehicle. If so, the drivers are not only required by law to use a CRD but also may find it more convenient to use one in the absence of other assistance.

The driver's relationship to the child is highly significant. Youngsters are protected by their own parents at a much higher rate than by those who are not their parents (15.1 versus 3.3 percent). People who were transporting child passengers and were not the children's parents had the lowest rate of CRD use of all respondents. Although a child under four years of age is in a vehicle operated by someone other than its parents only 12 percent of the time, the child is very likely to be unprotected during that period. For example, the data revealed that none of the young children who were in the care of retired people were placed in CRDs. Since the Tennessee law does not apply to anyone but parents and guardians, some warning should be given to the public regarding the vulnerability of children in these unprotected situations.

The marital status of respondents shows a pattern similar to that for parental relationship. Those who are married or living with a mate are more likely to make use of a CRD than those who are single, divorced, or separated. However, the difference in usage rates between these two groups is less dramatic (15.0 versus 8.4 percent) than the difference between parents and nonparents.

Finally, as the total number of children younger than four years of age in the vehicle increases, there is a significant increase in the likelihood that at least one of the children will be in a CRD. There are several plausible explanations for this: For example, CRDs may provide convenient mechanisms for separating children in the vehicle.

Measurements of safety-belt use, either for the driver alone or for the driver and other passengers aged four or older, show a clear relation with CRD use. Drivers who use safety belts are much more likely to make use of CRDs than those who do not use safety belts. In fact, of all the categories examined, the one with the highest rate of CRD use is drivers who use safety belts. When self-reported safety-belt use by all vehicle occupants aged four or older is examined, the data are again quite clear: Increased safety-belt use is related to increased CRD use. It appears that a child's safety is more likely to be provided for when there is a general awareness of safety considerations. Lonero and others (19) have already suggested that there may be a reciprocal safety-awareness relationship between parent and child, at least when children are verbal. This result, combined with the results of our study, indicates that a CRD campaign that is tied in with a safety-belt campaign might have particular benefit for children who are beyond the infant stage.

There is a relatively weak relation between CRD use and type of vehicle. Automobile size and manufacturer have no apparent relation with CRD use, and body style and year of manufacture show a somewhat tenuous relation. Station wagons are more likely to have a CRD in use than other types of motor vehicles, but two comments are in order: (a) Station wagons cost more than comparable sedans, and (b) station wagons are often found in multiple-automobile families. Both comments suggest the possibility that station-wagon ownership is not independent of income and that the rate of CRD use found among occupants of station wagons may be a consequence of income.

The division by year in the vehicle category was chosen because 1974 is both a recent year and the year in which safety-belt interlocks were mandated. Although the starter-interlock systems were outlawed almost immediately, the trend has been to make more acceptable safety devices standard on the more recent models. Drivers of newer automobiles might therefore be more safety conscious than those who drive older automobiles, which could account for the higher rate of CRD use among those who drive the 1974-1978 models. The interpretation, however, is clouded by the fact that the affluent tend to own late-model automobiles, and so the results may again indicate the influence of income.

Rates of CRD Use

The question remains, Can either the basic or the comprehensive levels of PI&E, in conjunction with the law, effectively promote the use of CRDs? The results are given in Table 2; they are based on the combined, nonoverlapping data from tiers 1 and 2. The data indicate that the basic state program accounts for an average in-

Table 2. Comparison of rates of CRD use by type of PI&E program.

Target Area	Level of PI&E	Baseline[a] Effective Sample Size	Baseline[a] CRD Use (%)	With Program[a] Effective Sample Size	With Program[a] CRD Use (%)	Change in Percentage of CRD Use: Increase	Change in Percentage of CRD Use: Level of Significance
Nashville	CP	821	14.0	737	22.1	8.1	0.10
Memphis	BSP	869	10.9	532	13.5	2.6	≥0.005
Knoxville	BSP	912	12.8	711	20.4	7.6	0.10
Chattanooga	BSP	749	10.9	742	16.5	5.6	0.10
Tri-Cities	BSP	990	10.7	519	17.9	7.2	0.10
Avg for BSP cities		880	11.3	626	17.3	6.0	0.10
Rural	BSP	872	6.5	521	12.5	6.0	0.10

[a] Estimates based on weighted averages of tier 2 and age-adjusted tier 1 data.

crease in CRD use of 6.0 percentage points in the four urban target areas, or a 53 percent increase over the baseline, and an increase of 6.0 percentage points in the rural target area, or a 92 percent increase over the baseline. The comprehensive PI&E program for Nashville produces an increase of 8.1 points, or a 58 percent increase over the baseline. All changes are statistically significant ($p < 0.10$ or better). To evaluate the additional effects of the comprehensive PI&E program, the change in percentage of use of CRDs in Nashville (8.1 percent) is compared with the average change in the percentage of use for the four urban target areas that received the basic program (6.0 percent). The changes in the rates of use are not significantly different, although the comprehensive program accounts for an increase of an estimated 2.1 percentage points.

Although the increases in the rates of CRD use are real, the question of program cost-effectiveness must be addressed. The basic state program is a low-cost activity that consists primarily of preparing, printing, and distributing brochures and posters. The attendant labor costs have been held to a minimum by using existing family-related agencies to assist in distribution. The benefits are the expected reductions in deaths and serious injuries among children under four years of age. The benefit from avoiding one or two serious accidents would make the program cost-effective when just the hospital and medical costs are considered.

A similar but more extended argument could be made for any additional effect of the comprehensive PI&E program, and the cost-effectiveness has been evaluated by Heathington and Perry (26). The rate of CRD use for Nashville was increased by an estimated 2 percentage points at a cost of less than $6000. The benefits estimated for the comprehensive program are neither dramatic nor significant, but the increase permits a similar claim to be made: The avoidance of a few serious accidents is worth the cost.

Realistically, however, the strength of the support for the comprehensive program lies in the emotional appeal of protecting young children, which will probably outweigh the impact of any cost-effectiveness study. It is anticipated that the comprehensive PI&E program will continue and will produce measurable benefits.

RECOMMENDATIONS

The target population for the CRD promotional activities consists of all Tennesseans who travel in motor vehicles with children who are younger than four years of age and is not limited to those covered by the state law. The first six months of the PI&E campaign concentrated on the use of television, radio, newspaper, and billboard messages directed at the mass audience and distribution through pediatric clinics of brochures and posters that focus on an audience consisting primarily of parents with young children. The campaign has been moderately successful, judging by the increased use of CRDs. However, to sustain the impetus of the drive, new market segmentation strategies need to be devised that can be operated within the necessary constraints.

The profiles that emerged from the study of characteristics of CRD users and nonusers indicate that the major differences in the rates of CRD use are related to socioeconomic status and use of safety belts. The PI&E activities should capitalize on this information. In addition, given the success of the basic state program, any group that has a high concentration of the target population should be singled out, as was done for the clientele of pediatricians' offices. Another market segment that can be used is the so-called "tastemaker" group, which is generally composed of the young and/or the affluent.

Three approaches to these different market segments appear to merit special attention. The first is to attempt to directly influence the rate of CRD use in the low socioeconomic group by implementing a loaner program administered through social service agencies and by distributing CRD promotional brochures through these same agencies.

The second approach is to attempt to influence the tastemakers of society with the expectation that increasing their use of CRDs will have a multiplier effect on the rest of the target population. Examples of this second approach are placing posters, displays, and brochures in new-automobile dealerships to reach the high socioeconomic group, distributing brochures to married students through college health facilities, and incorporating a CRD module in high school driver-education programs.

The final approach consists of revising the PI&E campaigns that cut across all socioeconomic groups. Mass-media public service advertisements can be used to promote the tie-in between use of safety belts and use of CRDs. The effort to distribute brochures to groups that contain a large concentration of the target population should be redoubled; these groups can be reached through offices of pediatricians and obstetricians, prenatal clinics, maternity wards, public health clinics, and day-care centers.

CONCLUSIONS

The new Tennessee law on child-passenger safety, combined with the PI&E program to promote the use of CRDs, has been effective in raising the rates of CRD use. The basic state PI&E program accounts for an increase of 6.0 percentage points in both rural and urban areas. The comprehensive PI&E program accounts for an estimated increase of 2.1 percentage points over the basic state program for the urban areas, but the increase is not significant. Whether the peak-decline phenomenon encountered with other mandatory passenger-safety programs will occur cannot yet be determined based on the data of this study. The proposed market segmentation strategies are expected to reduce the anticipated decline for the immediate future.

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Use of Safety Belts in Kentucky

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The use and effectiveness of safety belts in Kentucky are examined, and factors that affect their use are identified. Data were obtained from three sources: field observations, accident reports, and a questionnaire. Kentucky drivers and passengers were found to have lower rates of safety-belt use (slightly less than 10 percent) than drivers and passengers in other states. The accident data showed that safety belts reduced the chance of being killed by a factor of six and the chance of being severely injured by a factor of two. Several factors were found to have significant effects on the use of safety belts. Safety-belt use was higher among drivers who were over 25 years of age, those who had a college

education, and those driving in newer and/or out-of-state automobiles, on Interstates and parkways, and in large cities. The driving records of drivers who wore safety belts were found to be better than the records of those who did not wear safety belts. In regard to a law making the use of safety belts mandatory, it was found that approximately one-third of the drivers were in favor, one-third were neutral, and one-third were against such a law.

This paper examines the incidence and effectiveness of the use of safety belts among Kentucky motorists and identifies the factors that affect safety-belt use. The feasibility of legislating the mandatory use of safety belts is also investigated.

In a 1975 study that involved only 1975-model automobiles (1), 27 percent of the drivers used a combination of lap-and-shoulder belts and an additional 1 percent used only lap belts. That study gave an estimate made by the National Highway Traffic Safety Administration (NHTSA) of 15 percent use of the lap-and-shoulder-belt combination and an additional 5 percent use of lap belts in 1975 automobiles. The opinion of NHTSA was that this was a well-based estimate when apportioned over the lifetime of the automobile.

The effectiveness of safety belts has been established. In a 1974 Kentucky study (2), it was found that a vehicle occupant who did not wear a safety belt had approximately twice the probability of being injured and four times the probability of being killed in an accident as a person who did wear a safety belt. In a 1975 report by Consumer Reports that evaluated crashes of 1973 and 1974 domestic automobiles (3), occupants who wore only a lap belt suffered severe or fatal injuries one-third less frequently than those who wore no belt at all. The use of a lap-and-shoulder harness reduced the frequency of severe or fatal injuries by one-half. Another study of crashes that involved 1973-, 1974-, and 1975-model American automobiles (3) found nonuse of safety belts in about 60 percent of the crashes. Analysis of serious injuries in these crashes showed that the use of lap-and-shoulder harnesses prevented injuries in 42 percent of the cases whereas the use of lap belts alone prevented injuries in 27 percent of the cases. It was estimated that restraint devices reduced fatalities by 61 percent.

The relation between the use of restraint systems and various other factors has been studied. A study of drivers in 1975 automobiles (1) showed that, a few months after they purchased their automobiles, only one-third of them were using shoulder belts. The use of safety belts tends to decline by 2-4 percent each year of automobile life. Passengers were found to be less likely to use safety belts than drivers and children to be less likely to use them than other passengers. Safety belts were used considerably less in small towns than in large cities.

In another study (4), an attempt was made to identify attitudinal and cognitive variables related to safety-belt use. Five factors that affect the use of safety belts by drivers were identified: discomfort, worry, risk, effectiveness, and inconvenience. The discomfort factor was related to people's feelings of comfort or discomfort when wearing a safety belt (some people have a deep-rooted aversion to being constrained whereas others feel more secure). The worry factor concerned the driver's inclination to worry or not worry about being involved or injured in a crash. The risk factor related to how much risk of accident an individual felt when driving, the effectiveness factor to the individual's feeling about the effectiveness of safety belts, and the inconvenience factor to the amount of inconvenience the person felt when fastening or unfastening a safety belt.

Discomfort was found to be the best single predictor of safety-belt use. Inconvenience rated second, but the addition of the inconvenience factor to the discomfort factor did not improve the prediction because of a high intercorrelation between those two factors. Worry and risk both had very weak relations to safety-belt use; there was a somewhat higher correlation between the effect factor and safety-belt use.

Legislation to require the use of safety belts has been suggested as a method to induce motorists to use restraint devices. Nineteen foreign countries now have laws that require the use of safety belts (5): Great Britain, France, Australia, Canada (Ontario and Quebec), Switzerland, Belgium, the Netherlands, Czechoslovakia, Sweden, Spain, Finland, Norway, Denmark, Yugoslavia, New Zealand, Israel, Luxembourg, West Germany, and the Soviet Union.

Puerto Rico was the first major political unit of the United States to adopt a safety-belt law (6). The law became effective January 1, 1974, and applies to almost everyone who rides in a vehicle that is equipped with safety belts. Persons exempted include those with medical or physical problems, those who have "occupational reasons", children for whom the use of a safety belt would constitute a risk to their person, and delivery personnel when the speed of the vehicle between stops does not exceed 24 km/h (15 miles/h).

The federal government has taken an active role in promoting safety-belt legislation. In a U.S. Department of Transportation report to Congress in 1976 (7), major highway safety countermeasures were identified and the cost-effectiveness of each was evaluated. Adoption of safety-belt laws was identified as the most cost-effective measure by which to forestall highway fatalities. The cost per fatality averted would be $506. This compares with a cost of $20 000/averted fatality for enforcement of the nationwide 88.5-km/h (55-mile/h) speed limit.

A major incentive to the enactment of safety-belt legislation by the states was the Federal-Aid Highway Act of 1973. Under incentive grants (8), states could have increased their federal highway safety money by 10, 15, or 25 percent, respectively, if they enacted legislation that would require (a) use of lap belts by all front-seat occupants, (b) use of all available safety belts by all front-seat occupants or use of lap belts by all front- and rear-seat occupants, or (c) use of all available belts by all occupants.

Although there are considerable data to support the enactment of a safety-belt law, the principal argument that must be settled is whether or not such a regulation infringes on the individual's rights. A safety-belt law may face constitutional challenges under the concepts of due process, equal protection, and right to privacy (9). The constitutional question of due process is dealt with by the precedent of laws that require motorcyclists to wear helmets. Every driver is a potential agent of death or injury to self and others. A safety belt keeps the driver behind the wheel after the first impact and aids him or her in retaining control of the vehicle while avoiding secondary impacts with other vehicles, thus reducing the potential of death and injury. The challenge of equal protection has been found to be defendable only when the statute applied to occupants of vehicles that had safety belts as standard equipment. The third argument, right to privacy, has been answered by stating that the use of highways would hardly appear to fall within the constitutionally protected zone of "privacy".

DATA COLLECTION PROCEDURE

Data were obtained from three sources. Accident data came from a computer tape of all accidents reported in Kentucky in 1976. The safety restraints used were coded for each occupant involved in a reported accident. The use of safety belts was defined as wearing a lap belt with or without a shoulder strap.

A survey of safety-belt use was conducted, and data were collected in both urban and rural areas. Observers positioned themselves so that they could observe the use of safety belts by all occupants of stopped vehicles. Observations of more than 7000 vehicle occupants were recorded, as indicated below:

Location	Number of Observations	
	All Occupants	Drivers
Urban area		
Large	3205	2215
Small	1431	970
Rural area		
Interstate and parkway	1531	823
Two-lane	1151	693
Total	7318	4701

A questionnaire was sent to randomly selected licensed drivers and was given to drivers who attended driver-improvement clinics. The questionnaire was part of a study that dealt with the general characteristics of Kentucky drivers, but a number of the questions related specifically to safety-belt use. Of 3000 questionnaires mailed, 1465 (or 49 percent) were returned. The sample was representative of the driving population in the following areas:

1. The driving population consists of 56 percent males and 44 percent females. The questionnaire sample consisted of 57 percent males and 43 percent females.
2. The age distribution of the driving population is 24 percent under the age of 25, 48 percent between the ages of 25 and 49, and 28 percent 50 years of age or older. In the questionnaire sample, the percentages for these categories were 21, 49, and 30 percent, respectively.

The number of questionnaires completed at driver-improvement clinics was 931. Most of the analyses used only the randomly selected drivers, but summaries from the driver-improvement clinics were used for comparison in some instances.

RESULTS

Safety-Belt Use

Safety-belt use was determined from three sources: field observations, accident data, and questionnaires. As expected, the rates obtained from the questionnaire survey were higher than those obtained from the other sources since people tend to overestimate their use of safety belts. In general, the data showed that Kentucky drivers and passengers use safety belts less than people in other states. The accident data obtained are given below:

Age (years)	Percentage Using Safety Belt			
	All Occupants		Drivers	
	Male	Female	Male	Female
1-2	6.1	6.1		
3-5	3.4	3.2		
6-12	3.1	2.9		
13-15	2.5	2.4		
16-19	4.6	5.0	5.7	6.6
20-24	7.1	7.4	7.8	8.6
25-29	10.4	8.7	11.3	9.5
30-39	10.3	8.1	11.0	8.6
40-49	9.6	8.4	10.1	9.6
50-59	10.2	10.0	10.7	11.9
60-69	8.8	8.8	9.3	10.4
70 or older	7.2	7.6	7.5	9.5
Total	7.7	7.0	9.0	9.0

These data show that 9.0 percent of drivers and 7.4 percent of all vehicle occupants who were involved in accidents were wearing safety belts. Rates of more than 20 percent have been reported by other researchers (1, 10-13).

Field observations were made at various types of locations, and safety-belt use varied according to location (see Table 1). By obtaining the percentage of vehicle distance traveled for each type of highway and comparing it with total vehicle distance traveled in the state, a single usage rate was obtained. The overall usage rates from field observations were 8.7 percent for drivers and 7.3 percent for all vehicle occupants. These percentages are very close to the corresponding usage rates found above from the accident data.

When both accident data and observations were considered, several factors that affect usage rates could be seen:

1. The use of safety belts was highest on Interstates and parkways and lowest on rural, two-lane roads; in urban areas it was between the two extremes.
2. Safety-belt use was higher in newer-model and out-of-state automobiles.
3. Drivers used safety belts much more than passengers, and very few rear-seat passengers used them.
4. There was no significant difference between the usage rates of males and females.
5. Rates of safety-belt use among children were very low. For adults, the rate tended to increase for both drivers and all occupants over 25 years of age and then to decrease for people over 70 years of age.

In the questionnaire, drivers were asked to indicate how often they used safety belts. They were given four choices of answers: always, most of the time, occasionally, and never. For purposes of comparison, it was decided to use the percentage of respondents who answered either "always" or "most of the time" to approximate the reported use of safety belts.

The reported safety-belt use of high-risk drivers (drivers who were attending driver-improvement clinics) was 18 percent—less than that for the population at large, which was 25 percent. High-risk drivers reported that, as passengers, they used safety belts 16 percent of the time compared with 20 percent for the population at large.

During field observations, the use of a lap belt only versus a lap-and-shoulder combination was recorded (see Table 2). Among all occupants, use of lap-and-shoulder harnesses was greater than use of lap belts only. The difference was particularly pronounced among occupants of out-of-state automobiles. Usage varied with vehicle age. Occupants of newer automobiles used both lap belts and shoulder belts more often. This, of course, is related to older automobiles not being equipped with shoulder belts.

The rate of safety-belt use among passengers was found to relate strongly to whether the driver was using a safety belt. In field observations, it was found that only 2 percent of the passengers fastened their safety belts when the driver had not fastened his or hers but

Table 1. Results of field observations of safety-belt use.

Variable	Category	Drivers Wearing Lap Belt or Shoulder Belt (%)	Occupants Using Lap Belt Only (%)	Occupants Using Lap Belt and Shoulder Belt (%)
Location	Urban area			
	Large	12	5	5
	Small	11	4	4
	Rural area			
	Interstate and parkway	13	5	7
	Two-lane	5	1	3
Age of vehicle	Pre-1966	4	3	0
	1966-1971	8	5	2
	1972 to present	13	4	6
Residence	Kentucky	10	4	4
	Out of state	16	3	11
Position of occupant in vehicle	Driver		5	6
	Passenger			
	Front seat		2	4
	Rear seat		1	0
	All positions		4	5
Sex	Male	10	4	5
	Female	13	4	5
Age of occupant	Child (1-9 years)		3	0
	Pre-adult (10-15 years)			
	Adult		1	3
	16-30 years	11	4	5
	31-60 years	10	4	5
	≥ 61 years	12	4	4

Table 2. Type and severity of injuries associated with safety-belt use.

	Type of Injury				
Category	Fatal	Type A (incapacitating)	Type B (nonincapacitating)	Type C (possible injury)	Type A plus Type B
Percentage not wearing safety belt					
All occupants	0.23	2.25	4.89	5.42	7.14
Driver	0.24	1.95	4.27	4.59	6.22
Passenger					
Front seat	0.24	3.23	6.78	7.88	10.01
Rear seat	0.21	2.40	5.59	6.19	7.99
Percentage wearing safety belt					
All occupants	0.04	1.15	3.71	5.41	4.86
Driver	0.02	1.06	3.48	4.75	4.54
Passenger					
Front seat	0.14	1.89	5.21	9.37	7.10
Rear seat	0	0.84	4.41	7.13	5.25
Percentage of drivers not wearing safety belt					
Rural	0.37	2.78	5.71	5.67	8.49
Interstate and parkway	0.48	2.85	5.17	5.59	8.02
Urban	0.05	0.83	2.32	3.05	3.15
Percentage of drivers wearing safety belt					
Rural	0.04	1.56	5.24	6.00	6.80
Interstate and parkway	0.05	0.99	2.98	4.45	3.97
Urban	0	0.66	2.15	3.81	2.81
Percentage of all occupants injured wearing safety belt[a]	1.2	3.9	5.7	7.4	9.6
Ratio of safety-belt use for all occupants[b]	6.2	1.9	1.3	1.0	1.5

[a]Wearing lap belt with or without shoulder harness.
[b]Ratio of percentage of all occupants wearing safety belts to percentage of use in each injury classification.

Table 3. Injury severity in relation to part of vehicle damaged.

Safety-Belt Use	Type of Injury	Percentage of Accidents by Part of Automobile Damaged			
		Front	Rear	Side	Top
Not wearing	Fatal	0.31	0.04	0.33	1.74
	A	3.14	0.75	2.15	7.59
	B	6.68	2.15	4.61	20.00
	C	6.23	5.85	4.87	13.30
Wearing	Fatal	0.06	0.02	0	0
	A	1.51	0.43	1.38	5.38
	B	4.71	2.04	3.37	16.20
	C	5.64	5.87	3.97	9.23

that this increased to 47 percent when the driver was using a safety belt. This leads to the conclusion that, if drivers could be induced to use safety belts, the usage rates of passengers would significantly increase. The highest incidence in any category was 22 percent among drivers of new (1973 to the present), out-of-state vehicles on Interstates and parkways.

Accident Severity

Accident severity was related to safety-belt use (injuries involving pedestrians, motorcycles, farm equipment, and bicycles were excluded from the analysis). The percentage of occupants in each injury classification who were wearing a safety belt was calculated (Table 2), and this was related to the total percentage of occupants who wore safety belts (7.4 percent). If safety belts had no effect on minimizing injuries, the rate of use would be 7.4 percent for each type of injury. However, the percentage of occupants who were killed while wearing a safety belt was only 1.2 percent, and the percentage of

Table 4. Bodily injuries sustained by drivers.

	Percentage of Total Injuries			
	Pre-1974 Vehicles		1974-1977 Vehicles	
Injury	Not Wearing Safety Belt	Wearing Safety Belt[a]	Not Wearing Safety Belt	Wearing Safety Belt[b]
Head and face	46.7	40.5	47.2	36.0
Neck	8.8	14.1	9.6	13.9
Chest	6.4	5.7	5.8	5.6
Back	7.9	8.4	7.0	11.2
Abdomen and pelvis	2.4	2.9	2.0	2.5
Arms and hands	9.7	10.4	9.7	11.0
Legs and feet	10.9	13.8	12.3	14.0
Multiple, entire body	7.2	4.2	6.4	5.8

[a] Primarily lap belt only.
[b] Primarily lap belt and shoulder belt.

Table 5. Safety-belt use by all vehicle occupants in relation to variables that affect usage.

Variable	Category	Percentage Wearing Safety Belts[a]
Sex	Male	7.7
	Female	7.0
Age (years)	<6	4.6
	6-12	2.9
	13-15	2.4
	16-24	5.6
	25-49	8.7
	≥50	8.4
Occupant position in vehicle	Driver	9.1
	Passenger	
	Front seat	4.4
	Rear seat	2.5
Highway type of accident site	State or federal	5.8
	County or local	4.7
	Interstate or parkway	18.7
	Local street	8.7
Vehicle age	Pre-1966	6.5
	1966-1971	6.1
	1972 to present	11.6
Population of city of accident site	<2500 (rural)	6.1
	2500-10 000	3.4
	10 001-25 000	5.1
	25 001-50 000	3.3
	50 001-100 000	5.1
	100 001-250 000	14.5
	>250 000	15.4
Land use or locality	Rural	5.5
	Business	7.0
	Industrial	7.9
	Residential	7.2
	School	6.6
	Park	5.3
	Private property	6.8
Time of day	12 m.n.-3 a.m.	6.6
	12 n.-3 p.m.	6.7
	6-9 a.m.	8.3
	9 a.m.-12 n.	7.0
	12 n.-3 p.m.	7.1
	3-6 p.m.	8.0
	6-9 p.m.	7.5
	9 p.m.-12 m.n.	7.1
Day of week	Sunday	6.3
	Monday	7.5
	Tuesday	8.1
	Wednesday	8.0
	Thursday	7.5
	Friday	7.5
	Saturday	6.7
Month	January	8.4
	February	7.7
	March	8.7
	April	8.0
	May	7.5
	June	7.4
	July	6.9
	August	6.5
	September	7.0
	October	7.1
	November	7.5
	December	6.1

[a] Lap belt with or without shoulder belt.

serious (type A) injuries sustained was only 3.9 percent. The difference between safety-belt use and what would be expected if safety belts did not affect severity was a factor of six for fatal accidents and two for serious injuries.

The percentage of occupants who sustained a given type of injury was also determined as a function of safety-belt use, and these data are also given in Table 2. The data indicate the larger percentage of occupants who were either killed or severely injured while not wearing a safety belt. The most impressive statistic was that, of 653 fatalities, only 8 involved occupants who were wearing safety belts. The obvious conclusion is that the chances of being killed or severely injured in an accident are greatly reduced by wearing a safety belt.

Wearing a safety belt is of significant benefit regardless of where the occupant sits in the vehicle (Table 2). Passengers in the front seat sustained more severe injuries than those in the rear seat, but wearing a safety belt did reduce the severity of their injuries. The largest reduction in injury severity was for rear-seat passengers. Although severe injuries were substantially reduced, "possible" injuries (type C) increased for occupants who wore safety belts. This is attributable to the reduction in the severity of injuries from type A or type B to type C.

If only the total percentage of injuries is cited, there would appear to be no large difference between wearing and not wearing a safety belt. The most important difference, of course, is the severity of the injuries.

The effectiveness of safety belts for different types of accidents was also investigated. Safety belts reduced the severity of injuries in all types of accidents, but the greatest reduction occurred in fixed-object and single-vehicle accidents, as indicated below (drivers wearing a safety belt were wearing a lap belt with or without a shoulder harness):

Type of Accident	Safety-Belt Use by Driver	Percentage of Accidents: Fatal Injury	Percentage of Accidents: Type A Injury
Angle	Not wearing	0.09	1.5
	Wearing	0	1.1
Head-on	Not wearing	0.48	3.3
	Wearing	0.21	1.8
Rear-end	Not wearing	0.03	0.5
	Wearing	0.01	0.3
Fixed object	Not wearing	0.68	4.0
	Wearing	0	2.3
Single vehicle	Not wearing	0.37	8.1
	Wearing	0	6.6

The reduction in severity is better demonstrated by relating severity to the part of the vehicle damaged (see Table 3). Whereas damage to the top of the vehicle (rollover) resulted in far more fatalities and severe injuries than any other type of accident when the occupants were not wearing safety belts, there were no fatalities in rollover accidents when occupants were wearing safety belts. All fatalities that involved an occupant who was wearing a lap-and-shoulder harness were the result of frontal impacts.

The severity of injuries was also related to safety-belt use according to the type of highway on which the accident occurred (Table 2). When safety belts were used, the largest reduction in injury severity occurred on Interstate routes and parkways, and the least reduction occurred on urban streets. The speeds on these highways and the types of accidents peculiar to them were the primary distinguishing factors. However, injury severity was reduced on all types of highways studied.

It is not surprising that very few drivers in older automobiles used shoulder belts. In new automobiles, however, the lap-and-shoulder harness is a single device; if the driver fastens any of the straps, both the lap belt and the shoulder belt engage. Therefore, the percentages of shoulder-belt use from 1974 to the present time should be much higher. It is obvious that a radical change occurred in 1974, when shoulder-belt use increased from 6 to 28 percent; in 1977, shoulder-belt use was 31 percent.

The types of bodily injuries sustained by drivers who did not wear safety belts and drivers who did wear them were compared (see Table 4). The model year of the vehicle was also considered to illustrate the differences between injuries sustained by drivers while wearing a lap belt and those sustained while wearing a lap-and-shoulder harness. A major difference was the reduction in head and face injuries, particularly when shoulder belts were used. Multiple injuries were also reduced by using safety belts.

The percentages of some types of injuries—neck injuries, for example—were higher for some users of safety belts.

Factors that Affect Safety-Belt Use

Analysis of accidents, field observations, and questionnaire data produced relations between safety-belt use and several variables. These data are summarized in Tables 5-7. Usage rates increased markedly for the following categories: certain types of vehicles, newer automobiles, automobiles on Interstates and parkways and in large cities, out-of-state automobiles, drivers in comparison with passengers, drivers over 25 years of age, drivers with professional occupations, drivers with a college education, and graduates of driving schools.

Mandatory Use of Safety Belts

An item on the questionnaire asked drivers' opinions of a law that would require the use of safety belts. A summary of the response of the general driving population and that of high-risk drivers is given below:

Opinion	General Driving Population (%)	High-Risk Drivers (%)
Strongly in favor	10	8
In favor	22	19
Neutral	35	42
Against	23	24
Strongly against	10	7
Total	100	100

In both groups, approximately the same percentage of drivers were in favor of and against such a law. Among the general driving population, approximately one-third of drivers were in favor, one-third were neutral, and

Table 6. Safety-belt use by drivers in relation to variables that affect usage (based on accident data).

Variable	Category	Percentage of Drivers Using Safety Belts*	Variable	Category	Percentage of Drivers Using Safety Belts*
Sex	Male	9.0	Character of roadway	Straight	9.2
	Female	9.0		Curved	8.1
Age (years)	<25	7.0		Straight and level	9.5
	25-49	10.3		Straight and grade	8.0
	≥50	10.1		Straight and hill crest	7.9
Driver residence	Local	8.8		Curved and level	8.2
	Elsewhere in the state	9.9		Curved and grade	8.2
	Out of state	12.7		Curved and hill crest	7.5
Type of vehicle	Automobile	9.0	Number of vehicles involved	Single vehicle	8.4
	Automobile with trailer	10.5		Multiple vehicle	9.0
	Single-unit truck	6.6			
	Combination truck	12.1	Contributing circumstance	Alcohol	3.9
	Taxi	4.3		Drugs	4.3
	Bus	12.0		Physical disability	9.6
	School bus	15.6		Driver error	8.4
	Emergency	36.3		No driver error listed	9.4
Road surface condition	Dry	8.8	Make of vehicle	Buick	8.7
	Wet	9.6		Cadillac	11.5
	Snow or ice	10.7		Chevrolet	8.0
Weather condition	Clear	8.5		Chrysler	9.9
	Raining	9.8		Datsun	13.0
	Snowing	10.2		Ford	9.3
	Sleet or hail	12.7		Plymouth	9.4
Light condition	Daylight	9.0		Pontiac	9.5
	Dawn or dusk	9.5		Toyota	14.4
	Darkness, lighted	9.0		Triumph	14.7
	Darkness, not lighted	9.2		Volkswagen	8.9
Number of occupants, including driver	1	9.6		Volvo	19.8
	2-3	8.8	Model year	Pre-1966	4.2
	4-6	8.3		1966-1971	6.6
	>6	11.4		1972	10.2
Type of accident	Angle	9.9		1973	12.1
	Head-on	6.2		1974	12.6
	Rear-end	9.9		1975	13.2
	Fixed-object	7.6		1976	13.3
	Single-vehicle	8.4		1977	17.5

*Lap belt with or without shoulder belt.

Table 7. Safety-belt use as determined by questionnaire survey of the general driving population.

Driver Characteristic	Category	Percentage of Drivers Using Safety Belts
Age (years)	<25	23.9
	25-49	23.4
	≥50	29.8
Sex	Male	25.1
	Female	25.9
Occupation	Unskilled	21.2
	Semiskilled	20.6
	Skilled	21.8
	Professional	40.4
	Student	34.4
	Sales	25.0
	Housewife	23.6
	Unemployed	29.2
Education	Did not complete high school	20.0
	Completed high school	21.7
	More than high school	24.4
	Completed college	41.9
Population of city of residence	>60 000	29.1
	15 000-60 000	29.1
	2500-14 999	21.9
	<2500	20.9
Marital status	Married	24.8
	Single	30.9
	Divorced or separated	14.1
	Widowed	35.7
Annual family income ($)	<6500	23.2
	6500-12 000	24.5
	12 000-18 000	24.2
	>18 000	28.8
Number of dependents (other than self)	0	30.4
	1	25.7
	2	26.9
	3	22.3
	4	18.6
	>4	28.8
Driving experience (years)	1	24.4
	2-5	24.4
	6-10	24.5
	11-20	24.4
	>20	26.6
Avg distance driven per year (000 km)	<8	27.0
	8-16	24.2
	17-24	28.9
	25-32	20.1
	33-48	23.3
	>48	23.7

Driver Characteristic	Category	Percentage of Drivers Using Safety Belts
Method of learning to drive	Family and/or friend	23.8
	High school driver training	36.3
	Driving school	41.2
Night driving (%)	0-10	25.9
	11-20	30.0
	21-30	21.9
	31-40	26.5
	41-50	22.2
	>50	35.7
Road type on which most driving is done	Interstate and toll roads	31.1
	Other four-lane roads	27.6
	Two-lane roads	23.4
Trip purpose for which largest amount of driving is done	Work-related	24.8
	Short, non-work-related	25.8
	Long, non-work-related	30.4
Vehicle Model year	Pre-1966	28.0
	1966-1971	23.5
	1972 to present	26.3
Style	Compact	28.0
	Midsized	30.1
	Full-sized	24.1
	Sports	21.2
	Truck	20.9
Engine size (number of cylinders)	4	27.0
	6	23.0
	8	25.4
Points currently on driving record	0	25.8
	3	19.4
	4-6	18.2
Accident in past 2 years	No	25.4
	Yes	21.4
Self-testing attitude	High	20.1
	Intermediate	21.4
	Low	28.3

one-third were against a law that requires the use of safety belts.

An analysis was made to determine whether there were any major differences among drivers who were in favor of or against such a law. Several driver characteristics were compared with the answer given by the drivers, including age, sex, education, residence, marital status, income, driving record, safety-belt use, amount of driving, and method of learning to drive. As expected, the main difference between the two groups of drivers was in their reported use of safety belts: Twice as many drivers who wore safety belts were in favor of such a law as drivers who did not wear them. The other differences noted also related in some way to safety-belt use. For example, among drivers who favored such a law, the percentage who had a college education was greater than the percentage who had less than a high school education, and college graduates were also found to have a higher rate of safety-belt use.

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Automobile Fuel Economy and the Driver

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The results of a study of the effect of driver characteristics and behavior on automobile fuel consumption and methods for improving driver fuel economy are presented. The fuel economy of 74 drivers was recorded for each of 10 trips over a 5.6-km (3.5-mile) urban test route on which there were 14 stops and 21 turns. Deceleration and acceleration rates as well as engine vacuum and tachometer readings were recorded for each trip. Driver fuel economy was related to the age and sex of drivers, maximum deceleration and acceleration rates, minimum engine vacuum, and maximum engine speed during accelerations. It was found that driver fuel economy is not related to the driver's age or sex and is about the same whether or not the driver makes full stops at all intersection stop signs. Correlation between driver fuel economy and minimum engine vacuum and maximum engine speeds during acceleration was fairly good. Correlation was poor between fuel economy and maximum rates of deceleration and acceleration. The study findings include an assessment of the usefulness of the vacuum gauge in assisting drivers to conserve fuel. The data indicate that many drivers would use more fuel with the vacuum gauge than without it.

During the fall of 1975, the fuel-economy and driving habits of 74 drivers were observed as each drove a 1972 Chevrolet sedan 10 times over a 5.6-km (3.5-mile) urban test route on which there were many stops and turns (nonuniform driving). On each trip, total fuel consumption, patterns of acceleration and deceleration rates, engine vacuum readings, and engine speeds during acceleration were recorded. Pertinent remarks on driver behavior were also recorded, including observations on whether full stops were made at stop signs and whether speed was reduced near schools and hospitals. Vehicle, road, traffic, and weather conditions were the same for all trips.

The study was part of a Federal Highway Administration (FHWA) project reported on elsewhere (1). The results reveal how individual drivers affect automobile fuel consumption and how fuel economy can be improved without sacrificing driving convenience or safety.

DETAILS OF THE STUDY

Drivers

The drivers consisted of 44 men and 30 women, distributed by age as indicated below:

	Number of Drivers	
Age (years)	Male	Female
10-20	0	1
20-30	2	4
30-40	8	5
40-50	21	12
50-60	8	8
60-70	4	0
70-80	1	0
Total	44	30

Almost 50 percent of the drivers were in the 40- to 50-year-old group. Eleven were housewives; 29 were professionals; 29 were laborers, clerks, or salespersons; 3 were students; and 2 were retired persons. The drivers were all responsible people who agreed in advance to drive the test runs as they normally drove even if they were accustomed to exceeding the speed limit or tended to go through intersections protected by stop signs without making full stops (unless another vehicle was approaching). Each driver was in good health and accustomed to driving in urban areas.

Test Route

A sketch of the test route is shown in Figure 1. From the beginning point shown in the figure, the route followed a path over to the street that passes in front of the high school. From here the route went twice around the four-block area across from the high school and then retraced the path back to the beginning point. On each trip, the driver encountered 14 intersection stop signs, made 21 turns, and passed twice in front of a large church, a hospital, and a high school. Since traffic volumes were low and there were no traffic signals, the amount of delay at intersection stops was attributable to the habit of the driver rather than to the need to wait either for a gap in cross-street traffic or for a traffic signal to change.

Vehicle

The test automobile weighed 1996 kg (4400 lb) empty and had an eight-cylinder, 6554.8-cm^3 (400-in^3) engine and a three-speed automatic transmission. It was equipped with air conditioning, power steering, and front-wheel power brakes. The engine compression ratio was 8.5:1, the rear-axle ratio 3.08:1, and the frontal cross section 2.84 m^2 (30.5 ft^2). The vehicle had H78-15 bias belted tires that carried inflation pressures of 221 kPa (32 lbf/in^2).

Equipment

A photoelectronic fuel meter, a vacuum gauge, an accelerometer, and an engine tachometer were used in the

Figure 1. Test route.

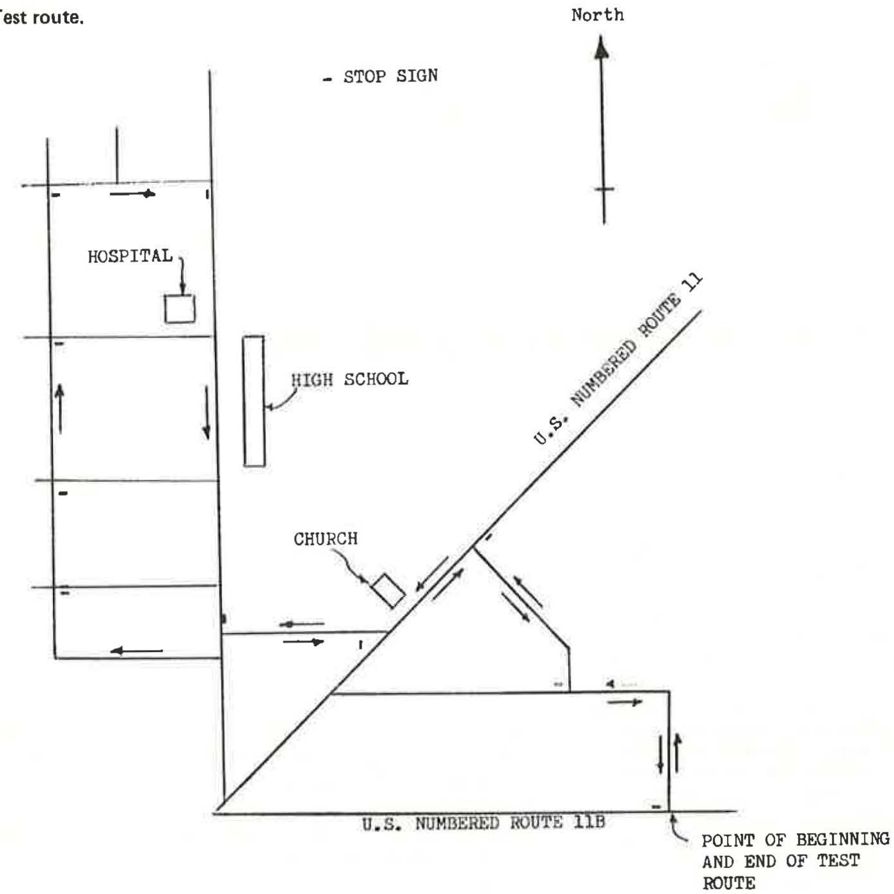
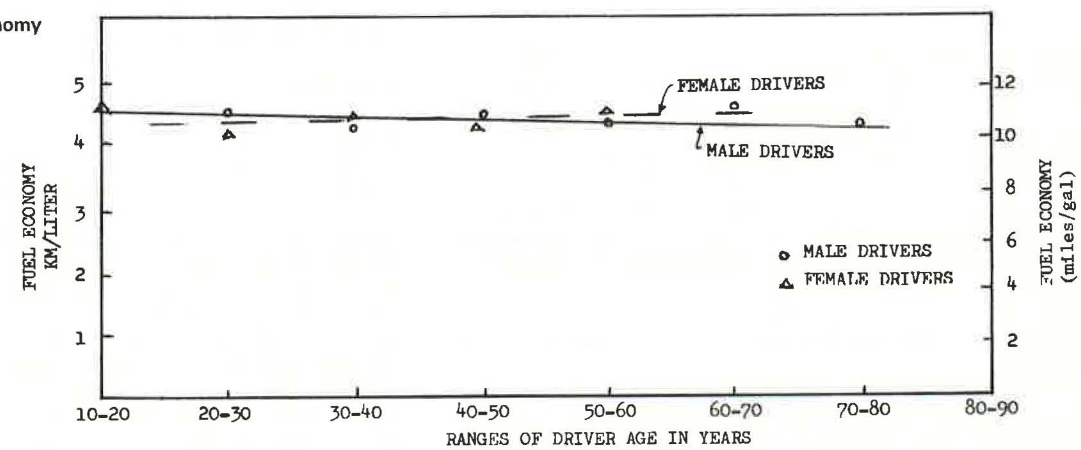


Figure 2. Driver fuel economy versus driver age and sex.



vehicle to collect data. Each was mounted so that readings could be made by the observer without distracting the driver. All data were recorded manually by the observer.

The photoelectronic fuel meter, which was mounted out of sight in the trunk, measured fuel consumption with dependable accuracy for all weather conditions and vehicle operating conditions likely to be encountered in automobile driving. A small display panel on the front seat next to the observer gave fuel consumption in units of 0.004 L (0.001 gal). The vacuum gauge gave intake manifold vacuum to the nearest 2.54 cm (1.0 in) of mercury, the accelerometer gave acceleration and deceleration rates to the nearest 0.61 m/s^2 (2 ft/s^2), and the tachometer gave engine speed to the nearest 100 revolutions/min.

Procedure

The drivers made their runs during the months of September, October, and early November of 1975. Air temperatures and wind conditions are generally stable at this time of the year. Runs were made each day between 2 and 8 p.m., partly to make it convenient for drivers who worked during the day and finished work late in the afternoon. No runs were made when it was raining, when air temperature was below 16°C (60°F), or when wind speed exceeded 4.8 km/h (3 miles/h).

Each driver, accompanied by the observer, drove over the test route 10 times. The only break between test runs was between the fifth and sixth trips. Fuel consumption, engine vacuum, acceleration, deceleration, and engine speed were recorded by the observer for each trip. Data recorded for each driver's first trip were used for checking purposes only, since the first trip was made to familiarize the driver with the route and to help him or her to overcome any initial tendency to drive in a stilted or unnatural manner.

RESULTS

Observed relations between fuel economy and the driver's sex and age, maximum deceleration and acceleration rates, minimum engine vacuum, and maximum engine speed during acceleration are shown in Figures 2-6. The observed effect on fuel economy of the driver's making or not making full stops at intersection stop signs (in daylight) is given below (1 km/L = 2.35 miles/gal):

Stopping Habit	Number of Drivers	Avg Fuel Economy (km/L)
Full stop	41	4.28
Slowdown only	33	4.42

Each driver's fuel economy was computed by dividing the total trip distance by the total fuel consumed on each trip and averaging for all trips. Each driver's maximum deceleration and acceleration rates were determined by reviewing the recorded patterns of deceleration and acceleration rates for all trips and selecting the consistently highest values. A high rate of deceleration or acceleration recorded for only one or two trips was rejected. The consistently lowest engine vacuum reading recorded for most of a driver's trips was selected as the minimum engine vacuum reading for that driver. Similarly, the consistently highest recorded engine speed during accelerations (in second gear just before upshift into high gear) was used as the driver's maximum engine speed during acceleration.

Sex and Age

Figure 2 shows fuel economy versus driver sex and age. Men and women drivers in each age group have about the same fuel-economy characteristics, and these change little from one age group to another. Fuel economy appears to be independent of both the sex and the age of the driver.

Driver Behavior at Stop Signs

The table above indicates the impact on fuel economy of driver behavior at intersection stop signs. Fuel economy for drivers who customarily make full stops is 4.28 km/L (10.06 gal/mile), and the average fuel economy for those who merely slow down to a crawl before accelerating across the intersecting street is 4.42 km/L (10.39 gal/mile). Evidently, whether or not a driver is careful to make full stops at stop signs does not have much effect on fuel economy.

Deceleration and Acceleration Rates

Maximum deceleration rates indicate whether a driver's fuel economy is good or bad only if the driver does not coast before braking. When a driver operates at open throttle nearly up to a stop point and then quickly brakes to a stop, more fuel is used than would be used if the driver either applied the brakes over a longer distance for a gradual stop or coasted almost up to the stop point before applying the brakes. Whereas low deceleration rates are always associated with good fuel economy during slowdowns, high deceleration rates are associated with poor fuel economy only if the vehicle is operated at open throttle up to the point of brake application. An analysis of study data indicates that the deceleration rate by itself is not a good indicator of driver fuel economy. The maximum deceleration rates observed for the 74 drivers are plotted versus driver fuel economy in Figure 3. Drivers who had low maximum deceleration rates had better fuel economy. However, the coefficient of correlation was only 0.4, and the coefficient of determination was 0.16. No more than 16 percent of the variation in driver fuel economy can be attributed to the maximum deceleration rate; 84 percent is attributable to all other factors.

Acceleration rates affect fuel consumption because of the way in which vehicles respond to acceleration demand and not because more energy is needed for rapid acceleration. The actual energy required to increase velocity from a stop or from a given velocity to a higher velocity equals one-half the product of the difference in the squares of the initial and final velocities times the mass. It is independent of the acceleration rate.

There are, however, two factors in the response of vehicles to acceleration that do result in more fuel being consumed for the higher rates of acceleration: (a) operation of the carburetor power jet, which injects a quantity of fuel into the intake manifold when the accelerator pedal is depressed sharply, and (b) delay in upshifting in order to develop the torque necessary for a high rate of acceleration. The power jet often wastes fuel because, instead of discharging the exact amount of fuel to fit demand, it usually discharges some excess fuel to ensure firm acceleration. Delay in upshifting means higher engine speeds during acceleration, which in itself adversely affects fuel consumption. When an automobile is accelerated by an even pressure on the foot throttle (no sharp jabs) and upshifting occurs at or near the minimum upshift speeds, the fuel consumed during acceleration is the same for all rates of acceleration up to 10 km/(h/s) [6.2 miles/(h/s)] (1, pp. 146-149).

The effect of the driver's acceleration rates on automobile fuel economy is shown in Figure 4, where observed maximum rates of acceleration are plotted versus fuel economy for the 74 drivers in the study. There is a definite drop in fuel economy at the higher maximum acceleration rates, but the coefficient of correlation is 0.5 and the coefficient of determination is 0.25. Only 25 percent of the variation in fuel economy is attributable to variation in maximum acceleration rates.

By themselves, neither deceleration rates nor acceleration rates correlate closely with driver fuel economy. For good fuel economy on deceleration, drivers need not apply the brakes for long, gradual slowdowns but need only take their foot off the accelerator and coast to the stop point, where they may stop suddenly if they wish. Fuel economy on acceleration will be the same at any rate of acceleration up to about 10 km/(h/s) [6.2 miles/(h/s)] if drivers apply a uniform pressure on the throttle (no sharp jabs) and upshift as close to the minimum upshift speeds as possible.

Accelerometer, Vacuum Gauge, and Tachometer

It has been suggested that accelerometers, engine vacuum gauges, or engine tachometers be installed in automobiles to help drivers improve their fuel economy. Many automobiles are already equipped with dashboard engine vacuum gauges for this purpose. Correlations

Figure 3. Driver fuel economy versus maximum deceleration rates.

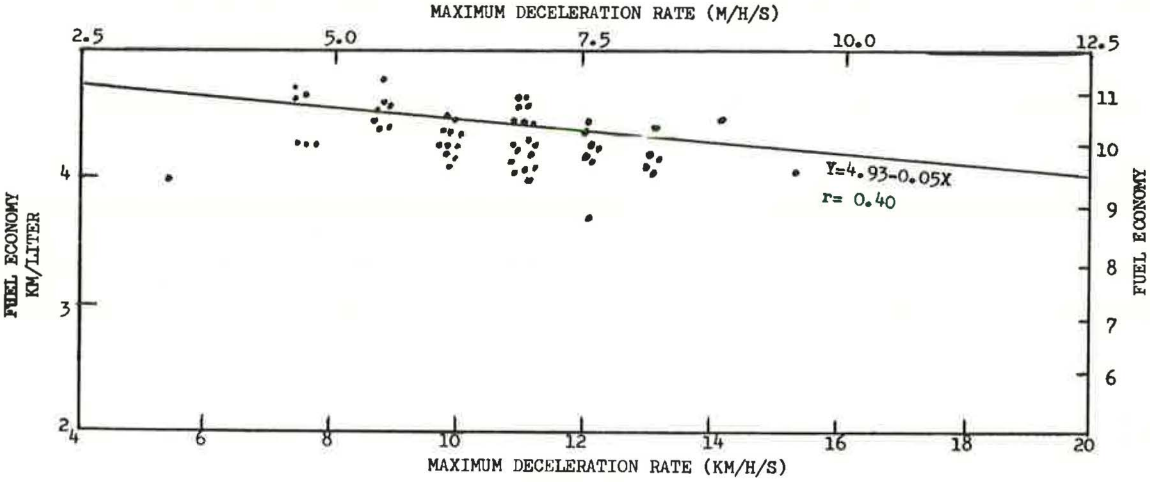
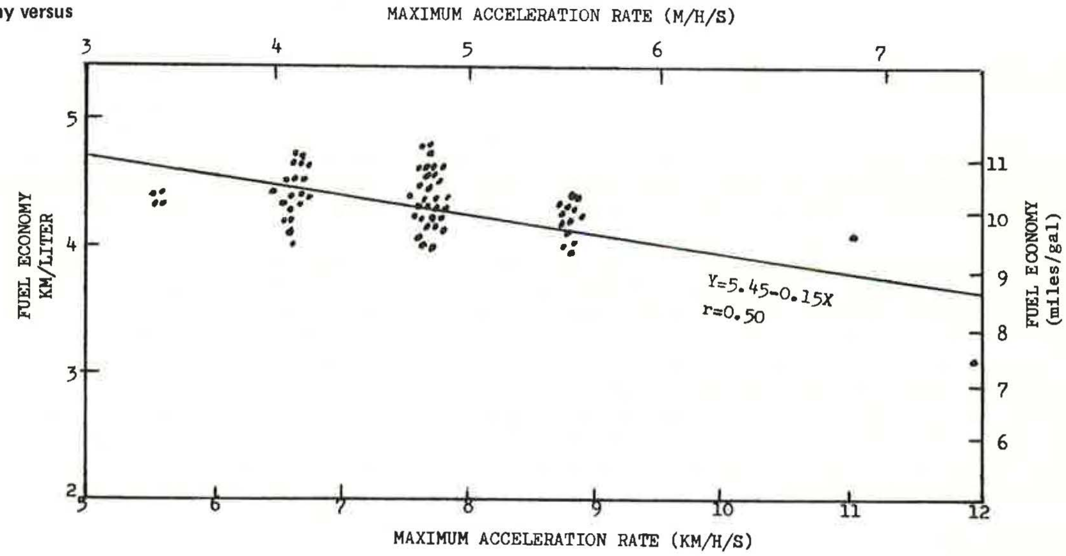


Figure 4. Driver fuel economy versus maximum acceleration rates.



between fuel economy and the appropriate dial readings are about the same for the vacuum gauge and the engine tachometer ($r = 0.6$), as shown in Figures 5 and 6, respectively; they are less for the accelerometer ($r = 0.4$ for the maximum deceleration rates shown in Figure 3 and 0.5 for the maximum acceleration rates shown in Figure 4). The devices that measure values most closely related to fuel economy are the vacuum gauge and the engine tachometer.

The engine vacuum gauge displays (in centimeters of mercury) the vacuum in the intake manifold developed by the pumping action of the engine pistons. Vacuum will be high if the throttle plate is closed (when a vehicle is idling or coasting) but will drop as the interior of the manifold is opened to the atmosphere at progressively wider throttle openings. Although vacuum is affected by engine speed and ambient air pressure, it is basically a measure of throttle opening. The gauge can help drivers to save fuel by letting them know when and for how long the throttle opening is excessive. In many automobiles, throttle opening is excessive when engine vacuum falls below about 25 cm (10 in) of mercury.

The tachometer gives engine speed in revolutions per minute. During acceleration, readings increase with vehicle speed except for a drop-off each time a transmission upshift takes place. Since fuel is consumed with every engine revolution, keeping engine speed down by early upshifting will promote fuel economy. The tachometer will also help drivers to save fuel by identifying minimum upshift speeds (on level roads) and by letting them know when engine speeds during acceleration are excessive. In many automobiles, engine speed during acceleration should not exceed about 2000 revolutions/min.

Both the vacuum gauge and the tachometer provide the driver with engine information related to fuel economy, particularly during acceleration. The engine tachometer, however, has two distinct advantages over the vacuum gauge:

1. The tachometer provides more information for the driver than the vacuum gauge. It not only gives engine speed at all road speeds but also can be used to identify minimum upshift speeds and to indicate when upshift takes place. This helps drivers to upshift at as low an engine speed as possible, either by manually shifting in a manual-shift automobile or, in an automatic-shift vehicle, by momentarily increasing engine vacuum by closing the throttle to force upshift. The vacuum gauge only indicates throttle opening.

2. As a tool for conserving fuel, the tachometer is probably less distracting to the driver than the vacuum gauge. During acceleration, tachometer readings rise

Figure 5. Driver fuel economy versus minimum engine vacuum.

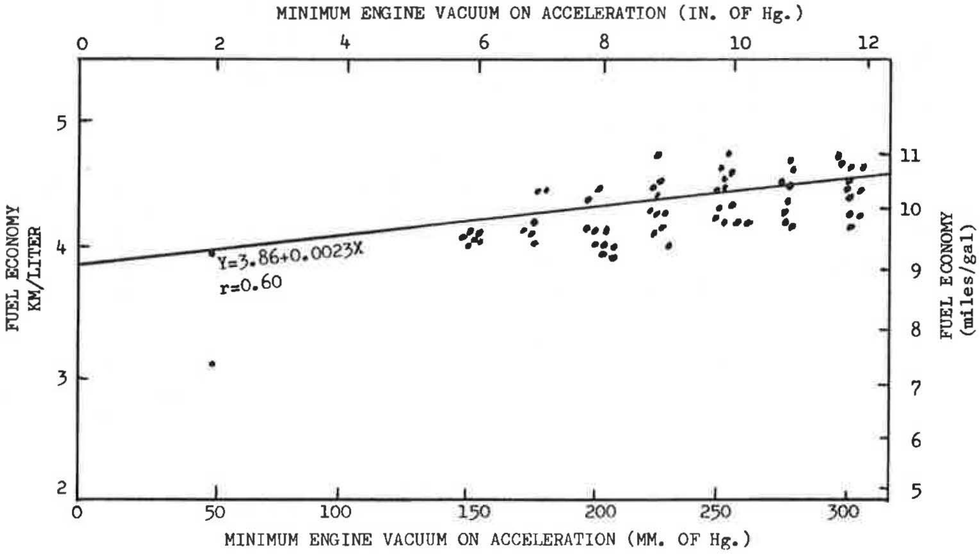
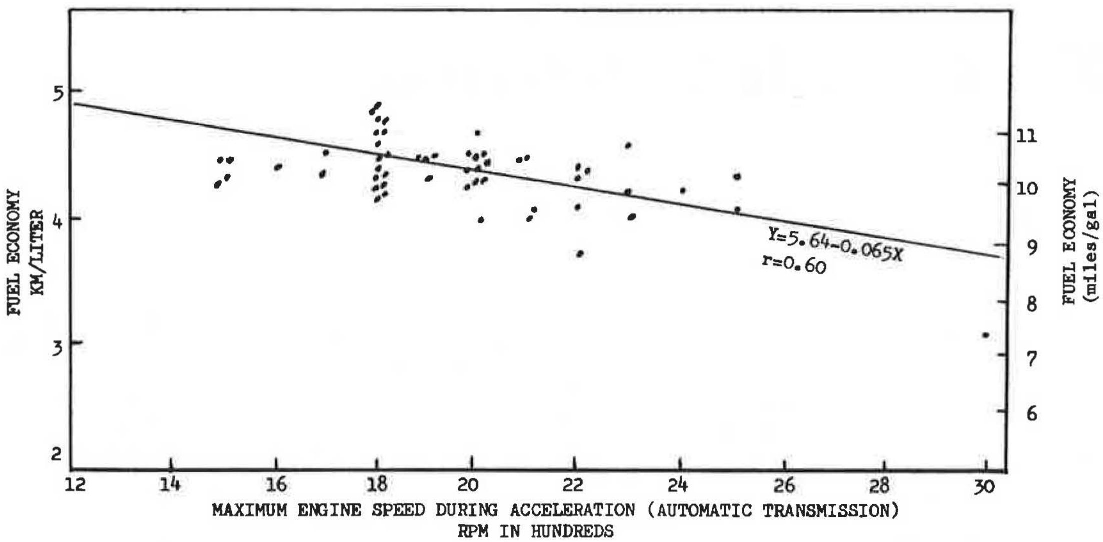


Figure 6. Driver fuel economy (for 58 drivers) versus maximum engine speed during acceleration.



steadily (except for drop-offs when upshifts take place) so that a few quick glances by the driver are all that is needed. The vacuum gauge, on the other hand, requires almost constant observation.

In the 1975 FHWA study (1, pp. 20-27), it was found that drivers accustomed to accelerating very rapidly—at rates greater than 10 km/(h/s) [6.2 miles/(h/s)]—at engine vacuums of less than 25 cm (10 in) of mercury might save fuel by using a vacuum gauge. But almost 50 percent of other drivers would use more fuel by trying to drive in conformance with vacuum gauge readings than they would use without the gauge.

Information developed in the study reported in this paper indicates the potential of the tachometer in helping drivers to save fuel. Further research is needed, however, to determine whether the instrument would actually contribute to fuel conservation and be safe to use.

Whether or not the average driver would even try to save fuel by using a dashboard instrument designed to help conserve fuel has not been investigated. This would depend on the driver's attitude toward fuel conservation, the amount of the driver's attention that would be taken from other driving tasks, and the extent of driver response required.

SUMMARY

The findings of this study indicate that fuel economy is not much affected by either the age or the sex of drivers or by whether drivers make full stops at stop signs. For normal ranges of deceleration and acceleration rates, the speed-change rate by itself is not important to fuel economy. If vehicles are coasted for a distance before the brakes are applied, fuel economy during deceleration is good regardless of the final rate of deceleration. On acceleration, drivers should avoid sharp jabs on the foot throttle and delays in upshifting. A smooth, steady acceleration at any acceleration rate up to 10 km/(h/s) [6.2 miles/(h/s)] provides good fuel economy.

The vacuum gauge is of little value as a dashboard instrument to help drivers save fuel. Although it might encourage the minority of drivers who customarily drive in a highly erratic manner to drive more smoothly, it would not help most drivers to conserve fuel. In fact, a substantial number of drivers would use more fuel in attempting to adjust their driving to the vacuum gauge. In addition, since the gauge should be monitored most closely during vehicle acceleration if it is to be useful, it could add a dimension of danger by distracting the driver's attention at these critical times.

The generality of the study results is somewhat diminished by the small size of the driver sample, the use of only one test vehicle, and the fact that the percentage of well-educated drivers in the sample probably exceeds that in the total driving population. However, the specific import of the study results is quite dependable. Other studies of the effect of driver characteristics and behavior on automobile fuel consumption have arrived at similar conclusions (2, 3).

ACKNOWLEDGMENT

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A Real-World Bicycle-Performance Measure

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A reliable and valid measure of the behavior of bicyclists in normal traffic is urgently needed for progress in bicycle safety. A measure developed based on observations by trained coders is presented. Types of bicycling behavior identified as critical for safety were drawn from accident and research data and a model of safe operator behavior. The reliability of observations depends on unambiguous definition of types of behavior and avoidance of information overload as well as intensive training. Only those types of behavior that occur frequently and are critical for safety are included. Three types of locations are used: (a) controlled intersections where the major variable is path, (b) midblock entrance, and (c) uncontrolled intersections were the variable of concern is search. Coding each type of location requires using a different form. Intercoder reliability was very high for all forms. This technique was used to evaluate the bicycle-riding behavior of approximately 600 elementary-school children and more than 3000 junior-high-school students on two occasions. This is the most extensive survey of bicycle-riding behavior available. It shows a very high error rate for all maneuvers and the greatest numbers of errors occurring on left turns and in search patterns. The instrument was shown to be both sensitive and reliable and is equally useful for measuring adult bicycling behavior.

Recently, traffic safety education has been extended to the elementary-school level and bicycle-safety curricula have burgeoned. It is advisable to evaluate the various options while there is still variability in the air, lest the nation's standard curriculum be cast in concrete before there is any evidence of effectiveness, as happened in the area of driver education.

In order to evaluate the effectiveness of bicycle-safety curricula, a reliable and valid criterion measure is necessary. A survey of the literature revealed no such measure. Accident data are not suitable in this area, even if one believes that they are the ultimate criterion, because, on the one hand, crashes are too few in any single jurisdiction to provide a reliable measure and, on the other hand, summing over a large number of jurisdictions introduces so many possibly relevant differences that the data would be meaningless. The proper kinds of validity to strive for are content validity, where the domain of relevant behaviors is sampled, and construct validity, where a model of traffic interaction is used to define safe bicycling behavior. If validity is defined in this way, it is possible to develop a measure that can be used to evaluate bicycle-safety curricula.

In their work, Cross and DeMille (1) reported no evidence that lack of skill in controlling the bicycle was a cause in any significant number of accidents. Therefore, range tests are not suitable for evaluating safe performance. Since interaction with traffic is of paramount importance in safe bicycling, a proper measure of bicycle performance must permit the evaluation of the bicyclist's ability to interact with traffic. We discovered no way to do that except to observe bicyclists in natural traffic situations. All artificial situations were either unacceptable to school authorities or failed to provide opportunities for interaction of any reasonable degree of complexity or risk.

PARAMETERS OF BICYCLIST PERFORMANCE

An appropriate measure for safe bicycle-riding behavior should sample bicycle-automobile interactions at a number of kinds of intersections and at midblock, where several other kinds of situations exist. Ideally, bicyclists should be unaware of any observation of their behavior; they must not be told that they are to take a test and then be given a set route. Their behavior must be free of constraints, and observation must be as unobtrusive as possible.

The facets of bicyclist behavior that were chosen for assessment were drawn from accident data, a model of safe operator behavior, and the behavioral objectives of the new bicycle-safety curricula of the California Department of Education. Accident data, in addition to providing no support for riding skills as a cause of bicycle-vehicle crashes, point to the importance of visual search, judgment, recognition of right-of-way, and observation of traffic rules. A model of traffic interaction based on human characteristics gives prime importance to perceptual expectations; that is, a person appearing in an unexpected place is not detected as often as one in an expected place. For example, a bicyclist on the wrong side of the street is not as readily detected as one on the proper side. The reason that such a large proportion of bicyclists are "at fault" in crashes is not because their behavior is unlawful but because they either are in unexpected places or are making unexpected maneuvers. Since the driver's capacity for information processing is often overloaded, especially at intersections, he or she may be unable to process the extra information necessary to detect an out-of-place bicyclist.

On this basis, types of bicyclist behavior that require unusual attention on the part of the driver should be evaluated. These include bicycling on the proper side of the street, obeying traffic signs and signals, signaling intent, maintaining a straight course and not swinging wide, negotiating an intersection in the expected path, maintaining reasonable speed, and not appearing suddenly from driveways or off curbs. The bicycle-safety curricula of the state of California are based on explicit behavioral objectives, which are given in the original report (2). They cover essentially the same ground as those discussed above except for some knowledge objectives, which can be measured only by paper-and-pencil tests.

Some important types of behavior are difficult or impossible to assess. Scanning for hazards can be observed, but hazard detection cannot. Judgment of time to contact cannot be measured in "free" conditions because the measurement cannot be unobtrusive. Right-of-way judgments cannot be measured in free conditions because critical situations do not occur with sufficient frequency. But a large number of critical types of behavior can be observed. It remains to be seen whether they can be coded reliably enough to serve as criteria for bicyclist performance.

GENERALITY OF THE PERFORMANCE MEASURE

A question of great interest is whether the performance test developed here is limited to measuring only the two curricula for which it was developed or whether it is suitable for evaluating the performance of any bicyclist. The parameters of performance are critical for bicyclists of any age. The method of coding is also of general applicability. Some of the right-or-wrong criteria may be specific to school children or even to the California curriculum; for example, riding in a crosswalk is forbidden in California, and elementary-school children are taught to make left turns by following the two right-side crosswalks. However, since the coders are trained to consistently apply the criteria that are given to them, the criteria can be changed to serve a different purpose. The system has been tested only with elementary-school and junior-high students, but there is no reason why it should not work equally well for adult bicyclists since the rules for safe riding are, in general, the same.

DEVELOPMENT OF THE INSTRUMENT

Because naturalistic observation is the only method that can provide valid information about desired bicyclist behavior, an observational system was developed to permit coding the real-world behavior of bicyclists. One problem that has plagued observers of bicyclist behavior has been the extreme difficulty of finding bicyclists to observe. To evaluate the effects of a training program, a large number of independent observations are necessary. To solve this problem, observation points were set up on major routes to schools, one or two blocks from the school. This made it possible to observe many bicyclists in a reasonable length of time.

The one question concerning this procedure is whether behavior on school trips is representative of general bicycling behavior. Since there is no sample of general bicycling behavior, the question cannot be answered except circuitously. Whereas it is true that few children are hit on trips to and from school, either as bicyclists or as pedestrians, it is clear from our observations of both of these groups that drivers behave much more cautiously when they are given the multiple cues that children are present (e.g., notice of a school zone and sighting of children in groups). In addition, the behavior in traffic of the children observed in this study was so bad that it is hard to see how it could be worse elsewhere. It is only in the case of the "best-behavior" phenomenon that one need worry about using the school trip as the data base.

After some unstructured observation of bicyclists near schools, a tentative coding form was devised based on the critical parameters of bicyclist behavior discussed above. This form was modified several times based on the comments of five coders and on their difficulties in achieving consistency in coding.

Some types of behavior cannot be coded reliably in spite of training procedures that are normally effective. The essential constraints are the attentional and information-processing capabilities of human observers. If these are exceeded, the entire procedure becomes unreliable. Therefore, the requirements were that the form be simple and that observations be restricted to one item at a time. Some types of behavior occur so rarely that they cannot be treated statistically. These were eliminated to permit the coders to concentrate their attention on types of behavior that were useful for evaluation.

In the development of the final form, five staff members coded bicyclist behavior in pairs, after considerable training with videotapes. Their agreements were calculated each day, and any consistent area of disagreement was discussed, revised, or made the object of intensive training.

There are three forms for three types of situations: intersection path, midblock behavior, and intersection search. The major variable for intersection path is the path chosen. The bicyclist may be going straight through, turning right, or turning left and in each case may choose the correct path (defined in the procedures manual), an incorrect path (too wide, in the traffic lane), or a wrong-side path (more dangerous because it puts bicyclists in a place where drivers do not expect them). Since being in a crosswalk is a different kind of error from swinging into a traffic lane, it is coded separately. In addition, special types of behavior are coded: riding off the curb or out of a driveway, riding double or "no-hands", carrying an object, excessive speed, or playing in the street.

The midblock form is simpler because the situation is simpler. Essentially, it permits the observer to

Table 1. Incorrect bicyclist behavior for three intersection paths.

School Level	Type of Path	Condition	Trained Group Percent	Trained Group Number	Control Group Percent	Control Group Number
Elementary	Right turn	Pretest	82	51	26	27
		Post-test	38	45	25	32
	Left turn	Pretest	90	41	90	30
		Post-test	76	34	73	26
	Through	Pretest	80	5	75	24
		Post-test	75	16	81	16
Junior high	Right turn	Pretest	38	82	44	116
		Post-test	51	72	28	65
	Left turn	Pretest	76	54	87	95
		Post-test	88	49	82	121
	Through	Pretest	59	243	53	679
		Post-test	45	197	55	636

Table 2. Incorrect bicyclist behavior for intersection-path, search, and midblock-path situations.

School Level	Type of Situation	Condition	Trained Group Percent	Trained Group Number	Control Group Percent	Control Group Number
Elementary	Path	Pretest	82	101	57	91
		Post-test	52	105	46	86
	Search	Pretest	88	102	78	98
		Post-test	86	79	80	66
	Midblock	Pretest	61	115	49	59
		Post-test	65	57	38	58
Junior high	Path	Pretest	56	387	54	919
		Post-test	52	325	56	833
	Search	Pretest	87	382	93	481
		Post-test	85	357	94	424
	Midblock	Pretest	54	373	58	515
		Post-test	54	325	54	473

code the path the bicyclist takes (for example, bursting out of a driveway straight across the street) and whether there is any evidence of visual search (head movement). The special types of behavior coded on the first form are also coded here.

Because visual search is a critical type of behavior and was an important course objective, its inclusion was essential. However, it could not be reliably coded at the kinds of intersections that were found to be best for path coding. Signalized intersections cannot be used because the delay makes it uncertain whether the bicyclist can remember the traffic situation. Since coding of search requires very close attention to the indicators of search throughout the traversal of the intersection, search coding could not be combined with observation of other types of behavior without greatly reducing reliability. A simpler type of intersection was necessary—one in a residential area and preferably without any traffic controls, although that is hard to find in some areas. The form for intersection search provided for coding the number of directions searched by the bicyclist before he or she entered an intersection, the number searched after a stop, and whether a rearward search was made before the bicyclist entered a traffic lane. Forward search could not be identified, since the indicator of search was head movement.

Approximately two weeks of training was needed for the coders to achieve satisfactory reliability on intersection path and midblock behavior. Coding was done for 30 min before school and 20 min after school, and there were several videotaped sessions early in the training period. Training in search coding came next and, because the indicators are so fleeting, required almost as much time. Training was continued until a high intercoder reliability was achieved for all pairs of the five coders trained. A procedures manual was developed to formalize the definitions and instructions.

RELIABILITY OF FIELD CODING

The reliability of these procedures was calculated for pairs of observers by using Cohen's kappa statistic (3) for nominal scale agreement. Kappa measures the proportion of agreement after chance agreement is removed. The mean of the kappas for all pairs of coders was 0.95 for intersection path, 0.88 for midblock behavior, and 0.75 for intersection search. These show excellent reliability, since a kappa of 0.60 is considered good. It is therefore concluded that this method of measuring real-world bicycle performance is satisfactory and will provide a useful criterion for the evaluation of countermeasures.

EVALUATION OF A BICYCLE-SAFETY CURRICULUM

These performance measures were used in an evaluation of the California Bicycle Safety Education Curricula in upper elementary and junior high schools. For each type of school, the experimental design was a pretest-posttest control group design. Four schools were randomly assigned to each group. This paper is not intended to be a full report of that study, but, since there are no descriptions of free bicycling behavior in the literature, the nature of the findings is of interest here.

The data are frequencies of the various behaviors in the three kinds of situations. In some cases, the raw frequencies at pretest are very informative. For example, virtually no bicyclists used arm signals, almost none stopped at stop signs, and half did not search at all. The pattern of incorrect behavior is also of interest. For example, most bicyclists use the "wrong-side path" on a left turn (making the left turn on the near side of the cross street, which puts the bicyclist in unexpected places twice), a very dangerous maneuver. This is frequently a strategy for avoiding stopping at a light and is often done at full speed.

The comparison of behavior frequencies for elementary-school and junior-high students shows some interesting differences. For example, few elementary-school students ride two abreast or no-hands, but many junior-high students do. Fewer junior-high students stop at signs or signals. Instead of learning to ride more safely, junior-high students appear to reject safer behavior.

Table 1 gives the percentage of incorrect behavior for intersection path for elementary-school and junior-high bicyclists in those categories that contained a reasonable number of cases. The statistical analysis was based only on correct versus incorrect behavior because the numbers in the finer subcategories were very small. The Minimum Discriminant Information Statistic (4), a method of contingency analysis that permits the evaluation of interactions among variables, was used to evaluate the differences between groups, testing times, and path types for elementary-school and junior-high bicyclists separately. For intersection path, errors on right-turn, left-turn, and through maneuvers were included in the analysis.

For the elementary-school data set, there was a statistically significant effect of training ($p < 0.0000$), a significant difference between pretest and posttest data ($p < 0.014$), and a very significant difference between the three types of intersection paths in negotiating an intersection ($p < 0.0000$), left turns generating more errors than the others. In addition, there was a highly significant interaction among type of path, time of test, and training ($p < 0.0000$), which implies that the effectiveness of the curriculum depends on the type of behavior examined and that there are differences that are affected by type of test, type of behavior, and group assignment, conjointly.

For the junior-high-school data, the picture is very different. The training effect is not significant ($p < 0.62$), nor is there a difference between pretest and posttest conditions.

Table 2 gives the data used for a second analysis that compared intersection-path, search, and midblock-path behavior for trained and untrained groups, pretest and posttest, for elementary-school and junior-high students. The elementary-school data set produced results similar to those above: Training, type of test, and type of behavior were all very significant effects ($p < 0.0000$), the last being once again the most powerful simple effect. Search accounted for the largest number of errors and midblock path the least. However, the interaction of all three variables accounted for a large proportion of the variation in the distribution of errors. For the junior-high data set, these results were also similar to those found previously: no training effect ($p < 0.82$) and no pretest-posttest effect ($p < 0.67$). The type of behavior made a significant difference in the proportion of errors, search contributing more heavily.

The picture painted by these results is rather dismal. Bicyclists at both age levels made a very large number of dangerous riding errors both before and after training. The fact that there is a statistically significant though slight improvement at the elementary-school level that is attributable to training holds out some hope that a massive training program might be effective.

CONCLUSIONS

The study reported here demonstrates that it is possible to collect naturalistic bicycle-performance data that have the reliability and validity necessary for a criterion measure. The instrument is sensitive enough to reveal small changes in behavior brought about by short-term training programs. The ability to detect behavioral changes at the elementary-school level, where the numbers were relatively small, and to find strong evidence of no change at the junior-high level, where the numbers were large, is impressive. Since the coders do not need special qualifications and the training time is short, this technique is cost effective. It is available to anyone who wishes to study changes in bicycle-riding behavior.

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Evaluation of the Eugene, Oregon, Greenway Bicycle Bridge

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The results of a study conducted as part of a National Bikeway Demonstration Program project that funded the construction of a bicycle bridge—the Greenway Bridge—in Eugene, Oregon, are reported. The bridge spans the Willamette River and connects the north and south parts of Eugene. It reduces the travel time for bicyclists between two major retail and employment centers and connects the bicycle paths that run along both banks of the river. Income and age; trip purpose, mode, and frequency; and reason for bicycling were among the variables studied. Surveys of bicyclists who crossed the river showed that approximately one-third of bicycle trips were commuting trips to or from work and an additional 10 percent were commuting trips to or from school. The new bridge is shown to have eliminated approximately 500 automobile trips/week. All income categories were well represented among bicyclists, but the < \$5000/year group was overrepresented. The income distribution of bicyclists is almost the same as that of the city as a whole for non-university-related trips. Those in the 16- to 34-year old age groups constitute a larger percentage of bicyclists than they do the city population. As the Eugene bicycle system grows, it should continue to attract more bicyclists and more utilitarian trips.

In 1976, the city of Eugene, Oregon, successfully applied for a National Bikeway Demonstration Program grant (Section 119 of the Federal-Aid Highway Amendments of 1974) to finance a bicycle and pedestrian bridge to cross the Willamette River near the Valley River shopping center (see Figure 1). In the application, the city indicated that this bridge was the "most important missing link in the city's bikeway network". It was pointed out that the Willamette River forms a

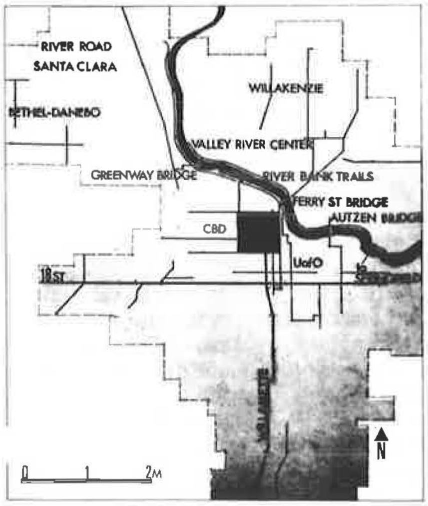

Figure 1. Eugene, Oregon, bicycle route and bridges.

physical barrier that separates the River Road, Bethel-Danebo, and West Eugene areas and the central business district (CBD) from the Willakenzie-Goodpasture Island area as well as separating the north- and south-bank bicycle paths and parks. With the construction of this new bridge, the barrier would be reduced, and this would result in increased recreational, work, and shopping-related bicycle trips.

The Greenway Bridge is a link between a major shopping center (Valley River Center) and a residential area as well as the CBD. It also connects class 1 bicycle paths that run along the north and south banks of the Willamette River. These paths are, in turn, part of the Greenway park system that includes Alton Baker Park, jogging trails, and the public rose garden. The bridge is also linked with class 2 and class 3 bicycle paths. Therefore, the Greenway bicycle bridge is felt to have a great potential for influencing ridership on recreational and utilitarian trips.

The city of Eugene indicated that surveys would be taken before and after the construction of the bridge to evaluate the effects of the bridge on the following factors:

1. Recreational ridership (as a percentage of total ridership),
2. Commuter and shopping ridership (as a percentage of total ridership),
3. The reduction in vehicle trips attributable to substitution of bicycle trips for automobile trips,
4. Winter bicycling (by provision of easier access to routes at a time when it is most important to bicyclists not to travel out of their way), and
5. Increased use of other segments of the bikeway network as a result of their improved accessibility.

This paper is a summary of that evaluation.

In addition, the reasons why people choose the bicycle to travel from one side of the Willamette River to the other rather than other modes of travel, and their demographic characteristics, are reported. This additional analysis disaggregates trips to school and those going to and coming from the University of Oregon. This is done so that those who feel that a university and students are not typical of most communities can find some value in this federally funded demonstration project. Finally, an analysis of pedestrian use of the bridge is included.

CITY OF EUGENE AND BICYCLE PLANNING

Eugene, Oregon, is located in the southern end of the Willamette Valley. The city was initially developed on the south side of the Willamette River and grew into the south hills. Since the damming of the Willamette River in the 1950s, the flat land north of the river has been developed. The major industries are wood products, government, retail trade, and the University of Oregon. The urbanized area contains approximately 180 000 people.

In 1970, the city council established a staff committee to study bicycle use. In 1971, five citizens were added, and the committee became the Mayor's Bicycle Committee. Consultants were used to help develop the Eugene Bikeway Master Plan. Before the plan was adopted in 1975, public hearings were held and citizen input was obtained. The plan calls for 242 km (150 miles) of bicycle paths, 66 km (41 miles) of which is to consist of separate trails. Approximately 80 km (50 miles) of bicycle paths of all sorts have been completed.

The city of Eugene has committed more than $50 000 annually for bikeway construction. Additional funds are available from state gasoline taxes. The state of Oregon has also mandated that the land along the Willamette River be available to the public. Monies from the Greenway fund have been used for park development, and this has helped in the establishment of bicycle paths along the river.

The commitment of the community to bicycles has helped to generate additional funds. Three entities pooled their resources to build the first bicycle-pedestrian bridge, the Autzen Bridge: the Eugene Water and Electric Board, a public utility, which was planning to put steam lines across the Willamette River; the University of Oregon, which bussed students from the campus to the football stadium on the other side of the Willamette River; and Lane County, which was developing the Greenway park systems. A second such crossing is being considered.

STUDY METHODOLOGY

Sampling

The proposal for the National Bikeway Demonstration Program grant indicated that bicycle surveys were to be taken at the Willamette River crossings and on the north- and south-bank trails before and after the Greenway Bridge was built. A survey of shoppers at Valley River Center was also to be made to determine current modes of transportation and expectations of use of the bridge. In addition, manual counts of bicyclists and pedestrians were to be made. A comparison of the surveys and counts was to form the basis for the evaluation.

In the course of the work, the following modifications were made by the staff:

1. No surveys were conducted at the Beltline Bridge, which is not yet conducive to bicycle use.
2. No surveys were made on the trails along the north and south banks of the river. All bicyclists who used the bridges were surveyed, and it was felt that it was unnecessary and possibly redundant to survey bicyclists on the north- and south-bank trails as well.
3. Shoppers at Valley River Center were not surveyed. It was felt that to ask people whether they expected to use the facility would not provide any useful information beyond that to be derived from the other surveys.

4. Because limited staff made manual bicycle and pedestrian counts impossible, mechanical counters were used.

It was decided to survey people who crossed the bicycle bridges on both a weekday and a weekend in the summer and on a weekday in the winter, before and after the Greenway Bridge was built. This resulted in six surveys. It was therefore possible to compare the difference in trip purpose for different seasons and for weekends versus weekdays. No winter weekend survey was planned for fear of oversurveying and meeting resistance from bicyclists. Each person surveyed filled out only one form per day, usually on their first trip across the river.

Pedestrians were not surveyed before the bridge was built. This was an oversight. Joggers used the bridge but were not surveyed. It was felt to be too dangerous for the surveyors to try and stop Eugene's marathon runners for a survey.

Table 1 summarizes the survey schedule. Both weekend surveys took place on Saturday from noon to 6 p.m. The surveys before the bridge was built were in three 2-h segments, starting at 7:30 a.m. and ending at 6 p.m. After the Greenway Bridge was built, the entire 10.5-h period was surveyed. When comparisons are made between the before and after studies, compatible time periods are used.

The Questionnaire

The surveys taken before the Greenway Bridge was built consisted of four questions.

1. What is your age group: (a) 15 and under, (b) 16-24, (c) 25-34, (d) 35-49, (e) 50-64, or (f) 65 and over?
2. Is the purpose of your trip (a) recreational, (b) to or from work, (c) to or from school or college, (d) to or from shopping, (e) to or from personal business, or (f) other?
3. On this trip, where are you coming from and going to (the respondent was given a choice of 12 city locations and a category "other")?
4. What are your main reasons for riding your bicycle today (up to three choices): (a) only form of transportation, (b) cheap transportation, (c) convenient parking, (d) environmental concerns, (e) exercise, or (f) it's fun?

The questionnaire used in the surveys taken after the bridge was built consisted of these questions and nine other items.

A comparison of the responses to the second question above will give some indication of whether trip purposes have changed over time. It is difficult to say, however, whether these changes are attributable to the Greenway bicycle bridge or to other factors, such as modifications to other parts of the bicycle system. Respondents were asked whether they knew that a new bicycle bridge had been built and where it was. These questions will be useful in measuring how well known the existence and location of the bridge are to regular bicyclists. The remaining questions were added because they were of general interest to the staff. A question that asked respondents whether they would have made this trip to a given destination by bicycle if the new bridge had not been built was added by the staff to get at this information more directly. Respondents were also asked about the change in frequency with which they used four given travel modes (bicycle, automobile, bus, and walking) because of the existence of the new bicycle bridge. This question will, of course, aid in measuring the impact the bridge has on each mode of travel.

Critique of the Methodology and Problems

The following points should be made concerning the survey results:

1. The number of days the surveys were administered was limited and not randomly chosen. Therefore, the study may be criticized for not being representative of bicyclists over the entire year. However, the days that were surveyed were chosen to be similar with regard to factors such as weather conditions and day of the week as a way of standardizing before and after characteristics as much as possible. It was felt that this experimental control would give better results than sending inexperienced surveyors out to the bridges at randomly scheduled times over a period of a month. This latter methodology also ran the risk that the environment would change over the month. It is felt that comparison of the before and after surveys may lack reliability because of the lack of a random sample. The three questions mentioned previously that were designed to determine respondents' knowledge about the bridge were added to the survey form after the bridge was built to strengthen the evaluation. A possible methodology for the future may be a randomly sampled mail survey with follow-ups. This would result in getting more data than it is possible to obtain in a survey of bicyclists in the field.
2. The number of bicyclists and the tendency for bicyclists to come in groups often overwhelmed the survey team. Some inaccuracy in the responses may have resulted, but this was not felt to be too great a problem.
3. Even though there has been considerable publicity concerning the Greenway Bridge, it will take time before all potential users know about its existence. Sixteen percent of bicyclists who used other bridges did not know of the existence of the Greenway Bridge five months after it was completed. The percentage who do not know about the Greenway Bridge should be considerably higher among people who do not regularly use these bridges. The long-term impacts will therefore be greater than those measured in this study, data collection for which concluded only five months after the bridge was opened because of the need to complete the evaluation by September 1978.
4. It was difficult to get accurate bicycle counts by using mechanical counters. The counters malfunctioned and were often vandalized. However, it was possible to ascertain that the number of bicyclists crossing the Greenway Bridge during the survey periods after the bridge was built was considerably lower than on the average typical weekday and was considerably higher for a typical weekend. It is recommended that permanent counters be built into future demonstration projects.
5. It was assumed in this analysis that respondents answered the questionnaire correctly.

Since a concerted effort was made not to overstate the impact of the Greenway Bridge, it is felt that the conclusions are conservative and the methodology is sound.

Table 1. Survey schedule.

Study Phase*	Date	Day of Week	Time of Day	Weather Conditions	Group Surveyed
Before	5/21/77	Saturday	Noon-6:00 p.m.	Warm and sunny	Bicyclists
	5/31/77	Tuesday	7:30-9:30 a.m., 11:00 a.m. -1:00 p.m., 4:00-6:00 p.m.	Warm and sunny	Bicyclists
	11/17/77	Thursday	7:30-9:30 a.m., 11:00 a.m. -1:00 p.m., 4:00-6:00 p.m.	Cold, overcast, with light rain	Bicyclists
After	4/4/78	Tuesday	7:30 a.m. -6:00 p.m.	Cold, windy, cloudy	Bicyclists and pedestrians
	5/20/78	Saturday	Noon-6:00 p.m.	Warm and sunny	Bicyclists and pedestrians
	5/31/78	Tuesday	7:30 a.m. -6:00 p.m.	Warm and sunny	Bicyclists and pedestrians

*Before and after opening of Greenway Bridge, February 1, 1978.

Table 2. Weekday trip purpose of bicyclists who would not have made the trip if the Greenway Bridge had not been built.

	4/14/78 Survey						5/30/78 Survey					
	Greenway Bridge		Autzen and Ferry Bridges		Total		Greenway Bridge		Autzen and Ferry Bridges		Total	
Trip Purpose	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Recreation	21	40.4	9	34.6	30	38.5	36	46.8	18	31.0	54	40.0
Work	14	26.9	9	34.6	23	29.5	20	26.0	18	31.0	38	28.1
School	5	9.6	6	23.1	11	14.1	5	6.5	9	15.5	14	10.4
Shopping	6	11.5	0	0	6	7.7	10	13.0	1	1.7	11	8.1
Personal business	6	11.5	2	7.7	8	10.3	5	6.5	8	13.8	13	9.6
Other	0	0	0	0	0	0	1	1.3	4	6.9	5	3.7
Total	52		26		78		77		58		135	

EVALUATION

Trip Purpose

The effect of the Greenway Bridge on the percentage of bicyclists who ride for recreational purposes, to and from work, and on shopping trips was measured in two ways.

First, each bicyclist crossing the river was asked if he or she would have made the trip if the Greenway Bridge had not been built. The responses of those who said they would not have made the trip were cross-tabulated with trip purpose for the two weekday surveys given in Table 2. In both surveys, approximately 40 percent of these additional trips were for recreational purposes, 29 percent were for commuting to or from work, and 8 percent were for shopping. Those being surveyed as they went over the Greenway Bridge made up almost all of those on shopping trips. The data given in Table 3 show that recreational trips predominated on the weekend. Again, the Greenway Bridge accounts for most of the additional shoppers.

Table 4 provides an additional comparison. The purpose of all weekday bicycle trips is given. Here it becomes obvious that the other bridges are being used for shopping trips but that the percentages of these trips are lower than those for the Greenway Bridge. This is as expected because of the proximity of the Greenway Bridge to the Valley River shopping center. Table 4 also indicates that 30-40 percent of all trips are for commuting to and from work. The Greenway Bridge showed a relatively constant percentage of work trips (32.5-34 percent), whereas the other bridges showed a higher percentage during the winter than during the summer.

Table 5 provides a comparison of bicycle trip purposes over all surveys. It is obvious that work trips make up a consistently high percentage (33-45 percent) of the trips of bicyclists surveyed on weekdays and that recreational trips make up, at most, one-third of the trips.

Table 6 gives the trip purposes of pedestrians who crossed all three bridges. Clearly, recreation is the major purpose of pedestrians in using the bridges. This would be expected, since the distance between non-recreational trip ends is great. Of pedestrians surveyed in the April 4, May 20, and May 30 surveys, 45, 50, and 37 percent, respectively, indicated that they would have not have made the trip if the Greenway Bridge had not been built.

Reduction in Vehicle Trips

Measuring the reduction in vehicle trips as a result of the substitution of bicycle for automobile trips presented a challenge. One measure is provided by looking at the number of trips that would not have been made by bicycles if the Greenway Bridge had not been built (see Table 7). Multiplying the number of trips by 5 to convert to a weekly weekday average and doubling this to take into account return trips results in 780 and 1350 bicycle trips being generated by the Greenway Bridge according to the two summer weekday surveys given in Table 7. However, not all of these trips are substitutes for automobile trips. If one considers commuting trips to school and work as necessary trips, a conservative estimate of 340 and 520 trips/week, respectively, is developed as an estimate for vehicle-trip reduction (Table 7) (because there were few pedestrian, work, and school trips that would not have been made, these were not included in this analysis).

An alternate methodology was also used (see Table 8). People who crossed the three bridges were asked to indicate the change in the number of trips made by each mode (bicycle, automobile, bus, and walking) because of the availability of the Greenway Bridge. If a respondent failed to answer this question, the conservative assumption that no changes occurred was made. Eighty-two bicyclists indicated that they drove their automobiles less during the summer because of the Greenway Bridge, and 146 indicated that they rode their bicycles more frequently (it should be noted that some bicyclists do not have access to an automobile). Thirty-one bicyclists said that they used the bus less often because of the new bridge.

An estimate of change in the total number of trips by mode was made by multiplying the change in frequency by the number of bicyclists who indicated that change and then summing the overall changes. For example, 56 people indicated that they used their automobiles 3-1 times less frequently, 30 that they used them 6-4 times less frequently, 10 that they used them 9-7 times less frequently, and 9 that they used them at least 10 times less frequently; 2 people indicated that they used their automobiles 1-3 times more frequently during the summer survey. By multiplying these frequencies by the midpoint in the range (or by 10 for the "10-or-more" answers), an estimated number of trips reduced of 428 trips/week is obtained $[(56 \times 2) + (30 \times 5) + (10 \times 8) + (9 \times 10) - (2 \times 2)]$.

The changes in number of trips by mode as reported by bicyclists and pedestrians in the surveys made after the bridge was built are summarized in Table 9. The reductions in automobile trips reported in the three surveys are relatively consistent. Surprisingly, however, a greater reduction in automobile trips was indicated during the winter survey. In fact, automobile trips decreased more than bicycle trips increased for the winter survey. Clearly, something is wrong.

An examination of Table 8 shows that 25 bicyclists in the winter survey versus 9 in the summer survey indicated that they made ≥10 fewer trips by automobile. It is possible that during the winter survey people did not have enough experience with the new bridge and overestimated the number by which their automobile trips decreased. Therefore, the figure of 428 fewer automobile trips, estimated by using the summer survey, is probably a better estimate of the impact of the bridge.

If the responses of pedestrians are included, the estimate increases to 529 fewer automobile trips because of the Greenway Bridge. This estimate is very close to the 520 fewer trips estimated by using the methodology that considers only trips to and from work and school. The lower estimates of 520 for summer automobile-trip reduction and 340 for winter automobile-trip reduction are therefore used and are considered to be conservative.

One final point should be made. The bicycle counts indicate that there were 10-15 percent fewer bicyclists on the bicycle system during the weekday surveys than on the average day. The average day was determined by looking at the bicycle counts over the bicycle path taken throughout the year. Therefore, the above estimate may be understated by that amount.

Increase in Winter Bicycling as a Result of Easier Access

As indicated earlier, 78 bicyclists reported during the winter survey that they would not have made the trip by bicycle if the Greenway Bridge had not been built.

Table 3. Weekend trip purpose of bicyclists who would not have made the trip if the Greenway Bridge had not been built.

Trip Purpose	Greenway Bridge		Autzen and Ferry Bridges		Total	
	Number	Percent	Number	Percent	Number	Percent
Recreation	172	78.2	167	86.1	339	81.9
Work	14	6.4	8	4.1	22	5.3
School	0	0.0	3	1.5	3	0.7
Shopping	30	13.6	6	3.1	36	8.7
Personal business	3	1.4	7	3.6	10	2.4
Other	1	0.5	3	1.5	4	1.0
Total	220		194		414	

Table 4. Trip purpose for all weekday bicycle trips.

Trip Purpose	4/4/78 Survey						5/30/78 Survey					
	Greenway Bridge		Autzen and Ferry Bridges		Total		Greenway Bridge		Autzen and Ferry Bridges[a]		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Recreation	31	32.0	89	20.3	120	22.4	65	40.6	183	31.8	248	33.8
Work	33	34.0	178	40.6	211	39.4	52	32.5	193	33.6	245	33.3
School	12	12.4	105	24.4	117	21.9	13	8.1	97	16.9	110	15.0
Shopping	10	10.3	17	3.9	27	5.0	19	11.9	13	2.3	32	4.4
Personal business	10	10.3	35	8.0	45	8.4	7	4.4	73	12.7	80	10.9
Other	1	1.0	14	3.2	15	2.8	4	2.5	16	3.5	20	2.7
Total	97		438		535		160		575		735	

Note: Survey from 7:30 a.m. to 6 p.m.
[a]Surveyors ran out of forms on Autzen Bridge at 4:45 p.m. It is estimated that 63 responses are missing.

Table 5. Trip purpose of bicycle trips for all surveys before and after opening of the Greenway Bridge.

Survey	Trip Purpose (%)						Sample	
	Recreation	Work	School	Shopping	Personal Business	Other	Total	Missing
Before								
Saturday, 5/21/77[a]	66.7	6.3	3.2	14.6	5.8	3.4	688	3
Tuesday, 5/31/77[b]	25.4	37.2	18.3	8.0	9.2	1.9	578	
Thursday, 11/17/77[b]	19.6	37.5	27.2	6.3	8.3	1.0	301	
After								
Tuesday, 4/4/78								
Sample[a]	17.6	45.6	22.3	3.8	7.5	3.5	347	1
Total[c]	22.4	39.4	21.9	5.0	8.4	2.8	537	2
Saturday, 5/20/78[a]	81.2	4.7	2.4	7.3	2.9	1.5	1498	12
Tuesday, 5/30/78								
Sample[b]	28.0	41.7	15.7	3.4.	8.7	2.5	477	1
Total[c]	33.7	33.3	15.0	4.4	10.9	2.7	736	1

[a]Survey from noon to 6:00 p.m.
[b]Survey from 7:30 to 9:30 a.m., 11:00 a.m. to 1:00 p.m., and 4:00 to 6:00 p.m.
[c]Survey from 7:30 a.m. to 6:00 p.m.

Fifty-two of these people were interviewed on the Greenway Bridge. Bicyclists were not asked directly whether ease of access was responsible. Instead, a trip table was constructed (see Table 10) to determine whether the 52 trips were between locations whose accessibility had increased because of the new bridge. Table 10 gives the number of trips between any two locations for bicyclists on the Greenway Bridge during the winter-weekday survey. The first number is the number interviewed who would not have made the trip if the Greenway Bridge had not been built. The second number is for the total trips indicated by bicyclists on the Greenway Bridge. Trips made between places whose accessibility is greater because of the bridge are footnoted.

Twenty-six bicycle trips that would not have been made if the bridge had not been built are between locations that have greater accessibility. Another 26, or 50 percent, however, are not between such locations. Fourteen of these trips are between Willakenzie and Valley River, which are both north of the river. This ambiguity also shows up in the comparison of the two summer-weekday surveys (which are not given here). Before the bridge was built there were no trips recorded between Willakenzie and Valley River; there were 20 such trips after the bridge opened.

It is possible that these people find the south-bank trail more pleasing and therefore now make a trip they would not have made if they had had to ride on the north-bank trail. Another explanation would be that they were going to make an additional trip that relied on the greater accessibility provided by the Greenway Bridge.

One additional statistic points to the bridge providing greater ease of access. Sixty-five percent of those crossing the Greenway Bridge during the winter survey indicated that the bridge was the quickest way to make the trip—clearly a reflection of greater accessibility.

Table 6. Trip purpose of pedestrian trips for all bridges.

	Trip Purpose (%)						
Survey	Recreation	Work	School	Shopping	Personal Business	Other	Total Sample
Tuesday, 4/4/78	34.6	24.4	3.8	15.4	21.8	0	78
Saturday, 5/20/78	77.2	1.9	0.6	8.9	3.2	8.2	158
Tuesday, 5/30/78	62.6	11.7	4.3	9.8	6.1	5.5	163

Table 7. Number of bicycle trips generated by the Greenway Bridge.

Category	Tuesday, 4/4/78	Saturday, 5/20/78	Tuesday, 5/30/78
Those who would not have made trip by bicycle			
Number	78	420	135
Percent	14.5	28.0	18.3
Number of trips per 5-day workweek and 2-day weekend	780[a]	1680[b]	1350[a]
Number who would not have made school or work trip by bicycle	34		52
Number of school and work trips per 5-day workweek	340[a]		520[a]

[a]Assumes that Tuesday is representative of weekdays and therefore that the same number of trips would be made on each workday. Therefore, multiply by 5 the number who would not have made the trip by bicycle. Then multiply this figure by 2 to take into account the return trips.

[b]Same as weekday except only two days.

Table 8. Change in frequency of trips by various modes because of the Greenway Bridge.

		Number of Responses							
		Winter Survey[a]				Summer Survey[b]			
Mode	Change in Number of Trips	Autzen Bridge	Ferry Bridge	Greenway Bridge	Total	Autzen Bridge	Ferry Bridge	Greenway Bridge	Total
Bicycle	Fewer								
	10	0	1	0	1	0	1	1	2
	9-7	0	1	0	1	0	1	0	1
	6-4	3	1	0	4	0	1	0	1
	3-1	0	7	0	7	0	0	0	0
	More								
	1-3	30	22	20	72	34	39	35	108
	4-6	5	11	22	39	23	11	31	65
	7-9	2	2	4	8	4	7	9	20
	10	6	0	22	28	7	12	18	37
	No change	194	155	29	378	290	213	66	569
Automobile	Fewer								
	10	9	0	16	25	3	0	6	9
	9-7	0	1	3	4	4	2	4	10
	6-4	7	7	15	29	9	9	12	30
	3-1	6	11	7	24	12	19	25	56
	More								
	1-3	2	4	0	6	2	0	0	2
	4-6	2	1	0	3	0	0	0	0
	7-9	0	0	0	0	0	0	0	0
	10	0	1	0	1	0	0	0	0
	No change	214	175	56	445	328	255	113	696
Bus	Fewer								
	10	2	0	4	6	0	2	0	2
	9-7	0	1	0	1	0	0	0	0
	6-4	1	4	4	9	3	1	2	6
	3-1	5	2	4	11	3	7	13	23
	More								
	1-3	3	0	0	3	0	0	0	0
	4-6	0	0	0	0	0	0	0	0
	7-9	0	0	0	0	0	0	0	0
	≥10	0	0	0	0	0	0	0	0
	No change	229	193	85	507	352	275	145	772

[a]Total sample sizes were Autzen, 240; Ferry, 200; Greenway, 97.

[b]Total sample sizes were Autzen, 358; Ferry, 285; Greenway, 160.

Table 9. Change in number of trips by mode reported by bicyclists and pedestrians.

	Change in Number of Trips								
	Tuesday, 4/4/78			Saturday, 5/20/78			Tuesday, 5/30/78		
Mode	Bicyclists	Pedes-trians	Total	Bicyclists	Pedes-trians	Total	Bicyclists	Pedes-trians	Total
Bicycle	+550	+91	+641	+1612	+119	+1731	+1038	+135	+1173
Automobile	-583	-94	-677	-533	-58	-591	-428	-101	-529
Bus	-129	-49	-178	-130	-11	-141	-96	-51	-147
Walk	-21	+124	+103	+166	+96	+262	+50	+177	+227
Total	-183	+72	-111	+1115	+146	+1261	+564	+160	+724

Note: Joggers were not surveyed.

Table 10. Trip table to determine effect of Greenway Bridge on increased accessibility between origins and destinations (winter weekday survey).

	Destination													
Origin	Valley River	Willa-kenzie	Down-town	Bethel	River Road	W. Willamette North of 18th	W. Willamette South of 18th	Uni-ver-sity	E. Willamette North of 18th	E. Willamette South of 18th	River-bank Trails	Spring-field	Missing and Other	Total
Valley River	0/1	14/15[a]	4/11[a]	0/0[a]	0/0[a]	5/7[a]	3/5[a]	1/3	0/0	1/4	1/1[a]	0/0	0/0	29/47
Willakenzie		0/0[a]	0/0[a]	0/0[a]	4/7[a]	0/0	1/1[a]	0/2	0/0	0/0	1/2[a]	0/4	0/0	6/16
Downtown			0/1	1/1	0/2	0/0	0/0	0/0	0/0	0/0	3/3[a]	0/0	0/0	4/7
Bethel				0/0	0/1	0/0	0/0	0/0	0/0	0/0	0/1[a]	0/0	0/0	0/2
River Road					3/3	0/0	0/1	0/2	0/0	0/0	0/0[a]	0/0	0/0	3/6
W. Willamette north of 18th						1/2	0/0	0/0	0/0	0/0	2/3[a]	1/1	0/0	4/6
W. Willamette south of 18th							0/0	0/0	0/0	0/0	0/0[a]	0/0	0/0	0/0
University								2/5	0/0	0/0	0/1[a]	0/0	0/0	2/6
E. Willamette north of 18th									0/0	1/1	0/0[a]	0/0	0/0	1/1
E. Willamette south of 18th										0/0	1/3[a]	0/0	0/0	1/3
Riverbank Trails											1/2[a]	0/0	1/1	2/3
Springfield												0/0	0/0	0/0
Missing and other													0/0	0/0
Total	0/1	14/15	4/12	1/1	7/13	6/9	4/7	3/12	0/0	2/5	9/16	1/5	1/1	52/97

Note: Trips that would not have been made if Greenway Bridge were not built/all trips on Greenway Bridge.
[a]Greater accessibility because of the Greenway Bridge (part of Willakenzie was accessible to downtown before the Greenway Bridge was built).

Increased Use of Other Segments of the Bikeway Network

It was not possible to measure the magnitude of increased use of other segments of the bicycle system brought about by greater accessibility. It is, however, obvious that they are being used more. As Table 2 indicates, 135 weekday bicyclists reported that they would not have made the trip if the new bridge had not been built. This represents 18 percent of all bicyclists surveyed. This 18 percent clearly used other parts of the system to reach the Willamette River.

Demographics

Two demographic variables were surveyed for each bicyclist: income and age. These were compared with estimates for the city to see whether a group of people who were representative with respect to these variables were using the bicycle facility. In addition, students and those traveling to and from the University of Oregon were separated out so that their impact on the bicycle system could be measured.

Income

The income distribution of bicyclists is compared with that for the city in Table 11. The lowest-income group ($0-$4999) is overrepresented by approximately 10 percent of the total. If the university and student community is removed, the two distributions are similar. It does appear, however, that upper-income non-university-related individuals make up a higher percentage of bicyclists on the bridge during the winter months.

As Table 11 indicates, the percentage of pedestrians who are in the lowest-income group is even higher than the percentage of bicyclists.

Age

The age distribution for bicyclists is given in Table 12. The distribution for the region is also shown. The regional figures exclude those 4 years of age and under, since they do not yet bicycle. Table 12 clearly indicates that those in the two age groups between 16 and 34 years of age make up the majority of the bicyclists. These age groups have higher percentages of bicycle ridership than the younger and older groups. The percentage of age groups riding bicycles decreases with each group beyond 35 years of age.

One interesting point should be made. Those in the age group from 35 to 49 years of age who are not going to or from school or making a trip to or from the university make up the same proportion of bicyclists as the regional population during the winter-weekday survey.

Pedestrians show a similar age distribution. As Table 12 indicates, 16- to 34-year-olds are over-represented and the younger and older groups are under-represented. As one might expect, younger adults clearly use the Greenway facility more frequently.

The demographics of those who use the Greenway Bridge are similar to those of people who use the other bridges. The one major difference is that incomes are higher. This is possibly attributable to fewer students using the Greenway Bridge. It is clear, however, that all age and income groups use the bridge.

Table 11. Income distribution of bicyclists and pedestrians using the Greenway Bridge in comparison with city population.

Category	Survey Date	Distribution by Annual Income (%) $0-$4999	$5000-$9999	$10 000-$14 999	$15 000-$19 999	≥$20 000	Total Sample
Bicyclists							
Total	Tuesday, 4/4/78	30.4	21.3	15.1	14.1	19.0	537
	Saturday, 5/20/78	29.8	16.9	18.6	12.4	22.2	1498
	Tuesday, 5/30/78	28.3	21.5	17.3	15.5	17.6	736
Nonuniversity[a]	Tuesday, 4/4/78	19.9	19.2	18.5	17.8	24.5	286
	Tuesday, 5/30/78	22.3	21.2	19.4	18.1	19.0	471
		18.3	25.1	19.3	16.9	20.3	
Pedestrians	Tuesday, 4/4/78	32.9	20.5	21.9	11.0	13.7	78
	Saturday, 5/20/78	35.7	27.9	12.9	9.3	14.2	158
	Tuesday, 5/30/78	35.0	18.9	14.0	14.7	17.5	163
City[b]		18.3	25.1	19.3	16.9	20.3	

[a]Excludes trips to school and trips to or from the University of Oregon.
[b]Estimates based on update of a 1975 survey of 6.7 percent of city households.

Table 12. Age distribution of bicyclists and pedestrians using the Greenway Bridge in comparison with region.

Category	Survey Date	Distribution by Age (%) ≤15 Years	16-24 Years	25-34 Years	35-49 Years	50-64 Years	≥65 Years	Total Sample
Bicyclists								
Total	Tuesday, 4/4/78	5.6	41.8	35.3	12.6	3.8	0.9	537
	Saturday, 5/20/78	13.7	45.8	29.7	7.6	2.8	0.4	1498
	Tuesday, 5/30/78	4.5	43.1	39.0	8.2	4.1	1.1	736
Nonuniversity[a]	Tuesday, 4/4/78	7.3	28.0	40.3	17.3	5.7	1.3	300
	Tuesday, 5/30/78	5.7	36.0	41.1	10.0	5.5	1.7	471
Pedestrians	Tuesday, 4/4/78	6.4	37.2	32.1	7.7	6.4	10.3	78
	Saturday, 5/20/78	5.1	51.9	29.7	7.9	5.1	0.6	158
	Tuesday, 5/30/78	4.9	42.3	31.3	9.8	8.0	3.7	163
Region[b]		20.4	23.6	16.3	17.1	13.8	8.9	

[a]Excludes trips to school and trips to and from the University of Oregon.
[b]Year 1975 estimate for urbanized area, excluding those 4 years of age and under.

Reason for Bicycling

Bicyclists were asked to choose as many as three of six possible reasons for bicycling. Exercise was the most frequent reason for bicycling. Cheap transportation was the second most popular reason for weekday bicyclists. Half of weekday bicyclists chose to bicycle for this reason. On May 30, the bicycle was being used because of economic considerations by more than 200 people sampled. The fact that bicycling is fun and that the bicyclist is concerned about the environment were also important.

For many people, the bicycle provides the quickest means of getting between two places. Some also bicycle because of convenient parking. In discussions with bicyclists, it was discovered that some checked this response because there was convenient bicycle parking whereas others checked it because it was easier to park a bicycle than an automobile.

It would be safe to say that a bicycle program designed to attract bicyclists for utilitarian trips will have to appeal to more than one reason for bicycling. Automobiles are driven because of such factors as convenience, style, freedom, and sex appeal. The bicyclist is attracted by convenience, the aesthetics of bicycling, environmental concerns, and, in some cases, cost. The design of bicycle systems and marketing programs should take this into consideration.

SUMMARY AND RECOMMENDATIONS

The overriding conclusion of this study is that the bicycle is no longer a child's toy. The evaluation of the Greenway Bridge has indicated that not only this bridge but the other two Eugene bicycle bridges as well (Ferry Street and Autzen) are used heavily for utilitarian trips by adults of all income groups. The provision of bicycle facilities creates an alternative to the automobile that is heavily used. The better the system is, the greater the diversion of trips from the automobile that can be expected. In addition, the bicycle system is the only form of transportation for one-third of the bicyclists surveyed.

These findings are supported by the following observations:

1. Work trips constituted as much as 30-40 percent of all weekday trips. During the summer survey, 735 bicyclists were surveyed on all three bridges, and 345 were traveling to or from work. During the winter survey, 211 of 535 bicyclists were commuting.
2. Trips to or from school constituted 15-20 percent of weekday trips.
3. Recreational trips constituted 20-35 percent of all weekday trips.
4. Approximately 50 percent of those crossing the Greenway Bridge would not have made the trip by bicycle if the bridge had not been built.
5. Approximately 500 automobile trips/week have been eliminated because of the construction of the bridge. This estimate is conservative and is likely to increase as more people learn of the bridge and additional segments of the bicycle system are developed.
6. On a weekday, 40-50 percent of those interviewed said they rode bicycles because it was fun.
7. Almost half the bicyclists rode because it was a cheap form of transportation. One-third had no other form of transportation.
8. The income distribution of the bicyclists roughly parallels that of the general population of Eugene. However, the lowest-income group (those earning less than $5000) is overrepresented.
9. Although bicyclists tend to be younger than the average population, 35-40 percent of the bicyclists during the weekdays were between 25 and 34 years of age and another 10-15 percent were between 35 and 49 years of age.

The following recommendations are made:

1. There is a need to improve the bicycle network leading to the Greenway Bridge from the Bethel-Danebo,

River Road-Santa Clara, and Willakenzie areas. No surveys were taken to verify this, but riding the system has convinced me of this need. Railroad and industrial property provide a barrier for those in Bethel-Danebo. The bicycle path running along River Road is narrow and automobile traffic there is heavy, thereby increasing the danger and reducing the enjoyment of bicycling for those in River Road-Santa Clara. Those in Willakenzie are faced with the barrier of major freeways (I-105 and Delta Highway) and must navigate through the parking lot at Valley River Center. These barriers must be eliminated if the Greenway Bridge is to meet its full potential.

2. Parking for bicycles should be expanded. Although only 20 percent of bicyclists indicated that convenient parking was a reason for bicycling, it is something that can be provided. A higher percentage of bicyclists indicated that parking was a factor in the winter when the weather was bad. Covered bicycle parking would be a pleasant addition. Casual observation indicates that covered areas for bicycle parking at the University of Oregon store a higher percentage of all bicycles in the winter than in the summer. There are not enough covered spots.

3. Surveys should be made of randomly chosen individuals to ensure that a representative group of bicyclists and nonbicyclists is interviewed. If this were done by mail, longer surveys could be used and more information could be gathered. Surveys on the bicycle paths should also be done. A comparison of both surveys would allow for some comparison and validation of the findings.

4. This evaluation took place shortly after the Greenway Bridge opened. An evaluation should be made in another year to measure the long-term effects.

5. Permanent counters should be installed in future demonstration projects. The rubber hoses on the temporary counters are vandalized, which makes accurate counts difficult. Permanent counters should also be installed at the Greenway Bridge to facilitate the long-term evaluation.

6. Signing is inadequate and should be improved. The approach to the bicycle-path system from River Road does not indicate that a bridge to Valley River exists.

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On-Road Improvements for Bicyclists in Maryland

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With the decrease of highway revenues, funds are not available to construct a large system of conventional bicycle routes that are separate from motor-vehicle lanes. The new transportation system management approach to transportation planning places emphasis on efficient use of the existing highway network rather than its expansion. For these reasons, it is now necessary to treat the bicycle as a design vehicle in the design and maintenance of highways without the construction of separate facilities for bicyclists. Three types of low-cost, on-road types of improvements for bicyclists implemented in Baltimore County, Maryland, are discussed: (a) wide curb lanes that provide additional width in the right-most lane by slightly narrowing adjacent lanes, (b) smooth shoulders that facilitate bicycle travel on existing roads, and (c) parking changes that provide more room on the street for bicyclists and increase sight distance for bicyclists and motorists.

Before 1900, bicyclists were a major impetus for improving both urban and rural roads, most of which did not have a hard surface. Bicycle route maps were published that showed roads suitable for bicycling. For example, an 1896 bicycle route map of the Washington, D.C., area (1) not only showed the roads that bicyclists could ride on but also indicated severity of grade and summits of hills by appropriate symbols. As more roads were resurfaced with brick, concrete, and macadam, to the benefit of bicyclists, motor vehicles became dominant and improving roadways for the benefit of bicyclists was forgotten.

Even today, with the increase of interest in the construction of bicycle facilities, adequate consideration is not being given to the bicycle as a design vehicle for the highway network. For the most part, improvements for bicyclists are strictly limited to officially marked or mapped bicycle routes or obvious hazards such as parallel-bar storm-drain grates, which trap bicycle wheels. Unfortunately, these improvements represent only a fraction of the potential improvements that can be made for bicyclists.

This paper reports on three types of improvements for bicyclists and moped riders that have been implemented in Baltimore County, Maryland, and that can be applied economically to many types of roads in the United States. These improvements are

1. Wide curb lanes that provide additional width in the right-most lane where most bicycle travel occurs (this additional width is obtained by narrowing slightly, where possible, the lanes for the same direction and adding this width to the right-most curb lane);
2. Shoulder improvements that facilitate bicycle travel on existing roads; and
3. Prohibiting parking near intersections based on bicycle design speed to provide better sight distance for bicyclists and motorists entering the intersection.

There has been a continuing discussion for the past several years between bicyclists and transportation officials as to what type of facilities should be provided for bicyclists. Some have favored emphasis on on-road improvements without marked bikeways, whereas others have favored conventional class 1 and class 2 bikeways. The basic argument of those who favor conventional marked bikeways is that bikeways tend to be safer because they remove bicycles from the traffic flow. Those who favor on-road improvements without marked bikeways have argued that designated bikeways will cause bicyclists to ride with the motor-vehicle traffic flow and not on bikeways to shorten trip time and in some cases, because of faulty design on conventional bikeways, to increase safety.

Regardless of how the bikeways versus on-road improvements argument is resolved, on-road improvements will remain very important to bicyclists. For example, even if a bikeway system similar to the excellent system in many European countries is developed in the United States, bicyclists will still need to ride on many existing roads to get to and from the bikeways. In most parts of the United States, however, the development of existing roadways occurred without consideration of the bicycle as a mode of transportation, and this often makes bikeway development expensive or impractical. This situation makes low-cost on-road improvements for bicyclists even more important. If bicyclists are legally permitted on a highway, then it is appropriate when designing or maintaining the highway to consider physical improvements for bicycles just as other vehicles in the traffic mix are considered.

Except for some recreational bikeways in parklands, most state and federal funding for bikeways is derived from highway user taxes. The largest component of highway user taxes, the motor-vehicle fuel tax, is unlike all other major types of taxes, such as income, property, sales, and excise taxes, because the revenues do not automatically increase with inflation. In the past, the almost continuous increase in the consumption of diesel fuel and gasoline often increased motor-vehicle fuel-tax revenues faster than inflation decreased the value of the revenues. In the next decade, however, the more fuel-efficient automobiles and trucks mandated by Congress and promised by the truck manufacturers will cause consumption of motor-vehicle fuel to level off or decrease with continued inflation. Unless increased funding is provided, which appears unlikely at this time, this will lower the value of revenues to the point where new construction of highways will be significantly curtailed.

One of the principles of transportation system management (TSM), which is an important part of the transportation planning process in most large metropolitan areas, is that emphasis is placed on the efficient management rather than the expansion of transportation facilities. Highways, public transit, private automobiles, pedestrians, and bicycles should be treated as elements of a single transportation system and not as independent systems. Rising construction costs and limited funds have made it more important than ever to use existing transportation facilities efficiently as an alternative to expensive new facilities. This applies as much to bicycles and mopeds as to other types of vehicles. Therefore, ways must be found to improve the riding environment for bicyclists and moped riders on the existing highway network.

In this paper, it should be assumed, unless otherwise stated, that references to bicycles and bicyclists also pertain to mopeds and moped riders.

WIDE CURB LANES

The National Advisory Committee on Uniform Traffic Control Devices, commenting on an official request by the Baltimore County Department of Traffic Engineering to approve the use of wide curb lanes on the Federal-Aid Highway system, indicated that the wording in the Manual on Uniform Traffic Control Devices (MUTCD) permits the narrowing of normal 3.7-m (12-ft) wide traffic lanes to 3.4 m (11 ft) for the purpose of widening the right-most curb lane for bicyclists.

A wide curb lane is basically a 4- to 4.6-m (13- to 15-ft) wide right-most curb lane that is obtained by reducing the adjacent lanes for the same direction of traffic flow to 3.4-3.7 m (11-12 ft). Reducing lane width to 3.4 m is permitted by standards of the American Association of State Highway and Transportation Officials (AASHTO) (2, p. 351). The wide-curb-lane treatment can be used on many curb-and-gutter urban arterials and collectors on which class 1, 2, or 3 bicycle routes may not be appropriate or possible.

Class 1 bicycle routes of the sidewalk type are not usually desirable along urban highways that have many intersecting streets and driveways because motorists exiting from the streets or driveways are looking for approaching motor vehicles in the roadway and not for approaching bicyclists set back from the roadway where the sidewalk or bikeway is located. This is especially true for two-way bikeways, on which bicyclists approach the street or driveway from the opposite direction of motor-vehicle flow. In such situations it is probably more desirable for bicyclists to be riding in a wide curb lane so that drivers exiting from streets and driveways will readily be able to see them when searching for approaching vehicles in the roadway.

According to AASHTO standards (3, p. 22), class 2 bicycle routes usually require at least 4.6 m (15 ft) of paving in the curb lane for a 3.4-m vehicle lane and a 1.2-m (4-ft) bicycle lane. This 4.6-m requirement cannot be met on many highways without reducing the width of the adjacent lanes to less than 3.4 m. In many instances, 4- to 4.3-m (13- to 14-ft) wide curb lanes are the only improvement possible for bicyclists. Even if 4.6 m is available, it may often be undesirable to stripe and sign a bicycle lane because of high traffic volume or speeds. A wide curb lane would, in this instance, be desirable for bicyclists, who would use the facility regardless of whether or not it was marked as a bicycle route.

A curb lane that is widened and yet is still not as wide as a travel lane and a bicycle lane, or 4.6 m, can be considered an incremental improvement for bicyclists. However, a curb lane of 4.6 m can be considered a quantum improvement because it is the same width as a travel lane and a bicycle lane. Class 1 and class 2 bicycle lanes can also be considered quantum improvements, but in many instances an unsigned and unmarked wide curb lane that is 4.6 m wide is preferable to a class 1 or 2 bicycle route. When a quantum improvement is not possible because of physical or cost limitations, it is logical to attempt to implement incremental improvements instead. In many instances, other than the incremental improvement of wide curb lanes (less than 4.6 m), no provisions can be made for bicyclists.

The Highway Administration of the Maryland Department of Transportation is currently planning to widen two curb-and-gutter urban arterial highways in Baltimore County that have commercial strip development. According to policy, consideration must be given to facilities for bicyclists. Because of right-of-way limitations, vehicle speeds of 65 km/h (40 mph), traffic volumes in excess of 40 000 vehicles/day, and many commercial driveways and turning movements, it was decided that wide curb lanes would be the most suitable improvement for bicyclists. Without wide curb lanes, no suitable improvements could be made for bicyclists because the traffic conditions make the marking of a class 1 or 2 bicycle route undesirable. In addition, there is not enough right-of-way available for a class 1 route.

In Baltimore County, wide curb lanes were marked on roads posted for speeds higher than 65 km/h only when the adjacent lanes were 3.7 m (12 ft) wide or wider. It was decided not to reduce the lane width to less than 3.7 m on these higher-speed highways. On highways that did not have a center turning lane or a median to separate opposing traffic flow, it was decided not to reduce lane width to less than 3.7 m unless the posted speed limit was 55 km/h (35 mph) or less.

Wide curb lanes have been marked on many multilane arterial and collector roads in Baltimore County. For example, on York Road (MD-45), a newly constructed 18.9-m (62-ft) wide, five-lane section was marked with two 4.3-m (14-ft) wide curb lanes. The 4.3-m lanes offer enough maneuvering room for motorists to avoid bicyclists without leaving the lane. On another, almost identical, 18.9-m section of York Road, where the curb lanes are only 3.7 m wide, there is considerably less room for motorists to avoid bicyclists. Wide curb lanes have also been successfully applied on other four-, five-, and six-lane roadways and have provided similar benefit for bicyclists.

Wide curb lanes can be advantageous to motorists for the following reasons:

1. On many urban roadways, fixed hazards are located near the edge of the curb, and motorists tend to shy away from these fixed objects. Wider curb lanes can add a 0.3-m (1-ft) or greater margin of clearance between motor vehicles and fixed objects.
2. Many high-volume urban arterials have numerous commercial driveways that do not have traffic-signal controls. Motorists exiting from these driveways frequently pull out into the curb lane, attempting to make a turn. This problem can be compounded when sight obstructions such as signs, poles, and vegetation restrict the driver's view to such an extent that the motorist is almost forced to extend the front of the vehicle into the curb lane. The additional clearance that a wider curb lane can provide enables vehicles traveling in the curb lane to more easily avoid vehicles in commercial driveways (see Figure 1).
3. In most cases, the additional width added to the curb lane is obtained by marking the other lanes 3.4 m (11 ft) instead of 3.7 m (12 ft). On roadways that have a posted speed of 65 km/h (40 mph) or less, it is difficult for a motorist to perceive the 0.3-m (1-ft) narrowing of the lanes. However, it can be quite evident to bicyclists that there is additional space between then and motor vehicles in the curb lane (see Figure 2).
4. The additional width in a wide curb lane can allow a vehicle making a right turn into a highway to stay completely within the wider curb lane. This might not be possible otherwise. This is especially true for larger vehicles that are turning where there are depressed curbs or small-radii curb returns at side streets or driveways. The same effect occurs when vehicles are turning into a side street or a driveway from a wide curb lane. In addition, the wide curb lane can effectively increase the radius of turns and thus increase the speed at which turns can be made, thereby reducing interruptions to through traffic in the curb lane.

One application of wide curb lanes is along roadways where many parked vehicles are encountered by bicyclists. If a midsized or larger two-door automobile is legally parked 0.3 m (1 ft) away from the curb and an occupant of the vehicle opens the door on the driver's side all the way, a bicyclist cannot maneuver around the opened door without leaving the 3.7-m (12-ft) lane. A wide curb lane is needed in this situation to allow width for the bicyclist to pass. Figure 3 shows that the normal 3.7-m curb lane is not wide enough to allow a bicyclist to pass the open door of a 1977 midsized Chevrolet without leaving the lane. A 4.0-m (13-ft) lane is the minimum necessary for a bicyclist to maneuver around a fully opened automobile door without leaving the lane; a 4.1- or 4.3-m (13.5- or 14-ft) lane is desirable to permit more maneuvering room. Although most vehicle occupants do not open the door all the way when exiting a parked vehicle, many bicyclists do not ride exactly at the far left side of the parked-vehicle lane either.

The new MUTCD guidelines for grate delineation could conceivably effectively reduce a normal 3.7-m lane to 2.7 m (9 ft) by making a 0.8-m (2.5-ft) grate with a required 0.15-m (0.5-ft) wide edge stripe. A 2.7-m lane is a near minimum for motor-vehicle flow. The effective 2.7-m lane could conceivably be shared by both a bicyclist and a motor vehicle, but the situation would permit little or no clearance between them. If, however, the wide-curb-lane treatment were applied, at least an additional 0.3 m (1 ft) would be available between the bicyclist and the motor vehicle (see Figure 4).

Use and implementation of the many kilometers of wide curb lanes in Baltimore County were observed and studied over a 3-year period. Some of the observations and conclusions made are as follows:

1. Wide curb lanes are best suited for curb-and-gutter highways. On highways that have no curbing, bicyclists would be removed farther from motor-vehicle traffic by providing smooth and adequate shoulders.
2. A 4.9-m (16-ft) lane is wide enough to function as two unmarked 2.4-m (8-ft) lanes by permitting two narrower vehicles to occupy the 4.9-m lane side by side. This is also true, to a lesser extent, of a 4.6-m (15-ft) curb lane, which can be used in this way if severe congestion and capacity problems exist.
3. Older multilane roads in many areas are too narrow to permit the marking of 4- to 4.6-m (13- to 15-ft) wide curb lanes without narrowing other lanes to less than 3.4 m (11 ft). For example, many four-lane divided highways were constructed with two 3.7-m (12-ft) lanes and a 3.0-m (10-ft) parking lane for each half of the roadway, which resulted in two 10.4-m (34-ft) cross sections. As traffic volumes increased, many of these roads were posted with either full-time or part-time parking restrictions and the 3.0-m parking lanes became through lanes, which increased the roadway to six lanes. These 3.0-m lanes often have to be shared by a 2.4-m (8-ft) wide truck or bus and a 0.6-m (2-ft) wide bicycle and rider. This leaves no clearance between wide vehicles and bicyclists in the same lane. It is desirable, therefore, to mark the two left-most lanes 3.4 m (11 ft) wide and mark a 3.7-m right-most curb lane.
4. The standard width for high-volume and high-speed roads is 3.7 m/lane. In many instances, application of a wide curb lane requires a 0.3-m reduction in lane width, which is below the official standard of 3.7 m. A review of previous studies indicates, however, that this reduction in lane width should not adversely affect safety or capacity.

The Highway Capacity Manual (4, Figures 5 and 6) assumes a nearly linear relation between approach width and approach capacity in urban areas, where wide curb lanes are most applicable. Therefore, narrowing one lane and adding width to an adjacent lane for the same direction of flow should not affect the capacity of the approach. Other methods of calculating capacity take lane width into account, however, and would indicate slightly reduced capacity with 3.4-m (11-ft) lanes. But from a practical standpoint, the reduction is more than offset by the fact that the wide curb lanes effectively increase the radii of turns made by right-turning vehicles and thus enable drivers to negotiate turns with less delay and at a greater speed.

Studies conducted on accident rates versus lane widths tend to indicate either that accident rates are not related to lane width or that they decrease as lane width increases to 3.4-3.7 m (11-12 ft). For example, a study conducted by Dart and Mann on rural two-lane Louisiana roads (5, p. 9) concluded from a multiple linear regression of many geometric variables that the accident rate decreased significantly as lane width increased from 2.7 to 3.4 m (9-11 ft) but that the accident rate was slightly higher for 3.7-m (12-ft) than for 3.4-m lanes. Another study conducted by Gupta (6) indicated that, on two-lane urban streets with maximum average daily traffic of 12 000, lane width was unrelated to accident rate. A study by Mulinazzi (6) of 100 urban arterial highway sections in Indiana, which used multiple linear regression on many independent variables, showed that street width was also unrelated to the accident rate.

The results of these studies indicate that the narrowing of roadway lanes from 3.7 to 3.4 m would not adversely affect safety. It is not yet known, however,

Figure 1. Situation before and after wide-curb-lane treatment: approaching vehicle leaves lane and approaching vehicle stays in lane.

Figure 2. Clearance for bicyclists before and after wide-curb-lane treatment.

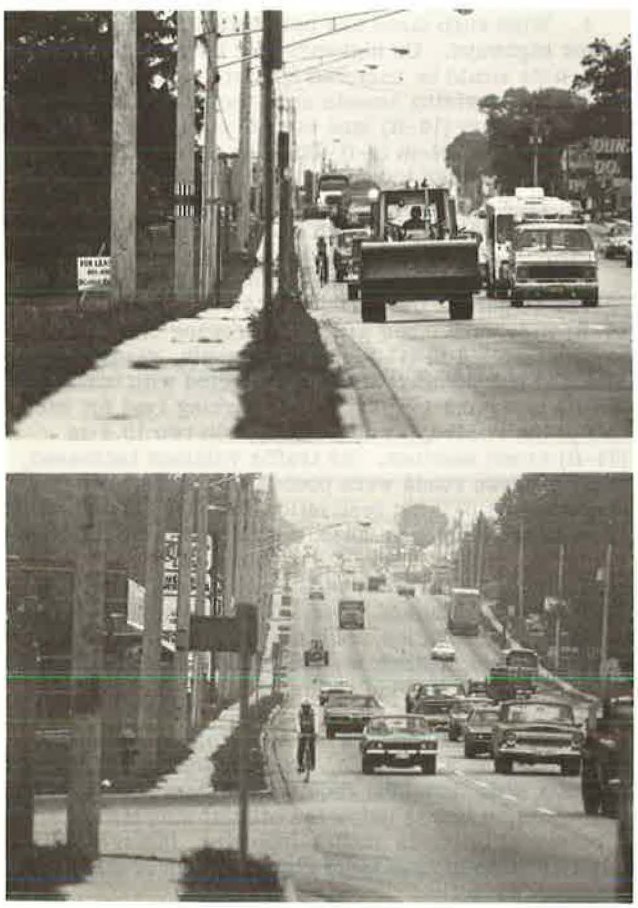
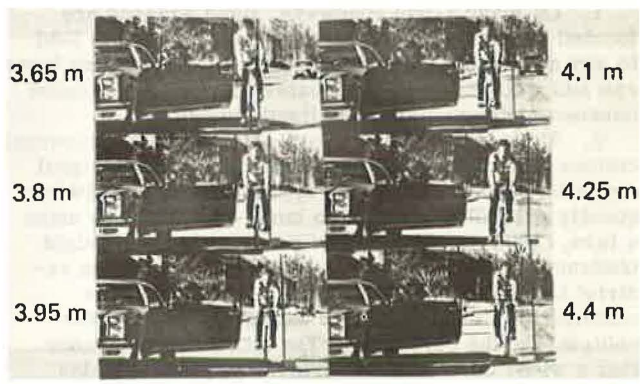


Figure 3. Examples of passing width for bicyclists when parking is permitted.



Note: 1 m = 3.28 ft.

Figure 4. Situation in which a wide curb lane can help bicyclists: avoiding a grate and an overtaking vehicle.

Figure 5. Shoulder before and after smooth-surface treatment.

whether wide curb lanes would increase safety for bicyclists. The wide curb lanes implemented in Baltimore County have not been in use long enough to permit a study of accident rates. Wide curb lanes could be expected to reduce rear-end accidents between motor vehicles and bicycles as well as other types of accidents, but this is currently only conjecture.

5. The best time to mark wide curb lanes on the roadway surface is just after new bituminous concrete is placed and before conventional lane-line configurations are marked. This is especially true when longer-life thermoplastic or tape lane markings will be used. Conventional paint with reflectorized beads has a considerably shorter service life, and it was found in this study that the old lane lines were sufficiently faded after 1-1.5 years that the laterally shifted lane lines resulting from the wide-curb-lane treatment could be applied. It was necessary, however, to repaint the new lines shortly after the first painting to ensure that the new lines would be more prominent than the older, faded lines. This is especially true on highly skid-resistant porous bituminous concrete resurfacing because more of the paint is absorbed into the pavement. The length of the new white skip lines could be increased to the same length as the old 4.6-m (15-ft) white skip lines until the old lines are sufficiently faded.

In most instances, the older lane lines were separated from the new lines by 0.3-0.6 m (1-2 ft). Because the tires of vehicles in the traffic stream were almost directly over the older lane lines, these lines were often almost completely faded one year after the wide-curb-lane treatment was applied. For this reason, grinding, sandblasting, or placing black paint over the older faded lines is probably not necessary.

6. The concept of wide curb lanes is not so well-suited for concrete pavements because the lane widths are predetermined by the dimensions of the concrete slabs. For wet-pavement conditions at night, the lane lines should coincide with the construction joint in the concrete as much as possible because the construction joint can be more visible to the driver than the lane markings. It is desirable, however, to mark lane lines on concrete surfaces to the left rather than the right of the construction joint, as is now done on concrete surfaces on Maryland highways. The original reason for this change was to increase the effective lane width on the right for larger vehicles, which are more likely to be in the right and slower-moving lanes.

Countermeasures for reducing different classes of accidents between bicycles and motor vehicles were listed in a recent study by Cross and Fisher (7). This study suggested that pavement-marking schemes to encourage drivers to drive farther to the left could decrease accidents in which the bicyclist suddenly swerves into a motor vehicle. Wide curb lanes could serve to reduce accidents of this type by enabling drivers to drive farther to the left and thus increasing the lateral distance between motor vehicles and bicyclists.

Cross and Fisher (7) list bicycle lanes as a possible countermeasure to reduce accidents that involve a motor vehicle overtaking a bicyclist but conclude that it is difficult to justify bicycle lanes from a cost standpoint. Wide curb lanes could serve to reduce overtaking accidents by increasing the lateral separation distance and at less cost. The cost is lower for wide curb lanes because the only thing involved on existing facilities is repainting of motor-vehicle lane lines. On new facilities, a meter or two of additional paving may have to be added, but the cost should still be less than that for bicycle lanes because there are no maintenance costs such as those for special bicycle-lane signing and marking.

It is possible that wide curb lanes could serve to reduce other classes of accidents between bicycles and motor vehicles. Further study is needed, however, to determine how effective wide curb lanes may be in reducing all types of accidents between bicycles and motor vehicles.

SHOULDER IMPROVEMENTS

On roadways without curbs, smooth shoulders are a definite benefit to bicyclists because they enable bicyclists to ride to the right, away from the motor-vehicle lanes (see Figure 5). For this reason, the bicycle should be considered as a design vehicle when plans are made to construct or resurface a shoulder. The design and construction of shoulders for bicyclists should not result in unfavorable benefit/cost ratios because shoulders, by decreasing the accident rate, also provide benefits to motorists (8).

Most bicyclists are reluctant to ride on rough bituminous concrete shoulders because the ride is uncomfortable and it requires more effort to pedal. One common type of rough shoulder surface that is unacceptable to most bicyclists is the double-surface-treated shoulder, which is formed by placing approximately 0.6 cm (0.25 in) of aggregate on top of a bituminous concrete base course with liquid asphalt, which partially cements the loose aggregate to the base. One advantage of this type of shoulder surface treatment is that the rough surface provides a visual and audible warning to motorists who stray onto the shoulder. A disadvantage is that bicyclists will usually choose to ride on the roadway surface, especially when they do not perceive a vehicle approaching from behind.

The Maryland Highway Administration has successfully applied slurry-seal treatment to bikeways on Maryland's Eastern Shore; these surfaces were in excellent condition after the 1976-1977 winter, one of the most severe winters in years. The advantage of slurry-seal treatment is that it is smooth enough for a comfortable bicycle ride yet rough enough to give an audible warning to motorists who stray from the roadway. Unfortunately, the sound and vibration in the motor vehicle are not as pronounced as those caused by the rougher double-surface treatment, but this is an engineering trade-off.

Slurry seal is a liquid asphalt emulsion with approximately 0.15 cm (0.06 in) aggregate that is applied on the shoulder. On the bicycle routes on the Eastern Shore, a 0.5-cm (0.2-in) layer of slurry seal was applied over a double-surface-treated shoulder. The resulting surface was more suitable for bicycle riding than the rougher double-surface-treated shoulder and yet provided both an audible and visual warning to motorists because the slurry is much darker and slightly rougher than most pavements. Some bicyclists, however, do ride on the smoother roadway surface rather than on the rougher slurry-seal surface.

The slurry-seal treatment is applied as a liquid, does not require rolling with heavy equipment, and is much thinner than most overlays, which lowers application costs. The texture of the final surface can be controlled by dragging burlap over the slurry seal before it has hardened. The dragging operation causes longitudinal striations to form on the surface; these striations produce an audible warning for motorists and a slightly rougher ride for bicyclists than the smoother roadway surface. A smoother surface can be produced by rolling the slurry-seal surface with heavy equipment, but this is not a necessary step in the application.

Another common type of shoulder surface treatment is continuing the roadway surface onto the shoulder. This treatment has been well received by bicyclists in Maryland. It has the disadvantage of not providing a visual or audible warning to motorists. But, since this has not precluded its use on freeways, where bicyclists are not permitted, it should have applications on other highways where bicyclists are permitted.

It is possible to pave shoulders with a bituminous concrete that is a different color than the roadway surface to provide a visual warning. However, in order to provide an audible warning, the shoulder usually has to have a rougher texture than the roadway surface. It is important to realize that any substantial increase in roughness will decrease the probability that a bicyclist will ride on the shoulder. This is true even if use of the shoulder is required of bicyclists under motor-vehicle law. For this reason, the shoulder surface should be substantially as smooth as the roadway surface if bicyclists are to be encouraged not to ride in the roadway.

One possible compromise suitable only for shoulders approximately 2.4 m (8 ft) wide or wider is to provide a smooth surface on the left for the first 1.2-1.5 m (4-5 ft) of the shoulder for bicycle riding. Then, on the rest of the shoulder to the right, an audible warning can be provided by using a rough surface for motorists who stray off the roadway.

On a wide shoulder, most bicyclists will choose to ride on the left portion of the shoulder near the roadway anyway. This occurs for many reasons, the most important being that the air currents generated by passing motor vehicles tend to sweep the left side of the shoulder free of debris such as stones, sand, soil, leaves, sticks, and trash. Much of the debris is swept from the left side to the right side of the shoulder, and this makes bicycle riding even more difficult or hazardous on the right.

Other conditions can cause the right side of the shoulder to be unsuitable for bicycle riding. These include a greater tendency for the right portion of the shoulder to deteriorate and break up, which can cause drainage problems with standing water or ice. Snow piles from plowing operations block the right side of the shoulder more frequently than the left. The right portion of the shoulder is often blocked by parked vehicles or by vegetation growing up through or hanging down onto the pavement.

The bicyclist who rides near the left edge of the shoulder is more visible to motorists who are exiting from side streets or driveways and also to drivers on the main highway who are turning left or right across the bicyclist's path.

The existence of at least a narrow strip of shoulder is an important factor for bicyclists because of their tendency to use the portion of the shoulder near the roadway edge. The AASHTO recommended minimum class 2 shoulder width is 1.1 m (3.5 ft) (6). Although this is certainly desirable, it is often not practical or economically feasible. It should be realized that any smooth surface shoulder is a definite benefit to bicyclists, even if the AASHTO minimum cannot be met, as a study of the lateral placement of bicyclists and motor vehicles (described later in this paper) has shown. Additional smooth-shoulder width on a narrow roadway enables bicyclists to ride away from the flow of motor-vehicle traffic, which reduces the risk of a rear-end accident and unacceptable wind forces from passing vehicles.

There are many conditions that preclude placement of continuous 1.1-m (3.5-ft) or wider shoulders. Some of these restrictions are limited right-of-way or slope easements, existing drainage ditches or structures, vegetation, poles, fire hydrants, slopes, or retaining walls. When roadways or shoulders are resurfaced or repaired, these adverse field conditions should not cause shoulder widening for the benefit of bicyclists to be dropped from consideration solely because the AASHTO minimum cannot be met. If the minimum cannot be met, the widened shoulders should not be signed as a class 2 route. Highways improved for bicyclists do not have to be signed as bicycle routes because the bicycle should be treated as a design vehicle in highway design and maintenance.

The study by Cross and Fisher (7) lists overtaking accidents on two-lane rural highways as a major cause of fatal accidents involving bicycles and motor vehicles. Smooth shoulders could be expected to reduce overtaking accidents by enabling bicyclists to ride out of the roadway. The fact that shoulders also reduce accidents for motor vehicles should help to justify shoulders from a cost standpoint. This, however, needs further study.

PARKING CHANGES

Parking on urban streets takes up space on the roadway that can be used by bicyclists. On-street parking is often necessary, but it can be controlled for the benefit of bicyclists by restricting the areas in which parking is allowed. A 32-city study made in 1965 (9) indicated that the parking-related accident rate decreases as street width increases and as parking is prohibited.

For the benefit of bicyclists, parking was prohibited on many roadway sections in Baltimore County that were not marked as bikeways. It was realized, however, that this is not possible in many locations, especially in front of single-family homes. Where parking could not be prohibited entirely, it was felt that prohibiting parking at intersections would improve the sight distance for both bicyclists and motor vehicles. Most residents who were prohibited from parking in front of their homes were able to accept these prohibitions because they lived on corner lots and could park around the corner. There was little need to prohibit parking along the entire frontage of both sides of a corner lot because only one side of a corner is on an approach to an intersection and there is more value in increasing the sight distance for the near side of an intersection than for the far side. In addition, most of the corner lots involved a collector street that intersected a minor street, and it was felt that there was less need to remove parking from the minor street.

Equations were developed to help in determining how far back from an intersection parking should be prohibited for both near-side and far-side situations (see Figure 6):

$$PD_{FS} = SD_{FS} [(2.4 \text{ m} + DE)/(DE + CL)] - FD \qquad (1)$$

Figure 6. Determining how far back from intersections parking should be prohibited to increase sight distance (Equations 1 and 2).

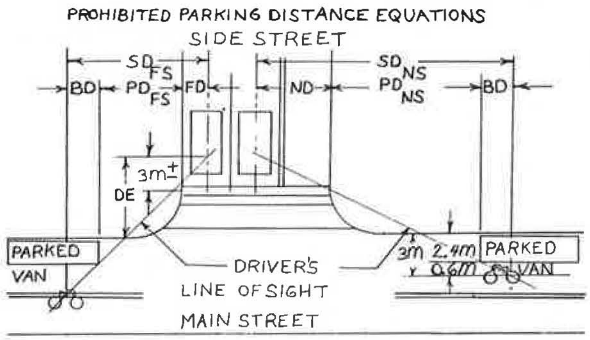
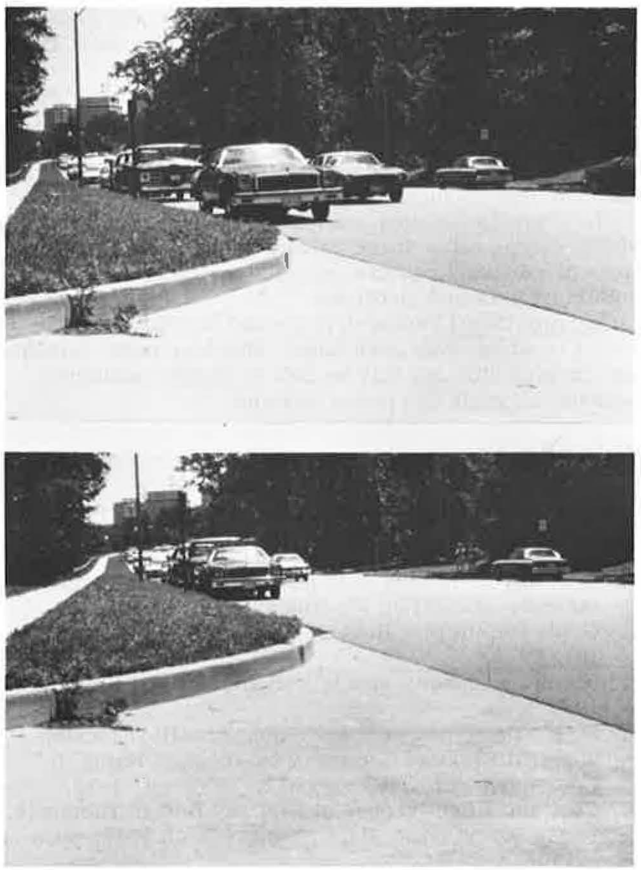


Figure 7. Situation before and after parking was prohibited farther back from intersection: limited sight distance and increased sight distance.



$$PD_{NS} = SD_{NS}\ [(2.4\ \text{m} + DE)/(3.0\ \text{m} + DE)] - ND \qquad (2)$$

where

- PD_{FS} = far-side prohibited parking distance,
- PD_{NS} = near-side prohibited parking distance,
- SD_{FS} = far-side bicycle-design-speed stopping distance,
- SD_{NS} = near-side bicycle-design-speed stopping distance
- DE = driver's eye distance from curb,
- CL = centerline distance to curb,
- FD = far-side distance,
- ND = near-side distance, and
- BD = behind-vehicle distance.

To determine how much of the view would be obstructed by a parked vehicle, a worst case was assumed: a van—which obstructs vision more than an automobile or a small truck—parked so that the left edge of the van is 2.4 m (8 ft) from the curb. It was also assumed for the worst probable case that a bicyclist would be separated from the van by 0.3 m (1 ft) of clearance. The design bicycle and rider are 0.6 m (2 ft) wide so that the center, or eyes, of the bicyclist would be 0.6 m from the van and 3 m (10 ft) from the curb. The prohibited parking distance from the intersection is then a function of stopping sight distance, which is based on AASHTO criteria for bicycle-design-speed sight distance.

Corrections would have to be made if there were a curve in the main-street section of roadway, if the cross street did not enter the main street at a right angle, or if an obstruction existed in the line of sight between the bicyclist's eye and the driver's eye. If wrong-way bicycle riding is a problem, it might be advisable to prohibit parking on the far side of the intersection as much as on the near side.

The study by Cross and Fisher (7) lists parallel parking as a contributing cause of accidents when a bicyclist rides out of a driveway into the path of a motor vehicle. Total removal of parking is usually not possible, but selective removal of parking at high-bicycle-volume driveways and public streets could serve to reduce accidents when motorists and bicyclists pull out in front of each other. The degree to which accidents could be reduced by selective removal of parking requires more study.

Angle parking, which is more hazardous than parallel parking, was removed from two streets in Baltimore County (9, Ch. 10, p. 10). The added width available for bicyclists was used as a warrant to remove angle parking (see Figure 7). The vision of a driver exiting from an angle parking space is obscured, and the view of a bicyclist can be obscured completely. Cross and Fisher (7) list the removal of parallel parking in favor of angle parking as a way of reducing accidents that involve a bicyclist riding out of a driveway into the path of a motor vehicle. It is possible that any reduction in this class of accidents would be more than offset by an increase in accidents that involve motorists backing out of angle spaces into bicyclists. This, however, should be studied further.

LATERAL PLACEMENT OF MOTOR VEHICLES IN RELATION TO BICYCLISTS

To determine the lateral placement of motor vehicles when they pass bicyclists, photographs were taken of a single bicyclist riding with traffic as motor vehicles passed him (because of the time that would have been required to photograph a statistically valid number of unwitting bicyclists, and since I am myself an experienced bicyclist, I was the bicyclist photographed). This experiment was conducted in a curb lane nominally 3.7 m (12.25 ft) wide, in a curb lane nominally 4.3 m (14.25 ft) wide, and on a shoulder nominally 0.8-1.1 m (2.5-3.5 ft) wide. The lateral placement of motor vehicles without the presence of a bicyclist was also photographed for the control part of the experiment.

The location of the bicycle on the road surface was approximately the same in all instances because chalk marks were placed on the pavement at closely spaced intervals. The chalk marks were placed approximately 0.7 m (2.25 ft) from the curb because the storm-drain grates on the roadway were nominally 0.6 m (2 ft) wide.

The two curb-and-gutter study sections used (the same ones described previously in the discussion of the advantages of wide curb lanes) were on York Road (MD-45), a five-lane urban arterial in Timonium, Maryland. Both sections are almost identical geometrically except that one section opposite the Maryland State Fair Grounds is marked with 4.3-m (14.25-ft) curb lanes and the other section, approximately 1.6 km (1 mile) to the south, is marked with 3.7-m (12.25-ft) curb lanes. These locations provided a unique opportunity to study the operating characteristics of the two different lane widths without the influence of other factors. To reduce the influence of turning movements caused by almost continuous commercial strip development, the study sections were selected to have the fewest commercial driveways, and the morning peak hours of 7:15-9:15 a.m. were used.

As the shadow cast by the bicyclist became even with the shadow cast by the passing vehicle, an inconspicuous photographer took a picture using a 300-mm telephoto lens and camera on a tripod. The photographs used for the data reduction were black-and-white negatives or color slides, which were projected onto a screen. Measurements were taken from the photographs of license plates, lane width, and bicycle height and were compared with field measurements.

From accuracy calculations and sample variance, it was determined that sample sizes of about 30 were needed to obtain a 95 percent confidence limit. A sample size of at least 40 was obtained for all six experimental conditions, however.

The findings were as follows:

1. The average lateral clearance between the bicyclist and motor vehicles was 1.5 m (5.0 ft) in the 3.7-m (12.25-ft) lane and 1.61 m (5.3 ft) in the 4.3-m (14.25-ft) lane, which is not a statistically significant difference. The variance of the data for the 3.7-m lane was 0.54 m (1.79 ft) compared with a variance of 0.44 m (1.47 ft) for the 4.3-m lane. The higher variance is explained by the tendency of motorists in the narrower lane to either travel closer to the bicyclist in the lane or to avoid the bicyclist completely by crossing far over into the adjacent lane. Both of these tendencies are undesirable for bicyclists because the closer-moving vehicles increase the risk of a collision and vehicles that are partially in the adjacent lane cause conflicts and interruptions in the traffic flow.
2. When no bicycle was present, the mean motor-vehicle placement was 1.25 m (4.1 ft) from the face of the curb in the narrower lane and 1.61 m (5.3 ft) in the wider lane. The difference in the means was 0.36 m (1.2 ft), which is approximately equal to 0.3 m (1 ft), the difference between the centerline locations of the two lanes. The increased displacement from the curb in the 4.3-m lane could benefit bicyclists because, presumably, the greatest danger posed to bicyclists by overtaking vehicles is the motorist who is unable to see or avoid them. The increased vehicle distance from the curb should therefore be a benefit to bicyclists.

A study of lateral placement was also conducted on Wilkens Avenue (MD-372), a two-way, two-lane road that is nominally 6.4 m (21 ft) wide and has shoulders that vary in width from 0.8 to 1.1 m (2.5-3.5 ft). The data indicated that the mean lateral clearance of vehicles from the edge line was 0.53 m (1.7 ft) when no bicyclist was present and 1.34 m (4.4 ft) when a bicyclist was present. The bicyclist maintained approximately the same position off the edge line—0.6 m (2 ft)—even though the shoulder width varied.

The results indicated that, even though the shoulder width was substandard for a class 2 bikeway, acceptable lateral clearances could be maintained between the bicyclist and the motor vehicle. When the bicyclist was not present, none of the vehicles observed encroached on space over the shoulder that the bicyclist would have occupied.

CONCLUSIONS

1. On-road improvements should be implemented for bicyclists where no alternate bikeways exist, and roads improved for bicyclists do not need to be marked as bicycle routes.
2. The bicycle should be considered as a design vehicle in highway design and maintenance.
3. By providing additional space between bicyclists and motor vehicles, wide curb lanes can be a benefit to bicyclists on many urban arterials and collectors when other bikeway facilities are not available.
4. Wide curb lanes can be marked on many lower-speed curb-and-gutter arterials without adversely affecting motor-vehicle safety or capacity.
5. Smooth-shoulder improvements can be a benefit to bicyclists even if minimum standards for a class 2 bikeway are not met.
6. Smooth shoulders should be considered on roads that are used by bicyclists.
7. Parking changes can benefit bicyclists by providing more usable space on streets. Parking restrictions at intersections can increase sight distance for both bicyclists and motorists.
8. Additional research is needed to determine the extent to which wide curb lanes, shoulder improvements, and parking changes may be able to reduce accidents between bicycles and motor vehicles.

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Evaluation of Techniques for Warning of Slow-Moving Vehicles Ahead

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This paper reports on an experiment undertaken to examine the relative effectiveness of roadside signs and vehicle markings for warning motorists about a slow-moving vehicle on the road ahead in a rural two-lane situation. In the experiment, a staged slow-moving vehicle was introduced into the traffic stream and data were taken on the reactions of motorists who overtook it. Samples of motorists were exposed to different combinations of roadside signs, vehicle markings, and types of slow-moving vehicles. The principal finding was that the use of standard four-way flashers is an effective device for reducing the hazards of the overtaking situation relative to reaction distance, speed reduction, and following characteristics. Although the effects of the roadside warning signs were positive in the vicinity of the sign placement (the slow vehicle could not be seen), there were no lasting effects relative to the actual overtaking maneuver.

In 1976, the National Safety Council (1) reported that 26 percent of all rural nonintersection accidents that involved two vehicles occurred when both vehicles were traveling in the same direction. Past research (2-4) indicates that one of the principal causes of such accidents was the differential in speed between the two vehicles involved and that the probability of a higher speed differential increased if one of the two vehicles was a truck (or other slow-moving vehicle) on a moderate or steep upgrade.

During 1977 and 1978, an experiment was undertaken at the Federal Highway Administration's (FHWA's) Maine facility in Pittsfield to evaluate several vehicle-mounted and roadside warning devices relative to their effectiveness in minimizing the accident potential when a slow-moving vehicle is overtaken by a faster one on a moderate upgrade in a rural two-lane situation.

THE EXPERIMENTAL SITUATION

The site for the experiment was a section of US-2 that was 1830 m (6000 ft) long and located between Canaan and Palmyra, Maine (Figure 1). The section includes about 1520 m (5000 ft) of grade varying between 3 and 7 percent. This section of road is part of a 24-km (15-mile) length between Canaan and Newport, Maine, which can be instrumented via use of embedded induction loops in the road at 61-m (200-ft) intervals. The loops are connected to a Raytheon 500 computer housed in the Maine facility building (5-7), which is located near the midpoint of the road test section.

The instrumentation allowed the computer to identify a subject vehicle at point B (Figure 1) and track it over this instrumented section as it overtook, and possibly passed, a slow-moving vehicle. To ensure that encounters with slow-moving vehicles were consistent with one another, a staged vehicle was inserted at point A and traveled upgrade at a fixed speed. The procedure is best illustrated by the sequence of events for a run outlined as follows:

1. The staged vehicle was at the ready on the side road at point A.
2. The computer identified the next vehicle (subject vehicle) entering the experimental section at point B and satisfying these criteria: (a) there were no other vehicles between the subject vehicle and point A and (b) the subject vehicle was moving at least 24 km/h (15 mph) faster than the staged vehicle's assigned running speed (this was to ensure that the actual overtaking occurred in zone D).
3. The computer gave the driver a go signal.
4. The driver pulled out onto the road, accelerated to the assigned running speed, and maintained that speed through the remainder of the instrumented section.
5. The computer tracked both the subject and staged vehicles relative to their positions on the grade and speeds at any point.
6. After the staged vehicle reached point E, the driver pulled off, returned to point A, and signaled the computer that he was ready to go again.

During the course of a run, the driver of the subject vehicle saw a specific sign condition at the roadside (relative to slow-moving vehicles) and then encountered a specific staged vehicle with specific markings. All data relative to the subject-vehicle driver's responses were recorded automatically on magnetic tape for later processing. Raw data were in the form of time intercepts of the embedded loops. They were later processed to reflect vehicle speeds, vehicle headways, and so forth.

INDEPENDENT AND TESTED VARIABLES

Although the principal independent variables examined in this experiment were those related to vehicle markings and roadside signs, several others were also considered and are discussed here.

Roadside Signs

One of the variables of primary interest concerned roadside signs. The basic hypothesis was that provision of a warning sign that conveyed information to the motorist about the possibility of encountering a slow-moving vehicle ahead would result in a less hazardous situation when such a slow-moving vehicle was actually sighted and overtaken.

The roadside signs that were actually deployed are illustrated in Figure 2. Briefly, the first condition was a base (i.e., no sign was deployed) that provided information regarding what motorists' reactions were when no signs were present. The second was a warning sign that read, SLOW-MOVING VEHICLES AHEAD. The message was nonstandard, straightforward, and unambiguous. The urgency of the information conveyed to motorists was typical of other warning signs.

The next sign condition had the same message but was made more emphatic by the addition of continuously flashing beacons mounted above the sign. It was hypothesized that the motorist who saw this sign received more positive (and urgent) information. The last sign condition conveyed the most positive information because the addition of the WHEN FLASHING plaque to the

Figure 1. Plan and profile of slow-moving vehicles experiment.

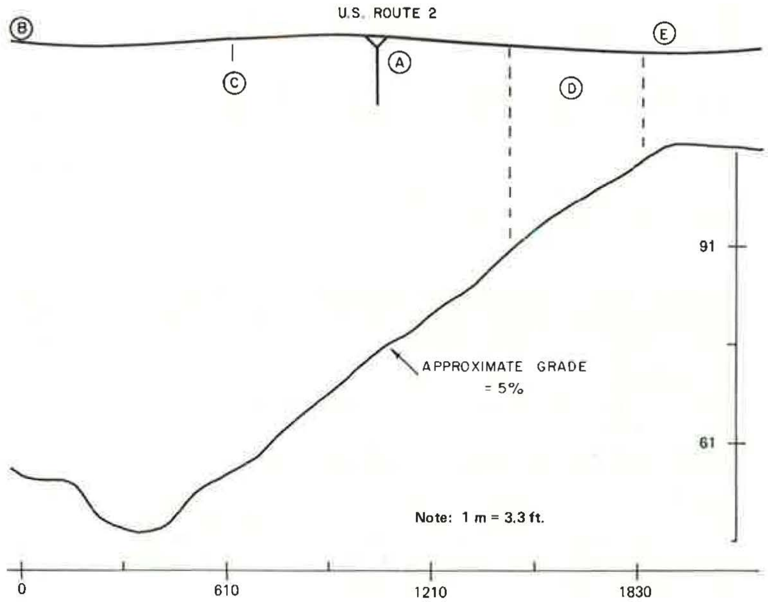
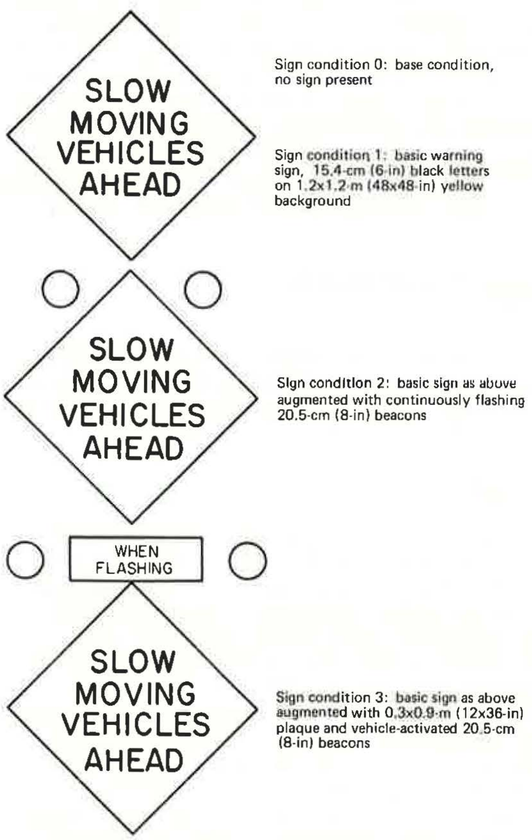


Figure 2. Roadside sign conditions.



basic sign informs the motorist with virtual certainty that he or she will encounter a slow-moving vehicle. The beacons in this condition were activated by the subject vehicle's crossing of an embedded loop. Thus, the driver of the subject vehicle actually saw the beacons begin to flash.

The four sign conditions represented a base and sequentially more positive information relative to the condition to be encountered on the road ahead.

Vehicle Markings

The other key variable concerned the warning conveyed by on-board vehicle markings. The markings differed according to the type of vehicle that was used as the staged vehicle. When the single-unit truck was used, the marking conditions were simply that the truck's standard four-way flashers were or were not activated. The consideration of using standard flashers as a warning device on slow-moving trucks should help to resolve some of the disagreement among the states (and regulatory agencies) about whether such use of flashers should be recommended (8, 9).

Three conditions were defined when the tractor was the staged vehicle, including no symbol, U.S. standard, and a modified New Zealand standard (Figure 3). This was similar to the truck-marking sequence because the modified New Zealand standard differs primarily in the addition of flashers.

Slow-Moving Vehicle Type

Two types of slow-moving vehicles were used in the experiment. The first type was a truck that, when typically encountered on a road, is sometimes but not always slow moving. The second type was a farm-utility tractor, which is always slow moving. The question is, Is this differentiation apparent in motorists' reactions to the vehicles?

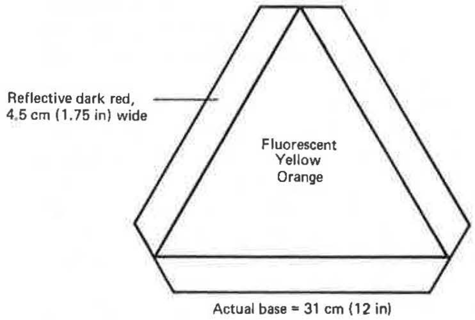
Slow-Moving Vehicle Speed

When the truck was used as the slow-moving vehicle, it was operated at two different speeds—32 and 48 km/h (20 and 30 mph). This was to determine if the effectiveness of the devices was consistent at different vehicle speeds. The tractor was operated at only 24 km/h (15 mph), a limitation imposed by the characteristics of the vehicle.

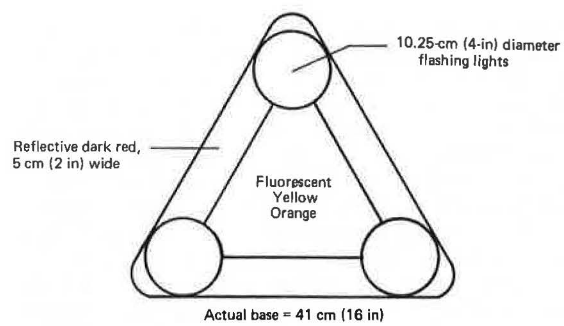
Ambient Light

The experimental situation was limited to two principal categories—day and night. In order to make this distinction as unambiguous as possible, data were not collected during dawn or dusk hours.

Figure 3. Vehicle marking conditions (tractor).



U.S. Standard Symbol
Vehicle Condition # 1



Modified New Zealand Symbol
Vehicle Condition # 2

Other Variables

Several other independent variables were considered. These included the initial speed of the subject vehicle, type of subject vehicle, weather and pavement conditions, and driver familiarity with the test situation.

The speed of the subject vehicle was disregarded other than as an initial condition of acceptance, that is, a subject vehicle had to be moving at least 24 km/h (15 mph) faster than the staged vehicle, under the assumption that all combinations of test conditions would have similar distributions of fast and slow drivers.

Weather was a controlled variable to the extent that only data collected under dry road conditions and good visibility were used. The night phase of the experiment gave a reasonable approximation of driver reaction under less-than-optimal visibility.

A stratification had been intended for those subject vehicles that passed the staged vehicle and those that did not. After data collection began, it was found that this stratification was meaningful only when the tractor was the slow-moving vehicle (not enough vehicles passed the truck). Therefore, most of the results are based on vehicles that did not pass.

Because of the difficulty of obtaining adequate numbers of nonpassenger vehicles in the samples, only passenger cars (and pickup trucks) were considered as subject vehicles (e.g., heavier trucks and recreational vehicles were excluded). The issue of driver familiarity with the site is discussed later in this paper. However, no distinction was made between familiar and unfamiliar drivers in the data-collection process.

DEPENDENT (RESPONSE) VARIABLES

Data were collected under the various combinations of independent variables—for example, roadside sign condition 1; vehicle marking 2; truck, 32 km/h (20 mph); and day—until the appropriate cells (variable combinations) were filled in order to undertake statistical testing.

As described, each subject vehicle was tracked from the time it entered the instrumented section to the time it left. During this period, the time interceptions of the sensing devices were recorded for the subject vehicle. This information was then processed on site to produce values for a variety of dependent, or driver response, variables.

Originally, data on 16 variables were produced. These included subject vehicle speed as it entered the system, speed reductions at various points, distance (headway) between the staged and subject vehicles, and passing characteristics. In addition, an attempt was made to directly consider the effects of a vehicle's entry speed by normalizing the basic variables by the entry speed.

The set of variables is divided into two groups—early grade and overtaking. Early grade variables are those that relate to a subject vehicle's behavior before the slow-moving vehicle was sighted. Overtaking variables are those that are relevant after the slow vehicle could be seen by the driver of the subject vehicle.

ANALYSIS AND RESULTS

The experiment design that has been described to this point is a multifactor design that theoretically results in 4(roadside sign conditions) × 2(vehicle markings) × 2(slow-moving vehicle speed) × 2(ambient light), or 32 cells with the truck as slow-moving vehicle. Similarly, considering the tractor, the analogous design consists of 48 cells (4 roadside sign conditions × 3 vehicle-marking conditions × 2 light conditions × 2 passing conditions). As will be noted, several cells were eliminated from the tractor design due to lack of data.

The analysis that took place had three levels: (a) consideration of basic descriptive statistics (for all variables on all cells), (b) one-way analyses of variances (ANOVAs) with several independent variables held constant and a series of multiple comparisons (contrasts), and (c) higher-order ANOVAs.

Overall Results

The general results are summarized in Tables 1 and 2. The major finding of the research was that the use of four-way flashers on a slow-moving vehicle has a significant positive effect on overtaking vehicles in terms of initial reaction distance, closing rate, and minimum following headway. The effect of the roadside signs was limited to an initial effect in the vicinity of the sign placement. After visual contact was made with the slow-moving vehicle and the actual overtaking maneuver was commenced, there appeared to be little, if any, carryover effect due to the signs.

Note that no results are shown for the "truck, 48 km/h (30 mph), night" or "tractor, night" categories in Tables 1 and 2. This is due to the fact that the night phase had to be curtailed because of a time restraint.

The following discussion is based on the first two levels of analysis: consideration of the descriptive statistics and one-way ANOVAs with appropriate multiple comparisons. The results stated were consistent for these two levels. The results of the third level of analysis (higher-order ANOVAs) were inconsequential. Several of the key two-way ANOVAs were

Table 1. Summary of four-way flasher effects.

Variable	Day Truck (32 km/h)	Day Truck (48 km/h)	Day Tractor	Night Truck (32 km/h)
Early grade				
Entry speed	No	No	No	No
Early grade speed	No	No	No	No
Initial speed reduction	No	No	No	No
Overtaking				
Reaction distance	Yes	M	No	Yes
Maximum speed reduction	Yes	No	No	Yes
Minimum headway	Yes	Yes	M	M
Time to collision	Yes	Yes	M	M

Notes: 1 km = 0.6 mile.
Comparisons were made (for all four sign conditions) between flasher and nonflasher effects.
Yes = Flashers generally had a significant positive effect.
M = Flashers generally had a marginally significant positive effect.
No = Flashers generally had no effect.

Table 2. Summary of roadside sign effects.

Variable	Day Truck (32 km/h)	Day Truck (48 km/h)	Day Tractor	Night Truck (32 km/h)
Early grade				
Entry speed	No	No	No	No
Early grade speed	Yes	Yes	Yes	Yes
Initial speed reduction	Yes	Yes	Yes	Yes
Overtaking				
Reaction distance	M	No	No	M
Maximum speed reduction	No	No	M	No
Minimum headway	No	M	No	No
Time to collision	No	No	M	No

Notes: 1 km = 0.6 mile.
Each variable was reviewed for the range of signs, and general trends were noted.
Yes = Signs generally had a positive effect on driver behavior.
M = Sign effect was mixed—no effect in some instances and a positive effect in others.
No = Sign effects appear to be negligible.

undertaken to examine the interaction between vehicle markings and roadside signs. However, the latter analysis showed no definable trend. When actual values are given in the following report of results on a variable-by-variable basis, it should be noted that the differences are statistically valid at the 0.05 level.

Early Grade Variables

Entry Speed

The average entry speeds of the subject vehicles in the cells provide the basis for a test to determine if each sample of vehicles was similar (i.e., same entry speed for all cells). Examination of the values obtained indicated that there were no significant differences among the samples other than the somewhat lower speeds in evidence at night—about 3 km/h (2 mph)—relative to those during the day and the difference between the samples obtained for the two truck speeds. The first result is typical of the difference between day and night average speeds in general. The latter result is explained by the selection rule for subject vehicles—that is, the initial speed must be equal to or greater than the slow vehicle's speed plus 24 km/h (15 mph)—which tends to eliminate some slower vehicles from the sample selected when the slow-vehicle speed was 48 km/h (30 mph). Typical entry speeds were somewhat in excess of 80 km/h (50 mph). These differences notwithstanding, the comparison of entry speeds showed that the samples were similar.

Early Grade Speed

If a slow-moving vehicle used four-way flashers is not relevant in this instance because the vehicle was not in sight when this variable was measured. Any differences among the samples due to the use of four-way flashers would have been cause for concern. However, no differences were noted.

Although the slow vehicle was not in sight when this variable was calculated, the signs were. The effect of increasing the amount of positive information conveyed by a sign was detectable and the lighted signs had the most effect. For example, when truck speed was 32 km/h (20 mph) during the day, the vehicle-activated sign resulted in early grade speeds of about 77 km/h (48 mph) or roughly 5 km/h (3 mph) less than the base condition. These results were typical of both the day and night phases, regardless of the type of slow-moving vehicle.

Initial Speed Reduction

The results from the consideration of the initial speed reductions are consistent with those for the early grade speeds. That is, the lighted signs resulted in a significant speed reduction relative to the base roadside sign condition. The unlighted sign did not prove to be any more effective than no sign. In fact, the motorists who saw no roadside sign (the base condition) or the basic warning sign tended to show a slight increase in speed. The increase may be due to the attempt to gain speed for the grade ahead, which indicates that the basic message had no immediate effect. These results are consistent for both ambient light conditions and vehicle types. Typical values for the initial speed reductions [truck speed = 32 km/h (20 mph), day] are a decrease of 1-2 km/h ($^2/_3$-$1^1/_4$ mph) for the vehicle-activated sign versus an increase of about 1.6 km/h (1 mph) for the base condition or the basic warning sign.

Overtaking Variables

Tractor Versus Truck as Slow-Moving Vehicle

The aforementioned results for the early grade variables were basically consistent regardless of slow-moving vehicle type. Reiterating an earlier statement, the slow-moving vehicle type should make no difference because it was not in sight when the early grade variables were calculated. The remaining variables to be discussed are concerned with the actual overtaking maneuver. The discussion is based primarily on data when the truck was the slow-moving vehicle. When the tractor was used, there were no readily discernible trends in the results. Although the slow-moving vehicle symbol that was augmented with flashers (modified New Zealand) was marginally more effective than the U.S. standard symbol, the differences were not statistically significant. Thus, the following is based on truck data. For all truck data, no passing vehicles were included in the samples.

Reaction Distance

Reaction distance is a measure of how far back (from the slow-moving vehicle) a 10 percent reduction from early grade speed actually occurred. Subject vehicles that overtook slow vehicles—trucks traveling at 32 km/h (20 mph) during the day—without four-way flashers had typical values for a reaction distance of 122-152 m (400-500 ft). When the slow vehicle was displaying four-way flashers, the reaction distance generally increased between 46 and 61 m (150 and 200 ft). Values at night ranged somewhat higher; the use of flashers increased the reaction distance to 198-229 m (650-750 ft).

Maximum Speed Reduction

In general, a lower maximum speed reduction is a positive effect; this indicates that the velocity profile of the overtaking (subject) vehicle is less abrupt (i.e., potential for panic braking decreases). Considering the sign effects, there was no recognizable trend of increasing or decreasing values. Thus, the sign effects appear negligible. However, when the subject vehicles were overtaking slow vehicles displaying four-way flashers, the maximum speed reductions were typically 15-20 percent lower than when they were overtaking slow vehicles with no display—for example, there was a reduction of 8.3 km/h (5.2 mph) versus 10.1 km/h (6.3 mph). These results were fairly consistent for different slow-moving vehicle speeds and for both day and night.

Minimum Headway

The minimum headway (between the subject vehicle and the slow vehicle) attained can be compared directly to such rules of thumb as one car length per 16 km/h (10 mph), the safe following headway, or the 2-s rule. In this experiment, headways of less-than-safe following distance were generally observed. However, in several instances, when the slow-moving vehicle was displaying four-way flashers, the rule was satisfied. When the truck was moving at 32 km/h (20 mph), the activated four-way flashers resulted in headways that were typically more than 4.6 m (15 ft). When the four-way flashers were not in use, values were about 6.7-8.2 m (22-27 ft). When they were in use, values ranged from 9.8 to 12.2 m (32 to 40 ft). For a truck speed of 48 km/h (30 mph), the results were similar. It should also be noted that there appeared to be a possible residual effect due to the roadside sign in the 48-km/h truck speed category. This effect could not be verified with additional analysis.

Minimum Time to Collision

Typical results showed that times to collision averaged 6.8 s when four-way flashers were not in use. Use of the flashers resulted in an average increase of about 35 percent to approximately 9.2 s. These results were similar for both truck speeds and at night.

Comparison of Passing and Nonpassing Vehicles

When the slow-moving vehicle was the truck, insufficient data were collected for any comparison at all. However, when the tractor was the slow-moving vehicle, there were a fair number of passing vehicles. Although there were not enough passing vehicles for significant testing, several trends did emerge. Subject vehicles that eventually passed the tractor generally entered the test zone at a higher speed, slowed less in the vicinity of the signs, and generally traveled through the zone more rapidly than their nonpassing counterparts.

CONCLUSION

One assumption in the experiment that deserves further comment concerns familiar (i.e., repeat) and unfamiliar drivers. It would seem reasonable to expect drivers who went through the test area several times to react to the test situation differently from those who encountered it only once. Most daytime data were collected during periods (summer) when the traffic mix on US-2 included out-of-state travelers (up to 50 percent) who could be considered unfamiliar with the area and who would have unbiased reactions. Likewise, many of the in-state drivers during this same period were probably only occasional users of the road. Thus, it is argued that the effects of familiar drivers were minimal for the daytime data. Furthermore, because the results of the night phase were quite similar to those of the day phase, it can be concluded that the effects of familiar drivers were minimal. The effects of familiar drivers notwithstanding, the results of the experiment may be summarized as follows:

1. Activation of four-way flashers on slow-moving trucks is an effective device for reducing the accident potential when such vehicles are overtaken by faster-moving vehicles. Measures of effectiveness included variables that describe the overtaking maneuver (e.g., minimum headway).
2. The four-way flashers are as effective during the day as they are at night.
3. In terms of the variables measured in this experiment, the roadside signs are relatively ineffective as warning devices for the overtaking situation. That is, motorists who saw the signs that caused immediate reaction did not generally behave any differently at the point of overtaking from those who saw no sign.
4. Roadside signs may serve to alert the driver of a potential situation (e.g., there is a difference in early grade speeds); however, no consistently positive effects were noted at the point of overtaking.
5. When the roadside signs are effective, those that are more emphatic (i.e., the lighted ones) are generally more effective.
6. There is some evidence of an interactive effect between the more effective roadside signs and the use of four-way flashers, but it is not statistically significant.
7. Reactions to the different warning devices on the tractor are inconclusive. The modified New Zealand symbol was often slightly more effective than the standard U.S. symbol, although the differences were not statistically significant. It may be that the impact of the odd vehicle on the road masks any difference in effect between vehicle markings.
8. Drivers who tended to enter the instrumented section at higher speeds also tended to respond less to the roadside signs, maintain a higher rate of speed through the section, and pass the slow-moving vehicle.

These results demonstrate the need for reconsidering state and federal standards that preclude the use of four-way flashers on slow-moving vehicles. Such use has been shown to be effective relative to reducing the accident potential of overtaking maneuvers. Roadside warning signs, on the other hand, were shown to be ineffective in the situation examined in this experiment.

The use of four-way flashers for slow-moving vehicles constitutes a cost-effective and easily implementable safety device because they are already standard equipment on recent-model vehicles.

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