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Human Factors and Motorist Information Needs

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Effectiveness of Written Tests of Drivers' Knowledge of Rules of the Road

C. B. STOKE

The results of an experimental evaluation of several alternative approaches to testing drivers' knowledge of rules of the road are presented. Members of the Virginia population of drivers applying for license renewal were randomly assigned to four study groups. The subsequent driving performance of members of the four groups was monitored, and data on accidents, convictions for major and minor offenses, accidents with associated convictions, and administrative actions taken under provisions of the Virginia Driver Improvement Program were tabulated at 6-, 12-, 18-, and 24-month intervals. Of the few statistically significant differences found between the study groups, none demonstrated that knowledge testing is an effective means of promoting highway safety. Most of the differences observed involved the group who had refused to take the test at home. Except for the minor-conviction entries for this group, no comparisons showed differences across all four time periods. The overall results of the study produced no substantial evidence that knowledge testing should be required of the general license-renewal population.

The U.S. Department of Transportation's Highway Safety Program Standard 5, Driver Licensing, mandates that each state have a program requiring "each driver to be reexamined at an interval not to exceed four years, for ... knowledge of rules of the road" (1, p. A-2). However, because there has been a lack of definitive evidence in the research literature that compliance with the standard would benefit driving safety, officials of the state of Virginia took exception to the requirement for periodic written knowledge testing and requested a waiver of this provision of the standard. The waiver was granted on the condition that the state would conduct the study described in this paper.

The testing of individuals who desire to obtain a license to operate a motor vehicle has been a standard practice in Virginia for more than 40 years. The current procedure requires the applicant for an initial license to pass a battery of tests that include (a) a knowledge test of traffic laws, signs, and signals; (b) a visual screening test; and (c) a vehicle operation and performance test. On the basis of their driving records, some applicants for license renewal are also required to be tested on knowledge and/or vehicle operation. These applicants, as well as all other renewal applicants, are given a vision test in compliance with a state statute that deals with vision requirements.

Under the 1974 Virginia Driver Improvement Act, the state conducts reexaminations on rules of the road when a person demonstrates, under the point system, that he or she does not drive safely. This practice allows the state to concentrate its resources on drivers who show that they need improvement rather than scattering its resources attempting to improve everyone.

It has not yet been thoroughly demonstrated that an increase in driver knowledge results in a decrease in traffic accidents or convictions for violating traffic laws. Among the studies reported in the literature that deal with the knowledge and performance issue, a study by Pursewell (2) concluded in part that relations between written or machine test procedures and subsequent driving records are inconclusive. Levonian, Case, and Gregory (3) studied traffic accidents and violations in relation to a number of variables. The results of their study did not show a correlation between knowledge score and recorded accidents, but they did find that the person who scores low in knowledge tests is likely to have more recorded violations than a person who scores high.

The California Department of Motor Vehicles (DMV) has initiated a number of projects in the general area of license testing and subsequent driving performance. One of these studies, begun in April 1972, was authorized by the 1971 California Senate Concurrent Resolution 104. The experimental program studied the beneficial effects of an automatic license extension for individuals with clean accident and conviction records as well as an incentive procedure to encourage drivers who have prior accident and conviction entries to avoid additions to their records. According to a report by the California DMV (4, p. 12), for drivers with clean records, the reward program had no effect on subsequent convictions but did have various negative effects on subsequent collisions. It was concluded that the "good-driver" population is not a viable target for such a program as it was implemented in this case. For drivers with prior accident and conviction entries, the incentive program had no reliable effect on subsequent convictions but did have various positive effects on subsequent collisions. The reduction in subsequent collisions among drivers with prior entries was felt to have important implications for the design of future driver improvement programs.

A 1977 California study (5) found that traffic-safety materials were not effective in reducing six-month accident and conviction frequencies of the general driving population. It was also found that tailoring the material for specific groups by age and sex had no effect on the participants' driving records.

The California DMV also conducted a study (6) in which renewal applicants were mailed a pamphlet on driving principles, a set of questions, and an answer sheet. It was concluded that there was no significant difference in the subsequent six-month driving records of the control and treatment groups. The study also found that for various subgroups the effects of the new program tended to increase accidents and convictions. It was recommended that the new at-home tests not be implemented (8).

California drivers who apply to renew their operator's license are required to pass a test of traffic-law knowledge before a renewal license is issued. A study was carried out to determine whether renewal applicants who were administered a test that stressed knowledge of the principles of safe driving and recent changes in traffic laws had better subsequent driving records than applicants who were administered the standard California DMV test on traffic law. In his report on that study, Carpenter (7) concluded that the written test on driving safety did not result in a change in collisions or convictions in the six-month period after testing and that the new form should not be used as a replacement for the standard test on traffic law given to license-renewal applicants.

The California DMV also conducted a study in which the test of safe-driving principles was administered to renewal applicants who had a moderate number of collisions and convictions on their record; their subsequent accidents and convictions were compared with those of a control group of drivers who were given the standard traffic-law test. It was concluded that there was no significant difference in total, fatal, and injury collisions or in convictions between the control and experimental groups in the 12-month period after testing. The report by Carpenter (8) recommended that this component of the selective testing program not be implemented.

In another study, the Highway Safety Research Center of the University of North Carolina and the North Carolina DMV evaluated a North Carolina law, effective June 1, 1974, that eliminated the requirement for license-renewal applicants to take a written examination. To assess driver performance, the records of two groups of drivers were monitored during the months after their assignment to study groups. According to the report by Waller, Hall, and Padgett (9), "Generally the evaluation has examined ... the impact of the law on violations and accidents...." As a result of the study, the researchers recommended that "the test waiver program should remain in effect for operator applicants with the exception of drivers below the age of 25." The North Carolina results seem to indicate that, except for young drivers, applicants for license renewal do not benefit from a retesting of their knowledge of driving rules.

STUDY OBJECTIVE

The primary objective of this study was to test the relation between driver knowledge--as measured by a written test given to selected subjects applying for a renewal of their driver's license--and the number of accidents, convictions, and administrative actions resulting from those applicants' subsequent driving performance. The study was designed to provide both the National Highway Traffic Safety Administration and the state of Virginia with information on the feasibility of implementing driver retesting on a statewide basis.

METHODOLOGY

Study Population

Except for individuals who were specifically identified by Virginia statute or Virginia DMV regulations as requiring a specialized retesting procedure, the license-renewal applicants involved in this study were randomly selected from the statewide license-renewal population and assigned to four study groups. Individuals who had to pass a written knowledge test because they had accident and/or conviction records that fit defined categories were not eligible for participation. In addition, the population from which the sample was drawn did not include individuals who had had their licenses revoked for driving while intoxicated or for other major offenses that required them to apply for a new license. (Before they can be relicensed, members of this group are required by statute to pass a complete test involving vision, written knowledge, and road performance.) These mandatory licensing requirements excluded only a small number of Virginia drivers from the population from which the study groups were drawn.

Study Groups

Four groups of subjects were involved in the study: a control group and three experimental groups. The control group was identified for statistical purposes only and, while its members were not given any materials, written examination, or other special treatment, they did receive the standard renewal notice and take the vision test as required by Virginia statute.

Applicants in experimental group 1 received the standard Virginia Driver's Manual at the same time at which they received their license-renewal notice. Although this group was not given a written examination at the time of renewal, a notice was attached to the Driver's Manual that encouraged the applicant to study it. Members of this group took the vision test when they applied for their license.

Applicants in experimental group 2 received a copy of the Driver's Manual and a written test that was to be completed at home (the "home test") and returned to the examining station when they applied for their operator's permit. A notice from the DMV asked the applicants to study the manual and then take the test. These applicants also took the vision test at the time of license renewal.

Applicants in experimental group 3 were mailed a copy of the Virginia Driver's Manual and a notice asking them to study it. The applicants were informed that a written examination would be administered when they applied for their operator's permit (the "station test"). This group also took the vision test.

Each experimental group was chosen to test a specific application or treatment:

1. Experimental group 1 tested the effectiveness of instructional materials alone in improving driving performance.
2. Experimental group 2 tested the ability of a take-home test to effect a change in driving performance.
3. Experimental group 3, which was designed to be synonymous with federal standards for driver reexamination, tested whether in-station knowledge testing can be used to improve driving performance.

The knowledge test used in this study was designed by the Virginia DMV. Even though this examination was not tested for validity (it does have face validity) and reliability, it is the same examination that Virginia would administer to all drivers if the state were to comply with the requirements of Highway Safety Program Standard 5.

Applicants in the two groups for which a knowledge test was part of the experimental conditions were not required to pass the test before being relicensed. Those individuals who did not pass the station or the home test were licensed anyway, and their driver history files indicated this action. A number of applicants refused to take the knowledge test; they also were licensed, and their refusal to take the test was recorded in their files. Data on accidents, convictions, and administrative actions were tabulated according to whether the applicant had passed, failed, or refused to take the knowledge test.

In computing study-group sample size, conservative assumptions were made concerning rates of accident and conviction involvement. Rates for 1973 (the most current year, before the development of the study proposal, for which data were available) were used for the computations. An expected reduction of 10 percent for each category (e.g., from 5 to 4.5 percent) was also used in the computations. The largest sample size was needed to determine a reduction in the accident category, and this determined the size of the study groups. More applicants were selected for each group than were calculated as being necessary because of expected attrition due to factors such as deaths and applicants moving out of the state.

Figure 1. Framework for within-group comparisons.

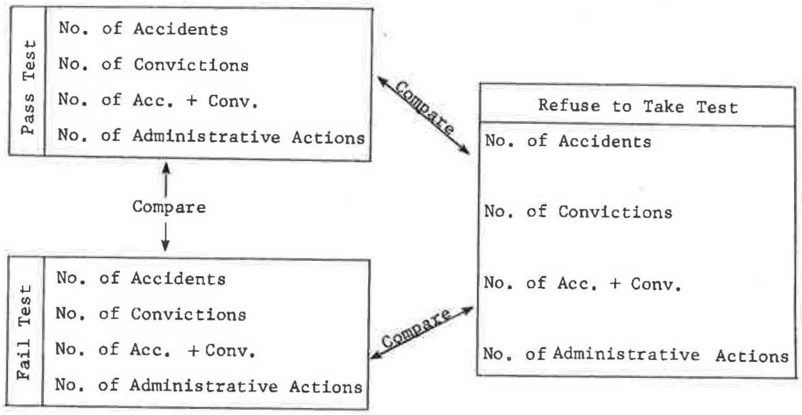
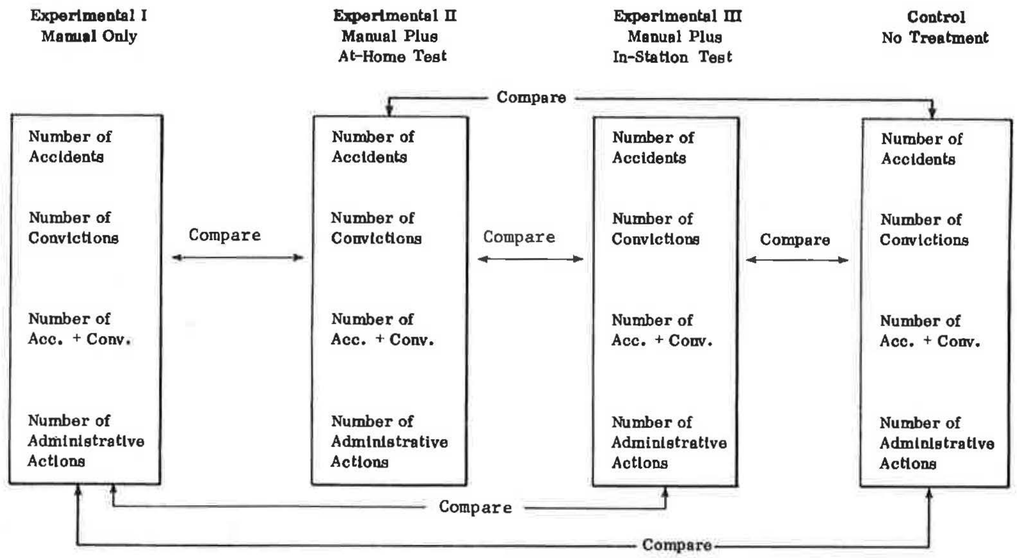


Figure 2. Framework for between-group comparisons.



Each month, a list of individuals was generated from the population of drivers whose licenses were due for renewal that month. The list was generated in a systematic way, so that every nth individual was chosen from the computer-tape list of renewal applicants. After the list was obtained, individuals were systematically assigned to one of the experimental or control groups previously described. The first person selected was assigned to the control group, the second to experimental group 1, and so on. By this procedure, 2084 subjects were placed in each study group for each of seven months, and a total of 14 588 persons were assigned to each of the four study groups.

Research Framework

An independent tape file accessed by a special identifier was developed by the state DMV for use in this project. The tape contained the applicant's test score and the number of knowledge items answered incorrectly. The tape file was matched to the applicant's driver-history file to obtain data for program analysis.

For four periods of six months each from the date an applicant renewed his or her license, DMV files were flagged and the following data were accumulated:

1. Convictions for traffic violations [both major (mandatory and six-point) convictions and minor (four- and three-point) convictions are included as separate categories],
2. Accident involvement (because fault in an accident is not determined by the DMV, the category includes all drivers involved),
3. Drivers who were involved in an accident and were convicted of a violation in connection with their accident involvement, and
4. Administrative actions of the Driver Improvement Program (advisory letters, group interviews, personal interviews, clinics, and probations) and suspensions (in this study, suspensions were not counted for failures to pay fines, failures to file or maintain insurance, failures to attend driver improvement interviews, etc.).

Figures 1 and 2 show the frameworks that were used in seeking answers to questions concerning the comparison of data (a) within each study group and (b) between study groups. These questions were as follows:

1. Was there a difference in the subsequent driving record of those who had passed the station test and those who had failed it or refused to take it?
2. Was there a difference in the subsequent driving record of those who had passed the home test and those who had failed it or refused to take it?
3. Did applicants who had received only the

Table 1. Number of comparisons and statistically different results for each study time period.

Criterion	6 Months C	6 Months D	12 Months C	12 Months D	18 Months C	18 Months D	24 Months C	24 Months D
Accidents								
Total	28	1	28	6	28	0	28	0
Two or more	6	1	6	0	21	0	28	0
With conviction								
Total	21	4	21	0	28	0	28	0
Two or more	0	0	0	0	0	0	0	0
Convictions								
Major								
Total	15	0	21	0	28	0	28	3
Two or more	0	0	0	0	3	0	10	1
Minor								
Total	28	4	28	6	28	6	28	6
Two or more	6	0	10	2	15	2	21	0
Administrative actions								
Advisory letter	10	0	21	0	21	0	21	1
Group interview	15	0	15	0	15	0	21	0
Personal interview	0	0	6	0	6	0	6	0
Improvement clinic	0	0	3	0	6	0	6	0
Probation	0	0	3	0	6	0	6	0
Suspension	6	0	6	0	10	0	10	0
Total	135	10	168	14	215	8	241	11

Note: C = comparisons (number of chi-square values computed); D = significant differences.

Table 2. Comparisons made and information sought.

Comparison	Items Compared	Information Sought
A	Control group with each experimental group	Did treatment reduce accidents and convictions in comparison with no treatment?
B	Experimental groups with each other	Was any part of the experimental program more effective than other parts?
C	Pass, fail, and refuse on each test	Were test performance and subsequent driving record related?

instructional material (the Virginia Driver's Manual) have different subsequent driving records than applicants in the no-treatment group or applicants in the other treatment groups?

4. Did applicants who had passed, failed, or refused to take the home test have different subsequent driving records than applicants in the no-treatment group or those in the other treatment groups?

5. Did applicants who had passed, failed, or refused to take the station test have different subsequent driving records than applicants in the no-treatment group or those in the other groups?

ANALYSIS OF THE DATA

Not all of the 14 588 applicants assigned to each of the study groups actually renewed their driver's license within 90 days of the required date. Anyone who does not obtain a license within this time is required by statute to be tested as an original-license applicant. Records were kept not only on those persons who had originally been assigned to the study groups but also on applicants who had renewed their licenses, and it was noted whether they had passed, failed, or refused to take the test they had been assigned. Accidents, convictions, and administrative actions posted on an individual's driver-history file were accessed and tabulated by categories.

Because of the design of the study, a large number of comparisons were theoretically possible. At the end of each 6-month period of vehicle operation after an applicant's license renewal, there were not sufficient data for the computation of chi-square values for every one of the possible comparisons. There were 135 comparisons of 6-month data, 168 for 12-month data, 215 for 18-month data, and 241 for 24-month data. The full report by Stoke (10) contains 13 appendix tables that present all of the chi-square values computed and their probabilities of occurrence. In only a few of the comparisons that were made were statistical differences reached--i.e., $p \leq 0.05$. There were 10 significant differences at the end of 6 months of vehicle operation after an applicant began participation in the study, 14 at the end of 12 months, 8 at the end of 18 months, and 11 at the end of 24 months. These data are given in Table 1 along with the number of chi-square values that could be computed for each of the criterion variables during each of the four time periods.

Table 2 describes the comparisons carried out and the information sought. Table 3 gives the results obtained based on the accident, conviction, and administrative-action data available in applicants' driver-history files.

Accidents

Accident data were analyzed with respect to three major divisions: (a) all applicants who had had an accident, (b) all who had been involved in two or more accidents, and (c) all who had been convicted of a violation in connection with their accident involvement. Each of these divisions of data was further categorized by comparisons made within each of the groups assigned to take a knowledge test and comparisons made between the various study groups (Figures 1 and 2).

Statistical analyses were performed in cases of applicants who were involved in an accident. At the end of six months of driving exposure, no differences were found in the number of individuals who had had an accident in comparison with whether they had passed, failed, or refused to take the station test. In addition, there were no within-group differences on the basis of whether the applicants had passed, failed, or refused to take the home test. When between-group comparisons were

Table 3. Statistical results obtained in comparisons based on accident, conviction, and administrative-action data.

Criterion	Comparison	Number of Statistical Differences			
		6 Months	12 Months	18 Months	24 Months
Accidents					
Total	A	ND	1	ND	ND
	B	1	3	ND	ND
	C	ND	2	ND	ND
Two or more	A	1	ND	ND	ND
	B	ND	ND	ND	ND
	C	ID	ID	ND	ND
With conviction	A	ND	ND	ND	ND
	B	2	ND	ND	ND
	C	2	ND	ND	ND
Convictions					
Major					
Total	A	ND	ND	ND	ND
	B	ND	ND	ND	2
	C	ND	ND	ND	1
Two or more	A	ID	ID	ND	1
	B	ID	ID	ND	ND
	C	ID	ID	ID	ND
Minor					
Total	A	1	1	1	1
	B	2	3	4	4
	C	1	2	1	1
Two or more	A	ND	ND	ND	ND
	B	ND	2	2	ND
	C	ID	ND	ND	ND
Administrative actions					
Advisory letter	A	ND	ND	ND	ND
	B	ND	ND	ND	1
	C	ND	ND	ND	ND
Group interview	A	ND	ND	ND	ND
	B	ND	ND	ND	ND
	C	ND	ND	ND	ND
Personal interview	A	ID	ND	ND	ND
	B	ID	ND	ND	ND
	C	ID	ID	ID	ID
Clinic	A	ID	ID	ND	ND
	B	ID	ND	ND	ND
	C	ID	ID	ID	ID
Probation	A	ID	ID	ND	ND
	B	ID	ND	ND	ND
	C	ID	ID	ID	ID
Suspension	A	ND	ND	ND	ND
	B	ND	ND	ND	ND
	C	ID	ID	ND	ND

Note: ND = no difference established; ID = insufficient data for chi-square computations.

carried out, in only one case, which involved applicants who had refused to take the home test, was a difference found. Statistical differences were not established in the other 21 between-group comparisons.

Differences still did not occur in the station-test accident comparisons after 12 months of subsequent driving exposure. For the remainder of the 12-month data, in the six cases that involved individuals who had refused to take the home test, statistical significance at $p \leq 0.05$ was reached: More applicants in the group that refused to take the test had had an accident. In the remaining 19 comparisons, in which 12-month accident results were used, no statistical differences were established. In addition, none of the 28 chi-square values computed on total accident data for both 18- and 24-month driving exposure were significant.

For applicants who had been involved in two or more accidents, there were not sufficient data to compute chi-square statistics in every 6-month driving exposure category. Of the six comparisons that could be made, applicants who had passed the station test had better records than those in the control group. This is the only accident-related finding over the first 6 months of the study that had practical value for driver-licensing officials. It must be pointed out, however, that both the rates and numbers of multiple accidents were very small and subject to the random variations associated with small sample sizes.

Of the applicants who had been involved in two or more accidents, there were data for the computation of six chi-square values at the end of 12 months of driving exposure, 21 at the end of 18 months, and 28 at the end of 24 months. A statistical difference was not proved to exist in any of these comparisons.

Statistical analyses were also performed on the data for applicants who had been convicted of a violation in connection with their accident involvement. In the 6-month data comparisons carried out for the station-test group, a statistical difference occurred only in the case of a comparison between those who had refused to take the test and those who had failed it: More drivers in the group who refused the test had an entry on their driver-history files than did those in the group who had failed the test. For applicants who had received a test to be completed at home, there were 6-month data for only one within-group comparison. More applicants who had refused to take the test had an accident-with-conviction entry than did applicants who had passed the test.

Seventeen accident-with-conviction comparisons were carried out between the various subgroups, and two reached statistical significance at $p \leq 0.05$. One case, a comparison between applicants who had failed the station test and those who had passed the home test, is of no practical importance to an operational driver-licensing program. In the other case, a comparison of applicants who had refused to take the home test with those who had refused to take the station test, the group who refused the home test had the worse record.

Of the 21 between- and within-group comparisons computed for 6-month data, 17 did not reach statistical significance at $p \leq 0.05$ in the number of applicants who had an accident combined with a conviction. Although statistical differences were found in 4 cases, the frequency of occurrence did not exceed 1 percent of those applicants in any category. Because of this low frequency rate and a small individual count (6 or fewer applicants), these statistical differences have little practical operational value. Chi-square statistics could be computed for 21 pairs of data at the end of 12 months and for all 28 pairs at the end of 18 and 24 months of driving exposure. None of the results reached significance at $p \leq 0.05$.

Insufficient data existed for the computation of chi-square values at the end of all four time periods for the category of two or more accidents with convictions. Even after two years of subsequent driving experience, multiple entries in this category did not seem to be a very common occurrence among Virginia drivers.

Convictions

Conviction data were broken down for analysis into four main divisions: major convictions, two or more major convictions, minor convictions, and two or more minor convictions. Comparisons for each of these data divisions were computed for applicants who had been assigned the station knowledge test and who had either passed, failed, or refused to take it. A second set of comparisons was computed for applicants who had been assigned the home knowledge test and who had either passed, failed, or refused to take it. A third set of comparisons, between the various study groups and subgroups, was also made.

Statistical analyses were performed for applicants who had a major conviction on their driving record. For the first three time periods (6, 12, and 18 months), none of the chi-square values that were computed reached statistical significance at $p \leq 0.05$. Three statistical differences were found in the 24-month data. More of the members in the group who had failed the station test incurred a major conviction than did the members of the group who had passed the home test or the group who had passed the station test. Applicants who had received only a test manual compiled worse records than those who had passed the home test; that is, more of them were found to have a major conviction.

Although mathematical differences were found in these three cases, the practical significance was less than firmly established. In the worst case, that of applicants who had failed the station test, less than 2.5 percent of the group had a major conviction on their driving record.

For applicants who had incurred two or more major convictions, there were insufficient data for computations of chi-square values at the end of 6 and 12 months of vehicle operation. The data at the end of 18 months allowed 3 comparisons, and those at the end of 24 months allowed 10. The only statistical difference was found in a comparison between applicants who had refused the station test and applicants in the control group at the end of 24 months of driving exposure: More of the former were found to have multiple major convictions. In this case, less than 0.3 percent of the applicants had a multiple entry on their record.

When comparisons were made in the minor-conviction category between those who had passed, failed, or refused to take the station test, only in the 12-month data was there a statistical difference: More applicants who had refused to take the test had an entry on their driver-history files than did those who had passed the test.

When comparisons were made within the group of applicants who had been assigned the home test, more of those who had refused to take the test had a minor conviction on their driving records than did those who had passed the test. This was found at the end of each of the four time periods. There were no differences in the number of minor convictions in the other two home-test comparisons.

Comparisons were also computed between the various study groups and subgroups to determine whether there were differences in the number of applicants who had a minor-conviction entry in their files. In every case in which a statistical difference was found, it involved members of the group who had refused to take the home test. Each time, a larger percentage of these applicants had a minor conviction than did those in the group with which they were compared.

Analyses were also done of applicants who had received two or more minor convictions. The data allowed the computation of 6 chi-square values at the end of 6 months of driving exposure, 10 at the end of 12 months, 15 at the end of 18 months, and 21 at the end of 24 months. A statistical difference was not proved to exist in any of the 6- and 24-month comparisons, whereas the same comparisons for 12 and 18 months did reach significance. These two results occurred in the between-group comparisons, where more applicants who had passed the home test had multiple minor convictions on their records than did applicants who either had passed the station test or had received only a driver's manual.

From the data collected on total major convictions and two or more major convictions, none of the within- or between-group comparisons had chi-square values that reached significance at the end of 6, 12, or 18 months of driving exposure. Four comparisons did reach significance at the end of 24 months of driving exposure: Three were in the data on total major convictions, and one was in the data on multiple major convictions. In only one instance did the results provide some evidence that knowledge testing is beneficial. Fewer applicants in the group that had passed the station test had a major conviction than did applicants in the group that had failed the station test (1.42 versus 2.46 percent). The other statistically significant results provided little guidance of practical value for licensing officials in developing and administering a knowledge-testing program. The majority of the 24-month within- and between-group comparisons did not result in findings of statistical significance between comparison groups. Therefore, no benefit for a knowledge-testing program was established in cases of major convictions or multiple major convictions.

For the data on total minor convictions, when applicants who refused to take the home test were compared with those in other groups, statistical differences were found at the end of each of the four time periods. In each case, more in the group who refused the test had minor convictions than did those in the group with which they were compared. Although these differences are important from a mathematical point of view, they have limited application for DMV personnel in an operational setting. The state of Virginia does not require license-renewal applicants to pass a knowledge test. Those who refused to take the test at home may exhibit personality traits and driving behavior that call for additional study. Except for applicants who refused to take the home test, comparisons of data on total minor convictions did not reach a statistical difference at the end of any of the four time periods. There were 22 comparisons (24 for 6-month data) for which a difference was not proved to exist in the data. Knowledge testing does not appear to improve the total-minor-convictions records of license-renewal applicants.

At the end of six months, none of the within- or between-group comparisons of the data on multiple minor convictions reached statistical significance at $p \leq 0.05$. For both 12- and 18-month data, more applicants who had passed the home test had a minor-conviction entry on their record than did those who had passed the station test or those who had received only a driver's manual. Data collected over the full 24 months of the study were also compared to see whether within- or between-group differences existed in relation to multiple minor convictions. Among the 21 comparisons carried out, none reached statistical significance at the level set. In the majority of cases in which the chi-square could be computed, no differences were proved to exist in the number of multiple minor convictions obtained by the various study groups during the four time periods. The taking and passing of a knowledge test, whether a station or home test, did not improve the subsequent driving records of study groups with respect to multiple minor convictions.

Administrative Actions

Under the Virginia Driver Improvement Program, there are six levels of administrative actions: advisory letters, group interviews, personal interviews, improvement clinics, probation, and suspension. The number of applicants who had been the subject of each type of action was analyzed with respect to the within- and between-group categories previously discussed.

There were insufficient data at the end of the first six months to allow any comparative analyses for three of the administrative-action criteria. The number of individuals who had attended personal interviews or improvement clinics or been put on probation was so small that statistical values could not be computed. In addition, not all of the 28 possible comparisons could be carried out for the other criterion variables at the end of each of the four time periods.

In the advisory-letter analyses, no differences were found in any of the comparisons performed on data at the end of 6, 12, and 18 months. A statistical difference was found for only 1 of 21 comparisons at the end of 24 months of driving exposure, and in this single case more of the applicants who had passed the home test had received an advisory letter than had those who had received only a driver's manual.

Where data existed for the computation of chi-square values for study-group applicants who had had to attend a group interview, a personal interview, or a driver improvement clinic, or who had received a probation notice and/or been suspended, there were no results that were statistically significant at $p \leq 0.05$. Out of all of the comparisons computed on data obtained as a result of administrative actions pursuant to points accumulated under the Driver Improvement Program, in 218 out of 219 comparisons no statistical differences were proved to exist at the $p \leq 0.05$ level.

OTHER STUDY ISSUES

There are several issues for which some additional elaboration would seem appropriate. One of these is a question of whether the hypothesized impact of the project was to screen out unsafe drivers--i.e., those with high accident and/or conviction records--or to educate drivers on safe driving practices. The design was to consider both of these issues. The use of experimental group 1, the applicants who were not given a knowledge test, dealt mainly with the educational aspects. The use of the other two experimental groups, the applicants assigned to either a home or a station test, dealt primarily with the screening aspects of the knowledge-testing portion of a state relicensing program. The results did not produce evidence of either a beneficial screening or an educational effect.

Another factor that deserves comment is the method of assigning applicants to the control group. They were assigned by a computer program developed by the Virginia DMV, which selected every nth subject from the driver file, and a special identifier was placed on the driving record of each person so selected. These people were not notified of their selection by the state, nor was a list of these applicants produced. During the first two months of the study, it was given some newspaper publicity, but this was general in nature and limited in its coverage (only some areas of the state) and contained few, if any, specifics. Since members of the control group were not informed that they were part of a study, there is no reason to suspect that a general news item would influence their driving behavior and thereby influence the results of the study.

All applicants for both the control group and the experimental groups were required to pass a vision test at the examining station before being licensed. No procedures were used to selectively eliminate applicants from the various study groups. There was no variation in the procedures used for the groups except in those procedures described earlier that involved the experimental conditions. Failing, passing, or refusing to take the knowledge test did not keep applicants from being licensed if they met all other requirements. There were no statistical differences among groups in the numbers of applicants who renewed their licenses.

It is recognized that the data from succeeding time periods encompass those from previous time periods; that is, the 12-month accident data included all accidents recorded in the driver-history files from the time an applicant began participating in the study and therefore included the counts made at 6 months. Even though there was a dependence of one time period on another, the statistical results for each of the four time periods reviewed did not indicate that the driving behavior of one experimental program was better than that of another or superior to that of the control group. Because of the lack of consistency in the results of the comparisons that were carried out and found to be different, it can be concluded that there were no program carry-over effects between the earlier and later stages of the study that would mask important but undetected factors.

In any research study, the emphasis placed on the results is based on the manner in which the data are aggregated. One method is concerned only with intact groups, or those that have not been reduced into subgroups, and it is only at this point that there is true randomization. A second method, which deals with comparisons of data other than those for entire groups, represents some subjective selection and therefore presents a potential for bias. In the study reported here, some applicants refused to take a test whereas others either passed or failed it. Each option--pass, fail, or refuse--represents a principle of selection for the two groups for which knowledge testing was part of the experimental program.

Although there may be some research conditions in which entire groups represent the only procedures to be used, this study was carried out under the driver-licensing procedures in use in Virginia when the study was conducted. The study was also being used to evaluate the program that would be put in operation if beneficial results were found. For these reasons, it was necessary to analyze the results in relation to the subgroups of applicants based on their performance on the knowledge test.

It is recognized that the three categories of data for each group of applicants assigned to take a knowledge test are not random samples in the true statistical sense. Even so, there is no indication that the results are biased in such a way as to mask the benefits that might be present in such a knowledge-testing program.

CONCLUSIONS AND RECOMMENDATIONS

The research reported here was designed to answer five questions concerning the effect on driver performance of administering a written knowledge test to persons applying for a renewal of their driver's license. Data on accidents, convictions, and administrative actions taken as part of driver improvement programs were used as measures of effectiveness for various experimental test conditions. The major conclusions can be stated as follows:

1. For applicants who were assigned to take the knowledge test at the examining station, there were no differences among the subsequent driving records of applicants who had passed, failed, or refused to take the test.

2. There were no differences among the subsequent driving records of applicants who were mailed a test to be taken at home, except among those who refused to take the test.

3. There were no differences between the subsequent driving records of applicants who received a Virginia Driver's Manual and those in the control group or applicants in the other treatment groups.

4. When comparisons were made between home-test applicants and those in the other study groups, the results generally indicated that subsequent driving records could not be distinguished on the basis of whether the applicant had passed or failed a knowledge test.

5. Comparisons between applicants in the station-test group and those in the other study groups generally indicated that subsequent driving records could not be distinguished on the basis of whether the applicants had passed, failed, or refused to take a knowledge test at the examining station.

Statistical tests on data obtained at the end of the four study time periods contained no substantial evidence to justify requiring the general population of license-renewal applicants to take written knowledge tests, since neither short- nor long-term driving performance was shown to improve as a result of such testing.

In light of these results, it is recommended that the U.S. Department of Transportation make permanent the temporary waiver of the requirement for reexaminations on knowledge of rules of the road in the driver-licensing standard granted the state of Virginia. The results further indicate that the standard should be amended to eliminate the requirement for such reexaminations.

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The opinions, findings, and conclusions expressed in this paper are mine and not necessarily those of the sponsoring agencies.

REFERENCES

1. Highway Safety Program Manual: Volume 5--Driver Licensing. U.S. Department of Transportation, Jan. 1969.
2. J.L. Pursewell. Project Driver Final Report: Phase 1A. Federal Highway Administration, U.S. Department of Transportation, Nov. 1970. NTIS: PB 195 133.
3. E. Levonian, H.W. Case, and R. Gregory. Prediction of Recorded Accidents and Violations Using Nondriving Predictors. HRB, Highway Research Record 4, 1963, pp. 50-61.
4. An Evaluation of California's Good-Driver Incentive Program. California Department of Motor Vehicles, Sacramento, Rept. 46, 1974.
5. J.W. Anderson. The Effectiveness of Traffic Safety Material in Influencing the Driving Performance of the General Driving Population. California Department of Motor Vehicles, Sacramento, June 1977.
6. D.M. Harrington and M. Ratz. The Effectiveness of an At-Home Drivers Licensing Law Test. California Department of Motor Vehicles, Sacramento, Res. Rept. 60, March 1978.
7. D.W. Carpenter. The Effects of Administering Written Tests Stressing Knowledge of Safe Driving Principles to Renewal Drivers License Applicants. California Department of Motor Vehicles, Sacramento, Res. Rept. 61, June 1978.
8. D.W. Carpenter. The Effects of Written Licensing Tests Stressing Knowledge of Safe Driving Principles for Intermediate Record Renewal Applicants. California Department of Motor Vehicles, Sacramento, Res. Rept. 63, June 1978.
9. P.F. Waller, R.G. Hall, and S.S. Padgett. The North Carolina Test Waiver Law: An Evaluation of Its Impact. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, April 1977.
10. C.B. Stoke. The Effectiveness of Written Driver Knowledge Tests. Virginia Highway and Transportation Research Council, Charlottesville, April 1979.

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Causes of Variation in Automobile Speed Along a Parkway

B. JANE ROSZELL AND JOHN P. BRAAKSMA

The results of research conducted to determine what factors most strongly affect variations in drivers' speed patterns along a roadway are described. Field surveys were conducted on the Gatineau Parkway in Quebec to collect data on the following factors: (a) driver age and sex, (b) vehicle age and size, (c) number of occupants in the vehicle, and (d) geometric configuration of the highway. Speed-change data were divided into three components: (a) frequency of speed changes along the parkway, (b) magnitude of the speed change, and (c) direction (increase or decrease) of the speed change. Analysis of covariance was used to determine the degree of relationship between the first two components and the driver, vehicle, and geometric variables. A manual overlay technique was used to analyze the third component, to check the statistical results, and to verify a technique developed by Leisch to obtain speed profiles. The study found that route geometry and driver age played a significant role in the frequency of speed changes. Driver variables such as age and sex were the most significant factors affecting the magnitude of speed changes. Route geometry affected the magnitude of speed change much less than did the location of the speed change, and it affected the direction of speed changes much less than did driver age.

Research has shown that sudden changes in vehicle speed contribute to accidents (1). For example, at an 8-km/h (5-mile/h) speed reduction, the accident-to-speed ratio is 2.0; at a 16-km/h (10-mile/h) reduction, the ratio is 3.7; at a 24-km/h (15-mile/h) reduction, the ratio is 8.9; and at a 32-km/h (20-mile/h) reduction, the ratio is 15.9 (2,3). There are many possible causes for these sudden speed changes. Some can be linked to the driver, some to the vehicle, and some to the geometry of the highway. Leisch (3), for example, believes that speed variations are directly related to characteristics of road geometry such as joint horizontal and vertical alignment, curvatures, and gradients. Leisch also devised a theoretical technique for using speed profiles to relate changes in vehicle speed to changes in road geometry. This paper summarizes a research project conducted at Carleton University on the causes of sudden changes in automobile speed along the Gatineau Parkway in Canada (4).

PURPOSE AND SCOPE OF STUDY

The purpose of this research was twofold:

1. To determine what factors most strongly affect the speed patterns of drivers along a route and
2. If geometric variables do affect speed variation, to determine how well Leisch's technique works in a practical situation.

The scope of the research was limited to studying private automobiles on a parkway and the following variables: sex and age of the driver; number of occupants in the vehicle; size, age, and physical condition of the vehicle; and horizontal curves, vertical grades, and tangents. These variables were selected from a literature review of the causes of speed variations.

CAUSES OF SPEED VARIATION CITED IN THE LITERATURE

Driver Capabilities

Vehicle operating speed is altered by such driver-related variables as sex, age, driving experience, and occupation (5,6). Various studies on driver-related variables have concluded that trip distance has the greatest effect on speed. The number of passengers in the car and the sex of the driver alter driving speed to a lesser extent. There is, however, no information to indicate whether these factors or others affect consistency in speed along a route. In this study, data on the following driver characteristics were recorded to determine whether they have any impact on variation in speed: sex and age of the driver, number of passengers in the vehicle, and (whenever possible) relationship of the passengers to the driver.

Vehicle Characteristics

The literature on performance characteristics has generally classified highway vehicles as passenger cars, single-unit trucks, combination trucks, and buses. This classification is based on factors of gross weight and power rating (expressed in kilowatts or horsepower), which affect such operating characteristics as maintainable speed, load capacity, safety, and service.

Gross Weight

In various studies carried out on gross vehicle weight (3,7,8), there is no consensus of opinion on whether operating speeds vary with different vehicle weights. Lefeve (7) indicates that operating speeds do not vary with weight, whereas Lawshe (8) and others suggest that operating speeds tend to be higher for heavier passenger cars. None of these studies shed any light on whether heavier vehicles show greater or lesser tendency to change speed than lighter vehicles.

Power Rating

Certain studies (6) suggest that vehicle operating speed is not affected by power rating, whereas other studies (9) indicate just the opposite. But, again, none of these studies dwell on the possible relation between speed variation and power rating.

Speed Maneuverability

Vehicle maneuverability is a third vehicle characteristic that can affect operating speed. Maneuverability tends to vary with the size of the wheel base. Small cars are better able to negotiate tighter curves than larger vehicles. No studies were found to show whether, in fact, small-wheel-based vehicles have the potential for fewer speed changes. It would appear that a dependent relation exists between vehicle maneuverability and consistency in speed.

Age of Automobile

Various investigations of highway travel characteristics have shown that new cars have higher average speeds than older ones (5,7,10,11). The reasons given for this are that new cars have higher velocities, ride more comfortably, travel more smoothly and quietly, handle better, and are generally in better mechanical condition. Thus, it is quite likely that consistency in speed will also differ between older and newer cars.

Route Geometry

Various studies have been done to determine to what extent geometric roadway features affect travel speeds. Geometric features that could affect operating speed include horizontal, vertical, and cross-sectional alignment and pavement type.

Horizontal Alignment

Various studies (9) found that "vehicular speeds are lower on horizontal curves than on tangent alignments". The horizontal components that affect vehicle speed on a horizontal curve are superelevation, sight distance, and degree of curve. Superelevation has been investigated by a number of authorities to determine its effect on speed reduction (12-14). These studies indicate that higher speeds occur as the degree of superelevation increases. But the changes were not significant.

Studies by Taragin (12,13) on the influence of curvature and sight distance under comparable conditions indicate that curvature caused almost three times as great a change in speed as sight distance.

Vertical Alignment

All vertical-alignment variables appear to cause some variation in vehicle speed. This variation is more pronounced for trucks than for passenger cars.

The effect of grades on passenger cars is to cause the driver to reduce speed on upgrades greater than 7 percent (15) and to increase speed on downgrades greater than 3 percent (9). Length of grade is not considered to affect the speeds at which passenger cars operate.

Drivers reduce their speed as they approach crest vertical curves. The rate of the speed reduction appears to increase with the decrease in sight distance (9). Sag curves do not affect speed variation to any great extent (9).

No research data were found to show the effects on speed patterns of a simultaneous change in horizontal and vertical alignment, such as the introduction of a horizontal curve on a vertical grade.

Cross-Sectional Geometry

Studies on cross-sectional geometry and its impact on speed variation show that there are three factors that can be related directly to speed variation: a sudden change in any one of the cross-sectional elements, the presence of a two-lane highway where a driver is constantly meeting traffic traveling in the opposite direction, and a restriction of lateral clearance created by an object on the shoulder of the route (16,17).

Pavement

Vehicle speeds tend to vary when the pavement type changes or when the pavement is in very poor condition (7). These two variables are subject to the control of the appropriate maintenance agency.

Environmental Factors

The operation of a vehicle on the highway is affected by factors independent of the driver's capabilities, the roadway geometry, and the characteristics of the vehicle. These factors include such variables as land use, traffic volumes, weather, time of day, trip purpose, and physical view. These factors occur randomly and are therefore difficult to correlate with speed variation. Studies have shown that speed varies with season, time of day, and the severity of the weather, but there is no conclusive evidence to show any direct relation in the variability of these factors (6). In this study, therefore, it was necessary to limit the influence of these factors on speed fluctuations.

FIELD WORK

From the literature survey, a number of variables were selected that have the potential of being related to speed changes. These were age and sex of the driver, age and size of the vehicle, number of occupants, and route geometry. Field work was conducted to collect the appropriate data to determine whether these variables are in fact related to speed.

Selection of Test Route

The selection of a test-route section was based on the following criteria. The route must

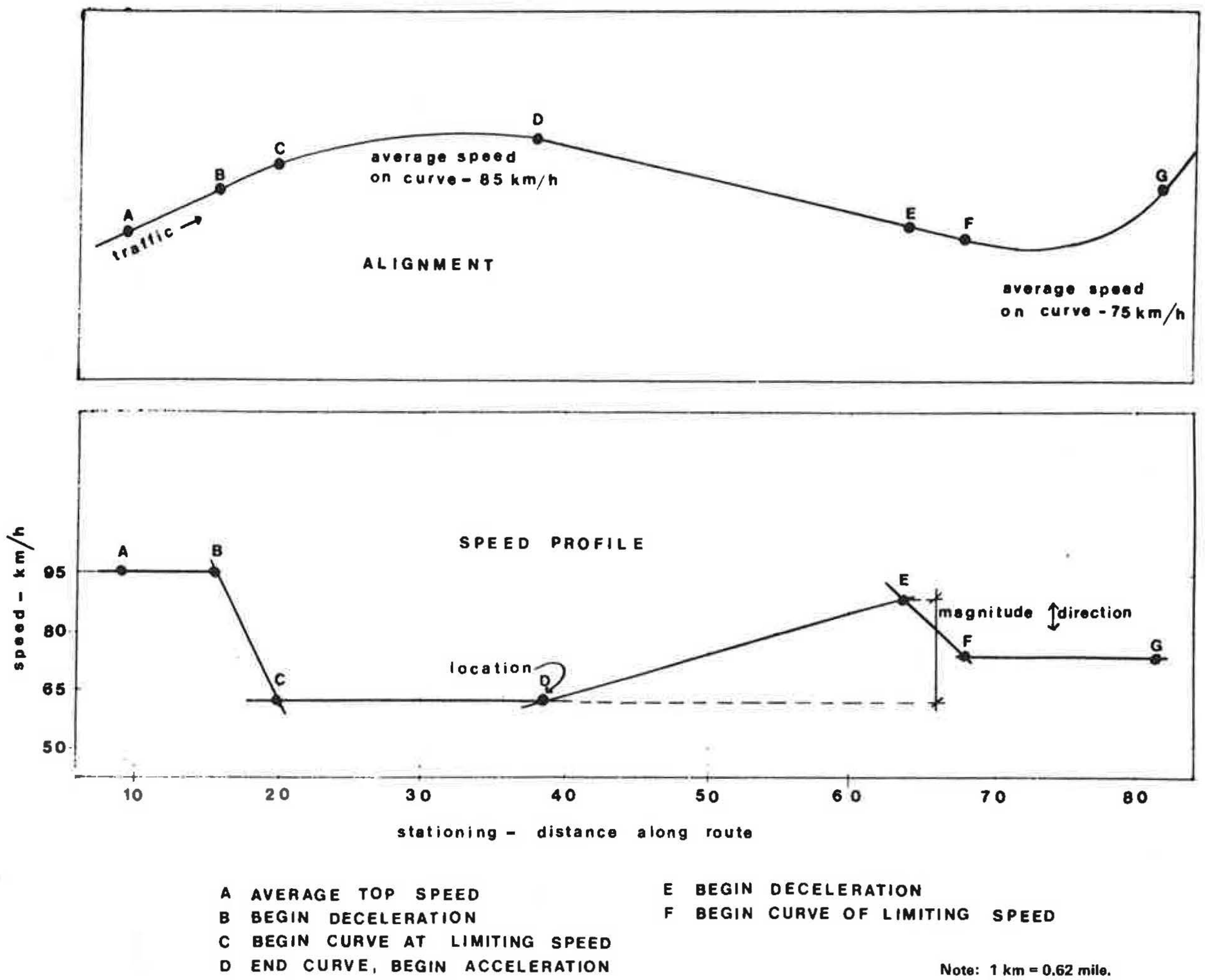
1. Be one for which standard design plans exist;
2. Contain a variety of horizontal curves, lengths of tangents, vertical curves, and degrees and lengths of grades as well as combinations of vertical and horizontal alignments;
3. Have a continuous type of pavement in good condition as well as consistency in cross-section geometry and superelevation;
4. Cater to one type of trip purpose and pass through only one type of land use area; and
5. Serve different types of passenger cars and drivers and varying numbers of passengers.

The Gatineau Parkway, a route approximately 65 km (40 miles) in length located approximately 25 km (15 miles) north of Ottawa in the Canadian province of Quebec, was felt to be most suitable for this research. Since the route was designed as a parkway and passes through the rugged, rocky, tree-covered terrain of the Gatineau Park, there is an abundant supply of curves and grades. The Gatineau Parkway provides access for the residents and visitors of the region to such recreational activities as picnicking, hiking, and general viewing of the scenic landscape. Because the route was built for recreational purposes, the land use pattern is consistent along its full extent. Furthermore, because the parkway has no destinations other than recreational ones, trip purpose is also constant. Another advantage in selecting this route for the study is the fact that it caters to a large variety of users whose primary mode of transportation is the private automobile.

The Gatineau Parkway was built with many adjacent belvederes and pull-offs to give users ample opportunity to view the surrounding terrain. These stopping points provided the necessary opportunities to gather the driver and vehicle data.

On weekends the parkway operates at near-capacity levels of traffic, but during the week traffic volumes are well within the level of "free-flow" conditions, which was a requirement for this research.

Figure 1. Speed profiles for passenger cars.



The parkway has been designed generally to meet the following standards (1 km = 0.62 mile; 1 m = 3.3 ft):

Criterion	Value
Design Speed (km/h)	60
Average running speed (km/h)	60
Maximum radius of curvature (m)	120
Maximum gradient (%)	10
Surface width (m)	6.8
Rounding	Variable
Shoulder width (m)	1.0
Side slopes	3:1
Back slopes	Variable
Minimum sight distance (m)	85
Minimum passing sight distance (m)	420

The geometric design data for various geometric variables were extracted from the original design plans (see Figure 1).

The pavement is bituminous asphalt along the full extent of the route and is in excellent condition. Even though the parkway has only two lanes, there is expected to be little interference from oncoming traffic because of the 3.75-m (12-ft) lane width and the paved shoulders.

Because the route is so long, only a portion of it was used for the research project. The section selected is at the terminus of the parkway--Champlain Lookout. Unfortunately, approximately 1.6 km (1 mile) south of the Champlain belvedere, the parkway splits and one route goes to Camp Fortune and the other returns to Hull and Ottawa. Because it is impossible to predict which route the user will take, two sets of data were collected, one for each route.

Besides the fact that it meets all of the data requirements, there are other reasons for selecting this section of roadway. Users must travel approximately 35-50 km (22-31 miles) through the park to reach this destination. By the time they reach it, they are well acclimatized to the landscape, so that any effects the scenic terrain may have on their speed patterns are reduced. A large pull-out is located at the terminus of the parkway. This was the point from which the necessary driver and vehicle data were collected. Because of the size of the pull-out, the data could be collected inconspicuously, from a distance.

Data Collection

Speed-Variation Patterns

To measure speed-variation patterns, a motor-driven camera was attached to the inside cab of an observation vehicle so that it focused on the speedometer and the odometer. This camera was operated by remote control by a second person so as not to interfere with the driving of the vehicle.

When a subject vehicle pulled into the belvedere, the responsibility for collecting all vehicle and driver data rested with the person riding in the back seat of the observation vehicle (this was necessary because the driver was fixed in position behind the camera equipment). This second person got out of the observation vehicle and closely approached the subject vehicle under the pretense of looking at the view, thereby collecting some of the necessary data. He took a photograph of the rear of the subject vehicle so that the license number was clearly recorded. This was easy to do because cameras are so frequently used to take pictures of the scenery. He then returned to the observation vehicle and, when the subject vehicle left the belvedere, the observation vehicle simply followed behind, recording the necessary speed data.

The observers followed a subject vehicle at a fixed distance, recording all speed changes on film from instrument readings. This method obtained both a continuous speed reading and, by means of the odometer, the distance location of all observed vehicles traveling through the test section of the parkway.

A distance of 90 m (300 ft) was kept between the observation vehicle and the subject vehicle so as not to influence the driving patterns of the subject. This distance requirement was maintained by using a transparent grid on the windshield that represented the width of a large car 20 m (65 ft) away.

Driver and Vehicle Characteristics and Route Geometrics

A camera and data forms were used to record the field data on vehicle and driver variables. The camera took pictures of the subject vehicle and its license number while it was stopped at the belvedere. Data such as the age of the driver, the number of persons in the car (by sex and age), the time of day, and weather conditions were recorded on forms.

Measures for route geometry were derived indirectly by using a new technique devised by Leisch (3), which involves regulating the road geometry to maintain the necessary consistency in operating speed along the road. This technique requires setting up a speed profile that takes into account the joint configuration of horizontal and vertical alignment as well as individual curvatures and gradients. The technique makes use of existing design standards outlined by the American Association of State Highway Officials (AASHO) (18). In setting up the required theoretical speed profile, design speeds on curves and tangents are used.

A speed profile developed from these standards (see Figure 2) provides a continuous plot of the average speed of vehicles along a highway under free-flow conditions. The configuration of the speed profile combines horizontal and vertical alignment features and instantly points out where speed changes occur because of the road geometry.

Sample Size

During 10 days in June 1977, the speed-variation patterns of 60 subjects were observed and recorded. Unfortunately, 18 samples had to be rejected because various extraneous factors affected the speed-variation patterns. This left 22 sets of data for route 1, 11 for route 2, and 9 for portions of the two routes, for a total sample size of 42.

DATA ANALYSIS

Dependent Variables

The primary purpose of this research was to determine which factors most strongly affect speed variation. The magnitude of the speed changes along a route segment was represented by the following variation term:

$$\text{Magnitude of speed} = [\Sigma(X - \bar{X})^2/n]^{1/2} \quad (1)$$

where

X = speed measurement taken every kilometer along the route segment,
$\bar{X}$ = sum of measured speeds divided by n, and
n = number of kilometers in the route segment.

The collected speed-variation data were plotted as speed profiles (Figure 2), and the various speed measures were extracted from these profiles. Further research into speed variation was also undertaken. This included determining the factors that most strongly affect the frequency and the direction (increase or decrease) of the speed change. Frequency of speed change along a route was represented by the number of times a vehicle changed its speed along the test section of roadway. The direction of the speed change was extracted from the speed profiles.

Independent Variables

It was hypothesized that each of the three measures of speed variation is a function of the following independent variables: age and sex of the driver, age and size of the vehicle, number of occupants in the vehicle, and route geometry. Measures for driver and vehicle characteristics were determined directly from the field data. Since the Leisch technique is based on geometric variables of the route, it is a simple matter to extract corresponding expressions for frequency of speed change and magnitude of speed change to represent the independent variable, route geometry.

Analysis Techniques

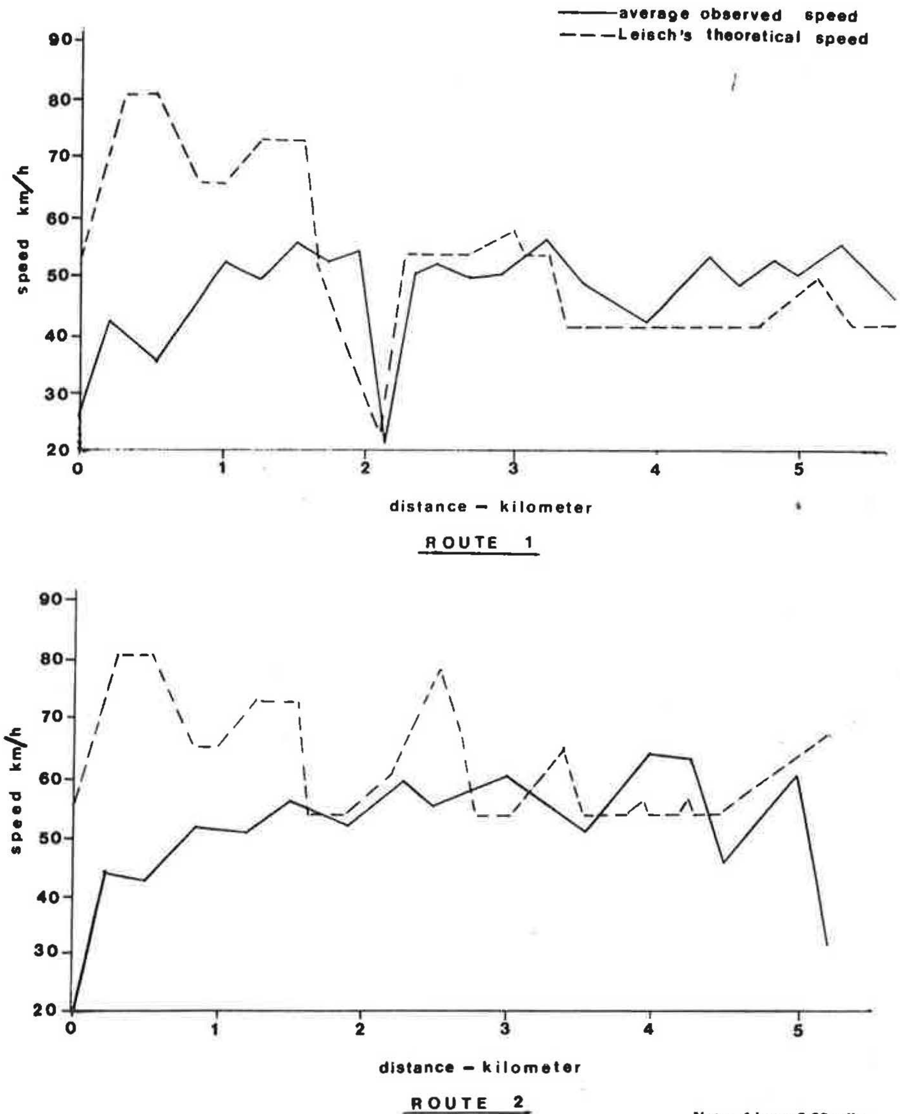
The first two measures of speed variation--frequency and magnitude of speed change--and the associated independent variables--driver age and sex, vehicle age and size, number of vehicle occupants, and route geometry--were analyzed by using statistical methods. The third measure of speed variation--direction of speed change--was analyzed by using a graphical overlay method.

Statistical Methods

Because the data base contained categorical (nonmetric) data as well as integral (metric) data, analysis of covariance was used to analyze the data. The nonmetric variables were the driver and vehicle characteristics, and the metric variables were the geometric and number-of-occupants variables (these variables are expressed as absolutes rather than as category data).

The first step in the analysis was to determine the interactions between the metric and nonmetric data. A correlation matrix that uses Pearson's correlation coefficient (R^2) was considered appropriate for this purpose. The results of this analysis are given in Table 1. There appear to be no significant interactions between any of the metric and nonmetric variables. The most

Figure 2. Speed profiles for routes 1 and 2 of the Gatineau Parkway.



Note: 1 km ≈ 0.62 mile.

significant interaction occurs between number of occupants and driver age (correlation 0.2542). These results indicate that analysis of covariance can be safely carried out on all of the metric and nonmetric variables listed without concern about possible interactions between the two types of variables that would confuse the results.

The results of the analysis of covariance are given in Tables 2 and 3. Table 2 gives the results of the analysis between the dependent variables and the independent variables. For frequency of speed change, columns 1 and 2 of this table show the overall model to be significant at the 0.0021 level. Therefore, the variables selected are the ones most likely to influence the location of a speed change, and no other possible factors have been omitted. The fact that there are no significant interactions between any of the nonmetric variables suggests that none of the nonmetric variables affect the dependent variable by affecting each other. Because this research considers a 0.01 level of significance to be adequate, the joint additive main effect is also insignificant. In the same way, none of the nonmetric variables independently account for any significant portion of the variation present in the dependent variable.

On the other hand, the covariates are very significant (0.0000); the significant factor is route geometry expressed in terms of frequency of speed change.

Table 3 elaborates on the statistical findings of Table 2 by showing both unadjusted and adjusted deviations (the mean of each category expressed as a deviation from the grand mean) for each nonmetric variable. The η^2 for each variable indicates the portion of variation in the dependent variable explained by that specific variable. In the frequency-of-speed-change variables (columns 2 and 3), the observed number of speed changes = 16 percent (0.397^2) by any one nonmetric variable. Age of the vehicle and sex of the driver each independently account for 7, 6, and 2 percent of the variation in the dependent variable. Route geometry independently accounts for the greatest portion of variation: 70 percent.

When controlling for the confounding effects of the other variables, the contribution made by each metric variable to the variation in the dependent variable decreases (column 2). Driver age still remains the one nonmetric variable that accounts for the largest portion of the variation in the dependent variable: 5.24 percent.

The multiple R, the statistic at the bottom of

Table 3, indicates the overall relation between the dependent variable and the independent variables, whereas R^2 represents the portion of variation in the dependent variable explained by the additive effects of all metric and nonmetric variables. Both statistics show the ability of the independent variables to explain the variation in the dependent variable ($R = 0.897$ and $R^2 = 0.805$).

From this analysis, it can be concluded that

1. The variables selected to study the frequency of speed changes are a fairly complete set.
2. The route geometry represented by Leisch's frequency of speed change is the strongest single factor affecting the frequency or the location of a speed change.
3. Driver age is the second most significant factor affecting frequency of speed change.

Columns 4 and 5 of Tables 2 and 3 deal with the analysis of the second measure of speed variation, magnitude of speed change. The fact that the overall effect is not significant suggests the possibility that other factors besides those listed affect the dependent variable. The overall two-way interaction approaches significance (0.02), and interactions occur between the variables for vehicle age and vehicle size, which are close to significant (0.08). But, as specified before, only levels of significance 0.01 or greater were accepted. Therefore, because of the nonsignificant two-way interactions, none of the nonmetric variables indirectly accounts for the variation in the dependent variable through another nonmetric variable. Neither the joint additive effect nor any of the main effects account for a significant portion of the total variation. Therefore, none of the nonmetric variables affects the dependent variable, and none of the metric variables or covariates affects the dependent variable.

Columns 4 and 5 in Table 3 show that driver age is the single most significant variable, accounting for 12.82 percent of the variation in the dependent variable. This variable is followed in significance by driver sex, vehicle age, and vehicle size, which are responsible for 1.06, 0.49, and 0.372 percent, respectively, of the total variation of the dependent variable. The two metric variables account for 1.35 and 1.3 percent of the variation. This makes these two variables the second and third most significant variables affecting the dependent variable. Because of the near-significant overall two-way interaction, this prohibits further analysis of the data (i.e., the adjusted nonmetric deviations).

The multiple R and R^2 indicate the small amount

Table 1. Correlation between metric and nonmetric variables.

Metric Variable	Nonmetric Variable: Driver Age	Driver Sex	Vehicle Age	Vehicle Size
Leisch's frequency of speed change	-0.020 4	0.097 76	0.058 81	0.032 25
Leisch's magnitude of speed change	0.052 58	0.113 61	0.157 86	0.095 4
Number of occupants	0.254 2	0.012 49	0.080 9	0.283 8

Table 2. Analysis of covariance.

Source of Variation	Frequency of Speed Change: F	Frequency of Speed Change: Significance of F	Magnitude of Speed Change: F	Magnitude of Speed Change: Significance of F
Covariates	43.535	0.000 00	0.810	0.458 92
Leisch's frequency of speed change	84.573	0.000 0	-	-
Leisch's magnitude of speed change	-	-	1.013	0.326 27
Number of occupants	1.736	0.202 51	1.257	0.275 59
Main effects	2.127	0.076 71	1.045	0.441 09
Driver				
Age	1.998	0.146 76	2.604	0.080 22
Sex	0.458	0.506 12	0.034	0.854 66
Vehicle				
Age	2.007	0.160 50	0.131	0.878 32
Size	0.478	0.627 04	0.011	0.989 48
Two-way interactions	0.569	0.819 79	2.661	0.029 96
Age and sex of driver	0.013	0.910 07	2.193	0.154 22
Age of driver and age of vehicle	0.489	0.620 18	2.189	0.138 12
Age of driver and size of vehicle	0.640	0.639 85	0.475	0.753 81
Sex of driver and age of vehicle	1.314	0.260 77	1.314	0.260 77
Sex of driver and size of vehicle	0.030	0.864 44	2.265	0.147 977
Age and size of vehicle	0.140	0.870 21	2.738	0.088 89
Explained	5.329	0.002 1	1.792	0.098 79

Table 3. Results of multiple classification analysis.

Variable	Frequency of Speed Change: Unadjusted Deviations	Frequency of Speed Change: Adjusted Deviations	Magnitude of Speed Change: Unadjusted Deviations	Magnitude of Speed Change: Adjusted Deviations
Leisch's frequency of speed change	-	β 0.835 544 3	-	
Leisch's magnitude of speed change	-	-		β 0.116 179 8
Number of occupants	-	β 0.443 428 8		β 0.114 689
Age of driver (years)	η 0.397	β 0.229	η 0.358	β 0.413
16-20	-0.642 285 28	-2.455 804	1.952 573	2.184 088
20-35	-1.880 948	-0.312 347 4	0.099 993 71	0.105 120 7
35-50	0.741 760 3	-0.810 638 4	-0.409 163 5	-0.483 649 3
50	4.357 147	2.793 198	0.180 948 3	0.270 786 3
Sex of driver	η 0.108	β 0.072	η 0.103	β 0.031
Male	0.199 249 3	0.133 056 6	0.036 590 58	-0.010 833 74
Female	1.892 853	-1.264 755	-0.347 621 0	0.102 840 4
Age of vehicle (model year)	η 0.242	β 0.198	η 0.070	β 0.137
Pre-1970	4.857 147	-0.606 079 1	0.152 485 8	0.669 809 3
1970-1975	1.489 014	-1.625 046	-0.109 162 3	-0.032 409 67
Post-1975	0.357 147 2	0.827 209 5	0.041 263 58	-0.034 021 38
Size of vehicle	η 0.164	β 0.103	η 0.061	β 0.023
Large	-0.279 220 6	-0.461 349 5	-0.038 514 14	0.040 445 33
Intermediate	1.357 147	0.875 396 7	0.098 528 86	-0.006 198 883
Compact	-0.809 524 5	-0.350 418 1	-0.047 625 54	-0.020 256 04
Multiple R^2		0.805		0.191
Multiple R		0.897		0.437

of explained deviation provided by the metric and nonmetric variables (R^2 = 0.191 and R = 0.437).

From this analysis, it can be concluded that

1. The variables selected to represent the variation in the magnitude of speed change do not adequately reflect this variation.
2. Among the variables studied, the driver characteristics (age and sex) seem to have the strongest influence on the magnitude of speed change.
3. Route geometry, in terms of the variables studied, is the second most significant factor affecting the magnitude of speed change, but the amount of variation it accounts for is very small (1.35 percent).

Comparing Overlays

Besides using analysis of covariance to determine the significant factors that affect speed variation, speed profiles of the observed vehicles were drawn up on transparencies based on the same format and scaling used in Leisch's speed profiles. The purpose of this was to verify the statistical results. By using relevant variables to categorize the observed profiles, composite drawings were produced that showed similarities and differences in speed patterns. These composite drawings also permitted the third component of speed variation--the direction of the speed change--to be studied.

In the attempt to group all profiles by some common denominator, grouping by driver age appears to provide the best possible fit. Driver age is therefore the factor that best accounts for direction of speed change.

Figure 2 shows, for each of the two routes, the relation between Leisch's theoretical speed profile and an average speed profile derived from the collected field data. These graphs reinforce the statistical findings. They also shed some light on the third component of speed variation, direction of speed change. It would appear that other variables besides route geometry affect this variable.

CONCLUSIONS AND RECOMMENDATIONS

This project had two objectives: (a) to determine which factors influence changes in automobile speed along a roadway and (b) to evaluate Leisch's speed-profile technique.

With respect to the first objective, the following conclusions are drawn:

1. Route geometry has a significant effect on the location of speed-change frequency.
2. Driver age is the only other variable that significantly affects the frequency of speed change.
3. Variables such as the age and sex of the driver are the most significant factors affecting the magnitude of the speed change.
4. Route geometry affects the magnitude of the speed change but much less than do driver characteristics.
5. Driver age seems to be the factor that most strongly affects the direction of the speed change.
6. Route geometry does not appear to have a strong effect on the direction of the speed change.
7. Other variables besides those researched in this project appear to affect speed variation to a certain extent, especially the magnitude of the speed change.

With respect to the second objective, it can be concluded that Leisch's technique, as it has been formulated, is an acceptable technique for determining where speed changes take place. But, since it does not incorporate into its diagnostics the driver element, which appears to affect the amount and the direction of speed changes, the technique should be researched further so that a driver factor can be incorporated into it.

In the area of research, the following recommendations are made:

1. Because certain speed patterns appear randomly across the various factors studied as seen throughout the manual technique, there is need to further assess other possible factors that affect speed variation. The following factors are felt to be worthy of study, to determine their impact on speed variation: (a) mood of the driver, (b) familiarity with the route, (c) trip purpose, (d) posted speed limit, (e) whether the route is a high-design highway, and (f) whether the route has fewer geometric changes.
2. Further research on Leisch's technique is recommended so that driver characteristics, such as age and sex, can be incorporated into the technique.

In the area of highway design, the following suggestions are made:

1. Because the variation in automobile speed occurs where the horizontal alignment changes, the designer should carefully check to ensure that adequate sight distances are provided in these locations, especially those that could cause speed changes greater than 15 km/h (9 miles/h).
2. As the results for the magnitude of speed change show, there is little the designer can do to control this factor.
3. The designer can do little to affect the direction of the speed change.

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REFERENCES

1. D. Solomon. Accidents on Main Rural Highways Related to Speed: Drivers and Vehicles. Public Roads, July 1964.
2. J. C. Glennon and C. A. Joyner. Re-Evaluation of Truck Climbing Characteristics for Use in Geometric Design. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 134-2, Aug. 1962.
3. J. E. Leisch and J. P. Leisch. New Concepts in Design-Speed Application. TRB, Transportation Research Record 631, 1977, pp. 4-14.
4. B. J. Roszell. A Study of Speed Variation Along a Parkway. Department of Civil Engineering, Carleton Univ., Ottawa, Ontario, Canada, master's thesis, July 1978.
5. Highway Practices in the U.S.A. Public Roads Administration, Federal Works Agency, U.S. Government Printing Office, 1949, pp. 64-80.
6. R. E. Schmidt. Highway Speeds vs. Horsepower. Traffic Quarterly, Vol. 8, No. 3, July 1954, pp. 339-350.
7. B. A. Lefeve. Speed Habits Observed on a Rural Highway. Proc., HRB, Vol. 33, 1954, pp. 409-428.
8. C. H. Lawshe, Jr. Studies in Automobile Speed on the Highway. Journal of Applied Psychology, Vol. 24, 1940, pp. 297-324.
9. J. C. Oppenlander. Variables Influencing Spot-Speed Characteristics: Review of Litera-

ture. HRB, Special Rept. 89, 1966, pp. 3-7, 11, 26-27.
10. H. R. De Silva. Why We Have Automobile Accidents. Wiley, New York, 1946, pp. 43-49.
11. W. H. Glanville. Report of the Director of Road Research for the Year 1954. Road Research 1954, 1955, pp. 12-13, 27-30.
12. A. Taragin. Driver Performance on Horizontal Curves. Proc., HRB, Vol. 33, 1954, pp. 446-466.
13. A. Taragin. Driver Performance on Horizontal Curves. Public Roads, Vol. 28, No. 2, June 1954, pp. 27-39.
14. K. A. Stonex and C. M. Noble. Curve Design and Tests on the Pennsylvania Turnpike. Proc., HRB, Vol. 20, 1940, pp. 429-451.
15. A. Werner. Effect of Recreational Vehicles on High Capacity. Department of Civil Engineering, Univ. of Calgary, Alberta, Canada, thesis, April 1974.
16. A. Taragin. Driver Behaviour as Affected by Objects on Highway Shoulders. Proc., HRB, Vol. 34, 1955, pp. 453-472.
17. A. Taragin. Driver Behaviour as Affected by Objects on Highway Shoulders. Public Roads, Vol. 28, No. 8, June 1955, pp. 152-169, 179.
18. A Policy on Geometric Design of Rural Highways. American Association of State Highway Officials, Washington, DC, 1965.

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Mandatory Safety-Belt Law: The Saskatchewan Experience

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The results of five surveys conducted in Saskatchewan to determine rates of safety-belt use are summarized. On July 1, 1977, legislation was passed requiring all front-seat occupants of motor vehicles to use the available safety restraints. The survey results indicate the changes in rates of safety-belt use from May 1977, the period just before the law was passed (when there was an intensive campaign to educate the public to the use of safety belts), to May 1979, two years after enactment of the law. Information was gathered on various driver, vehicle, restraint-system, and trip characteristics to determine what relations exist between these characteristics and safety-belt use. Among the characteristics considered were driver age and sex, educational level, level of driver education, frequency of safety-belt use, accident experience, and number of miles driven per year; roadway speed limit; length of trip; and vehicle size, model, and year of manufacture. Rates of safety-belt use were higher for various conditions, including drivers between the ages of 26 and 36; male drivers; drivers with a high school education or better; and compact, foreign-made, and/or newer vehicles. It was found that, since the passage of the safety-belt law, injury and fatality rates have decreased in the province even though total accidents and miles driven per year have increased.

In an effort to increase the use of safety belts in vehicles, the province of Saskatchewan passed a law on the mandatory use of safety belts on July 1, 1977. To measure the effects of the law and of publicity campaigns and enforcement, five surveys of safety-belt use were conducted and analyzed to obtain an unprecedented picture of safety-belt use before, during, and after the introduction of the law.

Table 1 indicates the extent of the major surveys, which were conducted in the month of May in 1977, 1978, and 1979. The surveys were made at sampling stations throughout the province, on urban streets, provincial highways, and municipal roads. All vehicles except emergency vehicles, buses, and trucks with a gross vehicle weight (GVW) greater than 10 000 lb were included in the surveys.

RATES OF SAFETY-BELT USE

The May 1977 survey indicates the rate of safety-belt use before the law was passed and reflects the effects of an intensive educational program conducted during that period. The average rate of use at that time was slightly less than 20 percent.

Rates of safety-belt use appeared to be a function of a number of factors. Various driver and vehicle characteristics had a favorable effect. Rates of use were better for post-1974 vehicles, American Motors vehicles, compact and subcompact models, vehicles equipped with safety-belt warning systems, drivers under the age of 45 and particularly between the ages of 26 and 35, and drivers with a high school education or better.

A limited survey conducted in July 1977 indicated the effects of the safety-belt legislation. The average rate of use had increased to more than 52 percent. A second limited survey conducted in October 1977 indicated the effects of enforcement and ongoing publicity campaigns. On an overall basis, the rate of safety-belt use had increased to more than 70 percent.

During May 1978, a fourth survey was conducted to determine the effects of ongoing publicity and varying levels of enforcement. Rates of safety-belt use had declined to slightly more than 55 percent. The effect of enforcement was more significant in larger urban centers than in smaller urban centers that had more nonlocal and out-of-province traffic. Nonlocal drivers may have been less aware of local laws and police policy.

A fifth survey was conducted in May 1979 as part of the continuing program to monitor safety-belt use. Rates of use had leveled off to an average of 64 percent. Enforcement levels were also being monitored and were compared with corresponding rates of use at specific locations.

The total number of accidents and miles driven in the province have increased each year, whereas since July 1977 injury and fatality rates have decreased. In order to keep injuries and fatalities to a minimum, it will be necessary to maintain a high rate of safety-belt use by means of publicity campaigns and enforcement.

SURVEY DESIGN

The design for the Saskatchewan surveys attempted to

1. Establish profiles of vehicle, driver, and environmental characteristics;

Table 1. Extent of three major surveys of safety-belt use.

Type of Roadway	No. of Sampling Sites 1977	1978	1979	No. of Vehicle Occupants Surveyed 1977	1978	1979	Percentage of Provincial Travel
Highway system[a]							
1	11	12	5	1901	1828	641	26.08
2	7	5	2	669	580	162	7.18
3	3	4	2	178	360	94	5.92
4	6	5	3	559	298	178	6.74
5	3	9	2	117	484	43	9.26
6	0	3	2	0	171	84	1.08
Grid roads	3	7	3	54	142	64	9.40
City streets	10	13	6	3352	3760	1797	22.30
	0	7	5	0	1633	785	
Urban streets in communities with more than 500 people	0	7	2	0	1223	680	2.80
Nongrid roads	0	0	0	0	0	0	9.30

[a]Highway systems range from major high-volume highways (system 1) to northern low-volume highways (system 6).

Table 2. Relation between type of reminder device and driver use of safety belts.

Reminder Device	Driver Use of Safety Belts: Did Use Number	Did Use Percent	Did Not Use	Total
None	25	58.5	16	41
Several-second buzzer	18	69.2	8	26
Continuous buzzer	13	81.3	3	16
Instrument panel light	4	80.0	1	5
Unknown	13	52.0	12	25
Total	73	64.4	40	113

2. Allow correlation between self-professed attitudes and observed use of safety belts;
3. Relate enforcement levels to rates of use; and
4. Relate changes in injuries and fatalities caused by motor-vehicle accidents to rates of safety-belt use.

Survey locations were randomly selected from the road systems in the province. Usage rates were determined by stopping each vehicle and obtaining the following information: vehicle make, model, year, and province of registration and the types of safety restraints available to and in use by each occupant. Every tenth driver was interviewed in more detail. The questions included the following: the driver's age, sex, and education level; level of driver education; frequency of safety-belt use; accident experience; number of miles driven per year; opinion of the safety-belt law; opinion of the practicability of his or her safety-belt system and whether he or she had ever been fined for not using a safety belt; the vehicle make, model, year, province of registration, and type of safety-belt buzzer (continuous or not); length of trip and whether the occupants were within 25 miles of home; and the type of safety restraints available to and in use by each occupant of the vehicle.

ANALYSIS OF SURVEY RESULTS

A computer data analysis of the survey results was carried out by using the cross-tabulation subprogram of the Statistical Package for the Social Sciences (1).

May 1978 Survey

The results of the May 1978 survey reflect safety-belt use during the intensive education program conducted prior to passage of the safety-belt law. There was a significant increase in safety-belt use under certain circumstances:

1. All devices installed in vehicles to remind drivers to use restraint devices were effective in increasing the driver's rate of safety-belt use. The effects of reminder devices on safety-belt use are summarized in Table 2. The most effective system was the continuous buzzer [it is significant to note that only 5 percent of drivers had disconnected this buzzer (2)]. The instrument panel light also served as an effective reminder device. It should be noted that the type of reminder device is also a function of vehicle type and year of manufacture. Vehicles with no reminder devices were likely to be older models or "nonpassenger cars".
2. The rate of use of some type of restraint system by drivers was found to increase in a cyclic fashion in relation to the year of vehicle manufacture (see Table 3). The extemely low rate of use prior to 1964 probably reflects the unavailability of such restraint systems in vehicles as then supplied by the manufacturer.
3. A dramatic change in the type of restraint used is shown for vehicles manufactured since 1973. Drivers' rate of use of the lap belt decreased only with a corresponding increase in use of the lap-and-shoulder restraint. This change in type of use corresponds to a change in restraint-system design, the result of which is that a large portion of the vehicle population now have permanently attached lap-and-shoulder restraints. Rates of driver safety-belt use and year of vehicle manufacture were found to have a high degree of correlation for the general vehicle population (see Table 4). No significant deviation was noted when specific subgroups, consisting of North American manufacturers or foreign countries of manufacture, were examined except in the case of vehicles built in the Scandinavian countries.
4. Vehicles manufactured in Scandinavia showed the lowest correlation between year of manufacture and rate of safety-belt use. However, as Table 5 indicates, the same group showed an extremely high rate of safety-belt use throughout the year-of-manufacture range considered. Vehicles in the categories of specific North American manufacturers or specific countries of origin did not show rates of safety-

Table 3. Driver use of safety belts by year of vehicle manufacture estimated from May 1978 survey.

Vehicle Year	Driver Use of Safety Belts							
	Lap-and-Shoulder		Lap		None			
	Number	Percent	Number	Percent	Number	Percent	Unknown	Total
Pre-1963	2	1.9	14	13.1	81	75.7	10	107
1964	1	1.8	19	34.5	35	63.6	-	55
1965	2	1.9	52	50.5	49	47.6	-	103
1966	1	0.8	65	51.6	59	46.8	1	126
1967	2	1.2	92	57.1	67	41.6	-	161
1968	15	8.0	101	54.0	71	38.0	-	187
1969	23	10.8	110	51.9	79	37.3	-	212
1970	32	15.1	96	45.3	84	39.6	-	212
1971	42	15.0	126	45.0	112	40.0	-	280
1972	93	20.9	189	42.4	164	36.8	-	446
1973	100	19.8	266	52.6	139	27.5	1	506
1974	220	56.7	76	13.5	168	29.8	-	464
1975	376	50.9	121	16.4	241	32.6	1	739
1976	520	57.5	89	9.8	295	32.6	1	905
1977	566	60.1	64	6.8	311	33.1	-	941
1978	384	64.1	24	4.0	190	31.7	1	599
1979	2	66.7	0		0		1	3
Unknown	-		-		-		139	139
Total	3281	53.1	1504	24.3	2145	34.7	155	6185

Table 4. Correlation coefficients between year of vehicle manufacture and driver use of safety belts for vehicles from various sources of manufacture.

Source of Vehicle Manufacture	r	Mean	Standard Deviation	n
North America	0.258 99	1.03	0.8815	5247
General Motors	0.268 27	1.03	0.8935	2283
Ford	0.245 37	0.99	0.8738	1646
Chrysler	0.288 22	1.06	0.8752	1179
American Motors	0.431 62	1.20	0.8097	106
Foreign	0.233 57	1.24	0.8956	938
England	0.484 70	1.31	0.9029	48
France	0.261 40	1.44	0.8819	9
Germany	0.494 47	1.34	0.8899	125
Italy	0.520 97	1.33	0.8165	15
Japan	0.173 93	1.28	0.8620	456
Scandinavia	0.171 35	1.75	0.6530	52
Overall	0.248 41	1.06	0.8869	6185

belt use that were significantly different from the norm.

5. Although drivers between the ages of 36 and 65 had the highest level of safety-belt use, there is no statistically significant difference in the rate of use between various age groups.

6. Proximity to home had no noticeable effect on safety-belt use.

7. The effect on usage rates of receiving a fine for violation of the safety-belt law was not significant.

8. Driver education had a favorable though not statistically significant effect on safety-belt use.

May 1979 Survey

A fifth survey conducted in May 1979 indicated the effects of continuing enforcement and publicity. The overall rate of safety-belt use had reached a level of 64 percent. This survey included all roadway systems but was not as detailed as the previous surveys.

ANALYSIS OF VARIANCE

A three-way analysis of variance was carried out to investigate the effects on safety-belt use of safety-belt availability and vehicle model, year, and manufacturer.

The first part of the analysis considered only vehicles manufactured in North America. Only the difference in safety-belt use between the various types of passenger vehicles was shown to be significant even after correcting for model, year, and safety-belt availability. A similar result was observed when manufacturer was substituted for model. However, when both manufacturer and model were considered along with year of manufacture and safety-belt availability, it was found that manufacturer and model were not significant to safety-belt use (see Table 6). When a similar analysis was carried out for cars of European and Japanese manufacture, it was found that country of origin was a significant variable whereas vehicle type was not. This probably indicates that in the Saskatchewan driving population there is a considerable degree of homogeneity among the drivers purchasing vehicles from each of the countries of origin.

Various factors that were thought to have an effect on rates of safety-belt use were analyzed to find linear regression models for restraint use (see Table 7). Once again, year of manufacture emerged as a favorable factor in increasing the rate of use when the overall North American and foreign samples and the source-of-manufacture subsamples were considered. An exception to this relation was vehicles manufactured in France and Sweden. This may have resulted from the small sample size of the vehicles manufactured in France and the consistently high rate of safety-belt use for vehicles manufactured in Sweden.

As one would expect, the rate of safety-belt use showed a high positive correlation with availability. To ensure that this relation did not overshadow other possible usage relations, an availability category was defined and coded as follows: 0 for no belt available, 1 for lap restraint available, and 2 for lap-and-shoulder restraint available.

The light-duty truck was noted to have a negative effect on the level of safety-belt use. This appeared to be true for all subgroups in which light-duty trucks were included.

USE OF PREDICTOR EQUATIONS

The probable rates of driver use of safety belts for specific vehicles in the overall population or in various subpopulations can be evaluated by using the linear equations given in Table 6. For example, for

Table 5. Observed relation between source of vehicle manufacture and driver use of safety belts.

Source of Vehicle Manufacture	Driver Use of Safety Belts: Lap-and-Shoulder Number	Percent	Lap Number	Percent	None Number	Percent	Unknown	Total
General Motors	903	37.3	643	26.5	872	36.0	4	2422
Ford	658	37.4	431	24.5	669	38.1	0	1758
Chrysler	497	40.9	308	25.3	409	33.6	2	1216
American Motors	47	44.3	33	31.1	26	24.5	0	106
International Harvester Company	1	3.6	12	42.9	15	53.6	0	28
England	29	60.4	5	10.4	16	33.3	0	48
France	6	66.7	1	11.1	2	22.2	0	9
Germany	78	62.4	12	9.6	35	28.0	0	125
Italy	8	53.3	4	26.7	3	20.0	0	15
Japan	251	55.0	82	18.0	123	27.0	0	456
Sweden	45	86.5	1	1.9	6	11.5	0	52

Table 6. Effect of model class on driver use of safety belts.

Vehicle Class	No. of Vehicles in Class	Class Effect: Raw	Adjusted[a]
Intermediate			
A-body	861	0.12	0.07
Specialty	169	0.08	-0.08
Standard or full size	1668	0.02	0.05
Luxury			
C- or D-body	97	0.14	0.00
E-body	76	0.06	-0.10
Mini specialty	46	-0.01	-0.11
Specialty	187	-0.08	-0.15
Compact	611	0.18	0.15
Subcompact			
Foreign	488	0.28	0.21
U.S.	162	0.21	0.08
Super sport	11	-0.06	0.03
Small van	165	-0.36	-0.22
Pickup	961	-0.38	-0.28
Utility	28	-0.13	-0.09
Carry-all	10	0.44	0.39
Pickup car	19	-0.69	-0.78
Foreign sports car	22	0.12	0.11

[a]Class effect when adjustments have been made for confounding effects of model year and belt availability.

Table 7. Predictor equations for safety-belt use for sample groups.

Source of Vehicle Manufacture	Predictor Equation to Determine Driver Rate of Safety-Belt Use
North America	0.3153 (availability) + 0.035 019 (year) -0.3227 (pickup) - 0.7894 (Ranchero) -0.3096 (van) - 0.2004 (compact) - 2.0206
General Motors	0.3627 (availability) + 0.0334 (year) -0.3050 (pickup) - 0.2083 (specialty) -1.9799
Ford	0.3689 (availability) + 0.029 43 (year) -1.0337 (Ranchero) - 0.2543 (pickup) -0.2129 (compact) - 0.3445 (Mustang) -0.2725 (van) - 1.7325
Chrysler	0.1569 (availability) + 0.059 02 (year) -0.5362 (pickup) - 0.6807 (van) -1.3808 (U.S. mini) - 0.4310 (compact) -3.4780
American Motors	0.0849 (year) - 4.9496
Foreign	0.4073 (availability) + 0.014 88 (year) -0.2988 (full size) - 0.4250 (pickup) -0.3214 (intermediate) - 0.5053
England	0.0884 (year) - 5.1264
France	1.4444
Germany	0.4892 (availability) + 0.051 92 (year) -3.2859
Italy	0.1854 (year) -12.17
Japan	0.4645 (availability) + 0.042 31 (year) -0.3456 (pickup) - 2.7496
Sweden	1.75
Overall	0.3372 (availability) + 0.0314 (year) -0.3121 (pickup) - 0.7866 (Ranchero) -0.2675 (van) + 0.4337 (Swedish) -0.1998 (compact) + 0.2552 (Volkswagen) -1.7826

Note: Year was coded as follows: 1900 = 0, 1975 = 75.

a Ford compact built in 1976, safety-belt use can be predicted by using the overall regression, the fit for American vehicles, or the equation that predicts safety-belt use for Ford vehicles. Since the car is a 1976 model, it will be equipped with a lap-and-shoulder belt combination, which gives an availability of 2. Thus,

$$\text{Overall use} = 0.3372\,(2) + 0.031\,41\,(76) - 0.1998 - 1.7826 = 1.08 \qquad (1)$$

$$\text{American use} = 0.3153\,(2) + 0.035\,019\,(76) - 0.2004 - 2.0206 = 1.07 \qquad (2)$$

$$\text{Ford use} = 0.3689\,(2) + 0.029\,43\,(76) - 0.2129 - 1.7325 = 1.03 \qquad (3)$$

If one uses the Chrysler use equation, a 1975 Dodge van would be expected to have a use of 0.1569 (1) + 0.059 02 (75) - 0.6807 - 3.4780 = 0.42.

It was found that detailed examination of these data did not provide an answer to what kind of active safety-belt system had the highest rate of use among drivers. Apparently identical belt systems in two classes of vehicles were observed to have greatly different rates of use. This was noted particularly for vehicles of the Chevelle-El Camino type: Safety-belt use appears to be much lower in the El Camino type of vehicle. This difference may be attributable to either a difference in trip type or a difference in attitudes toward safety and legal compliance between the two subgroups of drivers.

Cars manufactured in Sweden were observed to have a consistently high rate of safety-belt use. There are no other safety-belt combinations that are directly comparable to the ones in Swedish vehicles, but it would seem likely that the usage rate is only partly attributable to the particular restraint mechanism. It may also be caused by other factors, such as attitudes toward safety or compliance with traffic laws.

As noted previously, in May 1977 the use of lap-and-shoulder belts increased in vehicles manufactured since 1974, when the belts became a permanent combination. Foreign cars, American Motors vehicles, and compact and subcompact models still had higher rates of use.

EFFECT OF ENFORCEMENT OF SAFETY-BELT LAW

The effects of enforcement on safety-belt use can be illustrated as follows:

Size of Urban Center	No. of Tickets per 1000 Population	Rate of Safety-Belt Use (%)
Large	0.10	58
	1.59	68
Small	3.34	61
	17.21	60
	28.80	63

It can be seen that enforcement level has a significant effect on rates of safety-belt use in large urban centers.

The effects of enforcement in rural and small urban centers may not be significant because of the greater number of out-of-town and out-of-province drivers. The composition of vehicle registrations in large and small urban centers is given below:

	Vehicle Composition (%)		
Roadway System	Local	Saskatchewan	Out of Province
Larger urban centers	95.0	98.1	1.9
Small urban centers	87.5	99.1	0.9

Clearly, there are more nonlocal vehicles in the small urban centers. The difference, however, is not statistically significant.

Seatbelt use is also affected by local police department policy; i.e., some police detachments issue warning tickets for safety-belt violations or issue tickets only if the violator has been involved in a motor-vehicle accident. Abrupt or nonpublicized changes in enforcement policy had a noticeable effect on safety-belt use. During the October 1977 survey, safety-belt use on the municipal grid road system was found to be higher than anticipated from past trends (2). This was later found to be the effect of several police "roadblock safety-belt checks" that had been set up in the area during a two-week period before the survey.

In the vicinity of larger urban centers, combined enforcement by urban police and rural police forces had a significant effect on safety-belt use:

No. of Tickets per 1000 Population	Area Level of Safety-Belt Use (%)
0.26	55.4
6.12	75.1

INJURY AND FATALITY RATES

As Figure 1 shows, although the total number of accidents and miles driven per year increased in 1978, injury and fatality rates decreased (3,4). To keep injuries and fatalities to a minimum, it will be necessary to maintain a high rate of safety-belt use through publicity campaigns and enforcement.

In 1976, Ontario passed a mandatory safety-belt law and reduced speed limits on their provincial highways. During 1976, the injury rate declined 13.7 percent and the fatality rate declined 16.1 percent (5). In 1977, Manitoba had an increase in injuries and fatalities caused by motor-vehicle accidents. Without the safety-belt law, use of restraint devices has remained at 18 percent (6).

SUMMARY

During the period from May 1977 to May 1979, rates of safety-belt use in Saskatchewan varied significantly. The changes are shown in Figure 2. In May 1977, during an extensive publicity campaign and educational program, overall rates of safety-belt use were approximately 18 percent. Several driver and vehicle characteristics had a beneficial effect on rates of use: vehicles with safety-belt buzzers, drivers between the ages of 26 and 35, male drivers, and drivers with a high school education or better.

In July 1977, shortly after a mandatory law on safety-belt use had been passed, another survey was done. The overall rate of use had increased to more than 52 percent. During the period from July to October, the safety-belt law was in effect but was not being enforced. On October 1, enforcement began, and shortly thereafter rates of safety-belt use were again surveyed. The rate had increased to more than 70 percent.

Between October 1977 and May 1978, the safety-belt law was enforced at varying levels throughout the province. By May 1978, the rate of use had decreased to approximately 55 percent.

From May 1978 to May 1979, the safety-belt law continued to be enforced at varying levels. Publicity campaigns continued, and membership in the "Seatbelt Survivor's Club" grew considerably. In May 1979, rates of safety-belt use had increased to 64 percent.

Although total accidents and miles driven per year in the province have increased, injury and fatality rates have decreased. If rates of safety-belt use can be maintained at a high level, this trend should continue.

A higher level of law enforcement increases usage rates, particularly in larger urban centers. The effect of enforcement is somewhat diminished in smaller urban centers, where there is more nonlocal and out-of-province traffic.

CONCLUSIONS

As a result of the research reported in this paper, the following conclusions can be drawn:

1. The existence and enforcement of Saskatchewan's safety-belt law seem to have had a major effect on patterns of safety-belt use in the province. The safety-belt legislation originally increased the rate of use from 18 to 52 percent. After enforcement began in October 1977, the rate increased to 70 percent. After eight months of varying levels of enforcement, the usage rate decreased to 55 percent in May 1978. By May 1979, with increased enforcement and continuing publicity, the rate had increased to 64 percent.
2. Many vehicle, driver, and environmental factors had a favorable effect on rates of safety-belt use, including (a) vehicles of recent manufacture, subcompact and compact models, vehicles with buzzer or warning-light reminder systems, and foreign models; (b) male drivers and drivers with a high school education or better; and (c) high-speed, high-volume roadways and long trip distances.
3. Although total accidents and miles driven in the province have increased, safety-belt use has helped to decrease injury and fatality rates.
4. High levels of law enforcement increase usage rates, particularly in urban centers. In rural areas, the greater numbers of nonlocal drivers decrease the effects of local enforcement levels.

It is quite probable that attitudes toward safety and compliance with traffic laws, along with socioeconomic factors, affect both the type of vehicles that people buy and their use of restraint systems. This seems to be a severe confounding effect that serves to mask much of the change in use that can be attributed to more convenient safety-belt systems. In spite of this, however, it is clear that the use of safety belts is

Figure 1. Saskatchewan accident statistics: 1971-1979.

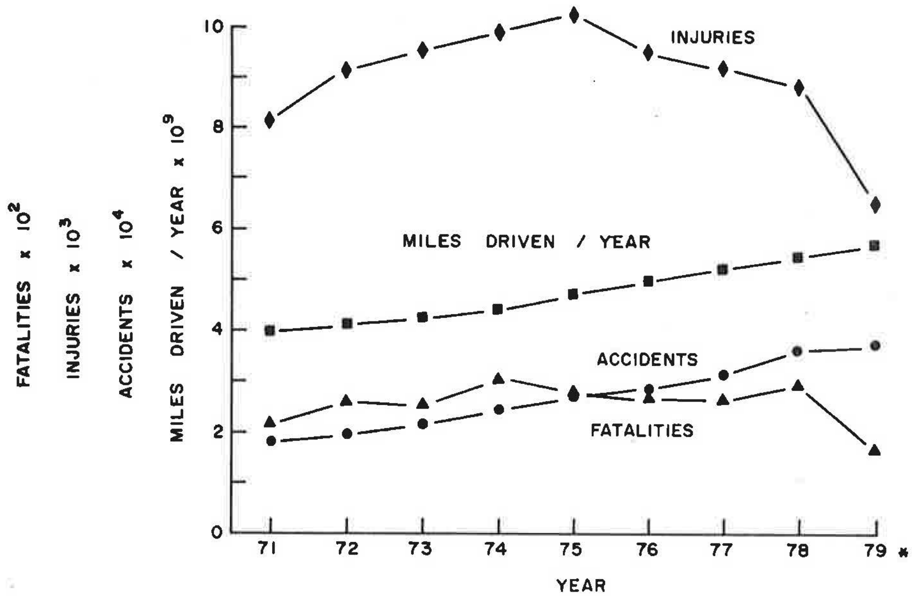
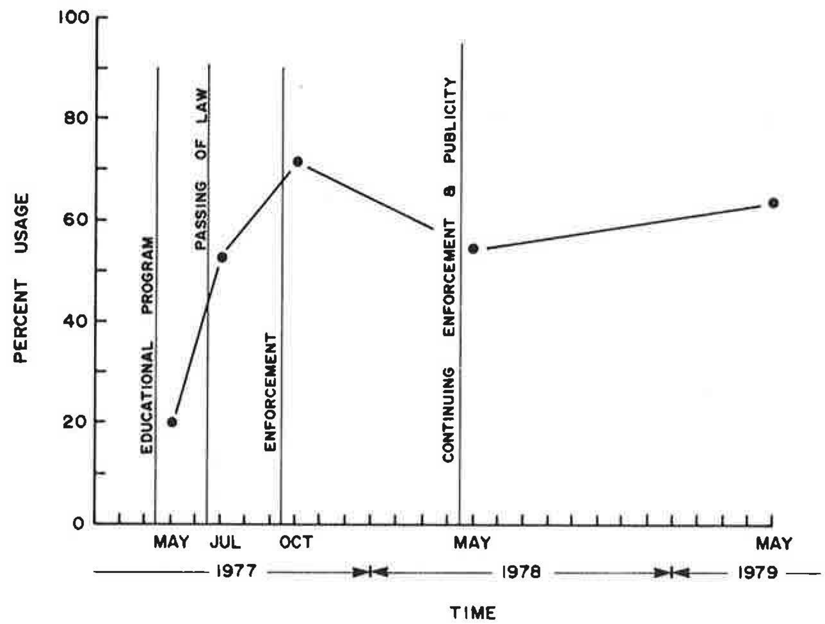


Figure 2. Safety-belt use in Saskatchewan between May 1977 and May 1979.



considerably greater among people who drive newer vehicles and thus that the changes in safety-belt systems over the past decade have favored increased use.

REFERENCES

1. N. H. Nie and others. Statistical Package for the Social Sciences, 2nd ed. McGraw-Hill, New York, 1970.
2. L. G. Watson and D. E. Rivett. May, July, and October Seatbelt Usage Surveys. Transportation Centre, Univ. of Saskatchewan, Saskatoon, Dec. 1977.
3. Highway Traffic Board Accident Statistics. Saskatchewan Highway Traffic Board, Regina, Annual Rept., 1977.
4. 1976 Accident Statistics. Saskatchewan Department of Highways, Regina, 1976.
5. Motor Vehicle Accident Facts. Canada Ministry of Transport, Ottawa, Ontario, 1976.
6. Relationship of Drivers Wearing Seatbelts and Accidents. Motor Vehicle Branch, Manitoba Department of Highways, Winnipeg, 1977.

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Evaluation of Signs for Hazardous Rural Intersections

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An experiment to evaluate the effectiveness of several different signs (or sign sequences) in informing motorists of an intersection on the road ahead in rural two-lane situations is described. Typically, intersections that would require these treatments would be those where stopping sight distances for prevailing speeds were inadequate. As random motorists approached and passed through two test intersections, they were "tracked" by means of a data-collection system that collected time intercepts of motorists at 60-m (200-ft) intervals in the vicinity of the intersection. These data were supplemented by manually collected vehicle registration and classification data and, in selected instances, survey data collected from motorists who had passed through the intersections. The results essentially showed that a regulatory speed-zone configuration and lighted warning signs were more effective than more traditional unlighted warning signs in reducing motorists' speeds in the vicinity of the intersection and increasing their awareness of both the signs and conditions at the intersection.

Motorist behavior at intersections is among the most important concerns of traffic engineers and safety officials. Literature in the field ranges from capacity- and operations-related issues to driver and pedestrian safety and complex simulations of traffic patterns. Whereas the urban motorist typically deals with intersection problems many times during the course of the average work or shopping trip, the motorist in rural areas faces a somewhat different problem--i.e., other vehicles turning on to, or off of, the primary route at isolated, often sight-restricted, locations, a situation that can be unexpected and hazardous.

In 1975, 16 percent of fatal rural accidents and 24.8 percent of all rural accidents occurred at intersections (1). Considerable research has been undertaken to identify methodologies to be used to assess how hazardous such situations are (2). King and others (3) have provided an extensive review of research dealing with warning devices used at intersections, especially those in rural areas. Their preliminary work provided the basis for the experiment reported in this paper.

The experiment discussed here was undertaken at two sites in central Maine (east of Waterville on ME-137) under the auspices of the Federal Highway Administration (FHWA) research program at the FHWA Maine facility. The general purpose of the experiment was to evaluate several alternative signs or sign sequences that could be used to warn motorists of a hazardous, sight-restricted intersection ahead in a rural two-lane situation. Signing alternatives that were examined ranged from the standard intersection warning symbol (a cross) to vehicle-activated signs with flashing warning lights.

Data that were collected during the course of the experiment included automatically collected speeds of vehicles as they entered the test sites and passed by the intersection, manually collected vehicle classification and registration information, and, for selected sign-site combinations, survey information from some motorists regarding their recollection of the signs and other details about the intersections and their reactions to them.

IMPLEMENTATION OF THE EXPERIMENT

The basic purpose of the experiment was to evaluate several types of signs that could be used to warn motorists of an intersection ahead. Individual motorists were tracked as they approached and passed through the intersections by use of a series of sensors placed on the road surface at 60-m (200-ft) intervals. The sensors were connected to a recording unit in a mobile data-collection vehicle, where the data were recorded on magnetic tape for later processing. The general capabilities of the facility's mobile data-collection system and processing equipment have been described elsewhere (4).

Site Selection

Two sites were used in the experiment, primarily to ensure that effects of various signs were not unique to a specific site. Both sites were on ME-137 between the cities of Waterville and China. ME-137 is a two-lane road with rural characteristics that is frequently used by nonlocal motorists (the nearby China Lakes region is a tourist area in central Maine).

The intersections at both sites were reasonably well hidden. Stopping sight distances were less than 150 m (500 ft), which requires some warning sign to be provided. One site was on a crest vertical curve, and the other was on a horizontal curve and was further obscured by considerable vegetation.

Figure 1 shows the layout of site 1 and the typical positioning of the data-collection equipment. Sign locations A, B, and C are for experimental signs and also for the sign in the base (existing) condition (see Figure 2 and the discussion below of the various sign treatments). Only sign treatment 4 requires three locations. Location B is the position for treatments 2, 3, 5, and 6.

Data Collection

In addition to the electronic data collected as motorists were tracked through the experiment area, some manual data were also collected. Observers were stationed at the mobile system vehicle (van) near the intersection, where they could observe vehicle classification (automobile or recreational vehicle), Maine or non-Maine license-plate classification, and whether or not an entering vehicle was present on the side road at the intersection. These data were observed and recorded for every "lead vehicle" (the first vehicle in a queue, if a queue exists) and were input to the magnetic tape record with the electronic data. The observers were also able to monitor the electronic equipment (e.g., the road sensors). In addition, on selected days a survey was administered to motorists who had passed through the intersection.

Data collection alternated between the two intersection sites and two others (from another experiment), so that data collection was not continuous in one area over the entire summer. In general, all data were collected between June and October of 1978.

VARIABLES AND MEASURES

Independent Variables

The principal variable of interest in the research was the sign condition displayed, but several other factors were also considered. These other factors ensured that the effectiveness of the signs was consistent over a variety of other conditions.

Figure 1. Layout of intersection at site 1 showing sensor and sign locations.

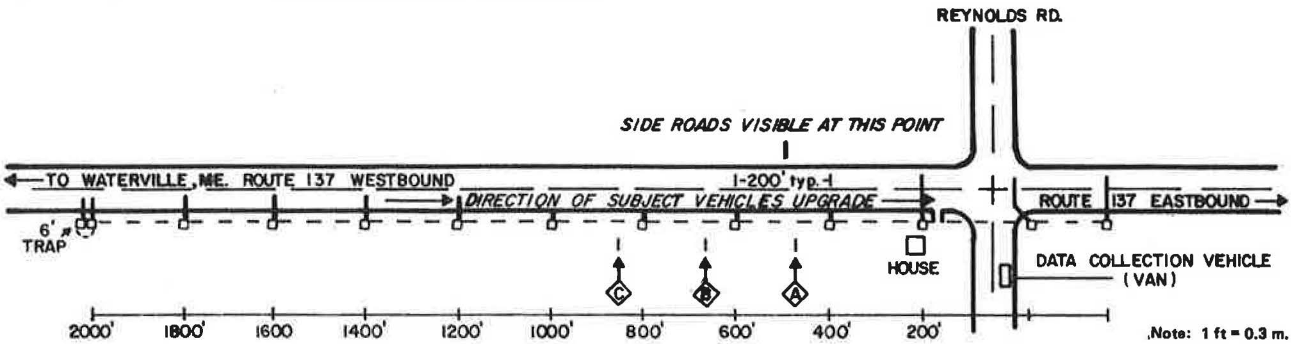
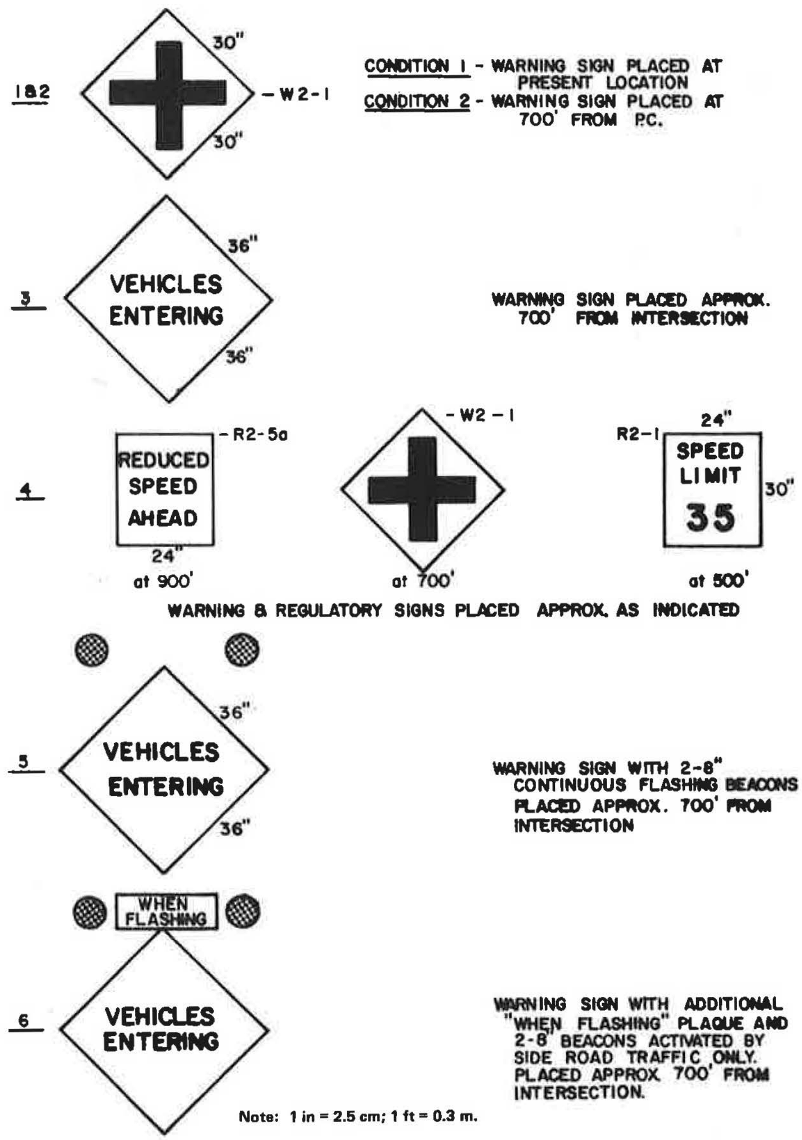


Figure 2. Sign treatments.



Sign Treatments

Five different sign treatments and a base (existing) condition were tested (Figure 2). The treatments covered a variety of approaches to intersection signing.

The first (base) condition was taken as the existing condition at each site. At both sites, the only sign warning of the intersection was the cross symbol (W2-1 in Figure 2). In each case, however, the sign had been placed somewhat closer to the intersection than the Manual on Uniform Traffic Control Devices (MUTCD) (5) suggests. The distance from the intersection to the sign in the existing position was approximately 150 m (500 ft).

The second condition incorporated the same sign

(W2-1), but it was located more in accordance with MUTCD standards [at 213 m (700 ft)] in order to maintain a constant relation between the data-collection equipment and each sign position.

The third sign condition was a warning sign that read VEHICLES ENTERING. A word message was chosen to provide a comparison between symbol and language messages and to provide a consistent message that could be used with activated signs. Although this is not a "standard" sign, the wording is quite common.

The fourth condition was a three-sign sequence that incorporated a regulatory speed zone (R2-1 and R2-5a) with the intersection warning sign. Inclusion of this condition allowed for a comparison between advisory and regulatory sign strategies.

The fifth treatment used the same message as the third but was made more emphatic by the addition of continuously flashing beacons. The lighted signs were included in the sequence primarily because of results from previous facility experiments (6), which indicated that such lights were successful as an attention-getting device (at a minimum).

The final treatment was the most emphatic and conveyed the most positive information to motorists. A WHEN FLASHING message was added to sign condition 5 to indicate that the flashing beacons were on only when a vehicle was present on the side road at the intersection. The flashing lights were activated by two events: (a) when a vehicle was present on the side road at the intersection and (b) when an approaching vehicle struck a particular sensor, turning on the lights. It should be noted that at one of the sites the motorist was always in a position to see the lights come on whereas at the other site the lights would be on (if a vehicle were present) when the motorist first saw the sign.

The sign treatments were randomly ordered at the two sites so that data were not collected sequentially from increasingly emphatic signs.

Sites

The primary differences between the two sites used in the research were as follows: One was on a vertical curve whereas the other was on a horizontal curve, one had an "extra" sign present (i.e., a standard curve warning arrow), and one had a few houses present at the intersection. Comparisons can be made based on the relative effects at both sites. Other geometric characteristics, such as lane and shoulder width, were quite similar at both sites, and the base speed limit was the same--80 km/h (50 miles/h).

Ambient Light

Data were collected during both day and night hours (twilight data were discarded). The day-night stratification provided a reasonable basis for determining whether light conditions caused any change in sign effectiveness.

Presence of a Vehicle at the Intersection

In general, it seemed safe to assume that motorists would behave differently if, when they could see the intersection, they saw a potential conflict--i.e., a vehicle waiting to turn on to or cross the road on which they were traveling. If the signs had any impact at all, the difference in behavior would be especially marked when the sixth sign condition was displayed. Thus, the data were stratified as follows: motorists who traversed the site when no vehicle was at the intersection and motorists who traversed it when there was a vehicle present.

Since side-road volumes were quite low and sporadic, a vehicle (van) was deliberately positioned on the side road for 50 percent of the data collection. The van was pulled up on the side road at the intersection so that it appeared ready to turn on to the main road. One of the observers was always behind the wheel, and at night the headlights were turned on.

Motorist Familiarity with the Road

Another issue of interest was the impact on sign effectiveness of motorists' familiarity with the road. For example, it could be argued that everyday users of the road would certainly be aware of the changing signs and the activity at the intersection and would therefore respond differently to the signs than would a one-time road user.

In order to study the potential difference in behavior between these two groups of motorists, manual data were taken by the observers so that motorists could be classified according to whether or not their vehicles were registered in Maine, a crude proxy for motorist familiarity with the road. It should be noted that it was possible to make this determination only during the day.

Entry Speed

Results from other experiments (6) have indicated a significant correlation between motorist response to road signs and speed; i.e., faster drivers react to signs differently than slower drivers. Motorists were therefore examined according to their entry speed; i.e., speed was used as a covariate in the analysis of the data.

Weather Conditions

Although a full sample of weather conditions was not possible, data were collected on rainy days so that at least a partial analysis was done for "good" versus "bad" weather conditions.

Type of Vehicle

In the past, axle counts have been used to represent the type of vehicle passing through a site. In this experiment, the observers classified vehicles as either automobiles or recreational vehicles. The former class included automobiles and pickup trucks (with or without low caps), and the latter included large motorized mobile homes, pickups with large (over-cab) caps, larger vans, and cars or pickups with trailers.

Other Variables as Restraints

There were several other factors that could be considered as independent variables and provide further levels of stratification. To keep the analysis (and data collection) manageable, the more important of these were used either as restraints in the experiment or as conditions for eliminating some data. These variables included

1. Day of the week--To provide as much homogeneity in the traffic mix as possible, data collection was limited to weekdays only;
2. Turning vehicles--Vehicles that entered the system but then turned off at the intersection were discarded;
3. Queue vehicles--Because vehicles that were in a queue (less than 6-s headway to the preceding vehicle) tended to react more to the vehicle

immediately in front of them than to other conditions, including signs, they were eliminated from consideration and only lead vehicles were considered; and

4. Slow vehicles--Vehicles that had an entry speed of less than 56 km/h (35 miles/h) were discarded as being anomalous.

Dependent Variables and Measures of Effectiveness

A set of 12 dependent variables were measured for each vehicle as it passed through the experiment area. The raw data took the form of time intercepts of the sensors on the road surface. These data were later processed so that a vehicle was "tracked" through the area. Each of the 12 dependent variables was then a speed or speed-related characteristic of the vehicle's passage. Each of these variables was selected so that the interpretation was directly related to the effectiveness of the particular sign treatment and thus to the minimization of the hazard. All speeds were measured over 61-m (200-ft) lengths except entry speed, which was calculated over a 1.8-m (6-ft) trap.

Entry Speed

As indicated, the entry speed of vehicles was used as an independent variable to account for faster and slower drivers. The other principal use for this variable was to establish the similarity among the various samples of drivers that passed through the experiment site. That is, the average entry speeds of motorists experiencing different combinations of experiment conditions--e.g., sign 4, dry pavement, night--were compared and tested for statistical similarity. The similarity of the samples established that speed differentials noted at other locations (at the intersection, for example) could be attributed to various experiment conditions and were not intrinsic to the samples of motorists used.

Initial Speed Change

Soon after each vehicle entered the experiment area, the sign treatment was visible, although not legible. The first variable that reflected any possible reaction to the treatment was the initial speed change, measured over the first 122 m (400 ft) of the experiment area.

Speed Changes at Signs

Three other speed changes were also measured. These changes were in the vicinity of the three test sign locations. Each of the speed changes was measured as the difference between the speeds calculated over the links ending 91 and 30 m (300 and 100 ft) ahead of the sign location. Measuring the speeds at these points illustrated any speed change that resulted from motorists' having read the sign. Measurement of these speed changes also provided a general overview of when speed changes occurred on the approach to the intersection.

Speed at the Intersection

One of the most important measures of the effectiveness of signing was the average speed of vehicles at the hazard itself (in this instance, the intersection). A lower speed indicated a safer situation.

Overall Speed Change

Another measure of the overall effectiveness of a treatment was the overall decrease in speed from entry to speed at the intersection.

Distance to Point of Minimum Speed

It was possible that the minimum speed attained on the approach to the intersection was achieved at some point other than the immediate area of the intersection. For example, motorists who saw no vehicle in the intersection may have speeded up as they went through the intersection itself. Thus, the location at which minimum speed occurs is of interest.

Maximum Speed Change

The maximum speed change was indicative of the abruptness of motorists' reactions to either the signs or the intersection itself. Assuming that speeds at the intersection were within acceptable limits, the more desirable sign treatments would result in a more gradual reduction in speed.

Location of Maximum Speed Change

The location at which the maximum speed change occurred was also observed. For example, if the maximum reduction in speed occurred in the immediate vicinity of the intersection, it could be interpreted to mean that motorists were surprised by the intersection, or by the activity there, which would indicate a relatively ineffective sign treatment.

Speed Change at the Intersection

The last speed change of interest was that which occurred at the intersection (the inclusion of this variable is based on the assumption that the maximum speed change typically did not occur at the intersection). Comparison of this value with the other speed changes provided an indication of the effectiveness of the various sign treatments in relation to the effect on the motorist of actually seeing the intersection and/or the activity in the intersection area.

Exit Speed

The last variable calculated was vehicle speed on leaving the intersection. Comparison of this value with vehicle speed at the intersection provided an indication of how rapidly motorists resumed their normal speed. It also provided the basis for a comparison with information obtained from the motorist survey--i.e., a comparison of actual vehicle speeds versus the speeds perceived by motorists.

MOTORIST SURVEY

An unknown in many experiments similar to the one described here results from the fact that only overt actions on the part of the motorist are detected--e.g., whether the average motorist slowed down at point x. It can be argued that motorists seeing certain signs may not actually slow down but do become more alert to the hazard that is present (6). To address this issue, a survey was designed for, and administered to, random motorists who had just driven through the experiment area.

Several kinds of information were solicited in the survey, including background information (e.g., how often the motorist used the road and the number of adults and children in the car), the driver's recollection of the intersection (e.g., whether

Table 1. Summary of data availability.

Sign	Presence of Vehicle at Intersection	Site 1 Day	Site 1 Night	Site 2 Day	Site 2 Night
1	Present	ND	ND	ND	ND
	Not present	NDA	NDA	NDA	NDA
2	Present	NDA	NDA	S	NDA
	Not present	NDA	NRDA	S	NDA
3	Present	NRDA	NDA	S	NDA
	Not present	NDA	NDA	S	NDA
4	Present	SNDA	NDA	NDA	NDA
	Not present	S	NDA	NDA	NDA
5	Present	NDA	NDA	NDA	NDA
	Not present	NDA	NDA	NDA	NDA
6	Present	S	ND	NDA	NDA
	Not present	SNDA	NRDA	NDA	NDA

Note: ND = no data; NDA = normal data available; S = survey; NRDA = normal and rain data available; SNDA = survey and normal data available.

Table 2. Motorist recall of signs and situation.

Sign	Presence of Vehicle at Intersection	Percentage of Drivers Sampled: Saw Correct Sign	Saw No Sign	Saw "Ringer"[a]	Saw Vehicle
2	Present	17	25	2	67
	Not present	20	29	8	15
3	Present	22	29	4	71
	Not present	21	21	3	15
4	Present	41	23	4	69
	Not present	51	19	3	49
6	Present	45	9	3	89
	Not present	41	14	2	62

[a] Sign not used in Maine.

another vehicle was present), the driver's recall of any signs present and their meaning, the driver's perception of his or her actions at the intersection (e.g, whether he or she became more alert, slowed down, etc.), and any awareness of the experimental situation.

Thus, for selected motorists on nine different days (covering four of the six sign treatments), data were available not only on how the motorists actually responded but also on their perceptions of the situation and their actions.

The survey was administered several hundred meters beyond the intersection, and the crew could not be seen until well after a motorist had exited the instrumented area. The survey was administered late in the summer, between August 10 and September 1, 1978, to minimize the effects that seeing the survey crew would have on local motorists during any subsequent data collection.

DATA ANALYSIS AND RESULTS

The data analysis is separated into two major sections: (a) analysis of the data obtained from personal interviews (including matched electronic data for each respondent) and (b) analysis of electronic data collected for each sign-site combination. Table 1 summarizes the types of data that were available for each basic combination. For the first section of the analysis, the results are primarily qualitative. The second section relies primarily on analysis of variance (ANOVA) techniques.

Analysis of Survey Data

The survey was administered on nine different days and covered the various combinations of sites, signs, and vehicle presence given in Table 1. Not all of the results from the analysis of the survey will be presented here; the more important results will be summarized.

Between 90 and 115 motorists were stopped during each survey period (day), and approximately 75 percent of those stopped on any day resulted in "good" responses; that is, they were willing to participate in the survey, and they had not been stopped previously. Approximately 20 percent of the respondents were nonregular users of the road (motorists who used the road several times per month or less), which was a somewhat lower figure than anticipated. Some of the key issues on which the survey was designed to provide data were whether or not motorists saw signs, understood the message to be conveyed, became more alert, and/or exhibited some other favorable reaction, such as slowing down.

Table 2 summarizes some of the information obtained on motorists' recall of signs and other vehicles. No less than 70 percent of the respondents always claimed to have seen one sign or another (they were given seven choices). The noticeable trend was that motorists were twice as likely to recall the presence of signs when the speed-zone configuration (sign 4) and the vehicle-activated sign (sign 6) were used. As a corollary, fewer respondents recalled no sign when sign 4 or sign 6 was displayed. It should be noted that the percentage of respondents who observed the "ringer" sign remains about the same throughout.

Accompanying the higher recall of signs 4 and 6 was a greater tendency to see the vehicle in the intersection. It should be noted that when the vehicle was "present" it sat on the side road at the intersection as if to make a turn or cross the road. When the vehicle was "not present" it sat between 75-100 m (250-330 ft) back from the intersection and on the side of the minor road. Thus, the van was always noticeable to the observant driver.

It can be concluded from these data that two of the four sign conditions elicited a better retention level than the others and, further, that notice of the signs appears to be related to a greater awareness among drivers of conditions in the intersection itself.

Very few motorists seriously misinterpreted the meaning of the signs. Typical of the responses to the VEHICLES ENTERING sign that might be considered technically "wrong" but were ultimately appropriate were the following: slow down, be cautious, reduce speed, and trucks turning. These responses were incorrect only in the most literal sense.

Motorists exposed to signs 4 and 6 were somewhat more likely to recall the intersection than those exposed to signs 2 and 3, although, in general, the recall of the intersection was high regardless of the sign displayed (the lowest figure was approximately 82 percent). Although the majority of respondents indicated that they slowed down for the intersection, no clear trend was evident from the survey data as to whether those exposed to signs 4 and 6 were more likely to indicate such a reaction. A direct comparison was made between respondents' estimates of how much they slowed down and their real (electronically measured) decrease or increase in speed, but it revealed nothing other than that people do not remember, or estimate, their speeds very well.

When motorists were asked how they responded to whatever sign they saw (many identified a sign that

Table 3. Typical summary of significance of main effects and interactions.

Dependent Variable	Significant Main Effect	Significant Two-Way Interaction
Entry speed	None	Signs/vehicle presence, signs/familiarity with road
Speed change		
Initial	Signs	Signs/vehicle presence
Sign A	Signs, vehicle presence	Signs/vehicle presence
Sign B	Signs	None
Sign C	Signs	Signs/vehicle presence
Speed at intersection	Signs, vehicle presence	None
Overall speed change	Signs, vehicle presence	None
Distance to minimum speed	Signs	None
Maximum speed change	Signs	Signs/vehicle presence, signs/familiarity with road
Distance to maximum speed change	Signs, vehicle presence	None
Speed change at intersection	Signs, vehicle presence	None
Exit speed	Vehicle presence	None

was not present on the day they were interviewed), results were mixed. However, no recognizable trends emerged as to differences in motorists' perceptions of their reactions to the signs.

One of the survey questions asked how often the respondent used the road in order to determine what effect familiarity with the road had on drivers' reactions to the signs. The actual reactions (values of the dependent variables) could then be compared with the survey response. Typically, there were no differences among groups of regular and nonregular users of the road.

In this connection, there was some evidence that respondents who said they slowed down for the intersection actually did although, as noted, their estimates of how much were typically inaccurate.

Also included in the survey was information on the sex of the respondent, the number of children in the car, and so forth. Women in the sample tended, overall, to go slightly faster than their male counterparts, both as they entered the test site (entry speed) and at the intersection (speed at the hazard). Whether or not there were children in the car seemed to have no relation to driver behavior; entry speed and speed at the hazard were almost identical in both situations. Not enough of the respondents were wearing safety belts to indicate whether they reacted differently from those who were not wearing safety belts.

In general, the following points emerged from the review of the survey responses:

1. Motorists exposed to signs 4 and 6 were more likely to recall seeing the correct sign than those exposed to signs 2 and 3;
2. Motorists exposed to signs 4 and 6 were also more likely to be aware of conditions at the intersection, as indicated by their recollection of another vehicle (a controlled situation) in the intersection; and
3. Regardless of what signs were displayed, similar percentages of motorists indicated that they reacted by becoming more alert and/or slowing down.

Analysis of Electronic Data

The principal component of the analysis was the review of the electronic data. The basic technique used was ANOVA based on observational data. The data for each cell in Table 2 were selected at random from all of the data collected under each combination of sign, site, light, and vehicle presence. Each subset of data consisted of 25 observations, which included some out-of-state motorists (motorists not familiar with the road) and some recreational vehicles or cars with trailers. The data selected were analyzed under the multiple-factor design, which allowed for adequate statistical significance testing. A 95 percent confidence level was used throughout.

The following discussion of the results of the analysis deals, on a variable-by-variable basis, with the effects of the signs on the independent and dependent variables.

General Observations

An initial multiple-way ANOVA, in which the factors were signs, site, conflict (whether a vehicle was in the intersection), and weather (wet or dry pavement), showed that the effect of the site was very significant. Thus, in much of the succeeding analysis, each site was considered separately. Overall analyses with and without entry speed as a covariate showed that entry speed was also significant. Thus, all analyses were done with and without entry speed as a covariate.

The site effects were not unexpected, since the two sites were geometrically different in that one site had an upgrade approach all the way to the intersection and the other had a slight downgrade at the intersection. These differences notwithstanding, comparisons of the trends at each site are valid and were made and reported. The overall multiple-factor ANOVAs also showed the general impact of other independent variables--e.g., ambient light and vehicle registration.

Independent Variables

Multiple-factor ANOVAs were used to assess the general effects (as measured on the dependent variables) of signs and other factors, both as individual impacts (main effects) and in various combinations (interaction effects). The overriding conclusions drawn from this part of the analysis were that (a) the effects of the signs were almost always detected (i.e., they were statistically significant) regardless of the situation; (b) absolute effects differed by site, although the trends were similar; (c) neither vehicle type (automobile versus recreational vehicle or car and trailer) nor state of vehicle registration caused significant main effects; and (d) on a few occasions, the presence of the vehicle in the intersection had a significant main effect.

Table 3 gives a typical summary of factor significance from daytime data for site 2. The factors tested were signs, conflict, vehicle type, and motorist familiarity with the road. Since a prior ANOVA had already indicated that the site was a significant factor, separate analyses for site 1 would show similar results.

Because of the recurring evidence of the impact of entry speed, the analysis illustrated in Table 3 was also undertaken with entry speed as a covariate. The outcome of that analysis showed that for most dependent variables the entry-speed covariate was significant. The significance of the main and interaction effects given in the table, however, remains the same except in the following instances: The interaction between signs and motorist familiarity with the road is significant for speed change (sign C), the vehicle-presence main effect is significant for distance to minimum speed, and the signs main effect is significant for exit speed.

Sign Treatment

Sign treatment, as indicated above, was almost always found to be significant, which indicated that there was some difference in motorist reactions to different sign configurations. The effectiveness of various signs is reviewed later in this paper, in the discussion of dependent variables.

Site

Site was also found to make a significant difference, presumably because of the difference in geometric characteristics. Although absolute speed changes might differ by site, the speed-change trend was the same regardless of the site.

Ambient Light

Analysis of day and night data for the same combinations of other factors showed that light did not generally have a statistically significant effect. In a two-way ANOVA that considered both light and sign effects (controlling for site and conflict), the main effects of light were typically not significant. There were several instances when the interaction between signs and light was significant, notably for initial speed change (sites 1 and 2, vehicle not present), speed change at sign A (sites 1 and 2, vehicle not present), distance to maximum speed change (site 2, vehicle present), speed change at intersection (site 2, vehicle present and not present), and speed change at sign B (site 2, vehicle not present). The interaction effect can presumably be attributed to the greater visibility of some of the signs (i.e., the lighted ones) at night. Generally, though, the signs were not much more or less effective at night than during the day.

Vehicle Presence

Vehicle presence at the intersection (conflict) has been mentioned previously as often having a significant effect (more often as an interaction with the signs) on motorists' reactions. Thus, in the analysis undertaken to determine the explicit differences in effect among the signs (i.e., which signs were most effective), careful note was taken of those differences both when a conflict situation was present and when it was not.

Familiarity with the Road and Type of Vehicle

Motorists' familiarity with the road and type of vehicle were two independent factors that had been anticipated to be important. The analyses, however, showed that little difference in motorist behavior could be attributed to either of these factors. For example, as Table 3 indicates, the main effects of these two factors were never significant, and in only two instances was an interactive effect noted. One of the instances in which the interactive effect was noted was when entry speed was considered, an effect that, if at all important, would be allowed for when entry speed was considered a covariate.

Weather

Weather conditions were not fully explored because of a scarcity of rain data. Although a superficial review revealed that weather was a significant factor in several instances, an examination of the trends in speed changes from one condition to another indicated that the effects were quite inconsistent. Thus, no conclusions can be offered on the impact of weather on motorists' reactions.

Entry Speed

All analyses were undertaken with and without entry speed as a covariate. Note, however, that there was a great deal of consistency in the results regardless of whether or not entry speed was a covariate.

Dependent Variables

The primary purpose of the following discussion of each of the dependent variables is to identify the differences in the effectiveness of the various signs. The discussion is based primarily on the results from site 2, although any variations between results at the two sites are noted. Otherwise, it should be assumed that the results were similar at both sites.

Entry Speed

Significant variation occurred in the effectiveness of signs within the sample of motorists in several instances, which indicates that some of the variation in speeds at later points (such as at sign B) might be better explained by the initial speed than by the effect of the signs. Using entry speed as a covariate (and thus implicitly controlling for it) makes the examination of subsequent variables meaningful. Thus, the typical procedure was to examine the variation in a dependent variable that is attributable to sign conditions with and without controlling for entry speed.

Speed Change

No conclusions were noted for initial speed change because, in most instances, the changes measured were quite small and the trend in the results was not consistent between sites or between day and night data. Similar problems were encountered with speed change at both signs A and B. There was overall statistical significance attributable to sign effects but no consistent trend, and actual differences were very small.

The results for speed change at sign C were somewhat more consistent. The overall significance of the sign effects had already been established. The trend in the data was that signs 4-6 (the speed-zone sign and both lighted signs) tended to be more effective than signs 1-3. A statistical comparison (contrast) of these two groups was significant: Signs 4-6 resulted in greater speed reductions than signs 1-3 for site 2, for both day and night, and for site 1, but only at night. The actual physical variations were rather small, although statistically significant. For example, the average decrease for signs 1-3 was about 0.8 km/h (0.5 mile/h) and for signs 4-6 ranged from 1.6 to 3.2 km/h (1-2 miles/h).

Speed at the Intersection

It can be argued that some of the best measures of effectiveness are those that describe motorists' reactions at the hazard itself. In this case, those measures included speed at the intersection, overall decrease in speed (for which speed at the intersection was used as a reference), and speed decrease in the vicinity of the intersection. The results for speed at the intersection appear more clear-cut than those for previous variables. The overall ANOVAs for speed at the intersection showed that the signs had a significant effect, whether or not a vehicle was present and whether or not entry speed was included in the analysis as a covariate. A direct comparison between signs 1-3 and signs 4-6 showed that the latter group of signs did result in a lower speed at the intersection. This result was consistent for both day and night data, whether or not a vehicle was present, and for both sites. Actual speeds averaged about 75 km/h (46 miles/h) for signs 1-3 and about 69 km/h (43 miles/h) for signs 4-6.

Overall Speed Change

Measuring overall speed change served to highlight the effects of the signs on the overall reaction of motorists to the intersection. In all instances, the sign effects were statistically significant. Although overall change in speed was based directly on entry speed, significance was still obtained when entry speed was included as a covariate. Direct comparisons of the signs indicated that signs 4-6 resulted in significantly greater decreases than signs 1-3: For site 2, decreases for signs 1-3 ranged from 0.8 to 3.2 km/h (0.5-2 miles/h), and decreases for signs 4-6 ranged from 6.3 to 7.9 km/h (3.9-4.9 miles/h). The absolute differences between the two groupings were similar for site 1 and for both day and night data at both sites. Additional comparisons showed little difference within the two groupings: For example, there was no significant difference between signs 1 and 2 or between signs 5 and 6.

It had been anticipated that whether or not a vehicle was in the intersection would make a difference in motorists' reactions to signs 5 and 6, since the lights in sign 6 were flashing only when a vehicle was present. Sign 6 typically resulted in a greater decrease in speed--about 0.8-1.6 km/h (0.5-1 mile/h)--but the difference was not statistically significant.

Maximum Speed Change

Signs 4-6 often resulted in slightly higher maximum changes in speed, although the difference--about 0.8-1.2 km/h (0.5-0.75 mile/h)--was generally not significant. Thus, although speed decreases for signs 4-6 were slightly more abrupt than for signs 1-3, the differences were not particularly meaningful, either statistically or practically.

A very general trend was noted in the location of maximum changes in speed. Maximum changes in speed occurred farther back from the intersection for signs 4-6, although some inconsistencies were noted.

Speed Change at the Intersection

Although speed change at the intersection showed a statistical significance attributable to the signs, this variable proved to be inconsistent when it was examined closely. At site 1, motorists exposed to five of the six signs increased speed in the vicinity of the intersection; at site 2, there was a speed decrease for all sign treatments. Presumably, this phenomenon was related more to site geometrics than to sign treatments.

Exit Speed

Exit speed was used (a) to indicate how quickly motorists resumed their speed after passing through the intersection and (b) as the basis for a comparison with the estimated speeds given by motorists who were surveyed. As previously indicated, there was little relation between actual and estimated speeds. In the attempt to measure how quickly motorists resumed speed, it was not possible to conclude anything other than that this effect was apparently overshadowed by the slower speeds attained at the intersection for the most effective signs.

CONCLUSIONS

The experiment reported in this paper was designed to test a series of progressively more informative (and emphatic) signs that could be used to warn motorists of a hazardous intersection (i.e., inadequate stopping sight distance) on the road ahead in rural two-lane situations. Both electronic and survey data were collected as part of a multifactor experiment design at two sites in central Maine. Random motorists were classified by type and whether or not their vehicles were registered in Maine. The survey data were collected for a selected number of sign-site combinations.

Based on the analyses described, the following conclusions can be drawn:

1. Presumed familiarity with the site (measured indirectly for most motorists by whether the vehicle was registered in Maine and explicitly for others by the survey) did not have a significant effect on motorists' reactions to the intersection situation.
2. Type of vehicle had no significant effect on motorists' reactions.
3. All motorists who were surveyed gave similar answers when asked how they responded to the sign(s) and the intersection, but those exposed to the speed-zone sign (sign 4) had a better recall of which sign they had seen, and those exposed to the vehicle-activated VEHICLES ENTERING WHEN FLASHING sign (sign 6) had a better recall of the intersection itself, i.e., of whether or not a vehicle was present.
4. Separate analysis of survey respondents by sex, whether children were in the vehicle, and whether safety belts were in use produced no discernible trends.
5. The effectiveness of the signs--as measured principally by the overall decrease in speed on the approach to the intersection, the speed at the intersection itself, and, to a lesser extent, the decrease in speed near sign C--can be divided into two categories. There were small differences in effectiveness among the standard warning signs (i.e., signs 1-3) and among the more informative (or emphatic) ones (i.e., signs 4-6). There was, however, a significant and consistent difference between the two basic sign groups. Signs 4-6 consistently resulted in more positive effects. The magnitude of the effects was illustrated by speeds at the intersection: Signs 4-6 resulted in speeds typically about 4.8 km/h (3 miles/h) slower.

A major concern in experiments of this type is whether the measurement of actual motorist reactions--e.g., a speed decrease--is an adequate basis for recommending acceptance or rejection of a particular sign. For example, the effect of a sign on a motorist's general alertness to a potentially hazardous situation is also important. In this experiment, an attempt was made to determine whether motorists' awareness was increased by different signs.

The survey indicated that, whereas all motorists tended to claim a positive reaction to the sign they saw (or thought they saw), motorists who saw either sign 4 or sign 6 actually had better recall, not only of the sign but also of the presence of the vehicle in the intersection. Furthermore, the same signs resulted in a positive physical reaction, such as a decrease in speed. Thus, the second group of signs did well on both awareness of the situation and reaction to it (because of other similarities among signs 4, 5, and 6, it is assumed that motorist response to sign 5 would have been similar to the response to signs 4 and 6).

A review of all of the analyses done reveals that differences among signs 4-6 were not always apparent or consistent. In general, however, sign 6 seemed to be the most effective in several instances. In a field application, however, the deployment of equipment for sign 6 would be quite complex. Sensing devices would be required on both side roads at a four-way intersection, and these devices would have to be linked to the sign several hundred meters down the road. In addition, failure of the sign could result in a serious situation at the intersection. A question thus arises as to whether the marginal increase in effectiveness is worth the additional cost of installation, maintenance, and risk associated with sign 6. It is my conclusion, based on effectiveness and anticipated cost, that either sign 4 or sign 5 would be a better choice than sign 6.

The overall conclusion of the experiment can be stated as follows: The regulatory speed-zone configuration (sign 4) and the continuously lighted VEHICLES ENTERING configuration (sign 5) appear to be superior to typical warning signs, such as the standard cross or plain VEHICLES ENTERING sign, in increasing motorist awareness of a hazard and inducing a physical reaction to it. Speed reductions in response to signs 4 and 5 appeared to be about two to three times those normally experienced with the more conventional signs, and awareness (as measured by sign recall and observation of the vehicle in the intersection) was increased by an overall factor of approximately two.

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REFERENCES

1. Accident Facts. National Safety Council, Chicago, 1976.
2. J. A. Deacon, C. V. Zegeer, and R. C. Deen. Identification of Hazardous Rural Highway Locations. TRB, Transportation Research Record 543, 1975, pp. 16-33.
3. G. F. King and others. Seven Experiment Designs Addressing Problems of Safety and Capacity on Two-Lane Rural Highways. Office of Research, Federal Highway Administration, U.S. Department of Transportation, Vols. 6 and 8, May 1978.
4. M. H. Lanman III. The Maine Facility: Capability for Rural Road Research. ITE Journal, Vol. 48, No. 12, Dec. 1978.
5. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, U.S. Department of Transportation, 1978.
6. M. H. Lanman III, H. S. Lum, and R. W. Lyles. Evaluation of Techniques for Warning of Slow-Moving Vehicles Ahead. TRB, Transportation Research Record 739, 1980, pp. 45-50.

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Improving the Accuracy of Information on Direction Signs

H. J. WOOTTON AND R. S. BURTON

Recent studies in Great Britain have suggested that more than £700 million/year (£1 = U.S. $1.80) is being "wasted" by drivers traveling longer distances than are strictly necessary. Most drivers state that they are seeking the shortest or quickest route to their destination, yet studies show that only 50 percent achieve their stated objective. Direction signs and maps are the most common and simplest form of route guidance. An analysis of data collected in Gloucestershire suggests that 86 percent of travelers follow a route that is signposted, that less than 50 percent of the signposted routes are minimum-cost routes, and that to change the signs to make them indicate the minimum-cost routes would require 7 place-name changes/junction, 3 distance or route-number changes/junction, and 1 directional change every 6 junctions. The cost of modifying all the signs in Great Britain to provide more accurate information is estimated at £70 million, and the annual savings that are likely to result from this investment are estimated to be in excess of £180 million. It is possible that the annual savings in fuel and accidents alone will cover the total investment.

In the recent past, four independent studies in Great Britain (1-5) have suggested that in 1976 (in 1976 currency, £1 = U.S. $1.80) between £700 million and £960 million was wasted in terms of fuel, operating costs, and time by drivers traveling distances in excess of those that were strictly necessary. Although one of the studies (1) was able to suggest that some of the excess could be attributed to "limitations in maps and road signs", none of the studies were able to identify deficiencies in existing signing or propose improvements.

The purpose of the work reported in this paper was to determine the importance of existing direction signs in driver route choice, to identify deficiencies and propose improvements, and to estimate the costs and benefits to be obtained by improving direction signs. This study used an existing set of travel information from the British counties of Gloucestershire and Avon (4) that was originally collected to determine drivers' route-choice criteria in terms of time or distance. To these data we added information from the existing direction signs and analyzed all the data by using a

Table 1. Reasons cited by drivers for choice of actual route.

	Percentage of Sample Citing Reason					
Trip Purpose	Quicker	Shorter	Scenic	Antimotorway	Route Was Specified	No Known Alternative
Journey to work	76.0	11.4	0.9	0.1	0.5	10.4
Company business	73.6	9.3	3.5	1.0	2.8	10.0
Commercial vehicle	68.6	8.5	0.8	0.4	15.4	6.5
Leisure	47.9	10.3	28.8	1.5	0.8	10.9

Table 2. Driver inefficiency in choosing a route.

	Percentage of Drivers Who Achieved Their Purpose for Selecting a Route		Percentage of Cost in Excess of Minimum That Was Strictly Necessary
Trip Purpose	Quicker	Shorter	
Journey to work	50.3	57.3	6.5
Company business	50.3	36.2	5.0
Commercial vehicle	49.1	40.1	6.0
Leisure	49.6	54.0	8.0

special suite of computer programs--SIGNPOST--that had been developed independently as a spin-off from the traditional traffic assignment models. The results suggest that there are important deficiencies in the existing signs, that more drivers (86 percent) follow direction signs than satisfy any other route-choice criteria, and that the benefits gained in a few months from improving the accuracy and consistency of information on direction signs will cover the costs of improvement.

EXISTING STANDARDS FOR PREPARATION OF DIRECTION SIGNS

The information given by a direction sign should be clear and accurate. Over many years the content, design, layout, and siting of traffic signs have been carefully studied, and most countries have adopted standards to cover these aspects of signposting. Consequently, most direction signs give their information clearly.

In the United Kingdom, the Traffic Signs Manual (6) gives guidelines for the preparation of direction signs. On motorways the signs should have a blue background with white lettering, and on other primary routes the signs should be green with white lettering for names and yellow lettering for route numbers. On these primary routes, the Traffic Signs Manual encourages the engineer to select the place names from a published list of "primary destinations". It is suggested that the engineer select from the list of primary destinations a name of a place that is nearest to the sign and then ensure that the name appears on subsequent signs.

Other direction signs are used on nonprimary routes and for local signing. These nonprimary signs are white with black lettering and surrounds, and the place names that appear are usually those of significant towns. Any other direction sign gives very local information and is used to indicate small towns and villages or local features such as car parks, libraries, or railway stations.

In all direction signing, the traffic engineer is given no formal guidance on the direction to be signed and must also use judgment in interpreting other constraints, such as the number of names to be included on a sign. Confusion may arise where different authorities are responsible for different roads and, hence, different signs. It is not unknown for nonprimary or local signs to be placed on the same mounting as primary signs, increasing the list of names to be scanned, implying conflicting directions, and assuming that drivers understand the relevance of different colors. There seems to be no certainty that direction signs will be consistent or efficient in the route they suggest.

GLOUCESTERSHIRE AND AVON SURVEYS

In 1976, the U.K. Department of Transport commissioned a study to establish the criteria used by drivers in selecting a route for their journeys and the extent to which the route driven satisfied drivers' criteria. A survey was carried out in Gloucestershire and Avon in which 7009 drivers were interviewed. The sample was selected by calling at 68 different sites within the study area and interviewing drivers immediately after they completed their journeys. More than 60 of the sites were industrial establishments or offices employing significant numbers of people.

The remaining sites were recreational areas, beauty spots, wildlife parks, and similar areas that attracted leisure trips. The surveys were designed to collect equal numbers of interviews for each of four trip-purpose categories: journey to work, leisure, company business, and commercial vehicles. The information collected included the origin and destination of the journey, the journey purpose, the frequency of the journey (daily, weekly, monthly, occasionally, or first time), the reason for the choice of route (quicker, shorter, scenic, specified, antimotorway, or no known alternative), and details of the actual routes followed. All of the journeys recorded took place between the hours of 9:00 a.m. and 4:00 p.m. and were more than 3 miles in length. No information was collected about the values or use of direction signs.

At the same time as the interviews were carried out, the average journey speeds were measured (by using the moving-observer technique) along each of the links that made up the road network in the survey area. The lengths of the links were also measured. The data were then used to compare the routes actually driven with those that satisfied the drivers' criteria for route choice and other general criteria such as minimum generalized costs, distance, or time. The reasons given by drivers for selecting a particular route are summarized in Table 1 (5). The success drivers had in satisfying their desired criteria is given in Table 2 (5,8).

Table 1 shows that an overwhelming majority of drivers try to select the quickest route, that approximately 10 percent try to select the shortest route, and that 10 percent have no known alternative. The other important choices are scenic routes for leisure trips and specified routes for commercial vehicles. Almost 30 percent of drivers choose a scenic route for leisure trips, and an even higher percentage desire a scenic route if they are away from home on a holiday.

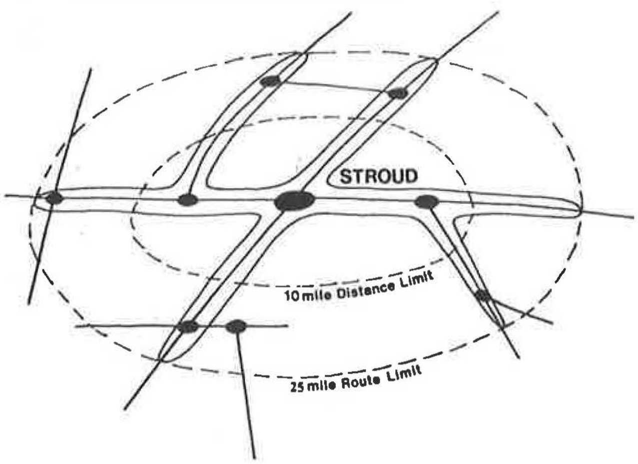
Table 2 demonstrates the inability of drivers to satisfy their own optimum criteria or the more general system criteria of minimizing generalized cost. Only 50 percent of drivers apparently

Figure 1. Example of output from SIGN program.

ENTERING NODE 125 FROM DIRECTION SE
(NODE 126) ALONG THE A 433

```
IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
I                                              I
I     *              B4014                     I
I    ***    STROUD              ( A  46 )      I
I   * * *   NAILSWORTH            B4014        I
I     *     AVENING               B4014        I
I     *                                        I
I                                              I
I----------------------------------------------I
I                                              I
I     *     DURSLEY               A4135        I
I    *                                         I
I   *****                                      I
I    *                                         I
I     *                                        I
I                                              I
I----------------------------------------------I
I                                              I
I           CIRENCESTER           A 433    *   I
I                                           *  I
I                                        ***** I
I                                           *  I
I                                          *   I
I                                              I
IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
```

Figure 2. Distance limits for the town of Stroud.



followed a route that was the same as the minimum-travel-time route calculated from the measured average speeds in the network. A similar though more variable percentage of drivers were able to follow the shortest-distance route. The excess cost above the minimum generalized cost was calculated by comparing the weighted sum of the distance and average time along actual routes followed with the minimum weighted sum of distance and time between the origin and destination. The weights attached to the distance and time were those implied by the survey data and conform to the concept of generalized cost. The percentage of excess costs observed in this survey are entirely compatible with the estimates given in three other independent studies (1-3), which range from 5 to 6.5 percent.

SIGNPOST SUITE OF PROGRAMS AND PLACE NAMES

During 1975 and 1976, independently of the studies discussed in this paper, a series of computer programs was developed to select names for signposts by using minimum-cost, minimum-distance, or minimum-time routes obtained from a suitably coded network.

Table 3. Distance and route limits for place-name categories.

Level	Distance Limit (miles)	Route Limit (miles)	Category of Place Name	Example
1	10	50	Regional destinations and "super primaries"	Southwest London
2	10	25	Primary place names	Gloucester, Stroud
3	5	10	Motorways	Motorway (M4)
4	3	10	Market towns Local centers	Chipping, Sodbury Tetbury
5	2	5	Small towns and other important destinations	Avonmouth, Stonehouse
6	1	3	Villages	Westonbirt
7	0.5	1	Hamlets	Dodington

These programs provided the opportunity to compare the routes driven by drivers in Gloucestershire and Avon with the signposted routes and were an important tool in the further analyses we carried out.

Originally, there were three programs in the SIGNPOST suite, but during the analysis of the Gloucestershire data it was necessary to collect information on the existing signs, and a fourth program was added. The functions of the programs are as follows:

1. The ROAD program is used to define the road network and the place names. The network is defined to the computer as a series of nodes and links. Every intersection is defined as a node and is given a unique number. The sections of road between intersections (nodes) are the links, and the characteristics required are length, travel time or speed, class of road, the direction in which the link leaves a node, and the route number. Place names are attached to nodes and given a level in a hierarchy of names. Several names, each of a different level, can be associated with the same node. The hierarchical structure is intended to give a finer definition of places with decreasing distance.
2. The GROUND program prepares a file of existing sign data from user-supplied information on the places signed at each node. This file can then be compared with sets of signs prepared by the SIGN program. GROUND can also print a pro forma for recording an inventory of existing signs. This program was added to the suite during analysis of the Gloucestershire data.
3. The SIGN program selects the place names to be signed at each node (intersection) in the network. The program prints direction signs for each of the arms entering a node (see Figure 1); these signs show the places reached by leaving on each of the other arms. The program also prints confirmatory signs for each of the arms leaving a node. Minimum distance, time, or cost can be used as the basis for route selection, and names can be selected on varying distance limits. The program can also compare two sets of signs to assess the changes needed in direction signs following changes in the network.
4. The GUIDE program prints route instructions for a particular journey, including details of which arm to take at an intersection and names to follow on signposts.

All of the road network data for our analyses existed in the original Gloucestershire study except for directions, route numbers, and place names. The original road network comprised the roads used by the drivers interviewed in the surveys and differentiated between trunk roads, principal A-class roads, other A-class roads, and unclassified roads. We reclassified these roads into primary roads and other A-class and unclassified roads because of the different standards for signs on primary routes and nonprimary routes. We also added a small number of nodes and links to give a proper representation of turning restrictions at some intersections.

The coding of directions was a straightforward process. The SIGNPOST programs allow the direction of each link of the network to be coded, as it leaves each intersection, to an eight-point compass bearing. To produce route numbers on signposts, the route numbers are added to the link descriptions. When one route number is temporarily replaced by another (the former often appearing in brackets), both route numbers are coded--e.g., A429 (A433).

To allow place names to be printed on the signs, the SIGNPOST programs require a name to be allocated to a node (intersection) in the network that most accurately represents its geographic location. Each name is given a "level" code to represent the importance of the name being signed. This allows a larger town or city to be signed from a greater distance than smaller towns or villages.

To illustrate the concepts of distance limits, Figure 2 shows how the town of Stroud, which is in the center of the Gloucestershire study area, will be signed at all intersections within 10 miles of the intersection designated as STROUD and how the limit is in this instance extended to 25 miles along continuously named routes that enter the Stroud area of influence. Since a name can be defined at any one of eight levels, great flexibility in naming is provided.

A list of place names was prepared from the names that were observed on existing signs so that a set of "idealized" signs could be produced. In a number of cases, the network was too coarse to include all of the place names that appeared on existing signs. Modifying the network to accommodate these place names was not considered feasible because the network would no longer have been compatible with the route data in the driver interview file. The final selection of place names, levels, and name structures was influenced by the type of sign on which they appeared. Thus, names in the list of primary destinations were always included and were assigned a higher level, and thus greater importance, than place names that appeared on nonprimary and local direction signs. The final classification, together with the distance and route limits, is given in Table 3. In all, more than 200 place names were included in the study-area network.

SIGNPOSTED ROUTES

The original surveys in Gloucestershire and Avon did not collect information on existing direction signs, nor were drivers asked specific questions about their use of signs. During 1978, this situation was partly remedied by making an inventory of the information on existing direction signs in part of the Gloucestershire study area. Only roads and intersections that were included in the road network were surveyed, and it was assumed that there had been no changes since the original survey data were collected in 1976.

The main objectives of collecting the signpost data were (a) to determine how well the actual routes were signposted, (b) to determine inconsistencies in the existing signs, (c) to prepare a set of idealized direction signs, (d) to compare the idealized signs with the actual signs, and (e) to establish the cost-effectiveness of implementing the idealized signs.

To determine how well drivers' actual routes were signposted, it was necessary to construct a file of equivalent signposted routes for each journey. A sample of 508 journeys was selected, and an approximately equal number were analyzed from each of the four journey purposes. The place name that corresponded to the destination was identified for each journey, and a search was made for this name in the existing signpost inventory at each intersection along the driver's actual route. If the name was found and the direction indicated on the signs was the same as the route chosen by the driver, it was assumed that the route driven was also the signed route. Alternatively, if the existing signposts indicated a different direction for that place name, the intersections on the driver's actual route were replaced by the intersections on the signed route until the destination point was reached. In some cases, a partial deviation from the driver's route was effected, whereas in others the whole route was modified.

For destinations represented by local place names, the signs frequently failed to mention the appropriate name at the start of the journey. In such instances, it was assumed that the driver would have looked for an associated "higher-order" place name to help find his or her destination--for example, a name on the list of primary destinations. Hence, if the destination place name was not signed at the origin, an appropriate alternative name was established from the route actually taken by the driver.

As well as recording the routes indicated on the existing signposts, two additional characteristics of the signposted routes were noted. These were the number of intersections on each journey that were without signposts and the number of changes of place names required before the destination was finally reached. The former served as a measure of the completeness of the current signposts, and the latter provided an indication of the complexity of the existing signs.

The results show that there is little difference between the actual and signposted routes; i.e., 86 percent of the journeys in the sample were the same. For the sample, there were an average of 2.6 intersections/trip without signposts and 1.8 place-name changes/trip. The average trip length was 10.8 miles, which means that there was one intersection without signs every 4.2 route miles and one change in place name every 5.9 route miles.

Tables 4 and 5 compare the actual and signposted routes in more detail. The astute reader will, of course, have noted that, in determining the signposted route, the actual route was used as a guide in selecting the place names. The reader may therefore not be surprised that such a high proportion of the signposted routes are the same as the actual routes (Table 4). However, in the case where the destination place name is signposted from the origin--the case of no change of name in Table 4--the driver who uses signposts is bound to follow this name. In this case, more drivers followed a route that was signposted than in any other case (95 percent) and, in percentage terms, they also incurred greater excess cost (13.4 percent).

Table 5 also has important repercussions. It not only suggests that drivers are strongly influenced by direction signs but also questions the assumption made in transportation planning studies for more than 25 years: that drivers follow a minimum-path route.

Table 4. Comparison of actual and signposted routes by number of place-name changes and excess cost of signposted route over minimum-cost route.

No. of Changes of Place Name	No. of Trips in Sample	Actual Routes the Same As Signposted Routes: No.	Actual Routes the Same As Signposted Routes: Percent	No. of Signposted Routes the Same As Minimum-Cost Routes	Percentage Excess Cost of Signposted Route over Minimum-Cost Route
0	102	97	95	41	13.4
1	135	119	88	99	3.5
2	121	103	85	63	5.6
3	87	74	85	26	8.0
4	34	28	82	5	5.0
5	19	10	53	4	7.9
>6	10	7	70	2	7.1
Total	508	438	86	240	7.1

Table 5. Comparison of actual and idealized routes for a sample of 508 journeys.

Trip Purpose	Number of Journeys in Sample	Percentage of Actual Routes the Same as: Signposted Route	Minimum-Cost Route	Minimum-Time Route	Minimum-Distance Route
Journey to work	128	78.9	55.5	60.9	74.2
Leisure	125	84.0	32.0	36.8	41.6
Company business	129	93.0	45.7	50.4	65.1
Commercial vehicle	126	88.9	60.3	65.1	72.2
All	508	86.2	48.4	53.3	63.4

COMPARISON OF EXISTING AND IDEALIZED SIGNS

The SIGNPOST suite of computer programs allows the user to prepare a set of idealized signs that conform to given criteria. Three sets of idealized signs were therefore created that conformed to minimum time, distance, and cost criteria. Our purpose was to look at the difference between such idealized signs and the existing signs. The following is a summary of the findings for the minimum-cost idealized signs.

Of 250 intersections in the Gloucestershire and Avon study area, at 204 intersections (82 percent) there were differences between the signs, and at 46 intersections (18 percent) a comparison was not possible because there were no "existing" signs on any arm of the intersection.

The classification of differences at the 204 intersections was as follows:

Category	Total Changes	Changes per Intersection
Change in place name	1417	6.95
Change in direction	35	0.17
Distance and route change	647	3.17

There is a general pattern of above-average changes for intersections in urban centers, particularly Gloucester, and below-average changes elsewhere in the rural areas. The signs on the A38 between Bristol and Gloucester also exhibited above-average changes. The number of intersections with more than 12 place-name changes are almost all confined to the city of Gloucester.

Although it is difficult to establish a definite pattern, the tendency is for sets of signs at intersections in rural areas, away from the primary road network, to experience a net gain in names and for signs at intersections in urban centers and on the primary road system to suffer a net loss in names. In the existing system, rural signs generally have fewer names on them than signs in urban areas and on primary roads; the idealized system balances out the differences to provide a similar number of names on all signs.

A further method of comparison involved the plotting of place-name trees for various places in the study area. A circle representing the distance limits for each place name was drawn on a network plan, and the signing of that place name was investigated at each intersection within the area. If a place name was signed at an intersection, a line was drawn along the link in the direction indicated. This was done for both the existing and idealized systems and allowed gaps in the existing system to be identified and a comparison to be made visually between the two signing systems. Figure 3 shows the place-name trees for Nailsworth, for which the distance limit was set at 2 miles and the route limit at 5 miles in the SIGNPOST programs.

The overall conclusion is that implementation of an idealized system of signposts may involve changes in most of the signs in the study area. There will be an average of seven place-name changes per intersection, intersections in rural areas will tend to involve fewer changes than average, and intersections in towns and on primary roads will tend to involve more changes than average. In general, the occurrence of above-average changes is coincident with a net loss in place names.

BENEFITS AND COSTS OF INSTALLING AN IDEALIZED SET OF SIGNS

The results obtained from the Gloucestershire and Avon surveys allow a simple cost-benefit appraisal to be made of implementing an idealized system of signs throughout Great Britain. The potential benefits to drivers of following minimum-path routes can be expressed as savings per vehicle mile. The total savings for Great Britain as a whole are then estimated by multiplying the savings per vehicle mile derived from the Gloucestershire and Avon surveys by the total miles traveled in Great Britain.

It seems extremely unlikely that all drivers will be persuaded to follow signposted routes or that the minimum-cost routes are ideal. The maximum savings of £960 million/year must be regarded as unattainable. To make an estimate of the likely savings, it

Figure 3. Place-name trees for the town of Nailsworth.

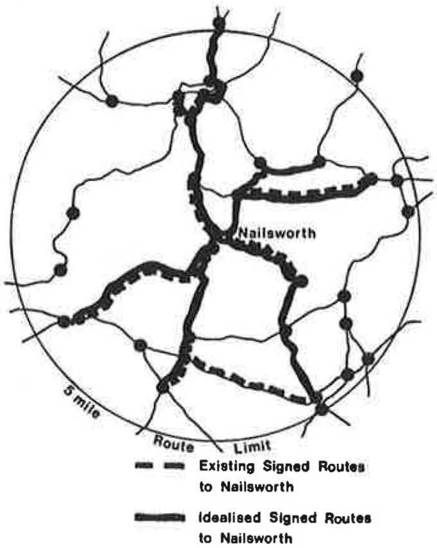


Figure 4. Comparison of potential savings and costs of introducing an idealized system of signs.

	Potential Annual Savings (£ millions)	Required Compliance by Drivers (%)	
	960	100	
	900	96	
Maximum Possible Saving -	780	90	
	700-------------	86	- Observed Compliance
	600	80	
	500	75	
	400	70	
	300	64	
Minimum Likely Saving -	180	58	
Maximum Fuel Savings -	117	55	
	100	54	
	70-------------	52	- Costs of new Signs
Maximum Savings from Accidents -	55	51	
Minimum Fuel Savings -	27	50	
Minimum Savings from Accidents -	12	49	
	7-------------	49	- Req'd Rate of Return

is necessary to make assumptions about the way drivers behave and/or about the routes to be signposted.

If it is assumed that 86 percent of drivers follow the direction signs, which is the percentage observed, then the maximum possible savings are £700 million/year. At the other extreme, the minimum likely savings seem to be £180 million/year. This minimum estimate assumes that minimum-distance routes are signposted and only drivers whose route-choice criteria--perceived or required--are the same as the signposted routes will follow the routes. An independent estimate of the likely savings has been made by Jeffrey and Taylor (8). They suggest that the likely savings are £215 million/year at 1976 prices plus a saving of £15 million/year from a reduction in the number of accidents.

Obviously, other criteria could be used to determine savings. For example, the vehicle mileage associated with the specific use of bypasses could be excluded from calculations, and other policy issues could be considered. From the many assumptions and calculations we have made, we doubt that the savings will be less than £180 million/year and, as will be seen later, any significant error in this figure is not critical in considering the return on any investment.

An estimate can also be made of the cost of modifying the signposts in the Gloucestershire and Avon study area. This estimate is almost £400 000 and requires completely new signs at 46 intersections and modified signs at 204 intersections. Given that the Gloucestershire and Avon study area comprises some 500 $miles^2$, and assuming that the density of the network, and therefore of signposting, is similar for the whole country, the equivalent cost for improving signs throughout Great Britain is of the order of £70 million. It must be emphasized that this calculation of costs is crude, since it makes other sweeping assumptions about the size of signs and the number of legends to be replaced. However, two important observations can be made:

1. A return of 10 percent/year on an investment in a new road scheme would be considered good. Even if there are substantial errors in the estimates of potential savings and the cost of improving signs, the return is likely to be very much higher than that normally required for an investment of this type. It is even possible that the cost will be covered by the annual saving in fuel alone. The results are summarized in Figure 4.
2. The cost is already being incurred during the normal course of maintaining signs. All that is required is to introduce the systematic procedures offered through the computer program to begin the improvement immediately.

CONCLUSIONS

The work discussed in this paper has suggested the following conclusions:

1. Drivers are not very successful at finding a route that satisfies their criteria for route choice. More than 75 percent of drivers are trying to follow the quickest or shortest route, yet only about 50 percent achieve these stated objectives.
2. More than 86 percent of drivers followed a route that was the same as the logically signposted route. If there is no change of name on the signposts between the origin and destination of the journey, 95 percent of drivers follow the signposted routes.
3. Implementing a set of direction signs that indicate minimum-cost routes would require approximately 7 place-name changes/intersection, 3 distance and route-number changes/intersection, 1 directional change every 6 intersections, and the construction of new signs where no signs currently exist at 18 percent of all intersections.
4. The total waste, in terms of fuel, operating costs, and time, incurred by drivers in Great Britain in using routes that cause them to travel a greater distance than is strictly necessary is estimated to be between £700 million and £960 million/year (1976 prices).

5. It is estimated that, after one accounts for drivers who are unlikely to follow signposted routes, the potential savings in Great Britain are at least £180 million/year and could be £700 million/year if 86 percent of drivers continue to follow the direction signs.

6. The cost of modifying signs throughout Great Britain to conform to the idealized set is estimated to be at most £70 million at 1979 prices (in 1979, £1 = U.S. $2.12). This implies that, even if there are gross errors in the estimates, an investment in improving the accuracy and consistency of direction signs is likely to be one of the most worthwhile transportation investments that can be made at the present time in Great Britain. It should also be noted that the savings in fuel costs or accidents alone can more than justify the investment based on normally accepted rates of return.

QUESTIONS THAT REMAIN

There are obvious and perhaps important deficiencies in the work we have done. We have not studied important questions of policy. For example, the requirement that forces heavy lorries to use a bypass rather than drive through the center of a small town has been ignored in creating the idealized set of minimum-cost signs. Some of these questions will be answered in a new study that is just commencing and that will examine the practical problems associated with installing the idealized signs and the policy issues this raises.

On the other hand, the results that have been obtained are sufficient to raise questions about existing signing practices and policies, not only in Great Britain but also in other countries. We have no doubt that there are substantial savings to be made by improving the accuracy and consistency of information on direction signs. Achieving accuracy and consistency requires a review of existing standards (for example, what names and route numbers should appear on signs and to what extent). It also requires more discipline in determining the content of signs than is obtained from "back-of-the-envelope" designs, a phrase that we have all too frequently heard in discussions.

ACKNOWLEDGMENT

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The SIGNPOST suite of programs discussed in the paper was developed by Wootton, Jeffreys, and Partners and has been purchased by the Department of Transport for use throughout the United Kingdom.

REFERENCES

1. Transport and Road Research 1976: Annual Report of the Transport and Road Research Laboratory. Her Majesty's Stationery Office, London, England, 1976.
2. C.C. Wright and H. Orrom. The Westminster Route Choice Survey: A New Technique for Traffic Studies. Traffic Engineering and Control, Aug.-Sept. 1976, p. 348.
3. Inter Urban Route Choice Study. Planning and Transport Research and Computation, Ltd., London, England, 1975.
4. V.E. Outram and E. Thompson. Driver Route Choice. In Transportation Models, Proc., Summer Annual Meeting, Planning and Transport Research and Computation, Ltd., London, England, Vol. P 153, 1977, pp. 114-121.
5. V.E. Outram and E. Thompson. Drivers' Perceived Cost in Route Choice. In Transportation Models, Proc., Summer Annual Meeting, Planning and Transport Research and Computation, Ltd., London, England, Vol. P 168, 1978, pp. 226-257.
6. Traffic Signs Manual. Her Majesty's Stationery Office, London, England.
7. Wootton, Jeffreys, and Partners. Effectiveness of Existing Signposts: Stage 2. Traffic Engineering Division, U.K. Department of Transport, Aug. 1979.
8. D.J. Jeffrey and N.B. Taylor. The Potential of Improved Route Guidance. In Highway Planning and Design, Proc., Summer Annual Meeting, Planning and Transport Research and Computation, Ltd., London, England, Vol. P 184, 1979, pp. 123-144.

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Experimental Evaluation of Delineation Treatments for Special-Use Lanes

RICHARD F. PAIN AND BEVERLY G. KNAPP

Results of a laboratory evaluation of 18 buffer-zone treatments designed to delineate special-use lanes on highways and arterials are reported. A slide presentation using a paired-comparison technique and a questionnaire were administered to 40 drivers to determine whether various delineation designs had any inherent permissive or prohibitive meaning and effect for driver entry into a given lane. The impact of several design parameters on the prohibitiveness and permissiveness of the various designs was evident: Any design that had repeated openings was clearly more permissive than treatments that included a continuous line, the stroke width of lines appeared to be relatively ineffectual, and colored treatments were somewhat more prohibitive than white ones, though by relatively small amounts. Questionnaire data were collected to supplement the paired-comparison data, and a Spearman rank correlation coefficient of r_s = 0.93 indicated that the results of the two methods were highly complementary. Several design characteristics, including delineation width, effect of spacing or density of design symbols, and driver perception of where the vehicle can be stopped relative to the delineated special-use lane, require further definition and study.

The research reported in this paper is concerned with the experimental evaluation of delineation treatments that might be used to separate a concurrent-flow special-use lane from the general lanes of traffic. In recent years, in order to improve the speed and capacity characteristics of high-occupancy vehicles (HOVs), one (or more) general traffic lanes have been designated for the use of these vehicles either full time or only during peak travel hours (1). Since many of these lanes operate as special HOV lanes for one part of the day and then revert to more general use during the remainder, the delineation must be useful under both operating conditions.

Delineation schemes are, of course, usually secondary to information provided by posted signing (2). The focus of this research was to determine whether adequate directions for vehicle entry or nonentry can be conveyed to drivers by HOV delineation treatments alone, without signing. This allows system designers to establish what delineation can best be coupled with signing in presenting information about HOV operation to road users.

Table 1. Delineation designs tested.

Treatment No.	Type	Illustration
1	Conventional dash	
2	Wide dash	
3	Broken-solid combination (white)	
4	Double dash (white)	
5	Conventional dash and MUTCD diamond (15-ft line, 25-ft gap), diamond every 1000 or 500 ft	
6	Diamond with solid line (white)	
7	Design 5 with filled-in (solid) diamond	
8	Diamond with dash line (white)	
9	Diamond with connecting line (white)	
10	Diamonds only	
11	Diagonal crosshatch (left slant)	
12	Diagonal crosshatch (right slant)	
13	Design 2 in bright yellow-green	
14	Design 2 in light blue	
15	Design 7 in bright yellow-green	
16	Design 7 in light blue	
17	Design 9 in bright yellow-green	
18	Design 9 in light blue	

EXPERIMENTAL METHOD

Experts on the research staffs of BioTechnology, Inc., and the Institute for Research, State College, Pennsylvania, initially developed ideas on candidate delineation designs. The resulting ideas were critiqued from several perspectives--e.g., space and application requirements, potential meanings, and conflicts in driver expectancy with other signs, markings, or symbols. Fifteen markings survived this initial critique and were submitted to the Federal Highway Administration (FHWA) for review and comment. Based on suggestions from FHWA, 11 designs were finally chosen for experimental testing. Variations on several of these designs, such as color coding, brought the total number to 18 (see Table 1).

Figure 1. Sample stimulus pictures used in laboratory evaluation of delineation treatments.

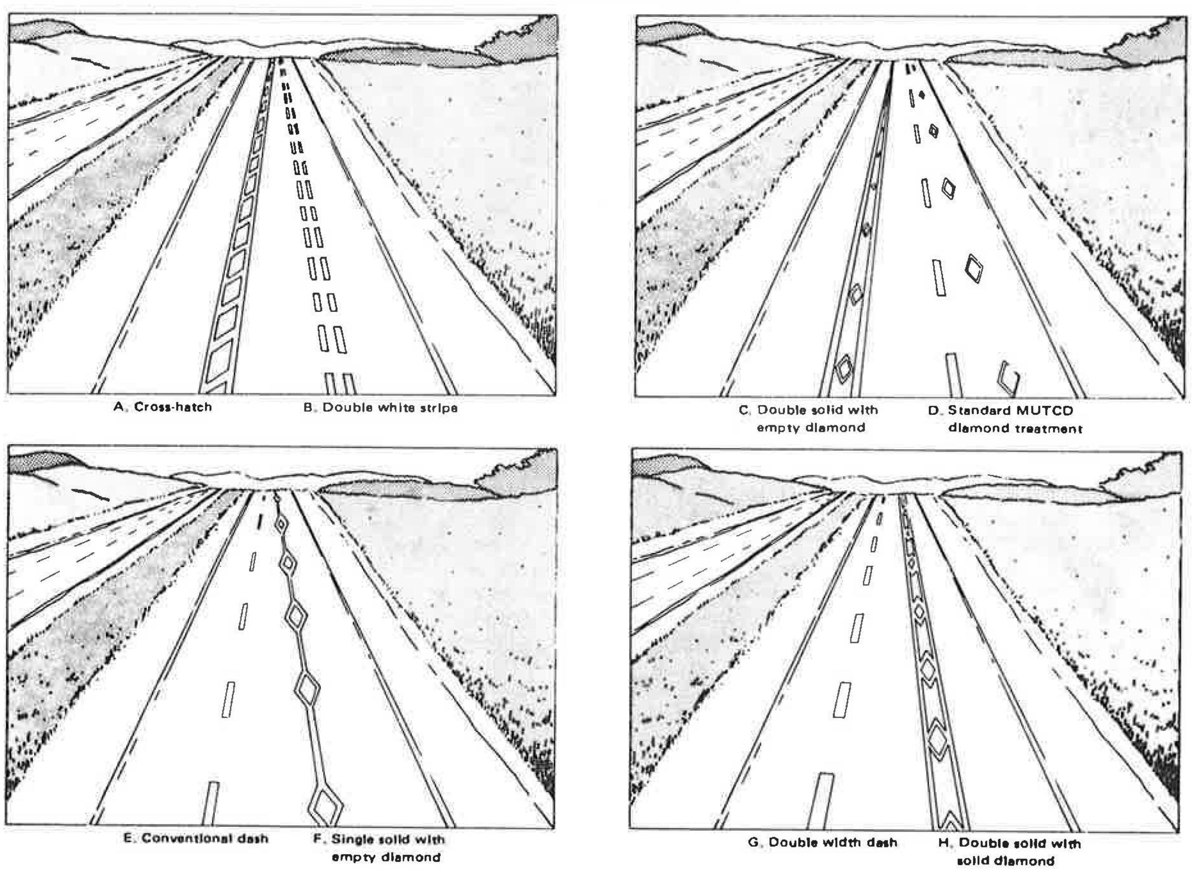

Table 2. Scale values obtained for delineation treatments.

Questionnaire Rank	Paired-Comparison Rank	Treatment No.	Paired-Comparison Scale Value[a]
2	1	1	1.3
			1.2
4	2	2	1.10
5	3	14	1.00
			0.9
1	4	13	0.8
			0.7
6.5	5	10	0.6
3	6.5	4	0.5
6.5	6.5	8	0.5
			0.4
			0.3
			0.2
			0.1
9	8	9	0.05
8	9	3	0
14	10	5	-0.1
10	11	17	-0.2
11	12	18	-0.3
			-0.4
12	13	6	-0.5
17	14	7	-0.6
13	15	16	-0.7
15	16	15	-0.8
16	17	12	-0.9
			-1.0
18	18	11	-1.1
			-1.2
			-1.3

Note: Spearman rank correlation $r_s = 0.93$.
[a]From most permissive to most prohibitive.

Each of the buffer-zone treatments was drawn on a clear acetate sheet. These sheets were laid on an artist's rendering of a three-lane freeway-type roadway. (The examples shown in Figure 1 are greatly reduced and, unlike the originals, are not in color.) Treatments were photographed in pairs so that every design was seen with every other design on a slide. Placement on the left or right side of the roadway picture was random. The resulting 35-mm slides were shown to groups of 10 subjects by means of a tachistoscope with 1-s presentation and a 5-s interstimulus interval. Since this was a study of inherent, not associative, meaning, no mention was made of special-use lanes.

In the first part of the experiment, the following instructions were given:

> Imagine that you are driving down the center lane of an ordinary three-lane highway (slide 1) when suddenly you see that something is blocking your way (slide 2). You must now make a choice, to go into the right lane or the left lane, in order to get by. For each of the following slides, please mark "right" or "left" to show which you think is the lane to take to get around the blockage. Don't be concerned with what is actually blocking your center lane; all we wish to know is which lane you feel you should take in each slide, right or left. There is no traffic behind you to worry about.

Subjects then indicated on a response sheet whether they would go around the truck (included in the stimulus picture) in the center lane by using either the left or the right lane. This is an applied use of the classical forced-choice paired-comparison technique described by Guilford (3), in which subjects must select one alternative over another in each stimulus presentation.

In addition to the paired-comparison experiment, each delineation treatment was shown alone, and subjects checked which of six driving behaviors was appropriate for that delineation or buffer-zone treatment. The following instructions were given here:

> Imagine you are still driving down the center lane as before. You notice a different stripe pattern on your right. Seeing this, please check all the statements that best describe the right lane to you.

The six statement choices provided and the percentage response to each for each delineation treatment are described later in this paper.

Forty subjects, aged 18 to 62, male and female, from the State College, Pennsylvania, area participated in the study. Each experimental session of 153 paried-comparison trials and 18 questionnaire trials lasted 30-40 min.

EXPERIMENTAL ANALYSES AND RESULTS

Paired-Comparison Data

Paired-comparison data were first summarized in a table of proportions, and then traditional scale values were calculated. Table 2 gives the scale and the position of each treatment. This procedure is described in detail by Guilford (3). Scale numbers are quite arbitrary--i.e., they could be transformed to all positive, all negative, times 100, etc.--but the distances between values are meaningful. For example, a standard dash line (scale value $\simeq 1.3$) is twice as permissive as a line of diamonds (scale value $\simeq 0.6$).

The impact of several design parameters, in relation to the prohibitiveness or permissiveness conveyed to subjects by the delineation treatments, can be seen in the scale in Table 2. First, any treatment that has repeated openings in the design--e.g., dashes or skips--is clearly more permissive than treatments that include a continuous or broken line. This appears to be a general design principle that is relatively unaffected by the specific pattern of symbology used.

An experiment on the I-95 priority lane in Miami provides supporting evidence for the laboratory findings (4). Over a 2.5-mile portion of that facility, a solid white lane line was used and then replaced with a standard dash. There were significantly greater weaving and higher rates of lane violation with the dash than with the solid line. This suggests that the differences found in the laboratory in subjects' reactions to dash and solid patterns will apply, at least to some degree, in an operational setting.

Width of line appears to have relatively little effect. The double-width dashes in treatments 3, 13, and 14 were less permissive than a standard dash but clearly less prohibitive than any other treatment. Whereas this one finding would usually not be considered conclusive, it is in complete agreement with the findings from the experiments with a priority bus-carpool lane on I-95 in Miami. In that project, 4-in and then 8-in skip lines were used to separate the general lanes from the priority lane over a 2.5-mile section of the roadway. For the three measures of effectiveness--weaving, lane-violation rate, and travel time--there were no differences between the two stripe-width conditions. Given the consistent laboratory and field results, further investigation of stroke width in buffer-zone design would not appear to be productive. These findings, however, do not fully explore the issue of

Table 3. Percentage response to questionnaire statements for each delineation treatment.

Treatment No.	Response (%) Pass and Travel Freely	Turns and Exits only	Repair or Emergency Lane	Special-Use Lane	Do Not Use	Don't Know
1	75	7	7	2	2	7
2	62	11	7	2	7	11
3	26	36	14	0	5	19
4	62	21	2.5	2.5	2.5	9.5
5	9.3	11.6	11.6	21	18.6	27.9
6	13.6	9.2	20.4	9.2	27.2	20.4
7	2	6	22	22	22	26
8	30.9	40.5	9.5	0	0	19.1
9	20	27.5	17.5	7.5	2.5	25
10	41.5	22	12.2	2.4	2.4	19.5
11	2.4	4.8	17.1	17.1	39	19.5
12	10	16	24	18	18	14
13	75	12.5	2.5	0	0	10
14	52	10.9	17.4	8.7	2.2	8.7
15	2.5	2.5	17.5	32.5	15	30
16	4.6	11.6	23.3	23.3	11.6	25.6
17	19	30.9	12	9.5	0	28.6
18	20.9	20.9	18.6	16.3	0	23.3

buffer-zone width, and further study of this will be required.

The impact of color was studied by including three buffer-zone treatments (treatments 2, 7, and 9) in different colors: white, light blue, and bright yellow-green. The relative positions of the colored designs on the scale in Table 2 show that (a) there is no consistent difference between light blue and bright yellow-green in meaning and (b) colored treatments were consistently more prohibitive than white treatments but by relatively small amounts. This suggests that color can be included in a buffer-zone design without drastically changing the prohibitiveness or permissiveness of a treatment.

Finally, the solid versus outline diamond design resulted in relatively small but consistent differences. The seven treatments in which diamond outlines were used were all more permissive in meaning than the three treatments in which solid diamonds were used. Since, however, this was not a completely factorial analysis and all treatment combinations (such as solid diamonds in a dash pattern) were not studied, this finding should be tested more extensively.

Questionnaire Data

In part 2 of the experiment, subjects were shown each delineation treatment and were instructed to choose which of the following questionnaire statements best describe the right lane:

1. I can enter the right lane for passing and travel as I wish.
2. I can enter the right lane for turns or exit ramps only.
3. I would enter the right lane for emergency repairs.
4. I should not use the right lane; it is reserved for special vehicles.
5. I should not use the right lane at all.
6. I have no idea whether I can enter the right lane or not.

The responses to the questionnaire were tabulated by treatment. Table 3 gives the resulting percentage response.

Since the six questionnaire alternatives for each treatment formed a loose scale or continuum, ranging from open or general use to assorted restrictions to "I cannot use the lane" and "I don't know", a weighted mean was calculated for each treatment. The number of the statement (1, 2, etc.) was multiplied by the frequency. These numbers were summed across responses for each treatment, and the total was divided by N to give a weighted mean. The lower the weighted mean, the more permissive was the meaning of the delineation treatment. Finally, the treatments were ranked from most to least permissive. These ranks appear next to the paired-comparison ranks in Table 2. A Spearman rank correlation of $r_s = 0.93$ indicates that the results from the two different measurement methods are highly complementary.

The questionnaire data supplement the paired-comparison data in several ways. Any treatment with a skip was seen as "restricted to special vehicles" or "not to be used" by very small percentages of the respondents. All treatments with a solid or continuous line or pattern elicited a higher rate of "restricted, I cannot use" responses; however, a relatively high percentage (12-25 percent) of respondents thought that the other side of the buffer zone could be used to stop for repairs. A much smaller percentage (2.5-17 percent) of respondents would stop on the other side of a dashed treatment. Further work on how drivers perceive where they can stop their vehicles is necessary before final buffer-zone design recommendations can be made.

Color had no strong impact on the perceived meaning of the designs. Blue tended to be associated slightly more with a reserved or special-vehicles-only meaning, and bright yellow-green with "can cross for turns and exit ramps". Based on the paired-comparison and questionnaire results, color appears to play a very secondary role in determining subjects' responses to buffer-zone designs.

Similarly, the paired-comparison finding regarding solid versus outline diamonds was supported by questionnaire results. Thus, a solid diamond appears to imply a more prohibitive meaning than an open diamond.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the laboratory evaluation reported here, the following conclusions can be drawn:

1. The various delineation designs tested do vary in terms of prohibitiveness and permissiveness of meaning.

2. Dash or skip designs are more permissive in interpretation than continuous designs, regardless of the symbology used.

3. Solid (or filled) diamonds appear more prohibitive than diamond outlines.

4. Line stroke width appears to have little impact on subjects' reactions to buffer-zone designs.

5. Color tends to add a degree of prohibitiveness to design meaning but generally is a secondary determinant of subject response.

6. The paired-comparison forced-choice and questionnaire techniques provide different types of information about buffer-zone design, and the data are highly complementary, resulting in a Spearman rank correlation of $r_s = 0.93$.

7. Several design characteristics must be further defined before design recommendations can be advanced. Included are delineation-zone width, effect of spacing or density of symbol (rungs in crosshatch), and driver perception of where a vehicle can be stopped relative to the delineated zone.

8. Any design recommendations emanating from laboratory study should be evaluated in an operational setting.

ACKNOWLEDGMENT

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REFERENCES

1. J. H. DuPree and R. H. Pratt. A Study of Low-Cost Alternatives to Increase the Effectiveness of Existing Transportation Facilities: Results of Survey and Analysis of Twenty-One Low-Cost Techniques. R. H. Pratt Associates, Inc., Silver Spring, MD, Jan. 1973.
2. R. F. Pain and others. Signing and Delineation for Special-Usage Lanes. Federal Highway Administration, U.S. Department of Transportation, Interim Rept. FHWA-RD-78-205, Vol. 1, Dec. 1977.
3. J. P. Guilford. Psychometric Methods. McGraw-Hill, New York, 1954, Chapter 7.
4. K. G. Courage and others. Traffic Control of Carpools and Buses on Priority Lanes on Interstate 95 in Miami. Federal Highway Administration, U.S. Department of Transportation, Rept. FHWA-RD-77-148, Aug. 1977.

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Study of Width and Density of Delineation Design Elements for Special-Use Lanes

BEVERLY G. KNAPP AND RICHARD F. PAIN

The results of a two-part study that investigated the effects of varying roadway delineation width and the density of design elements within the roadway line on driver lane-change behavior are reported. The width study consisted of a controlled field experiment in which drivers indicated their decisions on whether to cross 1-, 2-, and 3-ft delineation treatments laid on a closed section of roadway. In the second part of the study, a laboratory experiment, the number of elements in the line design was varied by overlaying various drawings onto a highway scene and showing these slides to subjects to elicit their lane-choice responses. The designs tested were generated from previous work related to delineation treatments for high-occupancy vehicle lanes, which often operate as special-use lanes during rush hours and then revert to general use during off-peak hours. Delineation markings must thus appear prohibitive at one time and permissive at another. Width of line was found to have relatively little effect on the prohibitive or permissive meaning of delineation treatments. Density of design elements, however, was found to be an important determinant of permissiveness or prohibitiveness in that the widely spaced elements invited lane crossover more than densely spaced ones. The study findings appear to be applicable not only to delineation designs for special-use lanes but also as general design parameters in the application of roadway markings.

In a paper elsewhere in this Record, various delineation marking designs for highways and arterials were evaluated in terms of their permissive or prohibitive effects on driver lane-change behavior. These marking designs were developed for potential application as delineators between concurrent-flow, high-occupancy-vehicle (HOV) lanes and general-use traffic lanes. The intent of the study was to determine the levels of prohibitive or permissive meaning conveyed by various delineation designs by using a paired-comparison process, since the final design chosen must operate in one mode during HOV lane operation and another mode during off-peak hours (i.e., must be prohibitive to some vehicles at certain times and not at other times). The delineation treatments tested are given in Table 1.

In general, the earlier study established that dashed "skip" designs permit or elicit vehicle crossovers while solid, connected lines prohibit them. It was also found that colored lines are somewhat more prohibitive in meaning than a white version of the same configuration. The results experimentally defined some basic design parameters.

This paper discusses the effects of two other parameters--width and density of design image--that were not resolved.

The data given in Table 2 indicate how the concept of "element density" emerged from the earlier paired-comparison data. Element density is the actual number of elements, either diamonds or crosshatch strokes, within any given line segment. This concept emerged from the results of the first experiments in the form of "clusters" of delineation treatments, according to varying degrees of what subjects perceive as a "wide, thick look" versus a "thin, sparse look." Treatments 1, 2, 4, 8, 10, 13, and 14 are a cluster--a separated, thin look; treatments 3, 5, 9, 17, and 18 are connected but still thin; treatments 6, 7, 15, and 16 are wide and connected; and, finally, treatments 11 and 12 (the crosshatch lines) are wide and strictly prohibitive, with a very dense look. Width is simply the varying of the total horizontal image of the line itself--i.e., the width of the total delineation or buffer-zone treatment.

Table 1. Delineation designs tested.

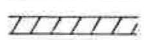
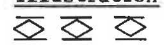
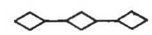
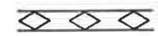
Treatment No.	Type	Illustration
1	Conventional dash	
2	Wide dash	
3	Broken-solid combination (white)	
4	Double dash (white)	
5	Conventional dash and MUTCD diamond (15-ft line, 25-ft gap), diamond every 1000 or 500 ft	
6	Diamond with solid line (white)	
7	Design 5 with filled-in (solid) diamond	
8	Diamond with dash line (white)	
9	Diamond with connecting line (white)	
10	Diamonds only	
11	Diagonal crosshatch (left slant)	
12	Diagonal crosshatch (right slant)	
13	Design 2 in bright yellow-green	
14	Design 2 in light blue	
15	Design 7 in bright yellow-green	
16	Design 7 in light blue	
17	Design 9 in bright yellow-green	
18	Design 9 in light blue	

Table 2. Clustering of delineation designs by appearance in relation to paired-comparison rankings.

Cluster	Appearance	Paired-Comparison Rank[a]	Treatment No.	Paired-Comparison Scale Value
1	Separated, thin	1	1	1.3
	look			1.2
		2	2	1.10
		3	14	1.00
				0.9
		4	13	0.8
				0.7
		5	10	0.6
		6.5	4	0.5
		6.5	8	0.5
				0.4
				0.3
				0.2
				0.1
2	Connected, thin	8	9	0.05
	look	9	3	0
		10	5	-0.1
		11	17	-0.2
		12	18	-0.3
				-0.4
3	Connected, wide	13	6	-0.5
	look	14	7	-0.6
		15	16	-0.7
		16	15	-0.8
4	Connected, wide,	17	12	-0.9
	dense, strictly	18	11	-1.0
	prohibitive look			-1.1
				-1.2
				-1.3

[a] 1 = most permissive; 18 = most prohibitive.

In order to study the effect on subjects' perceptions of these delineation treatments when the parameters of horizontal width and vertical image are varied according to stroke-element density, one treatment was selected from each of the clusters described above. Since the effect of color is tentative and would confound treatments of interest, only white designs were considered. The following designs were selected because they are relatively equidistant in ranking on the comparison scale:

Cluster	Treatment	Illustration
1	8	
2	9	
3	6	
4	11	

In attempting to design stimulus materials to study both width and density, it was determined that an artist's drawing that attempted to portray varying widths of 1-3 ft was not a perceptually good simulation of a driver's view, since the differences would be so obvious. Density, on the other hand, was well suited to display on stimulus slides similar to the ones used in the previous study. To reconcile this dilemma, it was decided to study the issue of width in a more realistic, controlled field setting and to simultaneously design a laboratory investigation of the density parameter, in which the slide technique would be used. Thus, two experiments were performed instead of one. The methodology, results, and discussion of each of these experiments--called the field study and the laboratory study--are presented separately.

FIELD STUDY

Method

The field study examined the width of the delineation markings for each of the four selected designs described earlier. For each design, widths of 1, 2, and 3 ft were paired against each other. A total of 12 test pairs resulted, three for each treatment: 1 versus 2 ft, 1 versus 3 ft, and 2 versus 3 ft. The dimensions for each width and design are given in Table 3.

The paired-comparison technique discussed by Guilford (1) was used here. Subjects were forced to indicate which delineation treatment of any given pair they would sooner cross, given a blockage in their center lane of travel. A blockage "set" was given subjects to more closely replicate the laboratory study. The stimuli here were actual delineation stripes laid out on closed sections of roadway. Subjects were driven through each of the 12 pairs and asked to indicate a "left" or "right" choice for each.

The pairs were laid out on closed sections of MD-32 and MD-100, off I-95 north of Washington, D.C. Each pair of treatments was laid out by using construction-grade, temporary white lane tape. The pairs were each 100 ft long and 12 ft apart, and each pair was separated by 400-500 ft of driving distance. Figure 1 shows some examples of these pairs as they were laid out on the roadway. The 12 pairs were laid out in random order on three sections of roadway, and placement of any given treatment on the left or the right was also counterbalanced.

The basic testing routine consisted of two parts:

(a) the experimental drive through the test course and (b) completion of a form that contained questions about the markings just seen. When a subject arrived at the appointed meeting station, he or she was greeted by an experimenter and taken for a ride as a passenger in the test car. The car used was a 1978 Plymouth Volare automatic, a standard-sized vehicle with ordinary viewing distance and height for most drivers. The subject was driven through each test pair and told to indicate on the answer sheet whether he or she would, as a driver, sooner cross the line to the left or the line to the right.

After the drive-through, subjects were returned to their point of origin, where they filled out the remainder of the test sheet, which showed drawings of each of the four delineation designs they had just seen. As in the earlier study, subjects checked which of six driving behaviors was appropriate for each treatment:

1. I can enter the right lane for passing and travel as I wish.
2. I can enter the right lane for turns or exit ramps only.
3. I would enter the right lane only for emergency repairs.
4. I should not use the right lane; it is reserved for special vehicles.
5. I should not use the right lane at all.
6. I have no idea whether I can enter the right lane or not.

Subjects were asked to rank each treatment from best to worst (1 to 4), according to how it conveyed the meaning of a special-use lane. The subjects were then paid, thanked, and dismissed.

The entire test run took 30 min or less. Driving speed through the test pairs was 35-40 miles/h, which allowed an exposure of several seconds for each, in a dynamic driving mode.

Thirty-four licensed drivers participated in the study, 17 males and 17 females. They ranged in age from 17 to 65; half were under 30 years of age, and half were over 30. They learned about the study through various types of publicity in the Baltimore-Columbia, Maryland, area.

Table 3. Width and design dimensions for each delineation treatment: field study.

Treatment No.	Buffer Width (ft)	Stroke Width (in)	Spacing of Design Elements
6	1	2	5 diamonds 20 or 25 ft apart[a]
8	2	4	5 diamonds 18 or 20 ft apart[a]
9	3	6	5 diamonds 15 or 17 ft apart[a]
11	1	2	2-in crosshatch strokes at 45° angle, 5 ft apart
	2	4	4-in crosshatch strokes at 45° angle, 5 ft apart
	3	6	6-in crosshatch strokes at 45° angle, 5 ft apart

[a]Diamond length-to-width ratio = 3:1.

Results

The paired-comparison data were summarized in four small tables of proportions, one for each delineation treatment, and traditional scale values were calculated. This follows the scaling procedure detailed by Guilford (1).

Figure 1. Sample stimulus pairs of delineation designs with varying line widths laid out on closed sections of roadway.

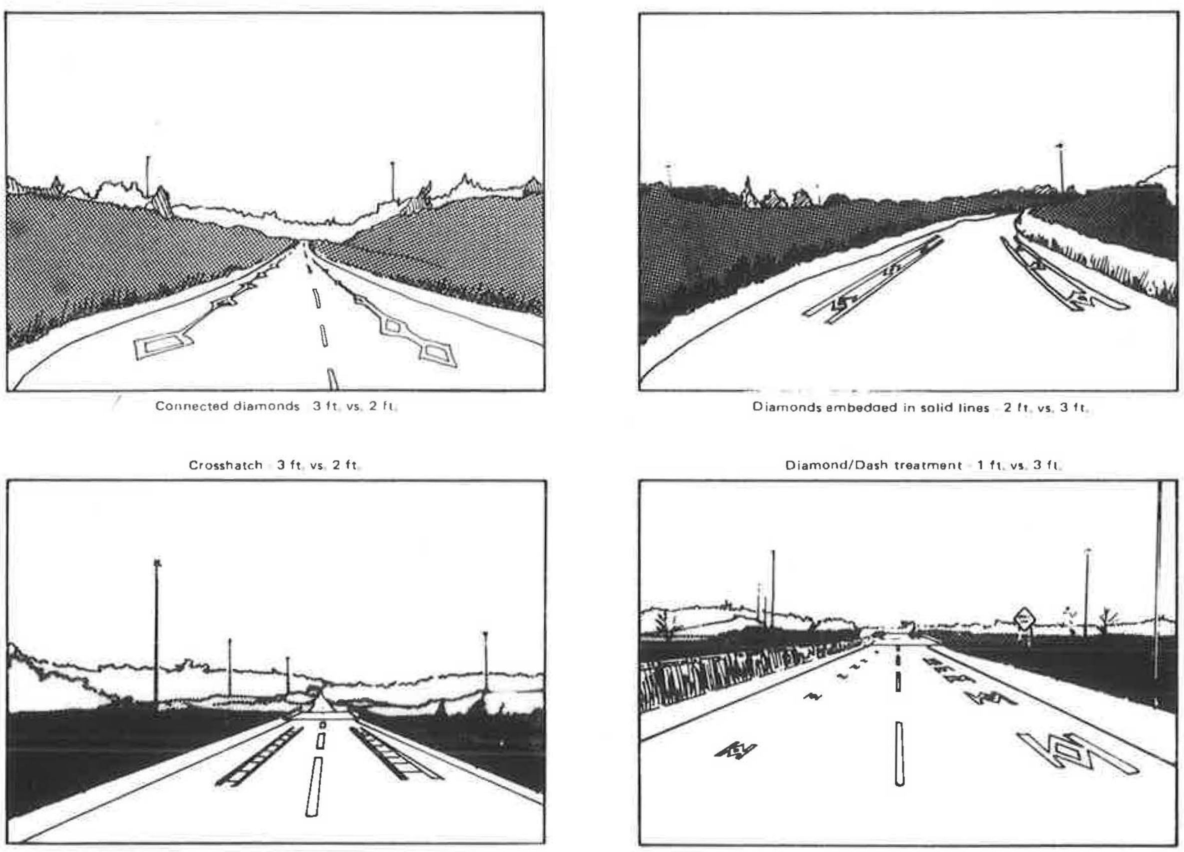


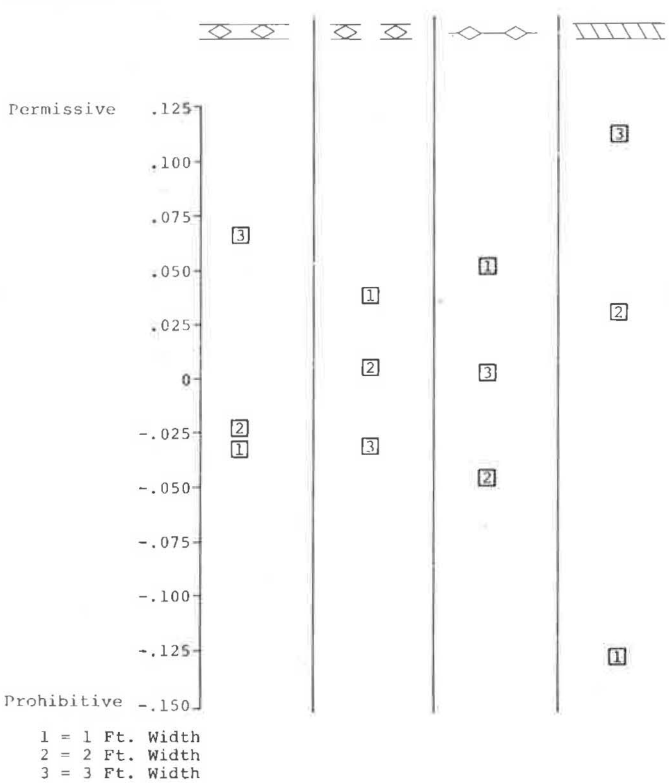
Figure 2 diagrammatically shows the scale values obtained for each of the four designs. Scale values are arbitrary numbers, amenable to transformation. However, the total distance between widths, even in the most separated condition--treatment 11 (the crosshatch design)--is not great in comparison with the wide scale obtained in the previous study (Table 2). In scanning across each treatment, the more crucial issue is whether any one width is more permissive or prohibitive than any other, and simple inspection reveals almost totally random results for the widths tested. So the 1-, 2-, and 3-ft widths have essentially the same effects, and thus the cost-effective, space-saving, 1-ft image is acceptable for use. In fact, it is desirable to avoid the wider widths because they may have a tendency to indicate to drivers a shoulder or breakdown area, especially the crosshatch design.

The data from the questionnaires replicate previous data quite well. Table 4 gives the frequency of response for each of the four treatments. The six questionnaire responses form a loose scale ranging from open, permissive connotations to assorted restrictions and ending with "Keep out" or "I don't know." The number of the behavior alternative (1, 2, etc.) is multiplied by the response frequency, summed for each row, and divided by N to yield a weighted mean. This indicates a ranking of permissiveness, since the lower the weighted mean, the more permissive is the meaning of the treatment. Thus, the dash-diamond treatment (treatment 8) is the most permissive delineation, followed in order by the connected diamonds (treatment 9), the crosshatch (treatment 11), and the solid lines with embedded diamonds (treatment 6).

A final task for the test subjects was to rank order the four design treatments from best to worst (1 to 4) as delineation treatments for special-use lanes. In this case, the frequencies of selection for each rank per treatment are tabulated. Weighted rank sums are then computed (rank is multiplied by frequency and then summed for each treatment) to give an overall ranking for each design. Table 5 gives these rankings and the resultant ranking of the four designs based on these data.

This method of assessing the effectiveness with which a delineation design conveys the intended meaning clearly corroborates both the paired-comparison and questionnaire findings. Treatment 9 (the diamond design with a dash pattern) was judged least effective in conveying the meaning of special or restricted lane use. Treatment 6 (the double solid line with diamonds) and treatment 11 (the crosshatch design) were judged very similar in effectiveness. A closer look at the data for the crosshatch treatment reveals that many observers ranked this design as best but a surprisingly high number ranked it as worst. This suggests that the crosshatch may be so strongly prohibitive that the special-use connotation is masked for almost one-third of the subject drivers. During the test drive, many drivers volunteered the thought that they felt more comfortable with a "diamond look" to indicate special lane use and felt that they might belong in the lane only if there were some signs or other explanations as to what the diamonds meant.

Figure 2. Paired-comparison scale values: field study.



LABORATORY STUDY

Method

The laboratory study was concerned with determining the effects of stroke-element density--i.e., whether the number of diamonds or line elements within a given area would affect the driver's decision as to whether to cross over the delineation line. The paired-comparison, forced-choice technique was again used. Eighteen delineation designs of varying densities were paired against each other, and subjects indicated which of each pair they would sooner cross.

The delineation treatments were drawn on acetate sheets and overlaid on an artist's rendering of a three-lane highway. The 18 treatments were generated by using the four basic designs tested in the field study. The ratio of number of elements to gap was considered at three levels for each of the four treatments: 12-ft spacing (ratio of 2:1), 24-ft spacing (ratio of 4:1), and 36-ft spacing (ratio of 6:1). The remaining 6 design treatments considered

Table 4. Frequency of responses for each of six driving behaviors for four delineation treatments: field study.

Treatment No.	Frequency of Response: Pass and Travel Freely	Turns and Exits Only	Repair or Emergency Lane	Special-Use Lane	Do Not Use	Don't Know	Weighted Mean
6	6	4	8	6	0	14	24.3
8	18	3	5	3	1	9	18.3
9	1	8	7	8	2	9	22.3
11	2	7	9	6	8	6	23.8

Table 5. Frequency of responses ranking each of four delineation treatments from best to worst: field study.

Rank	Treatment 6	Treatment 8	Treatment 9	Treatment 11
1	10	4	2	14
2	14	7	4	5
3	6	9	12	3
4	0	9	12	8
Weighted sum[a]	56	81	94	65

[a]Lowest number is closest to "best".

represent a breakdown of the crosshatch design by color (bright yellow-green and light blue) for the three element spacings. This was done to determine the impact of color on the prohibitiveness of the crosshatch design, which was perceived as strictly prohibitive by study subjects.

The acetate overlays were placed on the three-lane highway painting, each paired against each other. This yielded a total of 153 pairs, which were photographed as 35-mm slides. Figure 3 shows samples of these slides. The resulting stimulus slides were shown in random order to three groups of subjects by using a tachistoscope with a 1-s exposure and a 5-s stimulus interval. As each slide was presented, subjects simply checked on their response sheet "left" or "right" to indicate which line they would sooner cross to bypass a center-lane blockage.

In addition, subjects filled out a questionnaire on the four delineation designs they had just seen, answering the same questions given to subjects in the field study. Subjects were required to check which driving behaviors seemed appropriate for each design and to rank the designs from best to worst according to how well they connoted a special-use lane. The entire test procedure, slides and questionnaire, took about 25 min.

Twenty-eight subjects from the State College, Pennsylvania, area participated in the study. There were 17 males and 11 females, ranging in age from 18 to 59 years.

Results

The paired-comparison data were first summarized in a table of proportions and subsequently transformed to traditional scale values for each of the 18 treatments. Figure 4 shows the scale and where each of the treatments falls on it. The scale ranges from permissive (promoting crossover) to very prohibitive (discouraging crossover). Although the scale numbers are arbitrary, the distance between values is meaningful in clustering and ordering the designs.

Several conclusions are clearly evident from the scale data:

1. The dash design with the embedded diamonds (treatment 9) is perceived as the most permissive, and the diamonds connected by a single line (treatment 8) is the next most permissive. Both are characterized by a thin, broken look. All six of these treatments, regardless of element (diamond) density, are above the zero point, which indicates permissiveness. The crosshatch treatments (treatment 11) of varying density and color, as well as the diamonds embedded between two solid lines (treatment 6), all cluster below zero on the scale, which indicates that they act to prohibit lane change. This directly validates previous findings.

2. Within the scale separations for permissiveness and prohibitiveness by design, each design becomes more prohibitive within its own space as the density of stroke elements increases. Thus, the most open dash treatment, the diamond-dash combination (treatment 9), is at the very top; and the tightly spaced, white crosshatch ladder design is at the very bottom, well separated from the initial prohibitive cluster.

3. No appreciable effects or advantages can be seen in the use of color; it seems to promote some relative indecision but generally does not affect perceptions of permissiveness. Its merit apparently lies in its being a cue to the driver to associate it with other available information, such as signing. Several subjects commented on this point.

The questionnaire data were taken exactly as in the field study. Subjects first checked which of six driving behaviors was appropriate for each of the four delineation designs and then ranked these from best to worst according to how well they connoted a special-use lane. This was, in a sense, the final validation of results from previous studies. Although the data do not provide a perfect match, the differences do not appear to be meaningful.

Table 6 gives the frequency of responses to each of the six behavior statements by treatment design. Response frequencies for the six types of behavior again formed a loose scale, from permissive to prohibitive to "I don't know", and were again transformed into weighted means for each design. The most permissive designs were the diamond-dash combination (treatment 9) followed by the diamonds connected by a single line (treatment 8). More prohibitive was the embedded diamonds within two solid lines (treatment 6), and the most restrictive design was the crosshatch (treatment 11). All treatments with solid lines were perceived as restrictive in some way. Except for the diamond-dash treatment, the diamond options are more associated with a special-use lane. The dash design again diminishes the effects of the associative meaning of symbols and conveys the more important factor--namely, "The line is dashed, so I can cross it." The crosshatch image is strongly prohibitive: None of the respondents elected the pass-and-travel option in the presence of a crosshatch design, and most (46 percent) responded "Do not use." For all of the connected treatments, especially the crosshatch, one-quarter to one-third of the subjects indicated that the lane could be used for emergency repair, a factor that needs further study.

Table 7 indicates the frequency with which the four delineation treatments were assigned to each rank, from best to worst, and the weighted sums computed. This is the same procedure used in the field study.

The crosshatch design (treatment 11) was ranked best of the four design alternatives, and the solid double lines with diamonds (treatment 6) a clear second. This is the reverse of the rankings from the field study. Is the switch in position a chance fluctuation, or is it related to the difference between real-life experience (full size and perspective) and exposure to artist-rendered image stimuli? Only further empirical work can provide the answer.

The single solid line with diamonds (treatment 8) was ranked third, and the dash pattern with diamonds (treatment 9) was ranked least effective in conveying the meaning of restricted or special use.

SUMMARY AND CONCLUSIONS

The two components of this study, the field setting and the laboratory setting, produced reliable findings regarding delineation width and element

Figure 3. Sample stimulus pictures used to test the effectiveness of element density in delineation designs.

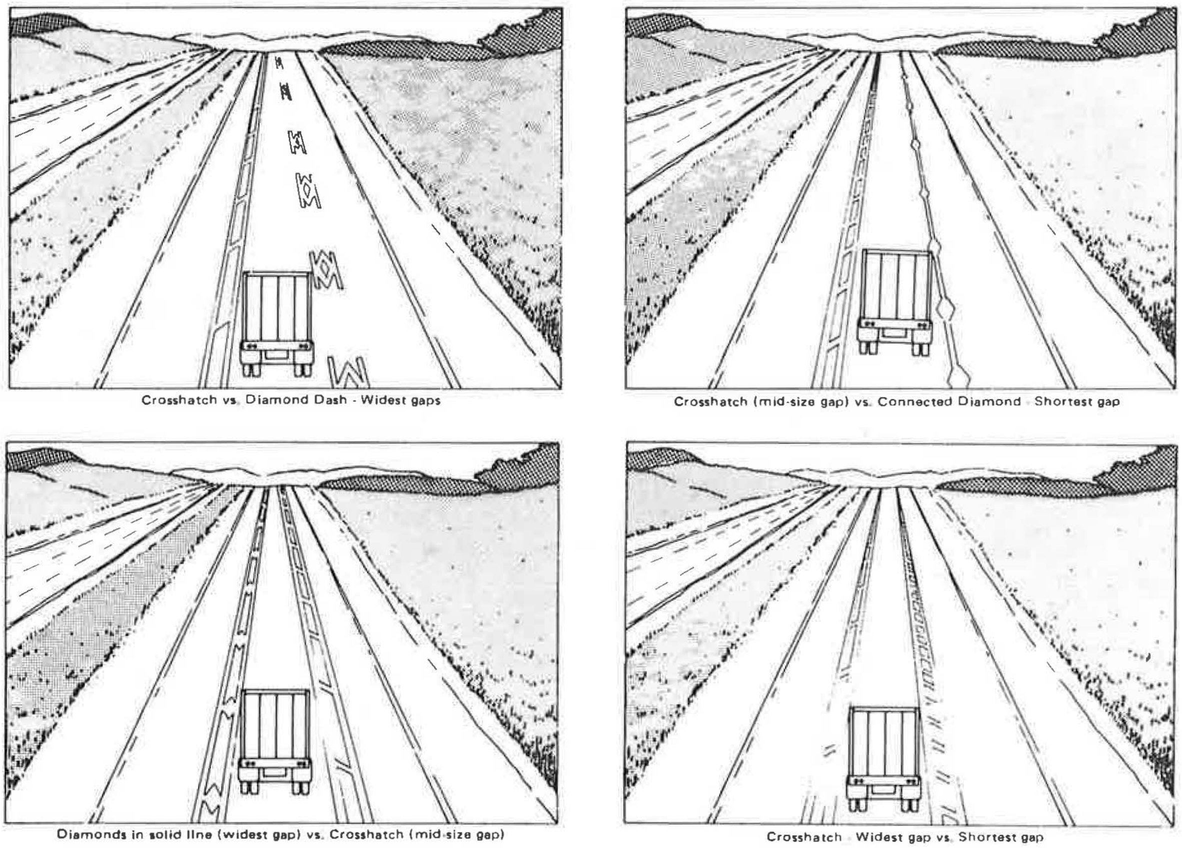
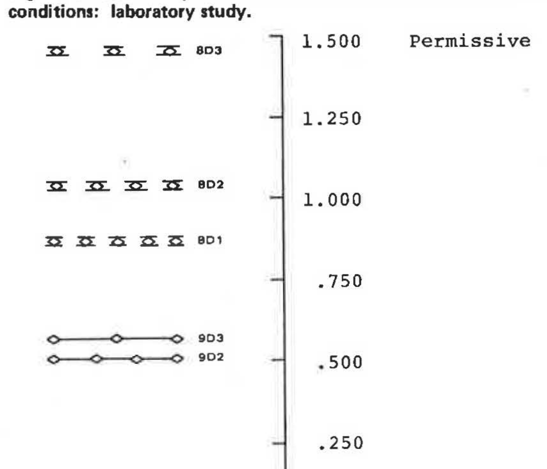


Figure 4. Paired-comparison scale values for each of 18 delineation-treatment conditions: laboratory study.



density. In the field, 1-, 2-, and 3-ft widths were found to be relatively interchangeable in terms of design permissiveness and prohibitiveness. In the laboratory, element density was shown to be an important determinant of permissiveness in that the delineation treatments with more widely spaced elements tended to invite crossover more than the treatments in which the elements were closer together.

In addition to these primary findings, the questionnaire and ranking data produced highly complementary results. One part of the study validated the other, and both in turn validated the previous study. This is particularly meaningful because the subject samples were drawn from two different geographic areas and represented a wide range in age and an almost even male-female split. Given such a stratified random sample and reliable data, it is felt that the results can be applied not only as inputs to final delineation designs for special-use lanes but also as general design parameters in the application of roadway markings.

The conclusions drawn from each component of the study are presented separately below.

Field Component

1. There is no appreciable difference in the prohibitive effects of 1-, 2-, and 3-ft widths for the four delineation treatments tested.

2. The dash-diamond treatment is the most permissive in terms of driver tendency to cross. This replicates findings from a previous study that revealed the tendency of a skip design to promote crossover.

3. Striping with diamonds connected by a single

Table 6. Frequency of responses for each of six driving behaviors for four delineation treatments: laboratory study.

Treatment No.	Frequency of Response: Pass and Travel Freely	Turns and Exits Only	Repair or Emergency Lane	Special-Use Lane	Do Not Use	Don't Know	Weighted Mean
6	1	9	6	8	4	4	18.8
8	14	5	4	1	0	7	13.6
9	7	9	6	4	0	4	13.8
11	0	1	8	3	13	4	21.1

Table 7. Frequency of responses ranking each of four delineation treatments from best to worst: laboratory study.

Rank	Treatment 6	Treatment 8	Treatment 9	Treatment 11
1	5	1	1	2
2	14	6	1	4
3	4	15	10	0
4	1	6	17	3
Weighted sum[a]	53	82	100	41

[a]Lowest number is closest to "best".

line or with diamonds embedded between solid lines is seen as associated with a special-use lane.

4. The special-use association of the diamond is apparently diminished somewhat when the diamond is part of a skip design.

5. The crosshatch (or ladder) type of striping is most effective in prohibiting drivers' tendency to cross. This also replicates previous findings.

6. There is some difference among various observers as to whether the prohibitiveness of the crosshatch design is necessarily associated with the concept of the special-use lane. Further investigation of this is warranted.

Laboratory Component

1. The more elements per length of line in a delineation treatment, the more prohibitive the treatment is.

2. Designs with a broken, thin look remain the most permissive to drivers, regardless of the symbology used.

3. Solid, connected delineation lines with embedded diamonds or crosshatching are a highly effective prohibitor of lane change.

4. Color does not appreciably affect the prohibitiveness or permissiveness of delineation markings but could trigger associative meanings if accompanied by signing. Further testing is needed.

5. Questionnaire and ranking data on the four designs tested correlate well with the results from the paired-comparison trials and previous experimental studies.

6. The crosshatch design must be tested further in the field to determine its true effectiveness as a prohibitor of lane change and its potential for association with the concept of the special-use lane.

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REFERENCE

1. J. P. Guilford. Psychometric Methods. McGraw-Hill, New York, 1954, Chapter 7.

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