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SEVEN EXPERIMENT DESIGNS ADDRESSING PROBLEMS OF SAFETY AND CAPACITY ON TWO-LANE RURAL HIGHWAYS
Volume II: Experimental Design to Develop and Evaluate Dynamic Aids for Narrow Bridges

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16. Abstract This is Volume II. A large number of bridges on two-lane rural highways are narrow bridges. While there is no universally accepted definition of this type of bridge, it is generally considered to be one where the roadway and/or shoulders narrow significantly. It has been recognized that this situation produces accidents with either the bridge structure, oncoming vehicles or both. In this volume, an experimental design was developed to measure the relative effectiveness of various types of active and passive devices to warn motorists of the presence of a narrow bridge ahead. Suggested measures of effectiveness and the necessary statistical tests are described. In addition, a state-of-the art survey and bibliography are presented. A sample questionnaire which can be administered to motorists traversing the test section is appended. This Technical Report consists of seven other volumes. They are:

Vol.	pp.	Title
I	38	Introduction, Description of Experiments and Common Elements
III	72	Evaluation of MUTCD and Other Traffic Controls for Highway Construction and Maintenance Operations on Two-Lane Highways
IV	58	Develop and Evaluate Remedial Aids to Warn Drivers of Slow Moving Vehicles on a Grade
V	62	Vehicle Equivalency and Capacity Including Effects of Commercial and Recreational Vehicles on Rural Non-Controlled Access Highways
VI	54	Comparative Evaluation of Warning-Advisory and Regulatory Traffic Control Devices
VII	50	Develop and Evaluate Measures for Reducing Effects of Roadside Friction on Traffic Flow
VIII	70	Remedial Aids for Intersections with Inadequate Sight Distance

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1. INTRODUCTION

This report presents the Experimental Design entitled, "Develop and Evaluate Dynamic Aids for Narrow Bridges."* This is Volume II of an eight-volume report. Volume I contains background information and a discussion of those elements common to all seven experimental designs.

This volume includes:

- Background and Objectives
- A State-of-the-Art Review
- The Experimental Design
- A Bibliography

1.1 Background

The hearings of the Committee on Public Works of the House of Representatives (34) entitled "Narrow Bridges--Driver Dilemmas," highlighted the serious safety problem faced by motorists traversing narrow bridges. A history of serious accidents involving vehicles impacting the bridge structure or colliding with other vehicles on the bridge was presented at these hearings.

Although there is an obvious lack of comprehensive documentation and statistics concerning the magnitude of the narrow bridge problem (44), narrow bridge accidents are common and often involve high loss of life. For example, in (39) it is shown that in Ohio twice as many deaths result from traffic accidents at bridges as from accidents at railroad crossings and that about 3 percent of all accidents in Ohio are narrow bridge accidents.

On non-Interstate highways, Hilton (39) showed that narrow bridge accidents account for 1.6 percent of all accidents and approximately 3.4 percent of all fatal accidents. Oklahoma's statistics for 1969 show almost 2000 narrow bridge related accidents (12).

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* This experiment is referred to as Experiment A in Volume I.

2. STATE-OF-THE-ART

Three initial document sources used for the state-of-the-art survey were, "Traffic Control Devices to Provide the Motorist with Positive Guidance Through Narrow Bridge Locations" (Ref. 44), the report of NCHRP Project 20-7, "Safety at Narrow Bridge Sites" (Ref. 74), and the Manual on Uniform Traffic Control Devices" (Ref. 22). These identified important research reports and results bearing on the narrow bridge problem. The significance of the problem is evident from the hearings of the Committee on Public Works of the House of Representatives (Ref. 77) entitled "Narrow Bridges--Driver Dilemmas." These items supplemented by document searches both at the Transportation Systems Center facility in Cambridge and through the Transportation Research Board in Washington, D.C. lead to the bibliography herein presented.

The state-of-the-art survey was implemented by supplementing KLD's library resources with TRIS and HRIS document searches. An interactive TRIS search was done using the TSC facility in Cambridge and an HRIS search was performed through TRB in Washington, D.C. Based on the searches and on information gathered from other reports, researchers and DOT personnel, a bibliography relevant to the narrow bridge experiment was compiled. The items in the bibliography cover a variety of subjects relating to the operational and safety aspects of traffic control on narrow bridges. For the most part, the items can be categorized into five areas according to their basic subject matter:

- Effect of narrow bridges on traffic operations;
- Warning devices for bridge approaches;
- Warning devices used in locations other than bridges;
- Safety and accidents on bridges;
- General -- including some aspects of bridge design and analysis methodologies.

Poles, bridge columns, parapets and other fixed objects set close to the pavement cause drivers to shy away while construction, actual or apparent, cause drivers to move out of their normal lane or change speed abruptly. (Ref. 51).

The research on the effect on vehicle operations of narrow bridges, shoulder width and other fixed object obstructions near the pavement thus indicates that lateral placement is a significant parameter. Although speed has also been measured in several cases, it has generally been noted that significant changes in speed have not been observed.

2.2 Warning Devices for Bridge Approaches

A second category of documents deals with the use of warning devices specifically intended for use on bridge approaches. The use of signing and pavement marking systems for narrow bridges is described and summarized in "Traffic Control Devices to Provide the Motorist with Positive Guidance through Narrow Bridge Locations" (Ref. 44). However, many of the research items in this category deal with hazards associated with the bridge other than the narrowness of the pavement. In particular, warnings of icy conditions on the bridge has been researched and dynamic aids to detect and warn have been developed (Ref. 16, 27, 44, 45, 54). Although these reports are not specifically concerned with the narrow bridge problem, the experimentation and warning systems can be applied to this research. For example, in Ref. 43, a field evaluation of an activated warning message together with an amber flashing light was performed. Data on speeds, lane distribution, lane changes and brake light occurrences were collected and it was concluded that the most decisive result was a reduction in speed when the activated message was compared with the usual warning system in use. This type of system, with the appropriate message, is a potential candidate for the narrow bridge situation. It has also been found that most motorists do not respond to warning signs in the manner desired (Ref. 27). Research in progress on ice detection and warning systems for motorists (Ref. 37, 45, 54, 78) can have important implications for the narrow bridge research and it is suggested that contact should be maintained with these efforts.

In the first subcategory, a few general items on traffic control methodology (Ref. 8 and 9) were examined to yield an overview of the state-of-the-art of traffic control and its relationship to roadway elements and to communications system technology. Driver reactions to stop signs and red flashers have been investigated (Ref. 52) and indicated that the red flashing beacon had as great effect on driver behavior as stop signs, familiarity with intersections had no great effect on the action of dfivers, and approach speed had no effect on vehicle stopping or intersection violations. KLD's current research on the use of flashing beacons is still in progress and the results will be incorporated in the final experimental design methodology. A three-step procedure for installing special hazard warning signs includes (1) ascertaining the hazard, (2) producing the sign and an accurate message, and (3) placing the sign with ample time for action (Ref. 37). These items present broad general principles relative to the use of warning devices for traffic control.

In the second subcategory, research items include work on specific types of hazard warning instructions including passing on two-lane rural roads, curves, advanced warning signs and grade crossings. Remedial aid systems for passing maneuvers on two-lane roads have been identified and evaluated (Ref. 15). For curves, the effectiveness of advisory speed signs has been studied (Ref. 3 and 48); however, a particularly unique approach is reported on in Ref. 60. The severity of curves was indicated by using special symbols, such as numerals, stars or diagrammatics, or by placement of posts on the outside of the bend to indicate the shape of the curve. The descriptive symbols helped to eliminate surprise on some sharp bends and reduced congestion and accidents. However, similar work in this country indicated little difference in safe cornering speeds of a variety of cars (about 3 mph over the whole range.

Advance warning signs have been studied in several applications. Applications in maintenance operations as described, for example, in Ref. 26 and 64, are reported more fully in the Experiment B report. Mounting of flags and feedback system should exist to indicate the actual message displayed and not merely the message selected.

Variable message signs may have application to the narrow bridge problem particularly for enhancing the warning system when opposing traffic is detected. This type of signing warrants consideration in the selection of candidate warning signs or devices.

The examination of warning devices used in other applications has been included since the basic purpose of these devices is similar in all applications. If some device exhibits particular effectiveness in warning of a hazardous location, it should certainly be considered in the narrow bridge case. This study of other applications has also revealed important information on signing function and measures of effectiveness.

2.4 Accidents on Bridges

A great deal of research has concerned itself with the study of accidents on bridges and rural roadways. This work includes the compilation of accident case studies, the relationship between geometrics and accidents, and the relationship between warning devices and accidents.

Case studies and accident investigation research range from lists of accidents and statistical summaries to in-depth analysis (Refs. 13, 28, 34, 38, 48, 57, 77, 80). Severity indices and the effects of weather have been studied (Ref. 34). In one study (Ref. 13), variables contributing to bridge accidents were listed in order of their significance. Night was listed first, followed by several geometric factors which were, in order of significance; width ratio--the ratio of effective bridge width to trafficable approach width, right curved alignments, left curved alignments and then straight alignments. Note that this research was not done in this country and may not be directly transferable to conditions here (left and right alignments have been shown to be reversed in significance in the U.S.).

Bridge and rural road accidents and geometrics have been the subject of a great many research efforts (Refs. 1, 4, references are primarily concerned with geometric design or specific applications of mathematical analysis.

An overview of geometric design policy and the relationship of design and operational practices was studied to provide a framework for definition of the narrow bridge problem (Refs. 1, 2, 44, 77). Current signing practices and the variability in narrow bridge geometrics are provided in these sources.

Several papers (Refs. 6, 26, 63) deal with the application of mathematical techniques to the analysis of traffic variables. These include: determining vehicle overtaking times and distances, analysis of speed changes for large trucks and probability theory applied to the distribution of vehicles on two-lane highways.

A miscellaneous group of documents include studies of electronic vehicle location devices, electronic vehicle sensors, obstacle visibility and reflective qualities of road surfaces (Refs. 33 and 47). These constitute, of course, only a sample of the literature in this field. However, these items were consulted to get more background on the practical limitations to consider in proposing candidate remedial aids for the narrow bridge warning system.

2.6 State-of-the-Art

As noted, the pertinent research includes studies on the effects of narrow bridge on traffic operations and accidents as well as research on warning devices for a variety of hazardous locations including bridges. These studies have identified velocity and lateral placement as primary dependent variables (Refs. 14, 26, 40, 41, 51, 65, 66, 69, 70, 71, 72, 74). In particular, the velocity of faster vehicles is indicated as a variable of particular significance in the evaluation of remedial aids (Ref. 76). As for lateral placement, the centering ratio is a measure which has been used to indicate the relative lateral placement of vehicles within lane (Ref. 74). Warning devices which have been used in a variety of hazardous locations and shown to have positive effects includes flashing beacons, strobe lights, and variable message signs (Ref. 18, 43, 52, The above summarizes the important results obtained form the literature search and their impact on the experimental design for the narrow bridge. This will form the basis for most of the recommended devices and variables to be used. Specific references will be made to the past research sources in the presentation of the preliminary and final designs.

3. EXPERIMENTAL DESIGN

This section contains the detailed recommendations for the narrow bridge experiment. Included are specific description of the dynamic aid systems, data collection requirements and data analysis procedures. Cost estimates of the required systems are given as well as the expected accuracy and precision of the data collection equipment. The experimental hypotheses and dependent and independent variables are restated. Specifications for the questionnaire and the data plan are outlined and sample size requirements indicated. A summary of the analysis techniques and the methodology for their implementation and interpretation is presented.

3.1 Purpose

The basic form of this experiment is a stratified before and after study to be performed at the Sebasticook River Bridge site on the Maine Facility. Six remedial aid systems will be tested and compared with each other and with the base or current system. The comparison will be made using speed, lateral placement and structured interview data.

Relative effectiveness of a remedial aid system will be judged in terms of its ability to reduce speed, particularly of faster vehicles, and to improve the tracking of vehicles across the bridge. This latter effect is obtained by causing vehicle tracks to move toward the center of the lane. From previous research (Ref. 74), it has been observed that vehicles crossing a narrow bridge do not drive in the center of the lane but tend to drive closer to the center line of the highway. This phenomenon occurs even with opposing traffic.

Thus, improved tracking will be reflected by an increase in D_1, the distance from the outside of the left wheels to the center line of the roadway, and reduction in the centering ratio, D_3/D_1, where D_3 is the distance from the outside of the right wheels to the pavement edge.

toward a value of one. In any event, any remedial aid which causes increased turbulence relative to lateral placement is considered to be less effective and may, in fact, create a worse condition. For these reasons, it is essential that lateral placement effects be included in the evaluation of the remedial aids.

Two aspects of vehicle speed are safety related. Accident frequency increases with increases in speed variance and accident severity increases with increases in the average speed. Thus, reduction in average speed, particularly reduction in the speed of faster vehicles, and reduction in speed variance or speed range are to be considered as desirable outcomes. Furthermore, reduction in speed has a secondary beneficial effect on the tracking function since the ability to judge distances and, therefore, lateral position is improved.

3.2 Dynamic Aid Systems

Dynamic aid systems will be tested at the Sebasticook River Bridge site. The present sign and delineation system will be placed in good repair and will constitute the base control case. The experimental remedial aids are categorized in two types--attention enhancement and information content. Devices of each type, and a combination of both, will be tested. Two configurations will be employed for night-only experimentation. Each of these systems is described in the following sections.

3.2.1 Base System Configuration

The base system or present configuration includes edge lines, guard rails and warning signs. This system is essentially the last configuration used by Texas Transportation Institute (TTI) in their study under Contract NCHRP 20-7. Data collection equipment, employing Transportation Data Systems sensors, will be added to obtain the necessary information. Each aspect of the configuration is described in the following sections.

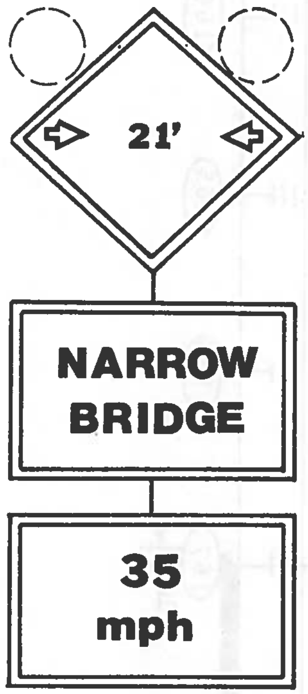

FIGURE 1: Non-MUTCD Warning Sign

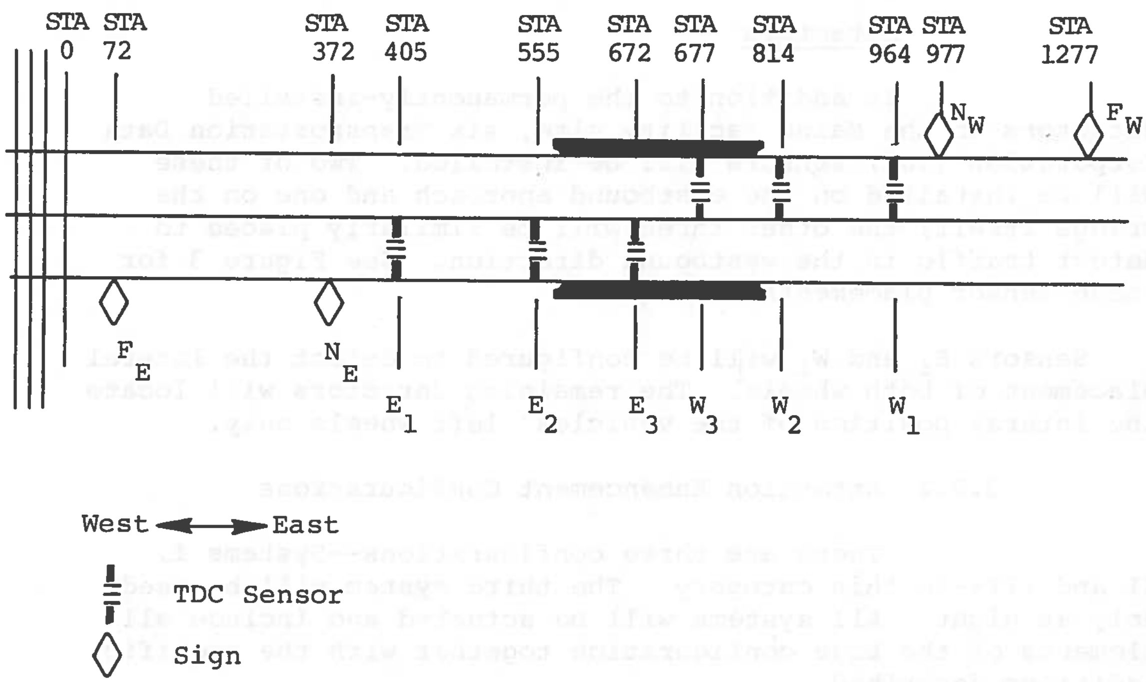

FIGURE 3: Locations of TDC Sensors and of Signs

Each beacon costs about $100 and the cost of mounting them on the sign is estimated to be at most $200. Maintenance and energy costs are nominal.

On the westbound approach, the beacon will be actuated by Sensor B_1 (See Figure 4), 600 feet (183 m) in advance of the sign having the flashing beacon. The beacon will be deactivated as soon as the vehicle crosses Sensor B_2, 50 feet (15.3m) past the sign. The beacon will remain flashing as long as the vehicle is between Sensors B_1 and B_2 or for a maximum of 30 seconds. A new actuation interval is initiated whenever a vehicle crosses Sensor B_1, regardless of whether the beacon is flashing or not at that time.

On the eastbound approach, Sensor A_1, located 300 feet (91.5m) in advance of the sign, activates the flasher. The flasher will be deactivated when the vehicle crosses Sensor A_2 50 feet (15.3m) beyond the sign. A similar 30-second maximum flashing interval is to be set. These sensors will be actuated only by vehicles travelling in the indicated direction.

System II

System II is identical to System I with the actuated flashing beacon replaced by an actuated flashing strobe. The strobe will be placed behind the diamond shaped panel and will be shielded to provide a "halo" effect around the sign.

This will be accomplished by building a special four foot diamond shaped box to be mounted behind the diamond shaped width sign. Maine Facility personnel have designed a housing whose front consists of the width sign bordered by 6 inches (15cm) of plexiglass. An aluminum reflector is mounted to the back of the box and the strobe is mounted behind the Width sign and in front of the reflector. Thus the strobe is completely shielded from direct view from any direction. The light will be seen through the plexiglass and thus create a "halo" effect around the width sign. Brightness and strobe frequency must be carefully controlled. The brightness must not produce excessive glare or a "scare" effect or interfere with the readability of the signs. Since certain strobe rates can induce epileptic seizures (flicker vertigo), the frequency of the strobe must be carefully set. Preliminary tests and previous uses of strobes indicate that both problems have been solved. The strobe unit that has been selected is a white strobe unit, RS-1, manufactured by the RAE Company, Indianapolis, Indiana). The strobe costs approximately $90 and the construction of the housing can be done for less than $200.

System III (Night only)

This system will be tested only at night. It is identical to System I except that the flashing beacons on the near advance sign are to be removed and Sensors A_1 or B_1 will, instead, turn on a set of lights to outline the bridge structure. The lights will be turned off when the vehicle crosses Sensors A_3 or B_3, respectively. See Figure 5 for sensor locations.

The lights will be mounted on both of the angled girders, left and right, which form the leading edge of the bridge superstructure. An incandescent 100-watt bulb, contained within a clear dome-like lamp, will be mounted approximately every 3 feet (90 cm) along the girder starting 3 feet (90 cm) from the bottom. There will be seven lamps on each girder or a total of 28 lamps for the entire bridge (14 lamps at each end of the bridge). The bulbs face out from the girder with the first bulb just above the steel rail. All of the bulbs will be lit simultaneously regardless of whether the actuation occurs due to traffic from the eastbound or the westbound direction. Each lamp costs approximately $15; materials and installation are estimated at $300, making a total estimated cost of $660.

3.2.3 Information Content

Two remedial aid systems are primarily intended to provide information to the motorist. These messages will be transmitted dynamically using variable message signs. These sign installations will replace the near advance signs, N_E and N_W (see Figure 5).

For this experiment, only the two messages, "NARROW BRIDGE" and "ONCOMING TRAFFIC" are needed. A neon tube sign will be used. Using 12-inch neon letters and double tubing to obtain wider letters, two-line message signs can be constructed. In the first, the word "NARROW" will be above the word "BRIDGE", and in the second, the word "ONCOMING" will be directly above the word "TRAFFIC." Each sign will be 8 feet wide and 3 1/2 feet high and cost $960 each. One of the concerns with this form of sign is that the wording of the sign must not be visible when the sign is not lit. In other words, the message should be discernible if lit by a motorist's headlights or directly by the sun. To avoid this, the interior of the sign housing will be painted black.

The 35-MPH sign will remain in place; that is, as a fixed sign mounted on the same pole but below the message signs.

System IV

The message sign for this system, Message 1, will read "NARROW BRIDGE" with "35 MPH" shown below. This sign is steady (not flashing), and it is activated and deactivated as in the previous system. The sign will be turned off as soon as the vehicle actuates Sensor A_2 or B_2, 50 feet (15 m) downstream of the respective sign.

System V

This system is the same as System IV when there is no opposing traffic; that is, when there is no vehicle in the "opposite approach zone." The opposite approach zone for eastbound traffic extends between Actuators B_1 and B_3 (approximately between Maine Facility Sensors 166 and 171). See Figure 5 for details.

In this system, each vehicle causes two actuations simultaneously. Westbound vehicles, crossing Actuator B_1, actuate Message 1 on Sign N_W and simultaneously Message 2 on Sign N_E. Eastbound vehicles crossing Actuator A_1 actuate two messages in a similar manner. When a westbound vehicle passes Actuator B_2, Message 1 disappears from Sign N_W; when that vehicle crosses Actuator B_3, Message 2 on Sign N_E disappears. Eastbound vehicles deactivate the two messages in analogous fashion.

Average centering ratio, D_3/D_1 is the ratio of D_3, distance from outside of right tire to pavement edge, to D_1, distance of left tire to highway centerline. The speed change and variance variables are next most likely to detect important effects.

It is expected that the dependent variables which are closely related to extreme levels of a parameter, such as the 85th percentile, or which measure the extent of change which a parameter undergoes, such as variance or relative speed change, have a better chance of detecting differences in driver behavior. Average values of some parameters, such as speed, tend to obscure secondary effects. These effects may, however, be extremely important in assessing the effectiveness of a remedial aid.

3.4 Independent Variables

The basic stratification or independent variables which define the conditions for which the dependent variables will be computed are:

1) Direction - westbound or eastbound;

2) Time of Day - Day or Night;

3) a) Traffic Conditions - Opposed vehicle or unopposed vehicle;

   b) Size of opposing vehicle - large or small;

4) Distance from bridge - Far region of bridge approach - upstream of near warning signs (combine data from sensors 169 and 170 eastbound and from sensors 166, 165 and 164 westbound)

   Near regions of bridge approach - downstream of near warning signs (combine data from sensors 168 and 167 eastbound and sensors 168 and 167 westbound)

Table 1
Dependent Variables For Each Stratification

Dependent Variables to be computed					
Variables 1,2**,3,4,5,6				Variables 3,4,5,7	Remedial Aid System
Stratification 1	Stratification 2	Stratification 3		Stratification 4	
Direction	Time-of-Day	Traffic Conditions		Distance From Bridge	
W - Westbound E - Eastbound	D - Day N_i - Night	O - Opposed U - Unopposed OL - Opposed by large vehicle OS - Opposed by small vehicle		N - Near Region F - Far Region	
W	D	O	OL*	N	Base Configuration & Systems I, II, IV, V
				F	
			OS*	N	
				F	
		U		N	
				F	
	N_i	U		N	ALL
				F	
E	D	O	OL*	N	Base Configuration & Systems I, II, IV, V
				F	
			OS*	N	
				F	
		U		N	
				F	
	N_i	U		N	ALL
				F	

*This stratification does not have a required minimum sample size and is not treated as rigorously as the others. If the sample sizes obtained are small (<30) the stratification is to be discarded.

**Centering ratio is to be used only for the opposed vehicle conditions.

Table 2
Sensor Data To Be Used for Each Variable and Stratification

For Stratifications 1-3				For Stratification 4	
Variables 1 & 2		Variables 3-6		Variables 3, 4, 5 & 7	
E Eastbound	W Westbound	E Eastbound	W Westbound	E Eastbound	W Westbound
E_1 = Middle TDC Sensor	W_1 = Middle TDC Sensor	E_3 = Sensor 171	W_3 = Sensor 163	E_W = Aggregate of Sensors 168 & 167	W_N = Aggregate of Sensors 167 & 168
E_4 = Aggregate of all TDC Sensors	W_2 = Aggregate of all TDC Sensors	E_4 = Sensor 169	W_4 = Sensor 165	E_F = Aggregate of Sensors 169 & 170	W_F = Aggregate of Sensors 164, 165 & 166
		E_5 = Sensor 167	W_5 = Sensor 167		
		E_6 = Aggregate of Sensors 170, 169, 168 & 167	W_6 = Aggregate of Sensors 164, 165, 166, 167 & 168		

If these hypotheses are indicated to be true, it can be inferred that the probability of the occurrence of serious accidents has been reduced.

It is to be noted that the centering ratio parameter will be computed only for the opposed traffic cases. As indicated earlier, data obtained by TTI at the Sebasticook River Bridge site shows that about 40% of westbound traffic and 23% of eastbound traffic violates the roadway center line when crossing the bridge in the absence of opposing traffic. This will lead to negative values of D_1 and therefore, negative values of the ratio D_3/D_1. (A minimum value of, say, D_1 = .1 feet, may need to be set so that the ratio is always defined.) Even in the opposed vehicle case, D_1 may be negative in some cases. Although important information is derivable in this event, the hypothesis stated assumes non-negative ratios. Thus, any negative values are to be omitted from the computation of average centering ratio.

The speed reduction as a percent of initial speed is defined only over a space interval. If V_1 and V_2 represents the speeds at the beginning and end of the space interval, then the parameter is computed by the expression,

$$\frac{V_2 - V_1}{V_1} \quad x \quad 100.$$

It is assumed that V_2 is taken at a point closer to the bridge than V_1 and that, in fact, V_2 is less than V_1. However, if $V_2 > V_1$, the computation is still to be included in the averaging process. The points at which V_1 and V_2 are to be measured will correspond with Maine Facility sensor locations and will be specified subsequently.

A significant change in the speed distribution in which both the mean and variance decrease or a distribution which has become skewed to the left would be desirable. This distributional change might be significant even though neither the mean nor the variance show significant decreases separately. The distribution can be obtained by sorting the recorded speeds into equal speed intervals. A 2 mph interval is suggested though this can be altered if the data is more conveniently grouped using some other interval size.

may show significant reductions in 85th percentile speed at night but not during the day or for the far approach region but not for the near region.

The statistical analysis to be performed consists of applying hypothesis tests to compare the values of the dependent variable obtained when different remedial aids are in use. Since the variables are either means, variances, proportions or distributions, there are four types of statistical tests. The first three are the hypotheses tests for mean, variance and proportion, respectively, and the fourth is the chi-square for comparing distributions. These tests are all comparison tests and will be applied to the appropriate values of the variables as computed for two different remedial aids. Thus, for those experiments run during the daytime, that is the base configuration and Systems I, II, IV and V, there will be 10 different pairwise comparisons to be made between systems. For each of these pairs and for each variable, the data subsets to which the hypothesis tests will be applied are defined by the stratifications (Tables 1 and 2). Table 3 lists in detail these data subsets for the westbound direction. The eastbound case is to be treated in exactly the same way.

Since all six experiments and the base are to be tested at night, there will be twenty-one different pairwise comparisons to make for the nighttime case. However, since no opposed traffic data will be obtained, the number of stratifications will be fewer. Table 4 lists the data subsets for the westbound direction. The eastbound case is treated analogously.

These tables detail the analysis plan in terms of the comparisons to be made. It should be noted again that if the stratification of opposed vehicles into small and large opposing vehicles leads to negligible sample sizes in one or the other or both subcategories, such subcategories should be dropped from further consideration.

3.6 Data Collection Requirements

Table 5 lists the data items which are to obtained, the method of obtaining the data and the general locations at which the data is to be recorded. In subsequent sections,

Table 4

Data Subsets to be Used for Comparing Base Configurations and Systems I - VI During Nighttime Experimentation

Variable	Data Stratifications (Stratifications 1-3)	Data Subsets (Sensor data to be used)
1,2	$W - N_i - U$ $W - N_i - U - N$ $W - N_i - U - F$	$W_1 + W_2$ $W_1 + W_2$ $W_1 + W_2$
3,4,5&7	$W - N_i - U$ $W - N_i - U - N$ $W - N_i - U - F$	W_3, W_4, W_5, W_6 W_N W_F
6	$W - N_i - U$	W_3, W_5

KEY:
W = Westbound
D = Day
N_i = Night
U = Unopposed
N = Near
F = Far

OL = Opposed by large vehicle
OS = Opposed by small vehicle
O = Opposed by vehicle

the implementation details of each of these methods will be described. For the base configuration and for Systems I, II, IV and V, all indicated items will be obtained during the daytime and night-time experimental periods. Systems III and VI are night-time only experiments.

3.6.1 Maine Facility Detectors

The Maine Facility detectors which will be used for all systems are loop detectors 162 to 171. These cover the stretch of roadway from 1000 feet (305 m) east of the the bridge entrance to approximately 600 feet (183 m) west of the bridge entrance. Detector 171 is the first detector east of the railroad tracks.

All data is to be vehicle-specific; i.e., the characteristics of the trajectory of each vehicle traversing the site will be recorded. The data to be collected using the detectors are the speeds at the detector locations and the speed profile for each vehicle passing through the test site. These detectors also record wheelbase to yield data on vehicle size and number of axles.

3.6.2 Lateral Placement Sensors

As already described, three TDC sensors will be installed for each approach direction as shown on Figure 3. These are surface sensors which record lateral placement data for each vehicle. The results are to be integrated with the data on the file produced by the Maine Facility equipment. Sensors E_1 and W_1, which record lateral placement for both wheels, will permit the determination of the width of each vehicle.

The lateral placement data to be obtained from all TDC sensors is accurate to within ± 6 inches (15 cm). Since three channels of a TDC recorder are needed to obtain both inside and outside wheel positions, one recorder will be needed for each of the two sensors, E_1 and W_1. Since only one wheel position is required at the other sensors, one recorder can be used for two sensors. Hence, a total of four recorders are are needed. The sensor placement and recorder wiring is shown in Figure 6. The trap length and center line intercept should be set so as to obtain correct lateral placement measurements for vehicle speeds between 30 mph and 50 mph (48 to 80 km/h).

Experiment ________ Day ________ Time ________

Weather: Clear ____ Wet ____ Overcast ____

Time: From ________ To ________

Weather Changes:

Clear ____ Wet ________ Overcast ________

Time: From ________ To ____________

Train: Time: From ________ To ________

FIGURE 7: Field Data Form

Table 6

Data Collection Plan and Sample Sizes

	Experimental System										
	Base Configuration	System I	Base	System II	Base Configuration	System IV	Base	System V	System VI	Base	System III*
Approximate Number of Weeks (consecutive)	2 / 2	2 / 2	1	2 / 2	2 / 2	2 / 2	1	2 / 2	/ 2	1	/ 2
Survey Questionnaires	120 / 0	120 / 0	–	120 / 0	–	120 / 0	–	120 / 0	–	–	–
Non-opposed Traffic	200 / 200	200 / 200	–	200 / 200	200 / 200	200 / 200	–	200 / 200	– / 200	–	– / 200
Opposed Traffic	200 / –	200 / –	–	200 / –	200 / –	200 / –	–	200 / –	–	–	–

Note: The numbers above the diagonal apply to daytime experimentation and those below to night time experimentation.

*Note: During this night-time only experiment, the base configuration, that is, the passive signal system, should be fully restored and base configuration retested.

questionnaire surveys are to be obtained, 300 for eastbound traffic and 300 for westbound traffic. This sample is to be equally divided between local and out-of-state motorists.

Systems III and VI are for nighttime experimentation only; however, the base configuration can have its final retest during the day while System III is tested at night. This is possible since the sign configurations for System III are identical to the base configuration. It is recommended that the base condition be retested during this period since this will permit further analysis of learning effects and a more reliable set of base line statistics when this data is combined with the initial base line results. Only nighttime bridge lighting is involved in System III. The base system is to be restored after System VI and before System III for at least a one-week period.

The extent of the entire project spans a 20-week period. The daytime experiments span a 15-week period. If the first experiment begins in early June, the foliage and other ambient conditions should be reasonably uniform over this 15-week period. Equipment failures and other problems may disrupt this schedule. In this event the entire remainder of the schedule would have to slide to accommodate the interruptions.

There are two quantitative operational parameters which are being collected as the basis for comparison and evaluation of the experimental remedial aid systems. The measures are: speed and lateral placement. A variety of statistics based on these measured values are to be computed and statistically compared for different conditions.

These statistics are the dependent variables in the analysis. The different conditions for which comparisons will be made can be described by organizing or stratifying the data. Each strata is defined by specifying the independent variables which describe the situation. These were described in the previous section.

If all variables indicate that one remedial aid system is more effective than another as a result of the hypotheses tests, the conclusion is obvious. However, it is more likely that mixed results will be obtained. That is, the variables yield contradictory results, or some results only hold for specific stratifications and not for others. In order to and the size of the opposing vehicle. The variable D_1, however, has some advantage over the centering ratio in that it will be meaningful even if the vehicle violates the roadway center line. The resulting negative D_1 thus indicates lane violations. The results of the experiment will probably permit the empirical determination of acceptable D_1 values for the various stratifications. The relative stability of D_1 over the entire bridge will be useful in comparatively judging the relative effectiveness of the remedial aids. This will be obtainable by comparing the values of D_1 computed at the middle TDC sensor with the average overall TDC sensors. Changes in speed distributions are, likewise, inconclusive in terms of their bearing on safety. As stated earlier, one possibility is to conclude that a distribution having a smaller mean and standard deviation, which is shown to be statistically significantly different from another, indicates an improved situation. Since both mean and variance of speed have already been tested independently, the comparison of distributions is intended to detect a combined effect not evidenced by these separate tests. The second element of the distribution is its relative skewness; that is, the lack of symmetry about the mean. This can be demonstrated by graphically comparing, on the same set of axes, the plotted speed distributions obtained from two different data subsets.

In addition to the relative impact of the variables, the relative importance of the stratifications must be considered. In the comparison of remedial aids some may perform better in terms of the primary variables just discussed, but only for certain stratified subsets. It will be particularly important if these improvements occur for one or more of the following conditions:

- nighttime operation;
- opposing traffic conditions;
- near bridge approach region.

Poor visibility conditions are inherently more dangerous than good conditons and an improved nighttime effectiveness would be a significant result in and of itself. Improvements in response of motorists faced with the more hazardous conditions of both the bridge and traffic must also be regarded as a highly significant improvement. The third primary stratification, the near approach region, is of obvious relevance. A remedial aid which does not transmit the information that the bridge area is the region of hazard has failed to

The details of the analysis of the structured interview depend of course on the specific form of the questions and responses. All limited response answers should be tabulated and counts and proportions computed. If semantic scaling is used for any question, the mean and variance of the numerical responses should be computed. These results can then be used to support or modify the operational results obtained.

3.9 Data Analysis

The analyses techniques described in the previous sections and in Volume I are considered to be minimal but sufficient to identify important results and suggest further analysis as warranted. For example, the measures of effectiveness have been computed only for specific sensor locations or combinations of sensors. With little additional effort, these measures can be computed at all appropriate sensors and for different aggregations of sensor data.

A specific alternative to consider is the computation of percent speed change over different pairs of sensors than those indicated in the analysis. In particular, for the eastbound direction the pair 170 and 168, and westbound, the pair 165 and 167, are suggested. Each of these pairs are made up of a sensor in the near region and one in the far region for each approach. This, in fact, may be more significant in detecting differences in effects of the different remedial aids than those previously recommended.

The 85th percentile speed was selected for statistical comparison because it represents a commonly used parameter in highway design and operations. Clearly a range of such percentage points, say from the 70th percentile to the 90th percentile, in steps of five percent, represents candidate levels to consider if the data leads one to believe that one of these levels may be of particular significance.

The proportion of vehicles that reduced speed between the first and last sensor in a given direction is a simple but potentially valuable data item.

The lateral placement parameter D_1 and/or the centering ratio D_3/D_1 are important to examine for stability over the region of measurement. It is of interest to determine whether or not a remedial aid has or has not increased the lateral movement per vehicle. The variance of D_1 over the three TDC

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APPENDIX

Specification for Development of Survey Instrument for the Narrow Bridge Experiment

Narrow bridges represent a serious safety problem which, due to economic reasons, cannot be resolved by structural changes or bridge widening. This is particularly true for rural areas where most narrow bridges are to be found. Although no universally accepted definition of a narrow bridge exists, reductions in the roadway width and/or the shoulder width, relative to the approach roadway, have appeared to be responsible for collisions between vehicles. The need, therefore, exists to provide adequate warning and positive guidance to motorists in the vicinity of a narrow bridge.

Intended Use of Survey

This questionnaire is intended to provide measurable data which can be used to analyze and evaluate motorist reactions to proposed dynamic aids for narrow bridges. It is assumed that many questions can be formulated on a seven- or five-point scale to obtain quantifiable results. These results can then be used to compare responses to different aspects of several dynamic aid treatments. This information is intended to supplement the data on motorist behavior as measured in the field tests and to aid in evaluating the safety and motorist acceptability of the systems being tested.

The questionnaire will be used as the format of a structured interview of motorists who have just driven through the narrow bridge experimental site in Maine. This will probably be implemented by stopping motorists at the side of the road, or some other safe and convenient location, beyond and out of view of the test site, and having a trained interviewer record their responses to the items on the questionnaire.

d. Does the motorist feel that the narrow bridge represents a hazardous driving situation?

2. Better warning systems are needed at narrow bridges.

   a. Did you see the narrow bridge warning sign?

   b. Did you slow down when approaching and/or traversing the bridge? Did you steer closer to the roadway center line? Closer to the shoulder of the road?

3. In the presence of opposing traffic, motorists driving is affected in approaching and/or traversing a narrow bridge.

   a. When there is opposing traffic does the motorist slow down when approaching or traversing a narrow bridge? Steer toward the center of the lane?

   b. Does the motorist react only if the opposing vehicle is on the bridge?

4. If the opposing vehicle is a truck or other large vehicle, then the motorists driving are affected in approaching and/or traversing a narrow bridge.

   When the opposing traffic is a truck or other large vehicle, does the motorist slow down when approaching or traversing a narrow bridge? Steer toward the center of the lane?

5. Night-time or poor visibility conditions represent a potentially hazardous situation.

   If the bridge were not visible at the warning sign location would you be more likely to slow down or prepare to slow down in response to the sign? Would you steer toward the center of the lane? Toward the center of the road?

The remaining hypotheses refer to the warning device system through which the motorist has just passed on the Maine test Facility, that is, the device currently being

a. How would you rate the attention-getting aspect of the narrow bridge signs (or warning system) through which you have just driven? (Very good, good, average, poor, very poor.)

b. How would you rate the visibility of the signs or message warning of the narrow bridge? (Very good, good, average, poor, very poor.)

c. Did you understand the message or sign?

d. How would you rate the message or sign in terms of its understandability? Information content? (Very good, good, average, poor, very poor.)

e. Did you slow down as a result of seeing the warning sign or system?

f. Did you slow down as a result of seeing the bridge itself?

g. Did you steer toward the center of the lane as a result of seeing the sign or warning system? Toward the center of the road?

h. Did you feel that there are significant problems with the warning system or sign?

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