INEXPENSIVE ACCIDENT COUNTERMEASURES AT NARROW BRIDGES

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Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

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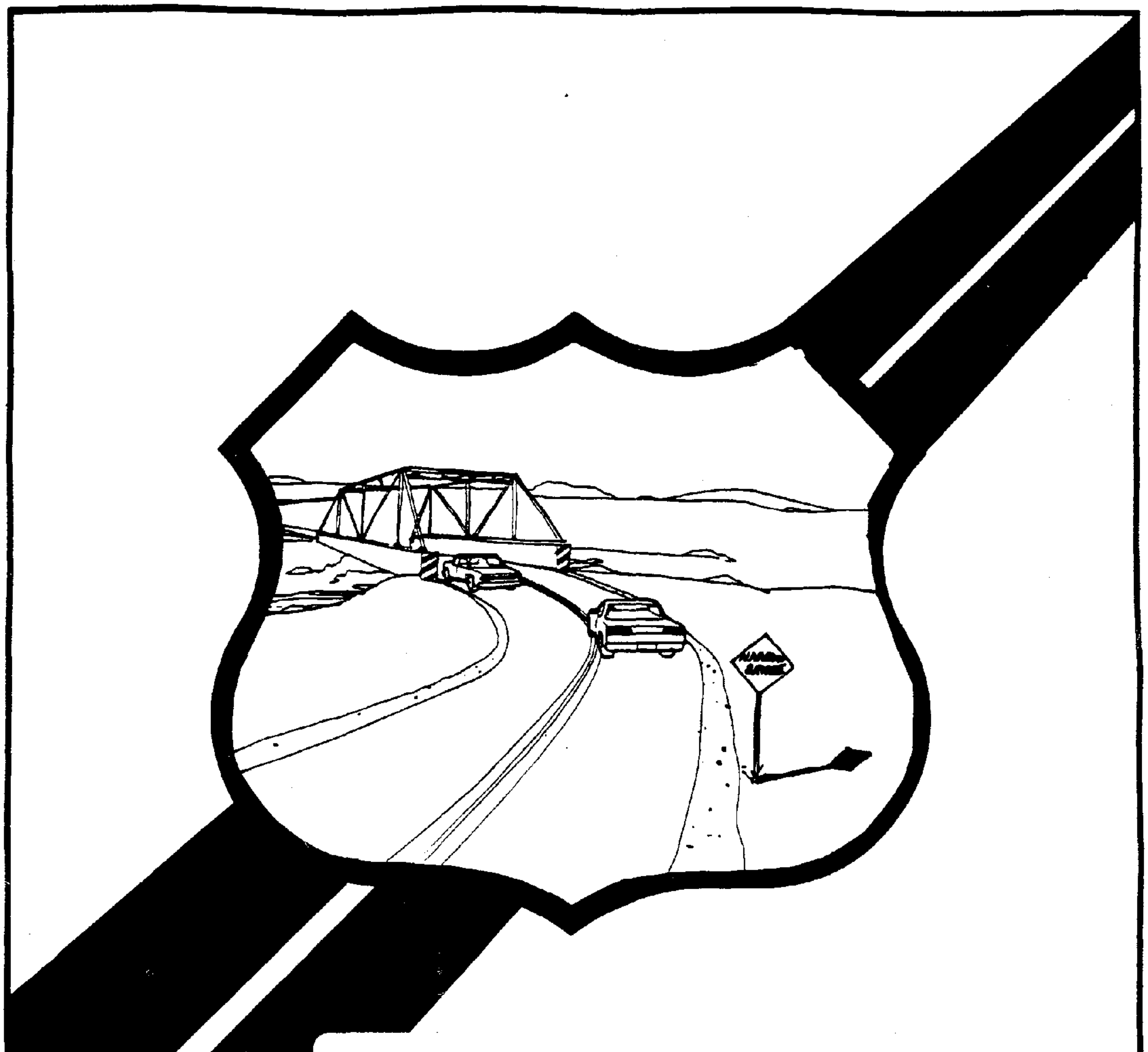

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7. Author(s)
Brian L. Bowman

9. Performing Organization Name and Address
Goodell-Grivas, Inc.
17320 W. Eight Mile Road
Southfield, MI 48075

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16. Abstract

This research effort was conducted to determine the effectiveness of low-cost countermeasures in reducing the number of accidents at narrow bridges. The principal tasks consisted of 1) developing an accident based effectiveness evaluation plan and 2) conducting an operational based effectiveness evaluation. This report describes the activities and results of the operational based effectiveness evaluation.

The operational based evaluation was performed by conducting before and after analyses of vehicle speed and lateral placement at 18 narrow bridge approach sites. The low-cost countermeasures that were evaluated consisted of combinations of advance warning signs, pavement markings, raised pavement markers, roadside delineators, type 3 object markers and adhesive delineators. The operational data were obtained by using the Federal Highway Administration's Traffic Evaluator System.

With the exception of one analysis category, the operational based effectiveness evaluation did not reveal significant difference, at the 10 percent level, between the before and after time period. The one exception was that the low-cost countermeasures significantly reduced speed variation when all vehicle types and time periods were analyzed together. For this analysis category, therefore, the low-cost countermeasures resulted in more uniform driving behavior.

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Narrow bridges, low-cost countermeasures, operational measures of effectiveness, lateral placement, Traffic Evaluator System (TES)

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
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yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
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lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
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gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

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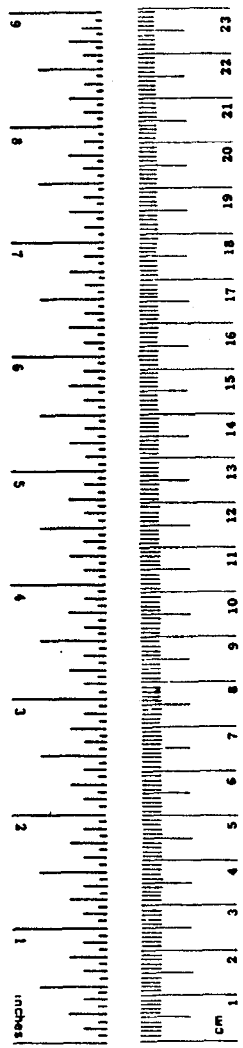

APPROXIMATE CONVERSIONS TO SI UNITS

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m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

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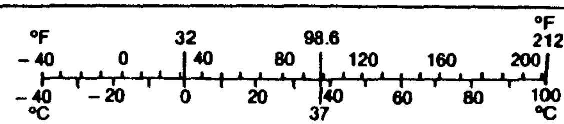

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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INTRODUCTION

Highway bridges are a necessary part of any roadway system and have always been the subject of specialized engineering efforts. Their construction requires more sophisticated engineering analysis for their design and higher construction cost than the roadways connecting them. In the past the primary purpose of the extra effort has been to insure that the bridge structure would support dynamic design loads without failure. Until relatively recently the width of bridges was not a major concern and would often be reduced for economic reasons. The results of this practice are narrow bridges, especially on the rural road system, that pose a threat to all motorists.

Since bridges are typically designed to provide longer service lives than the connecting roadways there are many instances where the roadway is upgraded and, due to cost constraints, the bridge is not. Due to the relatively high-cost of bridge widening and construction some bridges date back to the early 1900's. The physical obstructions of the bridge abutments and parapets, many of which are unguarded, present dangerous fixed objects to motorists. The changes in cross section width between the approaching roadway and narrow bridges result in traffic flow restrictions and present unexpected hazards to motorists. The result is an increase in erratic driving behavior, fixed-object accidents and vehicle-vehicle accidents.

The optimal solution would be to upgrade all narrow bridges on our Nation's roadways. The extreme costs associated with rebuilding all of the deficient bridges on our roadway system makes the optimal solution, at least on a short-term basis, unrealistic. The result is that highway agencies are implementing countermeasures designed to reduce crash severity and improve motorist information by providing increased advance warning, delineation and hazard conspicuity. The rationale behind these countermeasures is that if it is not possible to physically protect the motorist from hazards then efforts must be exerted to provide them with sufficient information to protect themselves. How effective these low-cost countermeasures are in actually increasing motorist safety is, however, difficult to ascertain from accident-based studies.

The difficulty in determining the effectiveness of low-cost narrow bridge countermeasures by accident based analysis is due to the low number of accidents per bridge per year, inaccuracies in identifying the exact accident location from report forms and identifying the exact date that the countermeasures were installed. This study was initiated in response to the recognized difficulties in conducting accident based effectiveness evaluations of low cost countermeasures at narrow bridge sites. The study concentrated on analyzing only operational data such as vehicle speed and lateral placement on countermeasures installed during the project tenure. Sites selected for project purposes consisted only of 2-lane, single structure, undivided bridges.

1. Study Scope and Objectives

The purpose of this research was to determine the effectiveness of low-cost countermeasures in reducing accidents at narrow bridges. The study concentrated on developing an accident based analysis methodology and on performing an operational based analysis of changes to driving behavior resulting from low-cost countermeasure implementation. The specific objectives of this study were:

- To develop an accident based methodology that could be used to evaluate the effectiveness of safety countermeasures at narrow bridges. The actual performance of the accident based analysis was not part of the study scope.
- To collect and analyze operational data such as vehicle speed and lateral placement to determine what changes, if any, result from the installation of low-cost countermeasures at narrow bridges.

2. Research Approach

The first objective resulted in a document that specified the steps, concerns and analysis methodology appropriate for conducting accident based effectiveness evaluations at narrow bridge sites. This document was submitted to the Federal Highway Administration under a separate cover.

The remainder of this (at hand) report consists of a description of the research approach and results of study efforts pertaining to the operational based evaluation. The individual study tasks and their sequence of performance are presented in figure 1.

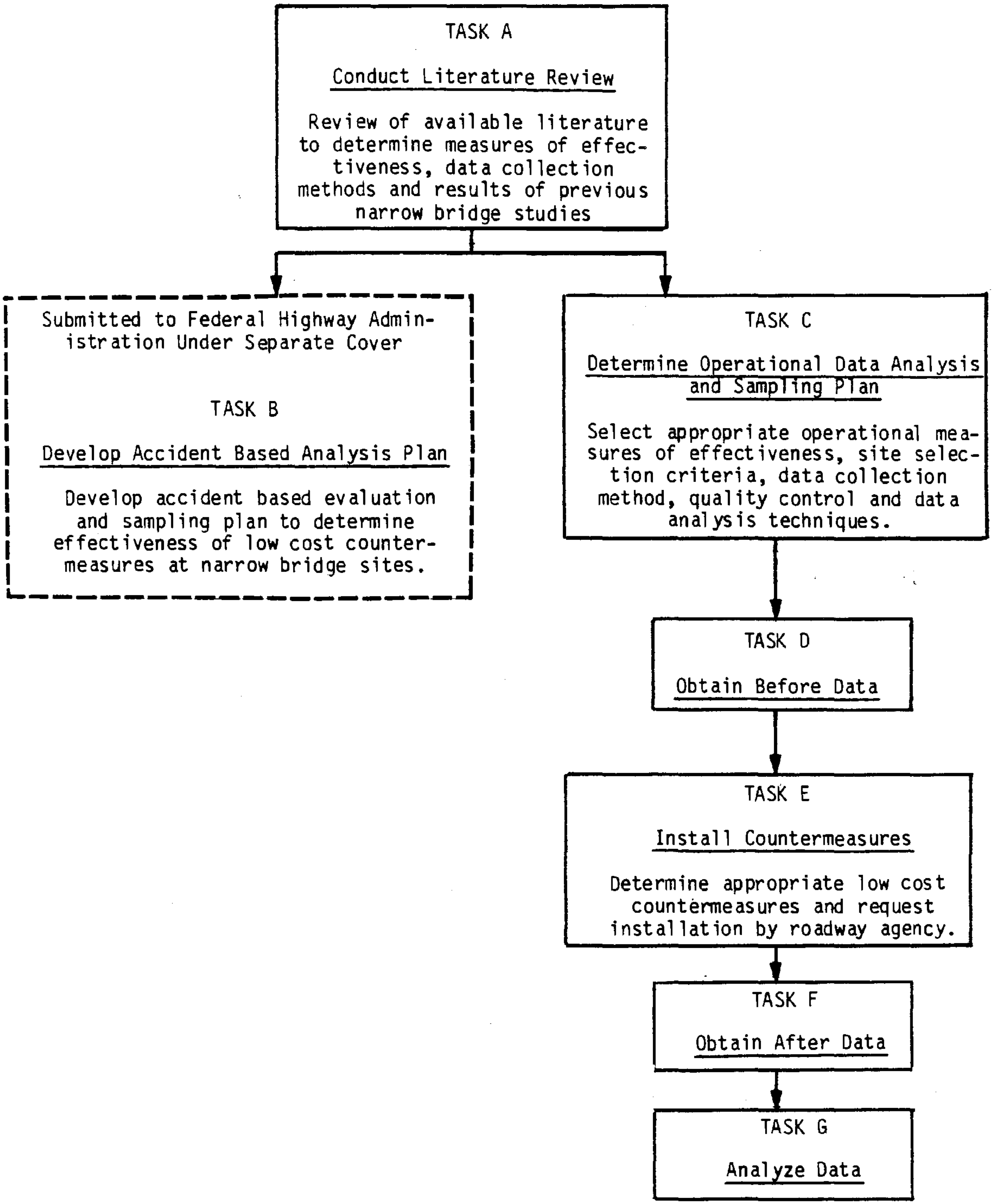


Figure 1. Flow chart of project tasks.

3. Literature Review

Narrow bridges have been recognized as a highway safety problem for many years. A 1978 study by NHTSA reported that the severity of bridge-related accidents is roughly twice that of average accidents.[1] Other studies have revealed that as many as 60,000 bridges are deficient in width.[2]

Studies have shown that bridge accidents result in high severity rates as emphasized by the accident experience for the States of Virginia and Kentucky as shown in table 1. These findings indicate that bridge-related accidents are considerably more severe than other accident types and their frequency represents cause for concern.

Table 1. Percentage of bridge-related accidents. (Source [1,2])

State	Interstate/Parkway Highways: Percentage of All Accidents	Interstate/Parkway Highways: Percentage of All Fatalities	Primary/Secondary Highways: Percentage of All Accidents	Primary/Secondary Highways: Percentage of All Fatalities
Virginia	3.2	7.1	1.6	3.4
Kentucky	7.6	17.2	2.9	3.8

A recent study by Mak and Calcote for the Federal Highway Administration provides considerable information on the extent of the accident problem relative to narrow bridges.[3] The authors recommend that emphasis should be placed on single structure bridges on two-lane undivided roads which have shown the highest accident rates and severity. One of the original objectives of the Mak and Calcote study was to evaluate the effectiveness of various accident countermeasures at narrow bridges. Difficulty was encountered, however, in evaluating low-cost countermeasures due in part to the inability to determine what and when countermeasures were implemented on the study bridges. The authors stated that there are indications that low-cost countermeasures are being used at many sites, even though it was not possible to evaluate their effectiveness in that study.[3]

Other researchers have also noted the safety problems with bridges. Kaiser determined that traffic accidents at bridges account for twice as many fatalities as railroad crossing accidents and represent about three percent of all accidents in Ohio.[4] Hilton estimated that narrow bridges account for 1.6 percent of all accidents and 3.4 percent of all fatalities on interstate highways.[5]

One of the major hazards associated with bridges is that many are functionally obsolete, being built prior to the adoption of current design standards. Michie states that, based on length alone, a bridge is more hazardous than the roadway in general and that a large number of bridge accidents can be attributed to narrow bridges, obsolete approach guard-rails and inadequate bridge rail installations.[6] Based on the Federal Highway Administration's national bridge inventory conducted in 1975, 75 percent of the nation's 564,000 bridges were built prior to 1935.[7] This report estimated that 20 percent or 105,000 bridges are structurally deficient or functionally obsolete and this number is expected to increase by 2,000 per year. Based on this National Inventory report, Weaver and Woods estimated that the number of narrow bridges on 2-lane rural roads was 37,000.[8]

Although bridge widening is thought to be the most desirable treatment for narrow bridge problems, the high cost [about $200,000 (1973 dollars)] of this countermeasure makes it infeasible in most instances.[9] Mak and Calcote have pointed out that limited resources necessitate the selection of cost-effective treatments, such as signing, roadway delineation, and longitudinal markings.[3] However, since the effectiveness of these countermeasures are controversial there exists a need to formally evaluate the effectiveness of the various low-cost countermeasures on accidents and traffic operations.

a. Definition of a Narrow Bridge.

No exact definition of a narrow bridge exists although several subjective classifications have been proposed. Most authors agree that bridge width alone cannot be used to define a narrow bridge. AASHTO considers a narrow bridge as any bridge which has a width less than the approach travelled way.[10] AASHTO also states that the term "narrow" is subjective and should be based on the following characteristics.

Geometrics

- Approach roadway width
- Approach sight distance
- Bridge width
- Bridge length
- Horizontal alignment
- Vertical alignment

Traffic Characteristics

- Approach speed
- Traffic volume
- Percent commerical vehicles

Other important factors requiring consideration may include area type and functional class of the highway. AASHTO provides a table that can be used to classify bridges as narrow based on factors of functional road type, average daily traffic, and percentage of commercial vehicles.[10, pg 84-85] Commercial vehicles includes buses, large recreational vehicles, and farm vehicles, as well as trucks. Applying the AASHTO definition of a narrow bridge results in bridges with clear widths (width between rails or curbs, whichever is less) equal to or less than the values in the table being classified as narrow. For example, for a minor road of 500 ADT with five percent commercial vehicles, a width of 22 feet (6.8 m) or less would be classified as a narrow bridge. The AASHTO report also states that:

> "Regardless of the classification or other conditions, any bridge which has a width less than the approach travelled way should definitely be considered as a narrow bridge."[10]

Thus, AASHTO considers a bridge to be narrow if it either meets specified roadway conditions or where the bridge width is less than the approach travelled way. A distinction is also given by AASHTO between one-lane and two-lane bridges. A one-lane bridge is considered to be any bridge with a width less than 18 feet (5.6 m).[10]

b. Area of Bridge Influence

Narrow bridges can cause accidents that do not occur at or on the physical structure of the bridge itself. Previous research has recognized that driver behavior is modified on bridge approaches resulting in changes in vehicle lateral placement and speed, which can result in increased accidents. This requires that an appropriate area of influence which includes roadway segments that approach and leave the bridge (i.e., the departure) be established.

A study by Turner and Rowan was conducted of accidents (1972-1979) on State routes in Alabama relative to 960 bridges.[11] A definite increase was found in accidents on bridge approaches and departures which was more than twice the rate of the adjacent roadway. This increase was found to extend approximately 0.35 miles (0.56 km) from the bridge ends. Also, police officers were found to record bridge accidents to the nearest one-tenth of a mile (0.16 km) in more than half the cases, although some accident report forms required recording to the nearest hundredth of a mile.[11] This implies that accidents occurring at the center of a short bridge may likely be incorrectly coded as occurring on the bridge approach.

In a 1982 study of accidents on narrow bridges, Mak and Calcote collected bridge related accidents which were coded as occurring on the bridge or within 500 feet (155 m) on either side of the bridge.[3] This study established an area of influence of a 200 foot (62 m) bridge as being the actual bridge length plus 1,000 feet (310 m), or a total of 1,200 feet (372 m).

The results of accident based studies indicates a need to consider the approach on each side of the bridge when collecting driver related operational data and for conducting accident based countermeasure evaluation. The length should be a minimum of one-tenth of a mile (0.16 km) on each side of the bridge to account for inaccuracies in accident reporting and changes in vehicle encroachments and speeds on bridge approaches. For highway agencies where locational reporting accuracy is low, a length of up to three-tenths of a mile (0.48 km) on each side of the bridge may be appropriate.

c. Evaluation of Countermeasures Based on Accident Data

There have been several accident studies conducted to determine the relationship between bridge width, roadway width and accident experience. Raff investigated the effect of differences in approach width versus bridge width on accident rates in 1953.[12] Structures narrower than the approach pavements by more than one foot (0.31 m) experienced significantly higher accident rates. Results also show that minimum accident rates occur when the structure is wider than the roadway by 7.1 to 9.0 feet (2.2 to 2.8 m). The study indicates that where bridges have the same relative roadway width that the accident frequency is influenced by the actual bridge width. Bridges less than 20 feet (6.2 m) wide have appreciably higher accident rates than wider bridges.

In 1966, Jorgensen analyzed data from two previous studies (Gunnerson 1961, and Williams and Fritts, 1955) and developed families of curves to forecast accident reduction by bridge width.[13] Both studies reported that accident rates decreased when both the bridge and roadway were widened. However, when only the roadway was widened, the accident rate tended to increase.

Another study of bridge accidents was conducted in Colorado over a four year period for 219 bridges on rural two-lane primary roads.[14] On the basis of the accident experience, it was found that the optimum structure width should be 30.5 feet (9.5 m), six feet (1.9 m) wider than the approach roadway or wide enough to carry the full approach roadway shoulder (which ever is greater). This study concluded that bridges on 2-lane primary highways which carry the full approach width have an average accident rate of 20 percent lower than bridges which do not carry the full approach width. In addition, it was found that narrow bridges have an accident rate seven times higher than bridges whose width is greater than the approach width and 14 times higher than bridges defined as having the optimal width. A study conducted in West Virginia, however, found no strong relationship between shoulder width and accidents.[15]

Agent, conducted a study of bridge accidents in Kentucky in 1975, which indicated that a smaller proportion of accidents occurred on bridges with full width shoulders.[16] Due to a high number of nighttime accidents, this study concluded that a problem of night conspicuity may exist. This apparent night problem was further supported by a three-year study in North Carolina where nearly two-thirds of the accidents occurred at night.[17]

Mak and Calcote completed a comprehensive accident study in 1983 in which bridge-related accident data were collected for a three-year period from five states.[3] Data from 11,880 sites were collected and bridges were classified into categories based on the prevailing design standards in each state. One of the conclusions was that the distribution of accidents by type is affected by bridge curb-to-curb width but not by bridge narrowness. The percentage of single vehicle accidents was determined as increasing with decreasing bridge curb-to-curb width. It was also determined that 2-lane, undivided, single-bridge structures have considerably higher accident rates than other types of bridges. This study disclosed that collisions with unguarded bridge ends resulted in high severity rates. These results compare favorably with other bridge accident studies leading the authors to contend that the severity of bridge accidents can be reduced 68.1 percent by using guardrails and proper transition treatments.

Mak and Calcote analyzed detailed bridge and accident data on a sample of 1,989 2-lane, undivided and 2-lane, divided twin structures.[3] The bridges and their associated accident data were stratified into narrowness categories and revealed the following:

- Accident frequencies increase with greater values of bridge length, bridge width, percent shoulder reduction, degree of curvature on the bridge and approaches, percent grade on the bridge and ADT.

- Accident rates also increase with greater values of bridge length, percent shoulder reduction, degree of curvature on the bridge and approaches, and percent grade on the bridge, but are unaffected by bridge width.

- Accident frequencies and rates increase drastically with increasing degree of roadside distraction.

- Accident severity increases with greater values of bridge length, percent shoulder reduction and speed limit but decreases with greater bridge width, higher level of roadside distraction and increasing ADT. However, the relationships are generally very weak except for roadside distraction.

d. Evaluation of Low-Cost Countermeasures by Using Operational MOE

An inherent difficulty in performing accident based effectiveness evaluations at narrow bridge sites is low accident frequency. Therefore, while the accident rate at a narrow bridge site may be far in excess of average roadway segments, the number of accidents are still relatively small at a given bridge site. Mak and Calcote concluded that performing accident analysis at an individual location requires unacceptably long time periods in order to accumulate sufficient data for statistical validity.[3] Evaluations based on operational measures of effectiveness have the advantage of not requiring long periods of time to obtain adequate sample sizes.

Operational evaluations can be conducted shortly after countermeasure implementation (within one or two months) and requires two days or less data collection for both the before and after the time periods. The use of operational measures of effectiveness (MOE) can provide an interim measure of effectiveness prior to an accident based evaluation. The inherent assumption behind a nonaccident based evaluation is that a significant change in appropriate MOEs (i.e., lateral placement, encroachments, and speed changes) is indicative of improved safety. It is assumed that if a countermeasure results in a significant reduction in vehicle encroachments and other hazardous maneuvers, then this reduction is synomonous with a reduction in accident potential.

The operational evaluation can also provide information on subtle effects of countermeasures on traffic operations (i.e., changes in vehicle speed or lateral placement at night versus during the day). Low-cost narrow bridge countermeasures that have been evaluated using operational MOEs have included: snow and ice detection sytems, delineation treatments such as roadside delineators and pavement edgelining, chevron markings, guardrails and various bridge warning signs and sign configurations. Operational data collected and used to evaluate the effectiveness of the countermeasures included vehicle speeds, vehicle lateral placement, brake light indications, vehicle encroachments and steering wheel reversals. A summary of these studies is presented in table 2.

MacWhinney, Lovell, and Ruden tested various snow and ice detection and warning systems (signs) on a bridge in the High Sierra Mountains in California.[18] The system consisted of snow and ice detectors and corresponding motorist warning signs. Speed data were collected using speed sensors at three locations. The speed differential caused by the presence of the warning sign was determined by comparing the initial speed before the warning sign and the speed after the warning sign. The results indicated that approach speeds were significantly lower (0.10 level) after the placement of warning signs for initial speed ranges of 31 to 60 mi/h (49.9 to 96.6 km/h) during the night. This speed reduction was attributed to the presence of the advance warning signs.

Powers and Michael examined the effects of a combination of delineation treatments for a narrow bridge in Indiana.[19] The delineation treatments tested included edgelining throughout the area, supplemental delineators on the curve, painting centerlines on the bridge deck and yellow curbs. Spot speeds were recorded using a radar meter before and after the treatments were implemented. The results indicated a slight increase in speeds (0.05 level) after placement of the delineation treatments except at the bridge approach and recovery zones.

Barness and Nesbitt evaluated the effects of the combination of various countermeasures for a narrow bridge in the state of Washington. [20] The countermeasures included repositioning and revising bridge warning signs, installing chevron markings and lowering a berm that hid the bridge from driver view. Speed data were collected using a videotape recorder, and the deceleration rate at the bridge approach was observed. Data were collected before and after the countermeasures were implemented. The results displayed a 5 to 9 mi/h (8 to 14.4 km/h) reduction in the 85th percentile speeds after countermeasure implementation, however, no statistical tests were conducted to determine significance.

Table 2. Summary of narrow bridge studies.

Study	State	Countermeasures Being Evaluated	No. of Narrow Bridge Sites	Operational MOE's Used	Results	Data Collection Techniques
Macwhinney, Lovell, and Ruden, 1975	California	Snow/ice detection and warning systems.	1	• Vehicle Speed	• Mean speeds lower in bad weather. • Approach speeds lowered by presence of sign.	Magnatometers (Speed Sensors)
Powers and Michael	Indiana	Delineation • Roadside reflectors. • Pavement edgelines. • Signing.	1	• Mean Speed	• A slight increase in mean speed after delineation treatments were implemented.	Electro-matic Radar Speedmeters
Barsness and Nesbitt, 1981	Washington	• Repositioning and revising signs. • Chevron markings. • Lowering a berm that blocks view of bridge.	1	• Speed Data • Deceleration rate by observation.	• 85th percentile speed reductions of 5 to 9 mph after countermeasures were implemented. • Vehicles decelerated at a more gradual rate.	• Unknown (probably radar gun). • Videotape to film deceleration.
Koziol, 1976	Maine	• Edge striping. • Lateral clearance warning sign. • Guardrail over bridge and approaches.	1	• Speed Data • Lateral placement of vehicles.	• No significant changes in speed for all three treatments. • Improved placement in one direction with edge striping sign. • Improved placement in both directions with edgelining and additional signs. • Vehicle placement closer to centerline for guardrail.	Unspecified
Quimby	Indiana	• Reflector button warning sign. • Reflectorized background with red clusters. • Reflectorized sign with panels at bridge.	1	• Lateral placement of vehicles (distance of outside edge of right front wheel with respect to right hand edge of pavement).	• At night vehicles move toward the centerline with the presence of warning signs.	• Photo-Velaxometer for multiple speed readings. • Movie camera for multiple lateral placement reading.

Table 2. Summary of narrow bridge studies (continued).

Study	State	Countermeasures Being Evaluated	No. of Narrow Bridge Sites	Operational MOE's Used	Results	Data Collection Techniques
Quimby (Cont'd.)		• Reflectorizing center line and above sign.		• Vehicle Speed	• Warning signs had no influence on vehicle placement during daytime. • Warning signs had no impact upon speed, but, the geometry of the bridge did effect speed.	
Khan, 1980	Ohio	Raised Reflective Pavement Markers	1	• Vehicle placement (measured from pavement marking to longitudinal axis). • Speed data (85th percentile). • Brake light indications. • Encroachment on paint lines.	• Vehicle placement variability remained constant. • Speed increased at night.	• Video surveillance system (with grid). • Radar speed meter.
Pigman and Agent, 1979	Kentucky	Raised Pavement Markers	1	• Visual observations. • Speed data. • Centerline encroachment data (encroachment rate).	• 85th percentile, speed dropped significantly at night. • Mean speed remained constant. • Encroachments were less severe at night.	• Manual observations. • Radar speed meter.
Koziol, 1978	Maine	Several Types of Dynamic (Activated) Sign Systems	1	• Vehicle speeds (average). • Lateral placements (distance to centerline).	• Speed reductions of up to 2 mph resulted. • Lateral placement was not affected.	• Nine Loop Sensors (speed data). • Pressure-Sensitive coaxial cables - (lateral placement data).
Roberts, 1976	West Virginia	Bridge Shoulder Width • No curbing. • Two-foot curb. • Four-foot curb. • Six-foot curb.	1	• Mean speed. • Vehicle placement.	• Speeds were lower when curbing was in place (60.7 mph vs. 62.36 mph). • With 6-foot curbing, vehicles travel further away from the shoulder edge at the center, upstream, downstream end of the bridge.	Tapeswitch System

Table 2. Summary of narrow bridge studies (continued).

Study	State	Countermeasures Being Evaluated	No. of Narrow Bridge Sites	Operational MOE's Used	Results	Data Collection Techniques
King and Plummer 1973	West Virginia	• Shoulder width on bridges.	1 (simulated)	• Vehicle lateral placement (distance from center of left wheel to centerline). • Steering wheel reversals. • Speed change. • Accelerator pedal movement. • Brake pedal applications.	• Very few accelerator pedal movements or speed changes (partially because subjects were told to drive at a steady speed). • Greater number of steering wheel reversals for narrow shoulders (<4-foot). • Placement was furthest from centerline with shoulder width of 4- to 6-foot.	• Greenshields Drivometer - in test vehicle. • Time-lapse movie camera to record lateral placement. • Radar speed meter.
Walker	Maryland Virginia Oregon	Bridge Width	11	Lateral Placement (distance of right wheel to curb).	Based on the transverse position of vehicles and roadway width, the required bridge width can be determined.	Unspecified
Hanscom	West Virginia	Snow/Ice Warning Signs	1	Mean Speed	Speeds were reduced from 1 to 6 mph for different sign combinations.	TES

Koziol tested various treatments on a narrow bridge including: edge striping, lateral clearance warning sign with advisory speed plate, and full guardrail at the bridge and approaches.[21] Speed and lateral placement information were collected at the site before and after the treatments were implemented. The author concluded that pavement edge striping improved lateral placement for one direction of travel since the vehicles were more centered in the lane. A combination of two narrow bridge advance warning signs, an advisory speed plate, pavement edge striping and a lateral clearance warning sign improved lateral placement for both directions of travel. However, the addition of the guardrail caused vehicles to drive closer to the centerline. There were no significant changes in speeds for all three treatments. No quantitative results or statistical tests were presented in the Koziol report.

Quimby tested three types of bridge warning signs and a reflectorized centerline at a narrow bridge in Indiana.[22] The three signs tested included a reflector button, a reflectorized background (with cluster) and a reflectorized sign (with panel). Also a reflectorized centerline was installed with the latter sign. Vehicle speeds were collected using a Photo-Velaxometer at several locations along the bridge and bridge approach for each sign type with a movie camera used to collect lateral placement data. The conclusions of the study are summarized below:

- At night, vehicles move toward the centerline with the presence of warning signs.
- Warning signs had no influence on vehicle placement during the daytime.
- Warning signs had no impact upon vehicle speeds at the narrow bridge site. Bridge geometry appeared to be the controlling factor.

Khan tested raised reflective pavement markers at a narrow bridge in Ohio.[23] Data were collected for vehicle lateral placement, speed, brake light indications, and encroachment on paint lines before and after the pavement markings were installed. The results indicated that the mean nighttime vehicle lateral placement increased significantly (0.05 level), but the variance remained the same in the before and after time periods. Also, speeds increased signficantly at night after the pavement markings were installed.

Pigman and Agent tested raised pavement markers at a narrow bridge in Kentucky.[24] Data collection consisted of vehicle speeds and centerline encroachments using a radar meter and visual observations, respectively. Data were collected before and after the pavement markers were installed. The results indicated that the 85th percentile speed dropped significantly at night and that encroachments were less severe after the pavement markers were installed.

Koziol conducted a before and after study to evaluate the effectiveness of four dynamic sign systems at a narrow bridge site.[25] The four signs tested included: flashing beacons, strobe lights, and two neon sign messages. Two of the dynamic signs were tested only at night. Vehicle speeds and lateral placement data were collected at several spots near and on the bridge before and after implementation of each device. Speed reductions of up to two mi/h (3.2 km/h) resulted for the various sign systems, however, lateral placement was not affected.

Roberts examined the effects of bridge shoulder width on vehicle speed and lateral placement at a bridge on a four-lane divided highway in West Virginia.[26] Various sizes of curbing were installed (no curbing, two-foot curb, four-foot curb, and six-foot curb) and evaluated. Speed and lateral placement data were collected using a tapeswitch system. Based on the analysis of variance test, the results indicated that speeds were lower when curbing was in place. Also, with six-foot curbing, vehicles tended to travel further away from the shoulder edge at the center of the bridge and upstream and downstream end of the bridge.

King and Plummer examined the effects of various bridge shoulder widths on operational parameters in West Virginia using a simulated bridge.[27] Subjects drove an instrumented test vehicle, and data were collected using a Greenshields Drivometer and an 8mm movie camera. Information collected included: vehicle lateral placement, steering wheel reversals (major and minor), speed changes, accelerator pedal movement and brake pedal applications. The results indicated that vehicle placement was furthest from the centerline for shoulder widths of four to six feet (1.2 to 1.9 m).

Walker examined the influence of various bridge widths on the transverse positions of vehicles.[28] Eleven bridges were tested with widths ranging from 23 to 50 feet (7.1 to 15.5 m) in Maryland, Virginia, and Oregon. On the average, a vehicle allowed between 5.9 feet (1.8 m) and 6.9 feet (2.1 m) between the right wheel and curb (in the daytime). This information was used to develop minimum adequate widths of bridges for various roadway widths. Based on the average transverse positions of vehicles, the authors recommended a minimum bridge width of 26 to 28 feet (8.1 to 8.7 m) for an approach roadway with a pavement width of 18 feet (5.6 m) and three foot (0.9 m) shoulders.

Hanscom tested four types of icy bridge warning signs at a bridge in West Virginia.[29] The Traffic Evaluator System was utilized to obtain speed data. The combination of the "WATCH FOR ICE ON BRIDGE" sign in advance and the "ICE ON BRIDGE WHEN FLASHING" sign at the bridge resulted in the greatest speed reduction.

In summary, nine of the twelve studies examined used operational parameters to evaluate the effectiveness of various countermeasures for problems at narrow bridges. The other three studies examined the influence of various bridge geometrics (shoulder width, total bridge width, curbing) on operational parameters.

For the studies that evaluated nongeometric (low-cost) treatments, two basic types of countermeasures were tested. They included: bridge warning signs (ice, narrowness, etc.) and delineation treatments (raised pavement markers, edge striping, etc.). The three studies that examined geometric countermeasures evaluated the impact of shoulder width, curbing and bridge width on operational parameters.

Eleven out of the twelve studies used vehicle speed as a measure of effectiveness. Eight studies used vehicle lateral placement as a measure of effectiveness. One study attempted to use information such as steering wheel reversals, accelerator pedal movement, and brake pedal applications. However, these variables can only be collected using an instrumented vehicle and, therefore, in most cases, would not be considered practical measures of effectiveness.

Most studies that evaluated delineation treatments found that there were improvements in lateral placement (vehicles moved away from the centerline) after the treatments were implemented. However, speed was found to increase in another study, decrease in two studies and not be affected in another study. For the various warning sign types, in general, speed was either reduced or not affected by the presence of the signs. Two out of the three studies that examined the effects of signing on lateral placement found that there was an improvement in lateral placement (vehicles moved away from the centerline).

Eleven out of the twelve studies used only one bridge to test the various countermeasures. In addition, one study used a simulated bridge erected in a parking lot and two other studies used a bridge at a test facility.

COLLECTION OF OPERATIONAL DATA

1. Measures of Effectiveness

The primary purpose of installing low-cost countermeasures at narrow bridge sites is to reduce accident frequency. Mak concluded, however, that the use of accident frequency as the measure of effectiveness (MOE) at an individual site is difficult due to the small number of accidents per year per bridge.[3] This study, therefore, concentrated on obtaining operational MOEs that were related to the ultimate objective of reducing bridge-related accidents while simultaneously providing a measure of the intended effect of each countermeasure being evaluated.

The selection of appropriate operational MOEs was accomplished by establishing a causual chain of the predominant accident types, probable causes, countermeasures, and safety objectives as presented in figure 2. Low-cost countermeasures at narrow bridge sites are intended to reduce accidents by altering driving behavior. These intended changes in driver behavior are referred to as intermediate objectives in figure 2. The MOEs selected to evaluate the low-cost countermeasures are primarily related to measures of vehicle speed and lateral position. The logical relationship to these measures and the intermediate objectives are presented below.

- Mean speed over all tapeswitch deployments. The low-cost countermeasures provide additional driver information and guidance. These driver inputs may result in changes in average speed through the bridge and bridge approach. The expected direction of this change between the before and after time periods is not, however, readily evident. The installation of a countermeasure to improve driver awareness (i.e., delineation) could result in either an increase or a decrease in average speed, depending on the physical conditions at the bridge site. For example, some bridge approaches with limited sight distance may pose problems for vehicles approaching too fast and then decelerating rapidly to pass safely over the bridge. In this instance, countermeasures such as advance warning signs would be intended to reduce average speeds on the approach. Evaluation of this countermeasure, using mean speed as the MOE, could interpret a reduction in speed as an indication that the countermeasure is effective. However, consider the case of a narrow bridge where the visibility is so poor (i.e., no lighting or delineation), that motorists must slow down at night to safely traverse the bridge site. An effective delineation treatment (i.e., raised pavement markers, paddle markers, striping, etc.) may improve visibility such that motorists can ade-

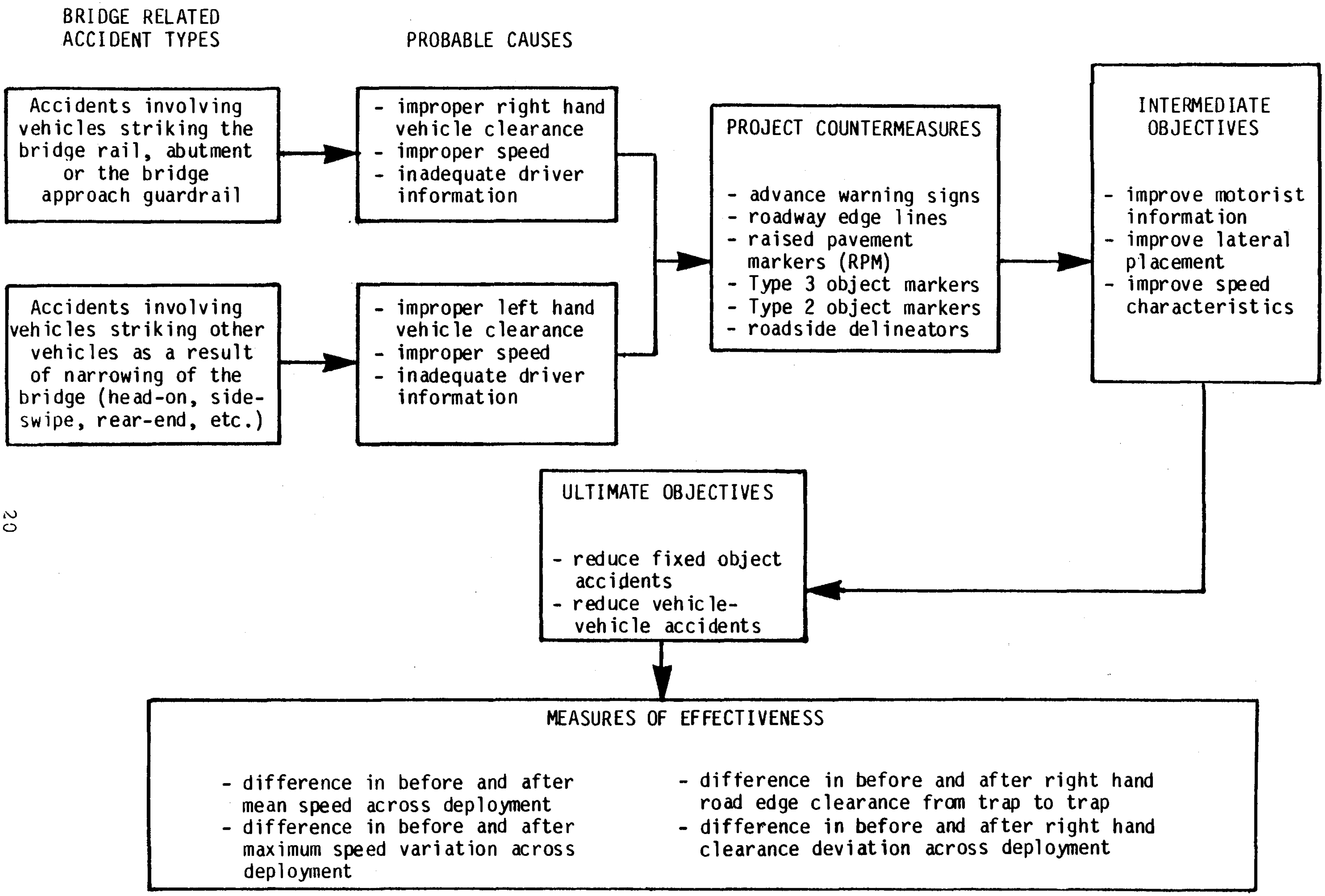


Figure 2. Causual chain and appropriate measures of effectiveness for low cost countermeasures at narrow bridge sites.

quately recognize the bridge site and maintain their approach speed to safely cross the bridge. In this instance, an effective countermeasure may result in vehicle speeds which remain unchanged or increase slightly.

- Maximum speed variation across deployment. This MOE was obtained by measuring the maximum variation in speed that individual vehicles exhibited in the trap array. This maximum speed variation was averaged over all of the observations to obtain the analysis value. The increased visual conspicuity and motorist information provided by the low-cost countermeasures can logically be expected to result in more uniform speeds through the bridge approach. Speed variability may be indicative of the potential for accidents. A sudden deceleration on the bridge approach could create unexpected hazards resulting in rear-end (from a trailing vehicle), bridge related or head-on accidents (excessive speed causing the inability to maintain proper lateral position). Increased motorist information (i.e., adequate delineation or advance warning) could theoretically result in a more gradual deceleration by the motorist and enhanced safety through the bridge site.

- Mean speed at tapeswitch deployments. This MOE was obtained by averaging the speeds at each trap of every valid vehicle that traversed the test site. The purpose of this MOE was to determine if the low-cost countermeasures resulted in changes to the speed profile at the bridge sites. The most advantageous condition would be to have identical average speeds, or a linear reduction in average speed, at every tapeswitch deployment. This would be indicative of increased motorist information and confidence in the vehicle guidance tasks required of the narrow bridge site. This analysis differs from the analysis of speed variance in that it provides a measure of the average speed at each trap. The analysis of speed variance used the average speeds at each trap to develop a variance measure of the entire approach site. The analysis of mean speeds by tapeswitch deployment permits the further analysis of which traps had the highest or lowest mean speeds if significant differences are revealed by the statistical analysis of the before and after time periods.

- Right hand lateral position at tapeswitch deployments. This measure of lateral placement was selected to provide an indication of the effectiveness of the countermeasure changing the lateral position of the vehicles. It provides an indication of the potential for accidents with fixed objects that are located to the right of the roadway and with opposing vehicular traffic. Analyzing lateral position from trap to trap allows the determination of the change in right hand distance from trap to trap and where on the approach these changes occurred. The lateral placement measures were obtained by measuring the distance from the right edge of the paved roadway surface to the outside edge of the right front tire.

- Deviations in right hand lateral placement between tapeswitch deployments. This MOE was obtained by determining the differences in the average right hand lateral distance between adjacent tapeswitch deployments for both the before and after time period. The purpose of these analyses was to determine if the low-cost countermeasures were effective in providing increased motorist guidance resulting in a more uniform vehicle path.

Many of the low-cost countermeasures evaluated during this project consisted of treatments that should benefit the motorist primarily at night. To evaluate the effect of light conditions on MOE effectiveness, the data were collected separately for daylight and night conditions. The type of vehicle was also noted to permit a determination if various classes of vehicles are impacted differently by the implemented countermeasures.

2. Characteristics of Selected Test Sites

Efforts were concentrated on identifying appropriate two-lane undivided bridges for the study. The selection of appropriate test sites was based on the narrow bridge definitions used in the Mak and Calcote study. These definitions are:[3]

- Narrow Bridge Definitions

  1) One-lane, 18 feet (5.5 m) or less in width.

  2) Two-lane, 24 feet (7.3 m) or less in width.

  3) Total approach width greater than total bridge width (curb-to-curb) and bridge shoulder width less than 50 percent of approach roadway shoulder width (i.e., greater than a 50 percent shoulder reduction).

  4) Total approach width greater than total bridge width and the bridge shoulder width is 50 percent or more (but less than) approach roadway shoulder width (i.e., 1-50 percent shoulder reduction).

- Non-Narrow Bridge Definition

  1) One lane, more than 18 feet (5.5 m) in width.

  2) Total bridge width equal to or greater than total approach roadway width.

Nine narrow bridge sites, six in Michigan and three in Ohio were selected for analysis. Data were obtained from both approaches to the nine sites resulting in measurements on 18 approaches. A summary of the physical characteristics of each approach is presented in table 3. Inspection of this table indicates that all of the narrow bridges selected for analysis were less than 24 feet (7.3 m) in total width (curb-to-curb). Measurements of approach widths were obtained by measuring the total distance from roadway edge to roadway edge. The bridge directional width was obtained by measuring from the curb, when present, or from undisturbed debris from the bridge rail (approximately six inches (15.2 cm)) to the center of the centerline on the bridge deck. All of the test sites consisted of total bridge widths that were less than the approach roadway width.

All of the test sites were located in rural environments with one-way volumes that varied from a minimum of 800 to a maximum of 2,625 vehicles per day. The majority of approaches consisted of straight roadway sections with sight distances greater than 900 feet (279 m). Those locations that had reduced sight distances due to horizontal and vertical curves were posted at speeds below 55 mi/h (88 km). In all cases, the available sight distance was greater than the minimum safe stopping distance recommendations of AASHTO for the posted speeds.[30, pg 138]

3. Descriptions of Implemented Countermeasures

The selection of countermeasures for project implementation was based on a consideration of what was already present and the standard practices of the respective highway agency. Standard practice for some agencies, for example, did not include the installation of raised pavement markers. In these instances, raised pavement markers were not considered for installation because they would have resulted in roadway conditions, especially at night, that were abnormal to the driver expectancy of area motorists.

A summary of the traffic control and delineation devices that were present prior to countermeasure installation and the actual countermeasures installed are presented in table 4. The countermeasures were always installed in addition to existing conditions with the only exception being

Table 3. Summary of physical features at narrow bridge test sites.

Site	Total Bridge Width (ft)	Length (ft)	Approach Designation	Direction	Approach Roadway Width (ft)	Bridge Directional Width	Shoulder Width and Type (ft)	Percent Reduction: Roadway to Bridge	Percent Reduction: Roadway and Shoulder to Bridge	Alignment and Sight Distance	Posted Speed	One Way Volume	Environment
1	24.0	24	11	EB	23.6	9.9	± 4' grass	13.6	35.4	Straight +900'	45	1750	Rural, Farm
			12	WB	23.9	10.5	± 4' grass	14.5	36.1	Vertical Curve 600'	45	1900	Rural, Woods
2	18.4	50	21	EB	20.0	9.2	± 4' grass	8.0	34.3	Straight +900'	45	1000	Rural, Woods
			22	WB	20.6	9.2	± 1' grass	10.7	18.6	Straight +900'	45	1000	Rural, Farm
3	20.5	56.6	31	NB	21.6	10.5	3.5 grass	5.1	28.3	Vertical Curve 600'	40	850	Rural, Woods
			32	SB	22.7	10.0	2.5 grass	9.7	26.0	Straight +900'	40	900	Rural, Woods
4	19.9	39.5	41	EB	23.7	9.9	5 grass	16.0	40.9	Horizontal Curve 321'	35	2625	Rural, Woods
			42	WB	24.0	10.0	1 grass	17.1	23.5	Horizontal Curve 525'	35	2625	Rural Woods
5	18.0	44	51	EB	22.1	8.4	3 grass	18.6	35.9	Straight +900'	45	1200	Rural, Farm
			52	WB	22.5	9.4	3 grass	20.0	36.8	Straight +900'	45	1200	Rural, Farm
6	20.2	46	61	NB	22.7	8.8	3 grass	11.0	29.6	Straight +900'	45	800	Rural, Farm
			62	SB	22.3	8.4	3 grass	9.4	28.6	Straight +900'	45	800	Rural, Farm
7	20.3	82.2	71	NB	22.3	10.1	1.7 gravel	9.0	21.0	Straight +900'	45	1075	Rural, Farm
			72	SB	22.4	10.1	1.7 gravel	9.4	21.3	Straight +900'	45	1075	Rural, Farm
8	19.4	44	81	EB	24.4	9.7	± 4 grass	20.5	40.1	Vertical and Horizontal curve +900'	55	650	Rural, Farm
			82	WB	24.8	9.7	± 4 grass	21.8	40.9	Vertical and Horizontal curve +900'	55	650	Rural, Farm
9	18.5	42	91	EB	18.8	8.5	± 4 gravel and grass	1.6	31.0	Straight +900'	55	525	Rural, Farm
			92	WB	19.0	8.3	± 4 gravel	2.6	31.5	Straight +900'	55	525	Rural, Farm

Table 4. Traffic control features at narrow bridge test sites.

Approach Designation	B = Before C = Counter-measure	Edgeline (inches) 4	6	8	Post Delineators (Type 2) LHS	RHS	Type 3 Object Markers	Raised Pavement Markers L&R Sides	CL	Adhesive Delineation Markers	Narrow Bridge Signs	Centerlines Approach Solid	Approach Skip	Bridge Solid	Bridge Skip
11	B	X	--	--	-----	-----	2	-----	-----	-----	1 @ ± 500'	X	--	X	--
	C	--	--	X	5 @ 50' yellow	5 @ 50' white	4	-----	-----	-----	-----	--	--	--	--
12	B	X	--	--	-----	-----	2	-----	-----	-----	1 @ 500'	X	--	--	X
	C	--	--	X	5 @ 50' yellow	5 @ 50' white	4	-----	-----	-----	-----	--	--	--	--
21	B	X	--	--	-----	-----	2	-----	-----	-----	1 @ 500'	X	--	None	--
	C	--	--	--	5 @ 50' yellow	5 @ 50' white	4	-----	-----	-----	-----	--	--	--	--
22	B	X	--	--	-----	-----	2	-----	-----	-----	1 @ 443'	X	--	None	--
	C	--	--	--	5 @ 50' yellow	5 @ 50' white	4	-----	-----	-----	-----	--	--	--	--
31	B	X	--	--	-----	-----	2	-----	-----	-----	-----	X	--	X	--
	C	--	--	--	5 @ 50' yellow	5 @ 50' white	4	-----	-----	-----	-----	--	--	--	--
32	B	X	--	--	-----	-----	2	-----	-----	-----	-----	X	--	X	--
	C	--	--	--	5 @ 50' yellow	5 @ 50' white	4	-----	-----	-----	-----	--	--	--	--

Table 4. Traffic control features at narrow bridge test sites (continued).

Approach Designation	B = Before C = Countermeasure	Traffic Control Features: Edgeline (inches) 4	6	8	Post Delineators (Type 2) LHS	RHS	Type 3 Object Markers	Raised Pavement Markers L&R Sides	CL	Adhesive Delineation Markers	Narrow Bridge Signs	Centerlines Approach Solid	Approach Skip	Bridge Solid	Bridge Skip
41	B	X	--	--	-----	-----	2	-----	-----	-----	-----	X	--	X	--
	C	--	--	X	-----	-----	-	-----	-----	-----	-----	--	--	--	--
42	B	X	--	--	-----	-----	2	-----	-----	-----	-----	X	--	X	--
	C	--	--	X	-----	-----	-	-----	-----	-----	-----	--	--	--	--
51	B	X	--	--	-----	-----	2	-----	-----	-----	-----	X	--	--	X
	C	--	--	--	-----	-----	4	-----	-----	-----	1 @ 587'	--	--	--	--
52	B	X	--	--	-----	-----	2	-----	-----	-----	-----	X	--	X	--
	C	--	--	--	-----	-----	4	-----	-----	-----	1 @ 573'	--	--	--	--
61	B	X	--	--	-----	-----	2	-----	-----	-----	1 @ 679'	X	--	None	--
	C	--	--	--	-----	-----	4	-----	-----	-----	-----	--	--	--	--
62	B	X	--	--	-----	-----	2	-----	-----	-----	1 @ 589'	X	--	None	--
	C	--	--	--	-----	-----	4	-----	-----	-----	-----	--	--	--	--
71	B	X	--	--	-----	-----	2	940'	940'	-----	1 @ 1318'	--	X	--	X
	C	--	--	--	5 @ 50' yellow	5 @ 50' white	--	@ 40' spacing	@ 80' spacing	8 on E. side of bridge	-----	--	--	--	--
72	B	X	--	--	-----	-----	2	873'	873'	-----	1 @ 430'	--	X	--	X
	C	--	--	--	5 @ 50'	5 @ 50'	--	@ 40' spacing	@ 80' spacing	8 on W. side of bridge	-----	--	--	--	--

Table 4. Traffic control features at narrow bridge test sites (continued).

Approach Designation B = Before C = Counter-measure		Traffic Control Features: Edgeline (inches) 4	Edgeline (inches) 6	Edgeline (inches) 8	Post Delineators (Type 2) LHS	Post Delineators (Type 2) RHS	Type 3 Object Markers	Raised Pavement Markers L&R Sides	Raised Pavement Markers CL	Adhesive Delineation Markers	Narrow Bridge Signs	Centerlines Approach Solid	Centerlines Approach Skip	Centerlines Bridge Solid	Centerlines Bridge Skip
81	B	X	--	--	-----	-----	2	-----	-----	11 on N side	1 @ 575'	X	--	X	--
	C	--	--	--	5 @ 50'	5 @ 50'	--	650' @ 40' spacing	650' @ 80' spacing	-----	-----	--	--	--	--
82	B	X	--	--	-----	-----	2	-----	-----	11 on S side	1 @ 575'	X	--	X	--
	C	--	--	--	5 @ 50'	5 @ 50'	--	650' @ 40' spacing	650' @ 80' spacing		-----	--	--	--	--
91	B	--	X	--	-----	-----	2	755' @ 40' spacing	755' @ 80' spacing	-----	-----	--	X	X	--
	C	--	--	--	5 @ 50'	5 @ 50'	--	-----	-----	11 on N side	1 @ 600'	--	--	--	--
92	B	--	X	--	-----	-----	2	763' @ 40' spacing	763' @ 80' spacing	-----	-----	X	--	--	X
	C	--	--	--	5 @ 50'	5 @ 50'	--	-----	-----	11 on S side	1 @ 600'	--	--	--	--

mutually exclusive countermeasures such as different edge line widths. Test approach 11, for example, initially had two type 3 object markers with an additional four added as part of the project countermeasures. There were, therefore, a total of six type 3 object markers, three on each side of the approach, present during the after time period. Figures 3 through 11 present the before and after countermeasure conditions.

4. Collection of Field Data

The collection of field data was accomplished by using the Federal Highway Administration's fully automated Traffic Evaluation System (TES). The TES is a computerized data collection system that obtains data through a series of tapeswitches. The tapeswitches consist of two copper strips separated by a thin plastic divider along each edge of the switch. As a vehicle passes over the switch the vehicle's weight causes contact of the copper switch which closes a circuit. The electrical impulse generated by each closed circuit is transmitted to a rheostat which identifies the switch location and the resultant current triggers the recording of a time, switch code and location code.

Four tapeswitch stations were deployed on each narrow bridge approach to record the speed, vehicle type, vehicle width and lateral placement of traffic. The approximate positions at which the four tapeswitches were deployed is presented in figure 12 and described below.

- At a free flow point on the narrow bridge approach. An additional diagonal switch was installed at this location to determine vehicle width which was necessary for the determination of encroachments. The free flow point was determined to exist at a distance from the bridge that was equal to or beyond the safe-stopping sight distance.
- At points that were 2/3 and 1/3 the safe stopping sight distance.
- At the beginning of the bridge.

The above criteria was used to guide the deployment of TES tapeswitches but the actual deployment was dependent upon the physical site characteristics. Roadway surface condition, the location of physical features (such as trees) for anchoring the TES unit and other site character-

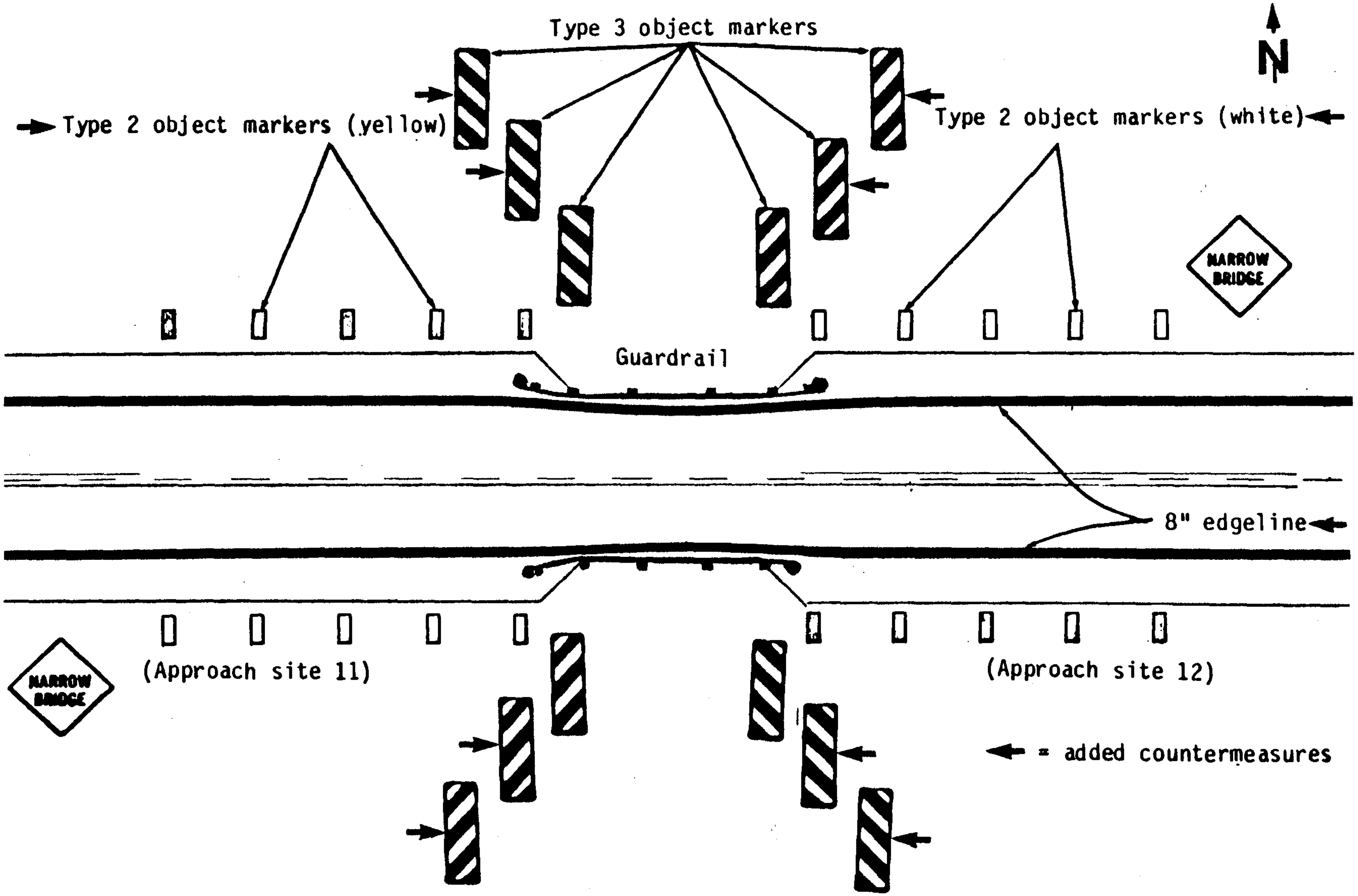


Figure 3. Physical and traffic control characteristics of approach sites 11 and 12.

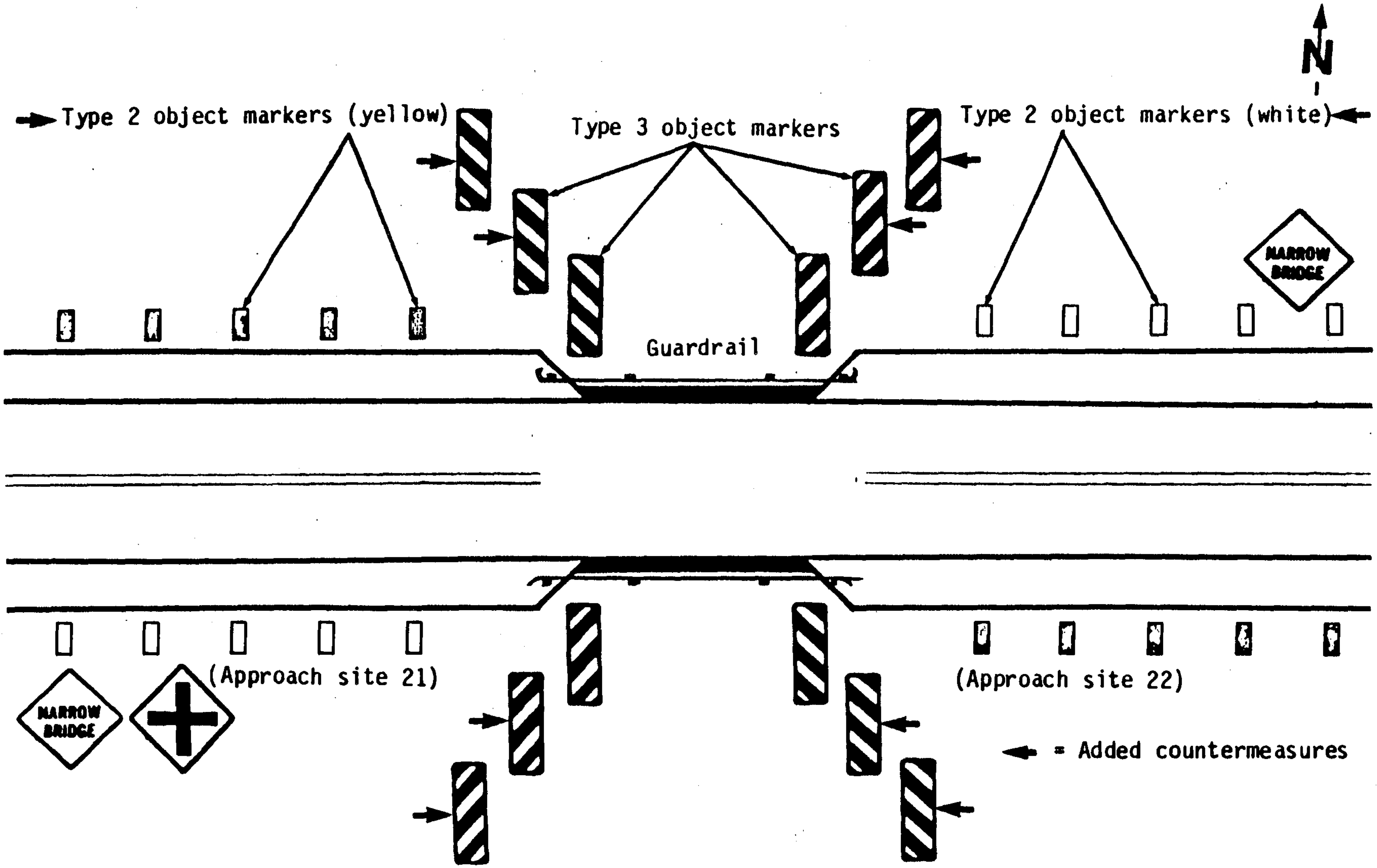


Figure 4. Physical and traffic control characteristics of approach sites 21 and 22.

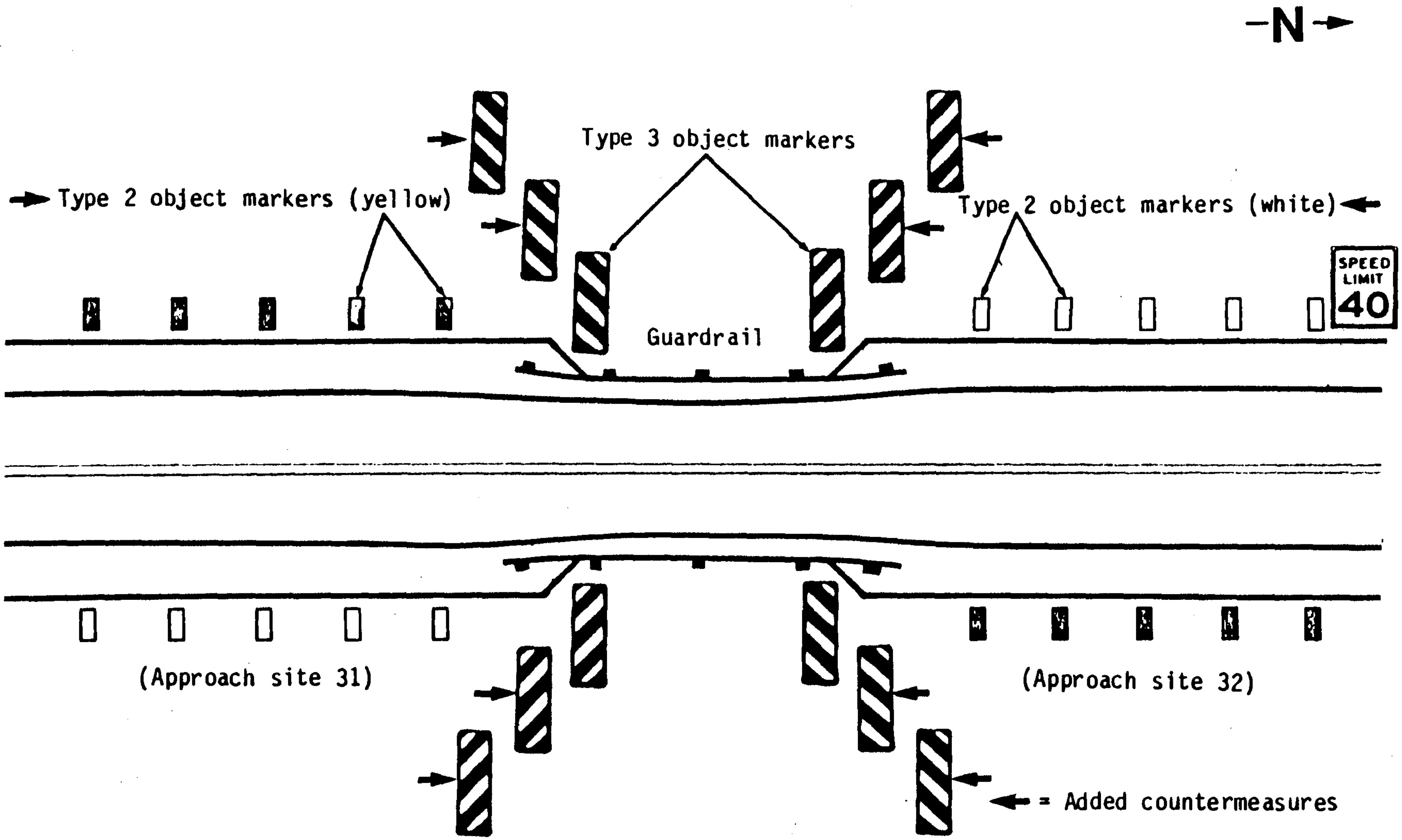


Figure 5. Physical and traffic control characteristics of approach sites 31 and 32.

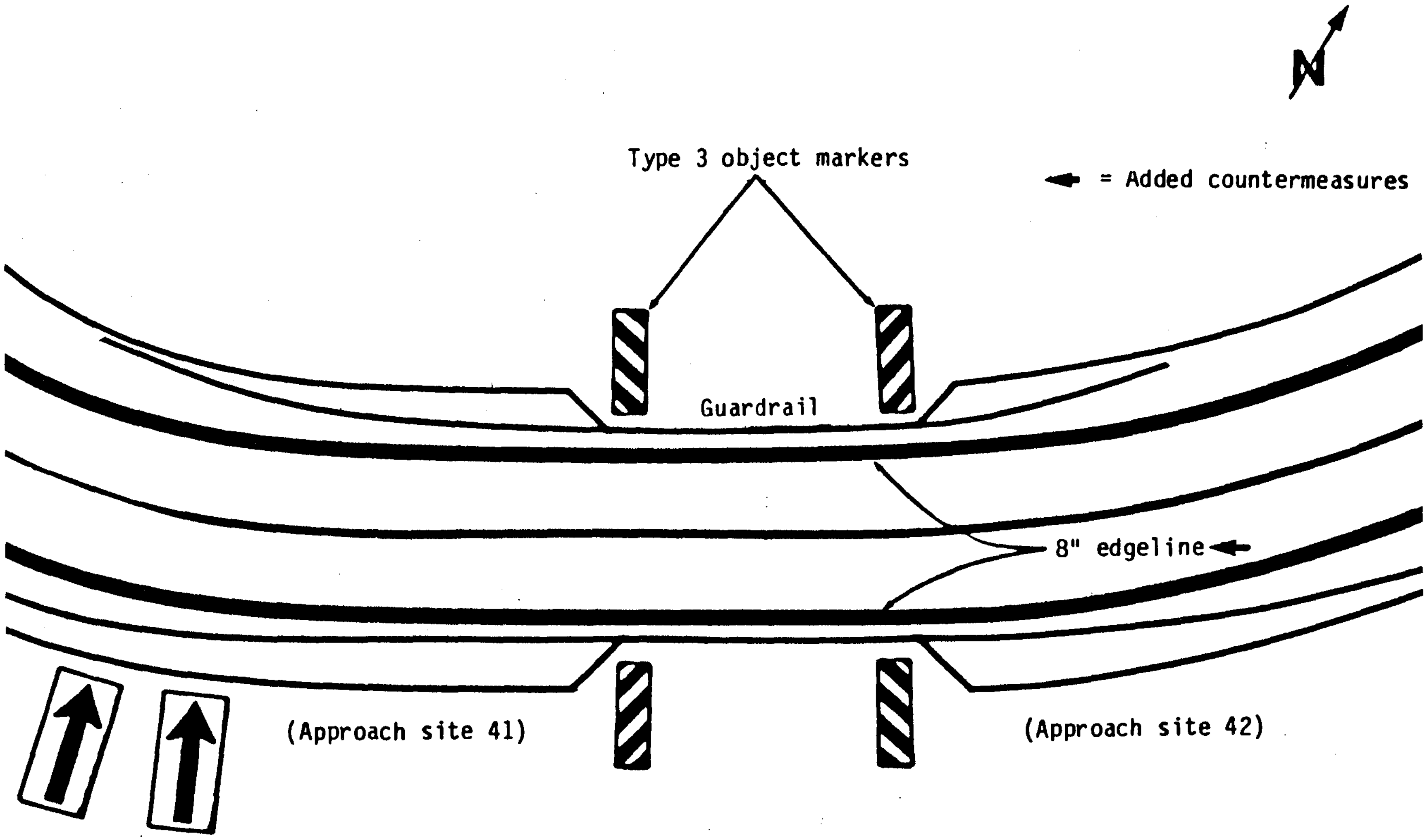


Figure 6. Physical and traffic control characteristics of approach sites 41 and 42.

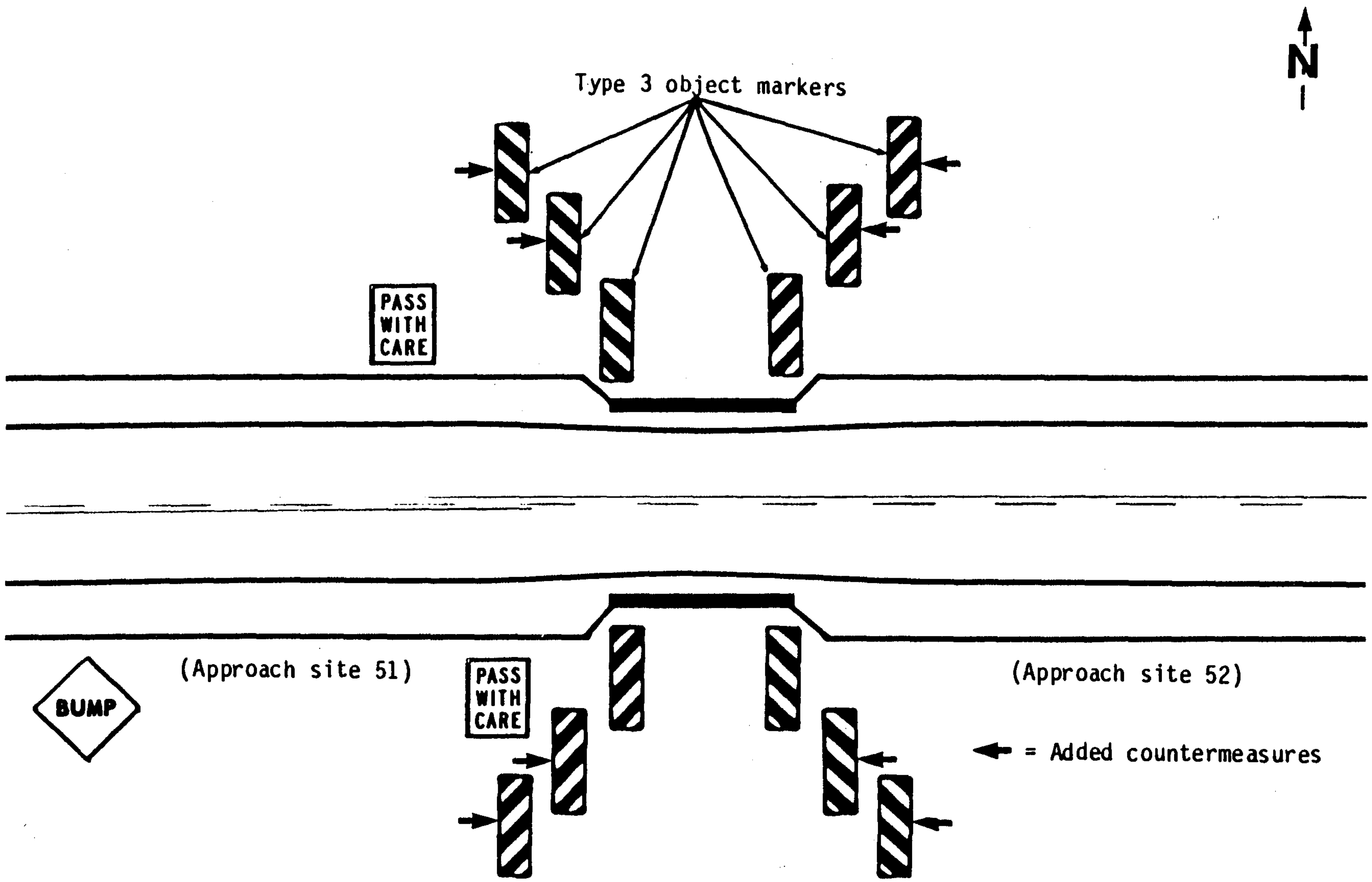


Figure 7. Phsyical and traffic control characteristics of approach sites 51 and 52.

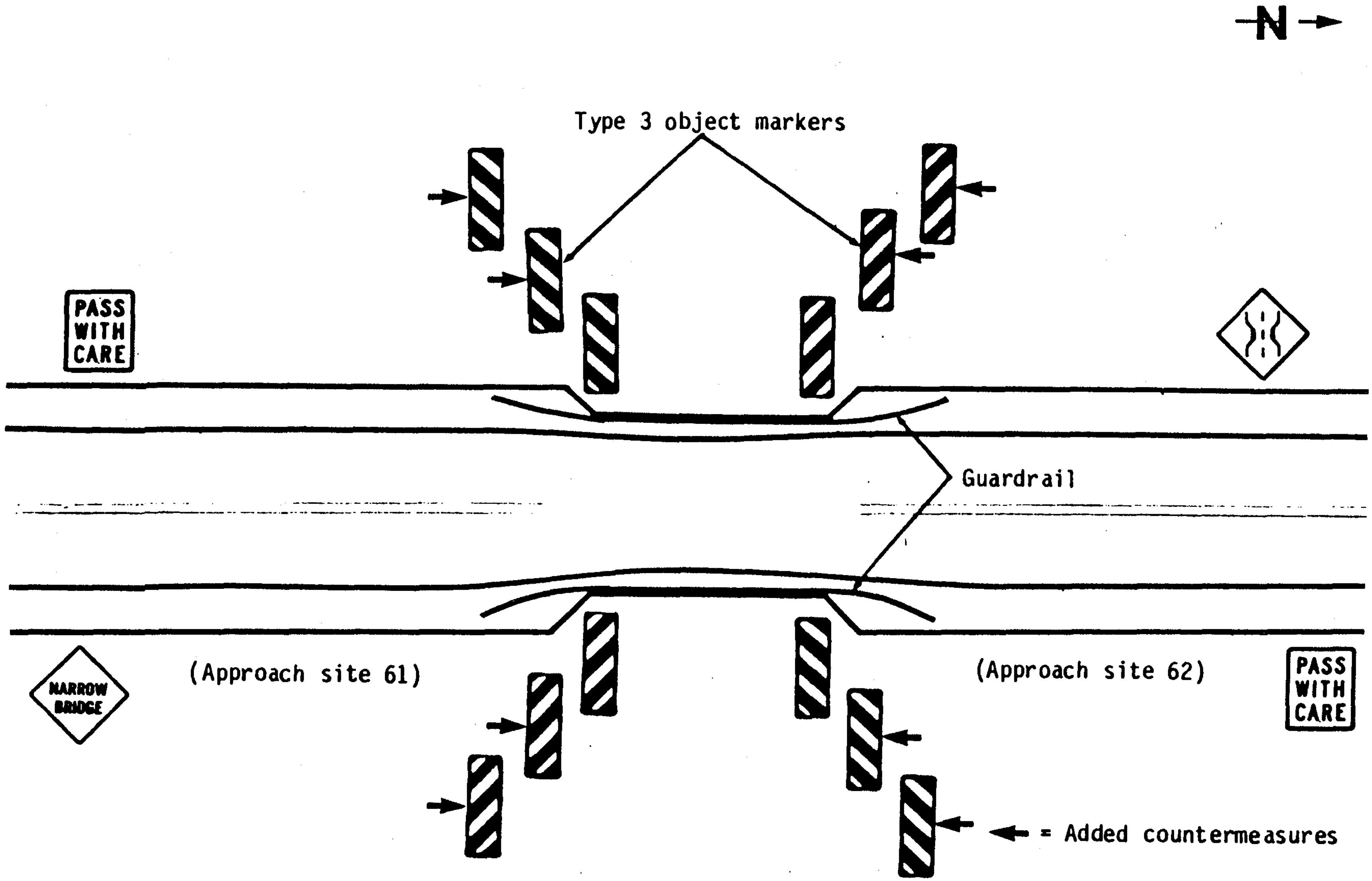


Figure 8. Physical and traffic control characteristics of approach sites 61 and 62.

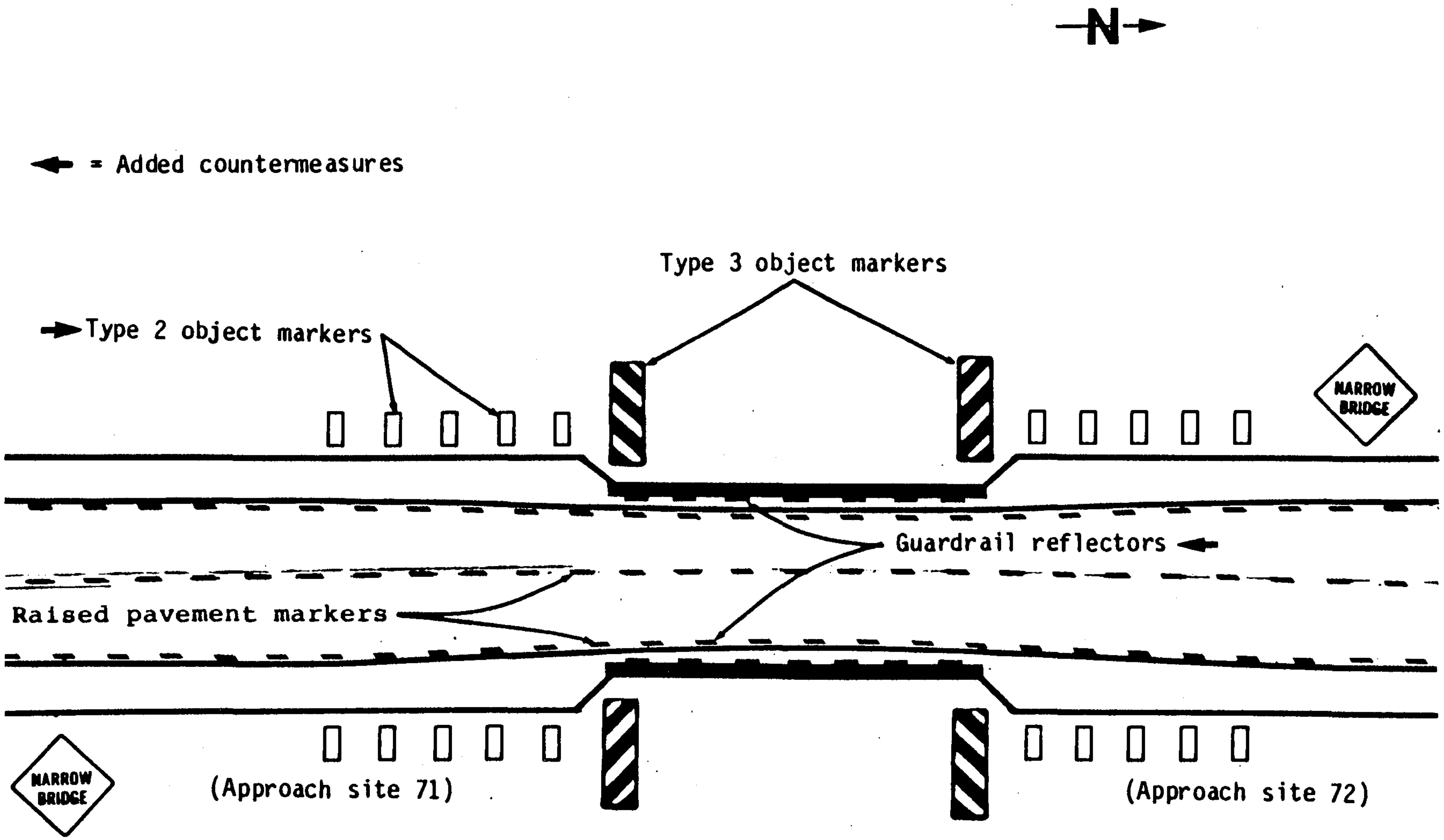


Figure 9. Physical and traffic control characteristics of approach sites 71 and 72.

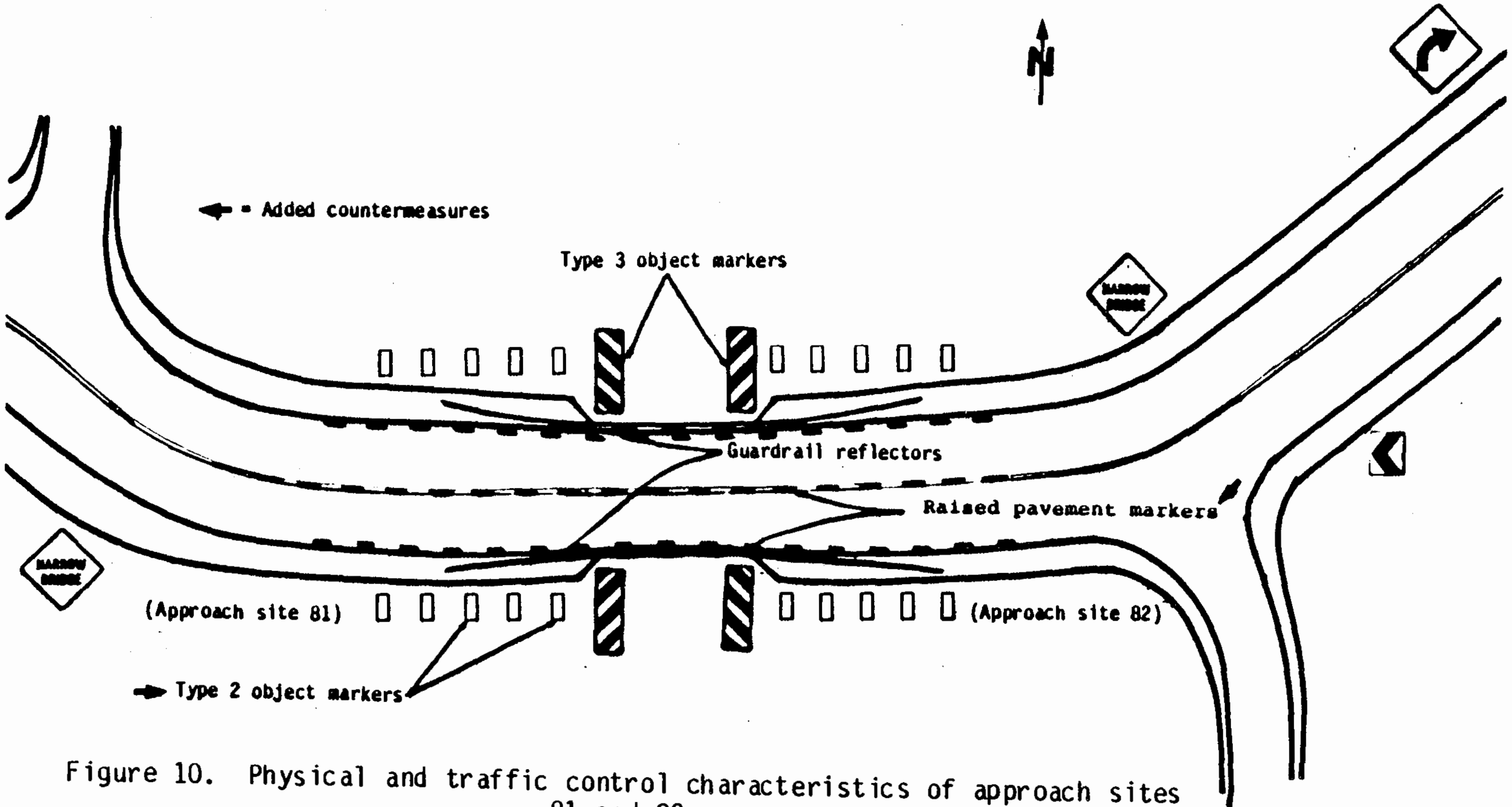


Figure 10. Physical and traffic control characteristics of approach sites 81 and 82.

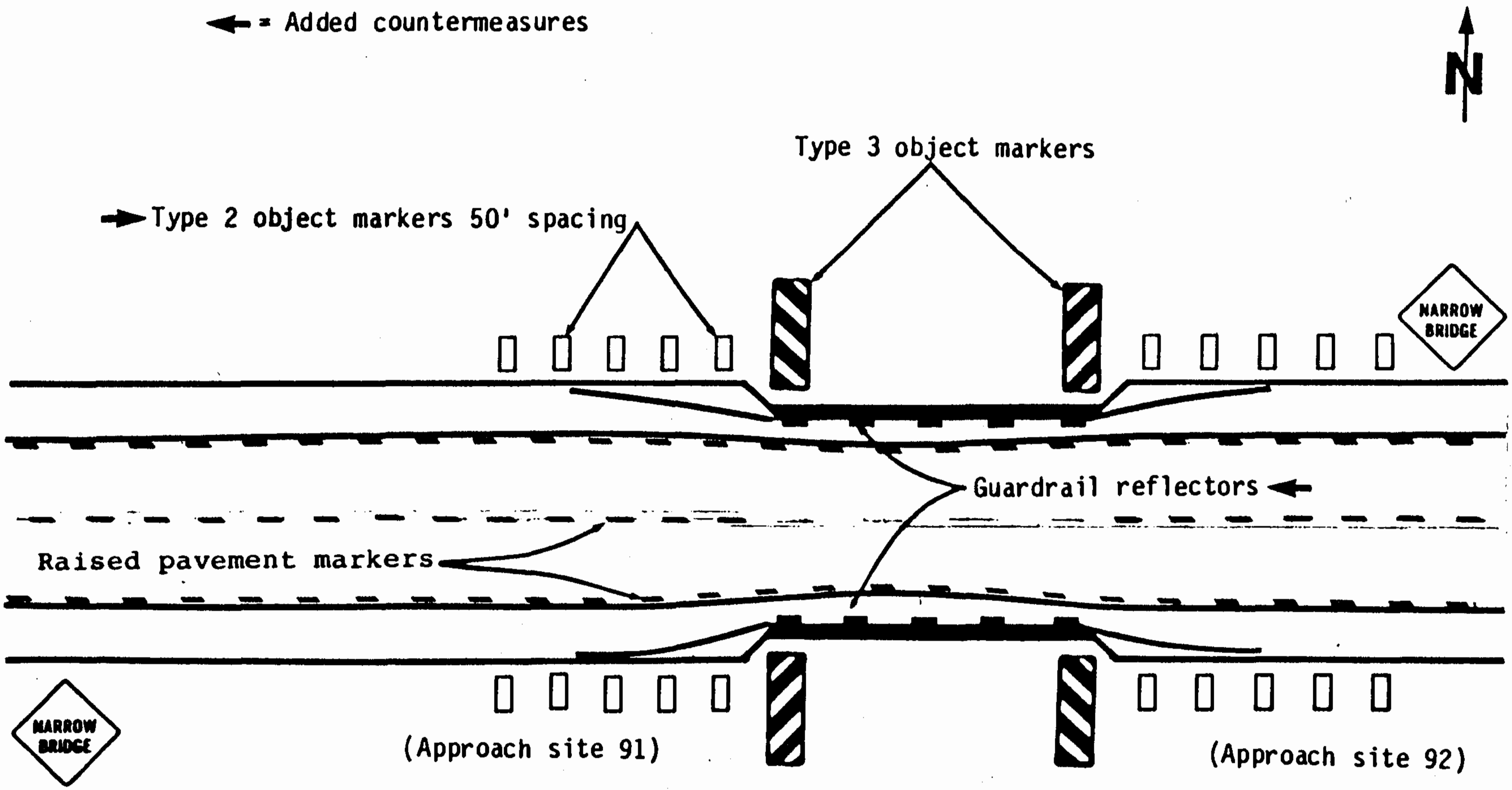
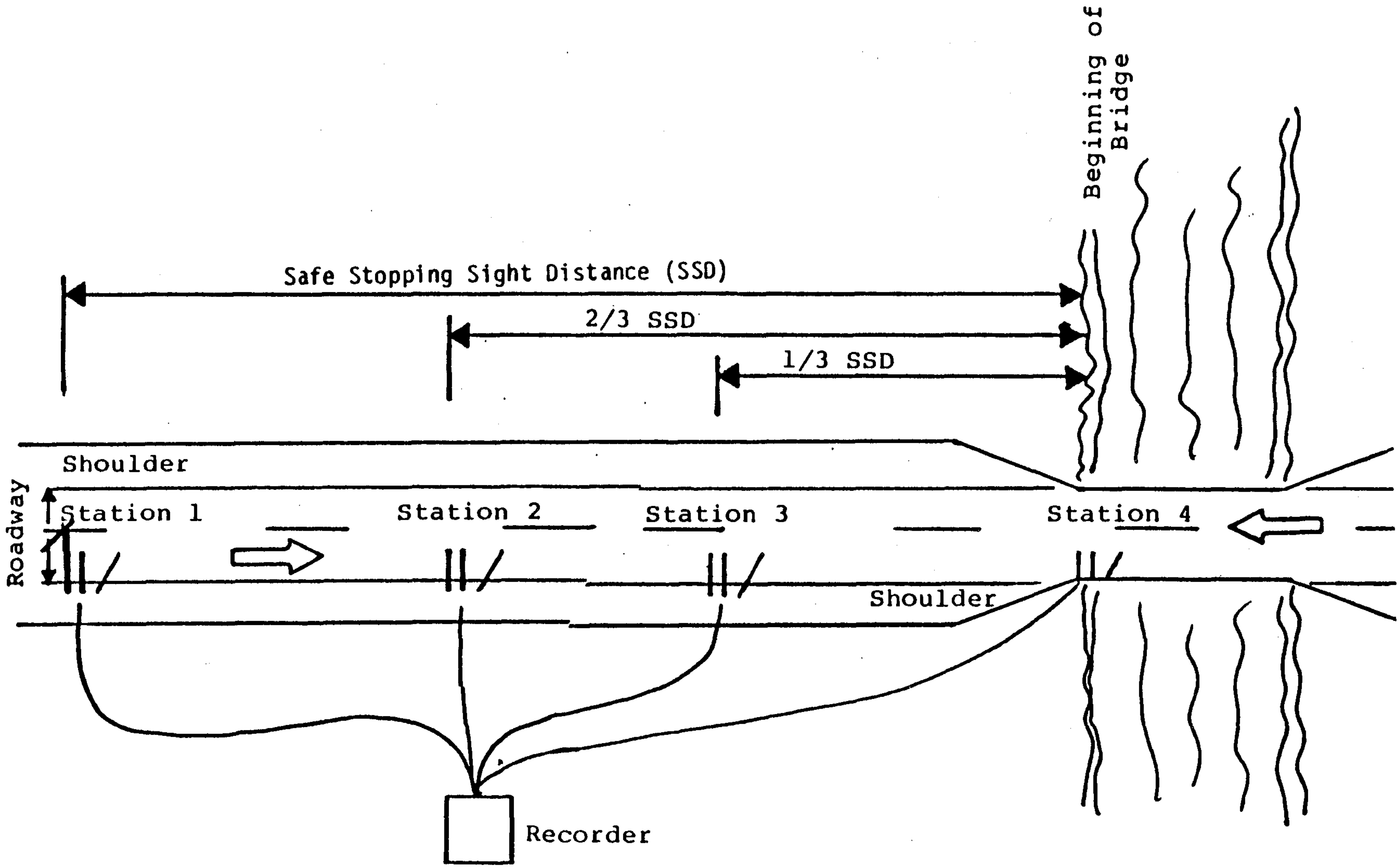


Figure 11. Physical and traffic control characteristics of approach sites 91 and 92.



The same tapeswitch configuration will be set-up on the other bridge approach.

Figure 12. Typical approach layout of TES tapeswitches.

istics resulted in variations of the actual tapeswitch locations. The actual location of each trap in the array for each approach is presented in table 5. This table presents the distance of the furthest edge of each trap from the start of the bridge.

Figure 13 indicates the arrangement of each tapeswitch deployment. In each case, the ends of the tapeswitches were located at a known distance, O_1, off of the edge of the roadway to minimize the potential damage to the lead wires at the end of the tapeswitch. Placing positions of the tapeswitch off the edge of the roadway also provided a means to collect shoulder encroachment data. The two tapeswitches perpendicular to the centerline (A and B on figure 13) provided a means to determine the speed of vehicles at the station. Since tapeswitches A and B were placed at a known distance apart, S, the speed of vehicles were determined by:

$$\text{Speed} = \frac{\text{S x conversion factor}}{\text{Time B - Time A}} \qquad (1)$$

For example, if the two tapeswitches are placed 10 feet apart, and the impulses are noted at the time points 231.02 and 231.22 seconds, then

$$\text{Speed} = \frac{10.0 \text{ ft. x } (0.6817)}{231.22 - 231.02 \text{ seconds}}$$

$$= (50 \text{ ft/sec}) (0.6817)$$

$$= 34.09 \text{ mph}$$

The lateral placement of vehicles was determined from the computed speed and the time of impulse on the diagonally placed tapeswitch with a known angle 'theta'. The distance travelled by the vehicle between tapeswitchs Band C (denoted by x) was determined from the known speed of the vehicle as it crossed tapeswitch B and the difference in the recorded time impulse between tapeswitches B and C. The function used was:

$$X \text{ (ft)} = (\text{time}_C - \text{time}_B) \text{ (sec) x speed (ft/sec)} \qquad (2)$$

Following the previous example, with impulse time of 231.22 and 231.45 leads to:

$$X = (231.45 - 231.22) \times 50.0$$
$$= 11.5 \text{ feet}$$

Table 5. Distance of lead trap edge from start of bridge (feet).

Approach Designation	Trap Number			
	1	2	3	4
11	900	600	300	0
12	600	400	200	0
21	904	600	300	0
22	900	604	300	0
31	600	400	200	0
32	935	600	300	0
41	321	214	107	0
42	525	350	175	4
51	920	600	300	0
52	900	600	300	0
61	900	600	300	0
62	900	600	300	0
71	900	600	300	0
72	900	600	300	0
81	950	500	250	0
82	900	600	300	0
91	900	600	300	0
92	900	600	300	0

1 ft = 0.31 m

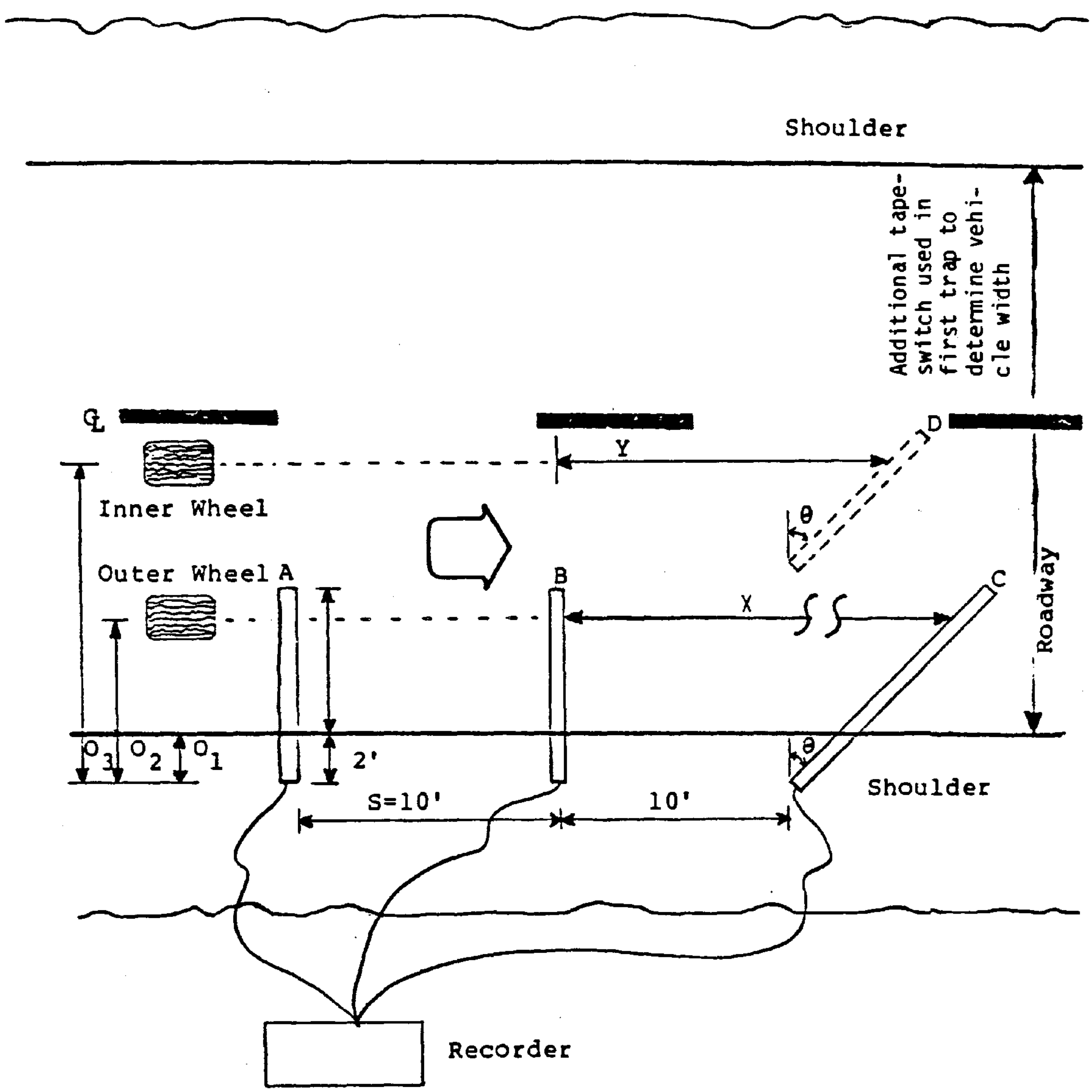


Figure 13. Typical tapeswitch deployment.

The trigonometric relationship for the tangent of theta (Ø) was then applied to compute the distance O_2.

$$O_2 = \frac{d}{\tan \emptyset} \qquad (3)$$

If Ø = 30 degrees, then

$$O_2 = \frac{(11.5 - 10.0)}{0.5773} = 2.59 \text{ feet}$$

The difference between O_2 and O_1, provided a measure of the lateral placement of the outer wheel on the roadway (or shoulder).

A similar set of relationships were used to derive the value Y and subsequently O_3 from data obtained from a second diagonal impulse from tapeswitch C. The difference between O_3 and O_2 indicates the tracking width of the vehicle which was used to classify the vehicle by type. The tapeswitch system allowed for the counting and classification of vehicles. Axle counts were obtained by noting the number of sets of axles crossing tapeswitch A. The axle count in conjunction with the measurements of vehicle width permitted a determination if the vehicle was a truck, bus or within the category of auto, van or pickup.

5. Data Quality Control

Quality control measures were applied during tape switch deployment, data collection periods and data analysis. The quality control procedures during deployment consisted of ensuring that the tapeswitches were securely fastened to the road surface and installed with the proper distances and deployment angles. The proper distances and angles were verified by performing a number of trial runs at known speeds with a vehicle of known width. If all the traps did not produce identical and correct speeds then adjustments were made and additional trial runs performed. Similarly, if the first trap did not produce the correct estimate of vehicle width then adjustments were made to the diagonal tapeswitches until correct measurements were obtained.

Personnel remained with the equipment continuously while it was deployed. This served to help prevent vandalism and to quickly identify when problems occurred. Typical problems encountered with the system included loosening of tapeswitches from the pavement, tapeswitch failure, loss of battery charge, shorting due to moisture buildup and disconnection of leads. These faults were evidenced by monitoring the record indicator lights of the TES unit. When a vehicle progressed through the trap array an indicator light was illuminated for each tapeswitch that was operational. Tapeswitches that failed to operate properly were repaired prior to the loss of an appreciable amount of data.

The quality control measures applied after the data was collected were accomplished by data reduction software. This software developed specifically for the TES system was designed to translate field-encoded data and check for erroneous or unreasonable data. A description of the faults identified by the software and the resultant actions that were taken are presented in table 6.

Table 6. Quality control checks on TES data base.

Identified Fault	Action Taken
Headway time < 0.33 seconds.	Note only, value not of immediate interest.
Acceleration > 10 fpsq or deceleration > -20 fpsq.	Data included. This is an evaluation measurement.
Invalid lateral displacement. (Disp. < 0.0 or > 5.5 ft.)	Value excluded from calculations of measurements.
Invalid wheel path width for vehicle type.	Value excluded from calculations of measurements.
Lead diagonal switch hit missing.	Unable to calculate wheel path width & clearance.
Multiple hits on lead diagonal switch.	Unable to calculate wheel path width & clearance.
Lateral displacement missing.	Unable to calculate any clearance.
Lead trap (1 or 5) data missing or invalid.	Unable to calculate wheel path width & clearance.
Invalid absolute speed. (Speed < 1 mph or > 95 mph.)	All data for trap excluded from calculations.
Absolute relative speed > 20 fps and headway time < 3.0 seconds.	All data for trap excluded from calculations.
Unlikely relationship between # of axles and # of tandems.	All data for trap excluded from calculations.
Unreasonable # of switch hits invented to create vehicle at trap.	All data for trap excluded from calculations.
Max wheelbase > 20% more than min wheelbase across deployment.	All data for vehicle excluded from data base.
The number of axles for this vehicle changed across deployment.	All data for vehicle excluded from data base.
The number of tandems for this vehicle changed across deployment.	All data for vehicle excluded from data base.
Invalid vehicle type (wheelbase error).	All data for vehicle excluded from data base.
Data missing or invalid for 2 or more traps.	All data for vehicle excluded from data base.
Compound severe data validity errors. (E.g., no valid trap data.)	All data for vehicle excluded from data base.

ANALYSIS OF OPERATIONAL DATA

The analyses of the measures of effectiveness (MOE) related to vehicle placement and speed were performed using a before-after experimental design. The before period consisted of TES deployment prior to the installation of any countermeasures. The after period data were obtained after the countermeasures had been in place for at least two months. The two month waiting period was used to allow any possible novelty effects to dissipate prior to data collection.

The before-after design was considered appropriate since; 1) data were being collected at the same sites for each time period; 2) the amount of total lapsed time between finishing the before and after data collection tasks was less than four months; and 3) the total amount of data collection at each site generally exceeded 24 hours. The result was relatively large sample sizes obtained within a short time interval. The possible effects of biasing factors such as trends over time and regression to the mean were not, therefore, considered as threats to statistical validity.

The obtained data for both the before and after time periods were divided into periods of day and night conditions and into categories of vehicle type. The categories of vehicle type were determined by establishing criteria based on the number of axles, wheel base and wheel path width. The criteria that were used to classify the vehicle types are summarized in table 7.

The type of analyses performed was dependent upon the MOE and whether each MOE was obtained on a site or a trap-to-trap basis. All of the data were divided into categories of bridge approach by time of day and vehicle type. A significance level of 10 percent (i.e., level of confidence of 90 percent) was used for all the statistical tests of this study. A general discussion of the analysis methodology and statistical tests that were applied are presented below. Complete discussions of how each test was applied to a particular MOE are presented in the following sections of this report.

Table 7. Summary of vehicle classifications criteria.

TES PROGRAM PARAMETERS			SPECIFIED WHEEL-PATH-WIDTH VALIDITY LIMITS (feet)			
Classification	Criteria: Axles	Criteria: Wheelbase	Suspect if less than	Suspect if greater than	Invalid if less than	Invalid if greater than
Small auto	2	≥ 6.0 ft. & < 8.3 ft.	4.053	5.390	3.840	5.647
Medium auto	2	≥ 8.3 ft. & < 9.3 ft.	4.124	5.498	3.907	5.788
Large auto	2	≥ 9.3 ft. & < 10.4 ft.	4.560	5.600	4.320	5.867
Motorcycle	2	≥ 3.5 ft. & < 6.0 ft.	-----	-----	-----	-----
Pickup/Van/Utility	2	≥ 10.4 ft. & < 13.0 ft.	4.123	5.958	3.901	6.235
2 axle truck	2	≥ 13.0 ft. & < 20.0 ft.	4.325	7.220	4.220	7.600
3 axle truck	3	< 25.0 ft.	4.325	7.220	4.220	7.600
Bus	2	≥ 20.0 ft.	6.150	7.220	6.000	7.600
Combination Truck	3	≥ 25.0 ft. (or 4-5 axles)	4.325	7.410	4.220	7.800
(Large) Comb. Truck	≥ 6	----	4.325	7.410	4.220	7.800

- Analysis based on individual observations. The software logic of TES enabled the system to identify a vehicle at the first tapeswitch deployment and to follow that vehicle through the trap array. A unique identifier was assigned to each vehicle and the speeds and lateral position at every tapeswitch deployment was recorded as part of that vehicle's data. It was possible, therefore, to determine the speed and lateral position changes exhibited by each vehicle as it progressed through the trap array. The individual vehicle data were used as input to the first battery of statistical tests. This resulted in group means and statistical tests that were based on large sample sizes and degrees of freedom. Statistical analyses between before and after MOE values of individual vehicle measures were conducted by using computerized statistical analsyis packages. The TES software programs were used to develop estimates of individual vehicle speeds and roadway lateral placement. The distributions of these data were determined by applying the normal option of the proc univariate statement. When a normal data distribution existed then the t-test procedure was applied to determine if a significant difference existed between the before and after MOE values. The first step in the application of the t-test was to develop a F statistic to test for equality of the before and after population variances. This was necessary because the t-test computes two t statistics; one based on the assumption that the variances of the two groups are equal and another, approximate statistic, based on the assumption that the variances are unequal. An example of the SAS output for a t-test on the mean speed across trap deployment is presented as figure 14.

  The level of significance used for both the F-test and the t-test was 10 percent. The F-test was conducted under the null hypothesis that the variances of the two groups were equal. If the probability computed by SAS was less than 0.10, then the null hypothesis was rejected and the t statistic for unequal variances was used. A similar analogy existed for the t-test which had the null hypothesis that the means of the before and after groups were equal. If the probability of a greater absolute value of t (two-tailed significance probability) was less than 0.10 then the null hypothesis was rejected with a significant difference in the group means being indicated. The underlying assumption of the t-test procedure is that the variables are normally and independently distributed within each group. The t-test has the properties of being applicable to small sample sizes while being almost identical to the standard normal distribution as the sample size increases.

- Analyses based on the individual vehicle t-test results. The results of the statistical analysis of individual vehicle measurements consisted of determinations as to whether individual sites or individual traps exhibited a significant difference in their before and after MOE values. The sign test was applied to the site specific data to determine if there were a sufficient number

SITE: 1 -- EASTBOUND -- "INEXPENSIVE COUNTERMEASURES AT NARRROW BRIDGES" STUDY, FHWA Contact No. DTFH61-83-C-00148 20
20:21 SATURDAY, JUNE 14, 1986
Analyses of "Measures-of-Effectiveness" (MOEs) and Allied Parameters

----> ANALYSES OF "MEAN SPEED ACROSS DEPLOYMENT" MOE (Questionable data EXCLUDED) - [AVGMPH22] <----

Vehicle-Group=AUTOS/LIMOS/VANS/PICKUPS

TTEST PROCEDURE

VARIABLE: AVGMPH Mean speed across deployment (MPH)

DEPLOY	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1=PRE-TREATMENT	9135	47.90048328	4.99732498	0.05228575	15.71590909	78.78409091	UNEQUAL	-2.4440	6740.8	0.0145
2=POST-TREATMENT	3597	48.13650106	4.86930858	0.08118898	25.70454545	76.10795455	EQUAL	-2.4166	12730.0	0.0157

FOR H0: VARIANCES ARE EQUAL, F'= 1.05 WITH 9134 AND 3596 DF PROB > F'= 0.0639

------------------------------ Vehicle-Group=TRUCKS/BUSES ------------------------------

VARIABLE: AVGMPH Mean speed across deployment (MPH)

	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1=PRE-TREATMENT	66	44.08626033	5.68615585	0.69991740	32.21590909	55.17613636	UNEQUAL	0.5091	83.5	0.6120
2=POST-TREATMENT	46	43.44997530	7.02253365	1.03541610	18.05113636	56.28409091	EQUAL	0.5286	110.0	0.5982

FOR H0: VARIANCES ARE EQUAL, F'= 1.53 WITH 45 AND 65 DF PROB > F'= 0.1180

------------------------------ Vehicle-Group=COMBINATION-TRUCKS ------------------------------

VARIABLE: AVGMPH Mean speed across deployment (MPH)

	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1=PRE-TREATMENT	34	42.69034091	3.67975926	0.63107351	33.49431818	50.38636364	UNEQUAL	1.7940	13.4	0.0955
2=POST-TREATMENT	11	39.65392562	5.20873656	1.57049316	32.13068182	48.22159091	EQUAL	2.1420	43.0	0.0379

FOR H0: VARIANCES ARE EQUAL, F'= 2.00 WITH 10 AND 33 DF PROB > F'= 0.1308

Figure 14. Sample SAS output for t test of mean speed across deployment.

of instances where a significant difference existed to conclude that the countermeasures resulted in a net difference over all of the sites. The sign test is a nonparametric procedure that does not make any assumptions about the form of the distribution of differences or that the data is drawn from the same distribution. The test is applied by focusing on the direction of the differences and whether the sign of the difference is plus or minus. In applying this test to the resultant individual vehicle t-test data positive signs were used to signify a significant increase between the before and after condition, and negative signs a significant decrease. The sign test works under the null hypothesis that half of the differences would be expected to be positive and half negative. The null hypothesis is rejected, and a significant difference assumed, if too few differences of one sign occur.

- Analysis of mean MOE values. The mean MOE values generated by the t-tests on the individual vehicle data were analyzed by site and by tapeswitch deployment. This was accomplished by using the appropriate mean from each test site and performing statistical tests to determine if significant changes had occurred between the before and after time periods. Since means instead of individual vehicle observations were being used in these tests the total number of observations used for each time period were approximately 18 and 72, respectively, for site and trap specific analyses. Tests for normality and variance homogeneity were first applied to the data. If both the before and after time period being analyzed exhibited a normal distribution, then statistical procedures using SPSS-X PC were applied to the data.[31] Site-specific data were analyzed using the t-test and trap specific data with the paired t-test. The paired t-test was used for trap specific analyses because the MOE values obtained were dependent upon the distance of the tapeswitch deployment from the bridge. The paired t-test controls for this source of variability and lowers the sampling error. It accomplishes this by computing the difference for each matched pair and making inferences about the mean of the corresponding population of differences.

1. Mean Speed Over All Tapeswitch Deployments

A summary of the before and after mean speed across all of the tapeswitch deployments is presented in table 8. This table contains the mean speed across the deployment, the total number of vehicles that were used to determine the mean speed and the results of each t-test. The results of the t-test are presented in such a manner that the direction of significant difference is known. The plus and minus signs indicate that there were significant increases or decreases in the mean speed between the before and after time periods. The use of zeros indicates that there were no significant increases or decreases in the mean speed.

Table 8. Summary of t-test analysis of individual vehicle speeds (10 percent significance level).

Analysis Approach and Time Period	All Time Periods and Vehicle Types Combined			Day: All Vehicle Types			Day: Autos, Van Pickups			Day: Trucks and Buses			Night: All Vehicle Types			Night: Autos, Vans Pickups		
	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)
11 Before	47.80	(9925)	+	47.99	(7740)	0	48.04	(7657)	+	44.03	(58)	0	47.16	(1495)	0	47.19	(1478)	0
After	48.04	(3851)		48.13	(3166)		48.23	(3115)		43.06	(42)		47.52	(488)		47.54	(482)	
12 Before	50.63	(10571)	+	50.85	(8930)	+	50.89	(8851)	+	47.23	(57)	-	48.99	(1059)	0	49.02	(1051)	0
After	50.93	(3806)		51.09	(3360)		51.18	(3320)		43.11	(29)		49.25	(309)		49.27	(305)	
21 Before	47.16	(2207)	+	47.10	(1708)	+	47.22	(1661)	+	43.22	(35)	0	47.15	(374)	0	47.30	(360)	0
After	48.17	(1235)		48.19	(1037)		48.32	(1008)		45.53	(18)		47.82	(131)		47.78	(130)	
22 Before	47.57	(1729)	+	47.65	(1301)	+	47.82	(1245)	+	43.95	(38)	0	47.26	(315)	+	47.29	(305)	+
After	48.78	(1086)		48.58	(887)		48.74	(853)		45.12	(26)		50.27	(122)		50.27	(122)	
31 Before	42.98	(3606)	0	42.99	(3042)	0	43.02	(3025)	0	Insufficient			43.43	(392)	0	43.77	(392)	0
After	43.15	(2095)		43.11	(1630)		43.14	(1622)		sample size			43.77	(307)		45.55	(307)	
32 Before	45.55	(3387)	+	45.59	(2802)	0	45.62	(2787)	0	Insufficient			45.75	(388)	0	45.76	(388)	0
After	45.98	(2233)		45.74	(1668)		45.76	(1659)		sample size			46.46	(306)		46.47	(304)	
41 Before	36.38	(12407)	+	36.17	(10406)	+	36.22	(10244)	+	33.55	(112)	0	37.82	(1248)	+	57.39	(1243)	-
After	37.48	(4932)		37.37	(3854)		37.43	(3799)		33.06	(39)		38.22	(643)		55.49	(637)	
42 Before	42.96	(14611)	-	42.88	(12157)	-	42.92	(12002)	-	40.55	(102)	0	44.07	(1231)	0	44.11	(1225)	0
After	42.63	(6015)		42.41	(4404)		42.44	(4363)		39.72	(28)		43.76	(811)		43.77	(810)	
51 Before	51.27	(346)	0	53.35	(12)	0	53.35	(12)	0	Insufficient			51.04	(278)	0	51.22	(273)	0
After	51.34	(1413)		50.93	(626)		51.16	(601)		sample size			51.76	(537)		51.78	(531)	
52 Before	51.68	(626)	0	52.37	(23)	0	52.37	(23)	0	Insufficient			51.49	(505)	0	51.60	(498)	0
After	51.35	(1513)		51.51	(760)		51.81	(717)		sample size			51.28	(606)		51.29	(601)	

(1) - S.D. = Significant difference, (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

Table 8. Summary of t-test analysis of individual vehicle speeds (10 percent significance level) (continued).

Analysis Approach and Time Period	All Time Periods and Vehicle Types Combined			Day									Night					
				All Vehicle Types			Autos, Van Pickups			Trucks and Buses			All Vehicle Types			Autos, Vans Pickups		
	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)
61 Before	51.72	(1411)	+	51.71	(1091)	+	52.01	(973)	+	45.92	(27)	0	51.92	(279)	+	51.94	(273)	+
After	53.63	(1194)		53.74	(826)		54.07	(773)		48.80	(43)		53.45	(244)		53.66	(232)	
62 Before	53.65	(1950)	+	52.76	(1144)	+	53.13	(1064)	+	47.93	(56)	0	54.68	(538)	+	54.74	(531)	+
After	54.61	(1390)		53.50	(709)		53.97	(653)		47.88	(47)		56.01	(467)		56.10	(458)	
71 Before	53.59	(1187)	0	53.67	(698)	0	54.13	(616)	0	50.78	(60)	0	52.95	(382)	0	52.88	(371)	0
After	53.56	(1578)		53.41	(1106)		53.59	(1054)		49.21	(34)		53.10	(321)		53.09	(309)	
72 Before	53.33	(1350)	-	53.70	(919)	-	53.88	(859)	-	51.79	(42)	0	52.26	(334)	+	52.43	(312)	0
After	52.65	(1779)		52.57	(1388)		52.69	(1314)		50.37	(46)		53.24	(301)		53.29	(287)	
81 Before	50.28	(576)	0	50.32	(504)	0	50.40	(490)	0	49.02	(10)	0	52.42	(42)	-	52.42	(42)	-
After	50.33	(1233)		50.39	(984)		50.44	(944)		49.20	(30)		49.44	(183)		49.59	(180)	
82 Before	45.32	(1085)	0	44.95	(680)	0	44.99	(665)	0	Insufficient			46.52	(295)	-	46.57	(292)	-
After	45.14	(498)		45.20	(375)		45.27	(366)		sample size			44.45	(89)		44.45	(89)	
91 Pefore	53.80	(673)	-	53.61	(466)	0	53.54	(452)	0	Insufficient			54.19	(155)	-	54.16	(154)	-
After	52.78	(2310)		53.49	(1803)		53.58	(1758)		sample size			49.95	(397)		50.08	(388)	
92 Before	53.92	(771)	-	54.27	(543)	-	54.36	(532)	-	Insufficient			53.18	(170)	-	53.06	(165)	-
After	51.32	(2037)		51.67	(1549)		51.75	(1518)		sample size			50.28	(420)		50.28	(420)	

(1) - S.D. = Significant difference, (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

Inspecting the direction of significant changes in mean speed from table 8 does not reveal any discernable patterns within the sites. Only sites 22, 61, and 62 had an increase with no accompanying decreases in mean speed across all analysis categories. Each of these test approaches consisted of straight roadway sections with no sight restrictions. The test approaches with horizontal curves (41, 42, 81 and 82) displayed a greater number of significant mean speed reductions across analysis categories than speed increases (eight reductions versus four increases).

Inspection of table 8 reveals that small changes in the mean speeds often result in significant differences due to the large sample sizes. This is understandable since the accuracy of the mean speed estimates increases as the number of vehicles on which the sample is based also increases. The relationship to sample size may explain why there were not a larger number of significant differences exhibited during the night than revealed by the study. Since the use of roadway delineators, reflectorized hazard markers, pavement markings, and raised pavement markings have a different impact at night than during the day, it was expected to observe differences between the day and night data. That this difference was not exhibited by the study may be due to the smaller sample sizes available during night conditions.

The results of the t-test, presented in table 8 were investigated to determine if a sufficient number of increases or decreases in mean speed had occurred to signify the presence of trends. This was accomplished by applying the sign test to determine if, at a 90 percent level of confidence, an increase or decrease in mean speeds could be expected to occur from the installation of low cost countermeasures. The results of these tests, performed on a combined category of all vehicle types for three time periods, are presented in table 9. The resultant probability of observing an equal or more extreme number of increases in mean speed are all greater than the desired significance level of 0.10. It cannot be concluded, therefore, that the countermeasures being evaluated resulted in an overall increase in speed.

Table 9. Summary of sign test on the change in mean speed (mi/h) between the before and after time periods.

	All time periods and vehicle types	All vehicle types Day	Night
significant increases (+)	8	6	5
significant decreases (-)	4	3	4
no significant difference	6	9	9
probability of a greater number of speed increases	0.19	0.25	0.50

1 mi/h = 1.6 km/h

The mean speeds at each test site were also analyzed to determine if there were any significant differences between the before and after data across all of the test sites. These analyses were performed separately for day and night conditions on the category of all vehicle types. The results of these analysis are presented in table 10. An inspection of the bottom of table 10 reveals that the probabilities for both the day or night conditions did not indicate a significant difference at the 0.10 significance level. The low cost countermeasures did not, therefore, result in significant changes in the mean speeds when evaluated over all the test sites.

2. <u>Speed Variation Across Deployment</u>

A summary of the site specific analysis of the maximum speed variation is presented in table 11. The intuitive logic used in the selection of this MOE was that a reduction in speed variation denotes increased safety due to more uniform vehicle speeds. An inspection of table 11 indicates that the only approach test sites that experienced an increase in speed variability for at least one analysis category were sites 12, 51, and 82. All of the remaining approach sites experienced either a reduction in speed variability across all analyses categories or no significant change. The large sample sizes resulted in relatively small changes in the speed variation as exhibiting significant differences. This is similar to the condition encountered during the mean speed analysis.

Table 10. Student t analysis of mean speeds at each test site (mi/h) for all types of vehicles.

Approach Designation	Day Before	Day After	Night Before	Night After
11	47.99	48.13	47.16	47.52
12	50.85	51.09	48.99	49.25
21	47.10	48.19	47.15	47.82
22	47.65	48.58	47.26	50.27
31	42.99	43.11	43.43	43.77
32	45.59	45.74	45.75	46.46
41	36.17	37.37	37.82	38.22
42	42.88	42.41	44.07	43.76
51	53.35	50.93	51.04	51.76
52	52.37	51.51	51.49	51.28
61	51.71	53.74	51.92	53.45
62	52.76	53.50	54.68	56.01
71	53.67	53.41	52.95	53.10
72	53.70	52.57	52.26	53.24
81	50.32	50.39	52.42	49.44
82	44.95	45.20	46.52	44.45
91	53.61	53.49	54.19	49.95
92	54.27	51.67	53.18	50.28
Mean	49.00	48.95	49.02	48.89
Standard Deviation	4.99	4.59	4.74	4.36
t value	0.03		0.08	
degrees of freedom	34		34	
probability	0.98		0.93	

1 mi/h = 1.6 km/h

Table 11. Summary of t-test analysis on maximum speed variation of individual vehicles across deployment (10 percent significance level).

Analysis Approach and Time Period	All Time Periods and Vehice Types Combined			Day: All Vehicle Types			Day: Autos, Van Pickups			Day: Trucks and Buses			Night: All Vehicle Types			Night: Autos, Vans Pickups		
	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)
11 Before	5.46	(9925)	-	5.47	(7740)	-	5.46	(7657)	-	6.05	(58)	0	5.50	(1495)	0	5.50	(1478)	0
After	5.19	(3851)		5.12	(3166)		5.10	(3115)		6.29	(42)		5.73	(488)		5.73	(480)	
12 Before	3.06	(10571)	+	3.09	(8930)	+	3.08	(8851)	+	4.96	(57)	0	2.94	(1059)	+	2.93	(1051)	+
After	3.24	(3806)		3.24	(3360)		3.24	(3320)		4.32	(29)		3.42	(309)		3.42	(305)	
21 Before	5.56	(2207)	-	5.83	(1708)	-	5.82	(1661)	-	6.29	(35)	-	4.62	(374)	-	4.67	(360)	-
After	4.53	(1235)		4.65	(1037)		4.69	(1008)		3.79	(18)		3.81	(131)		3.83	(130)	
22 Before	3.98	(1729)	0	3.96	(1301)	0	3.97	(1245)	0	3.68	(38)	0	4.17	(315)	0	Insufficient sample size		
After	3.87	(1086)		3.97	(887)		3.97	(853)		3.72	(26)		3.69	(122)				
31 Before	2.97	(3606)	0	2.90	(3042)	0	2.90	(3025)	0	Insufficient sample size			3.42	(392)	0	3.42	(392)	0
After	2.93	(2095)		2.85	(1630)		2.85	(1622)					3.23	(307)		3.23	(307)	
32 Before	4.97	(3387)	-	4.93	(2802)	0	4.93	(2787)	0	Insufficient sample size			5.23	(388)	0	5.23	(388)	0
After	4.83	(2233)		4.81	(1668)		4.81	(1659)					5.13	(306)		5.14	(304)	
41 Before	2.87	(12407)	-	2.93	(10406)	-	2.93	(10244)	-	2.77	(112)	-	2.54	(1248)	0	2.54	(1243)	0
After	2.60	(4933)		2.65	(3856)		2.65	(3799)		2.11	(39)		2.45	(643)		2.45	(637)	
42 Before	3.36	(14611)	-	3.38	(12157)	-	3.38	(12002)	-	3.18	(102)	0	3.32	(1231)	0	3.32	(1225)	0
After	3.29	(6015)		3.24	(4404)		3.24	(4363)		2.95	(28)		3.27	(811)		3.27	(810)	
51 Before	3.76	(346)	0	2.34	(12)	+	2.34	(12)	+	Insufficient sample size			3.83	(278)	0	3.81	(273)	-
After	3.39	(1413)		3.49	(626)		3.46	(601)					3.23	(537)		3.31	(531)	
52 Before	4.69	(626)	0	5.72	(23)	0	5.72	(23)	0	Insufficient sample size		0	4.60	(505)	-	4.56	(498)	0
After	4.75	(1539)		5.17	(760)		5.14	(717)					4.24	(606)		4.25	(601)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

Table 11. Summary of t-test analysis on maximum speed variation of individual vehicles across deployment (10 percent significance level) (continued).

Analysis Approach and Time Period	All Time Periods and Vehicle Types Combined			Day: All Vehicle Types			Day: Autos, Van Pickups			Day: Trucks and Buses			Night: All Vehicle Types			Night: Autos, Vans Pickups		
	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)
61 Before	5.41	(1411)	-	5.46	(1019)	-	5.43	(973)	-	5.26	(27)	0	5.02	(279)	-	5.07	(273)	-
After	4.01	(1194)		4.05	(826)		4.04	(773)		4.10	(43)		3.73	(244)		3.76	(232)	
62 Before	4.75	(1950)	-	4.95	(1144)	0	4.98	(1064)	0	4.22	(56)	0	4.57	(538)	-	4.59	(531)	-
After	4.42	(1390)		4.99	(709)		5.01	(653)		5.16	(47)		3.56	(467)		3.57	(458)	
71 Before	3.38	(1187)	-	3.69	(698)	-	3.64	(616)	-	3.83	(60)	0	3.10	(382)	0	3.11	(371)	0
After	2.95	(1578)		3.06	(1106)		3.06	(1054)		3.10	(34)		2.83	(321)		2.78	(309)	
72 Before	2.74	(1350)	0	2.79	(919)	0	2.75	(859)	0	3.66	(42)	0	2.67	(334)	0	2.70	(312)	0
After	2.69	(1779)		2.72	(1388)		2.72	(1314)		2.56	(46)		2.59	(301)		2.55	(287)	
81 Before	4.48	(576)	0	4.34	(504)	0	4.35	(490)	0	4.66	(10)	0	6.44	(42)	-	6.44	(42)	-
After	4.33	(1233)		4.31	(984)		4.31	(944)		4.13	(30)		4.65	(183)		4.67	(180)	
82 Before	6.73	(1085)	+	6.87	(680)	+	6.90	(665)	+	Insufficient			6.67	(295)	+	6.70	(292)	+
After	7.95	(498)		8.01	(375)		7.99	(366)		sample size			7.84	(89)		7.84	(89)	
91 Before	5.29	(673)	-	5.19	(466)	-	6.00	(452)	-	Insufficient			3.28	(155)	0	3.06	(154)	0
After	3.81	(2310)		3.91	(1803)		3.91	(1758)		sample size			3.58	(397)		3.03	(388)	
92 Before	3.36	(771)	0	3.52	(543)	0	3.56	(532)	0	Insufficient			2.92	(170)	0	2.94	(165)	0
After	3.25	(2037)		3.31	(7549)		3.31	(1518)		sample size			3.04	(470)		3.04	(420)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

The speed variations were analyzed by the sign test to determine if the frequencies with which increases and decreases in variability occur are significantly different. Inspecting the summary of the sign test, presented in table 12, reveals that there is a significant reduction in speed variability for the category of all vehicle types when analyzed for all time periods. The low cost countermeasures do, therefore, result in more uniform driving behavior. This uniformity is not evident, however, when analyzed on a site-by-site basis separately for day or night conditions.

Table 12. Sign test on the direction of change for maximum speed variation (mi/h).

	All Time Periods and Vehicle Types	All Vehicle Types Day	All Vehicle Types Night
significant increase (+)	2	3	2
significant decrease (-)	9	7	6
no significant difference	7	8	10
probability of a greater number of speed increases	0.03*	0.17	0.15

* denotes signficiant difference at significance level of 10 percent

1 mi/h = 1.6 km/h

The student t-test was performed on the mean speed variation to determine if there were significant differences between the before and after data for day and night conditions. A summary of the analysis is presented in table 13. Notice that the overall means for all of the time periods are relatively close to each other. Since the student t-test probabilities are greater than 0.10 it cannot be concluded that a significant difference exists between the before and after measurements for either day or night conditions.

Table 13. Analysis of mean variation in speed for all vehicle types (mi/h).

Approach Designation	Day Before	Day After	Night Before	Night After
11	5.47	5.12	5.50	5.73
12	3.01	3.24	2.94	3.42
21	5.83	4.65	4.62	3.81
22	3.96	3.97	4.17	3.69
31	2.90	2.85	3.42	3.23
32	4.93	4.81	5.23	5.13
41	2.93	2.65	2.54	2.45
42	3.38	3.24	3.32	3.27
51	2.34	3.49	3.83	3.32
52	5.72	5.17	4.60	4.24
61	5.46	4.05	5.02	3.73
62	4.95	4.99	4.57	3.56
71	3.69	3.06	3.10	2.83
72	2.79	2.72	2.56	2.74
81	4.34	4.31	6.44	4.65
82	6.87	8.01	6.67	7.84
91	5.19	3.91	3.28	3.58
92	3.52	3.31	2.92	3.04
Mean	4.29	4.09	4.15	3.90
Standard Deviation	1.30	1.29	1.27	1.29
t value	0.48		0.58	
degrees of freedom	34		34	
probability	0.64		0.56	

1 mi/h = 1.6 km/h

3. Mean Speed at Tapeswitch Deployments

Analyses of vehicle speeds at each tapeswitch deployment were performed to determine if the speed profile of motorists changed due to the installation of the low cost countermeasures. Inspection of the data in table 14 indicates that trends which were present during the before time period continued to the after period. For example, site approaches 11, 12, 32 and 41 exhibited higher speeds at the bridge than at any other tapeswitch locations on their respective roadway approaches. This continued to the after period. Only approach site 12 had a vertical curve on the roadway approach which would explain the speed increase at the bridge. Approaches 12, 31, 81 and 82, which also had vertical curves, did not exhibit similar speed characteristics at the bridge.

A paired t analysis was performed on the trap data to ascertain if there were significant differences in the before and after time periods. This analysis was performed by considering the data from the different time periods for each trap as being paired observations. The paired t analysis, for example, resulted in the before data from trap 1, approach 12, being paired with the after data from trap 1, approach 12. The paired t analysis compensated for the differences in trap distance from the bridges. The results of the paired t analysis, performed separately for day and night conditions on the category of all vehicle types, are summarized in table 15. There were no significant differences, at a significance level of 10 percent, indicated by either the day or night data sets. It cannot be concluded, at a 90 percent level of confidence, that the low-cost countermeasures resulted in significant changes in speed between tapeswitch locations.

Table 15. Summary of paired t analysis of mean speeds at tapeswitch deployments (mi/h).

	Day		Night	
	Before	After	Before	After
Mean standard deviation	48.50 5.13	48.61 4.61	48.48 4.64	48.59 4.56
t Value degrees of freedom probability	-0.80 71 0.43		-0.59 71 0.56	

1 mi/h = 1.6 km/h

Table 14. Summary of t-test analysis of individual vehicle speed at each tapeswitch deployment (10 percent significance level).

Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	All Time Periods and Vehicle Types Combined: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – All Vehicle Types: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – Autos, Vans, Pickups: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – Trucks and Buses: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Night – All Vehicle Types: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Night – Autos, Vans, Pickups: Mean Speed (mi/h)	No. Veh.	S.D. (1)
11	1 / 900	Before	44.96	(10340)	+	45.13	(8066)	+	45.19	(7978)	+	40.71	(61)	0	44.28	(1558)	0	44.32	(1540)	0
		After	45.20	(3974)		45.34	(3279)		45.45	(321)		39.51	(45)		44.33	(494)		44.36	(488)	
	2 / 600	Before	47.67	(10277)	+	47.84	(8012)	+	47.90	(7924)	+	43.64	(69)	0	47.06	(1550)	+	47.09	(1533)	+
		After	48.30	(3989)		48.35	(3294)		48.47	(3235)		42.57	(50)		47.96	(494)		47.98	(488)	
	3 / 300	Before	48.50	(10327)	+	47.69	(8058)	+	48.75	(7967)	+	44.02	(61)	0	47.85	(1553)	+	47.87	(1535)	+
		After	48.86	(3968)		48.90	(3275)		49.01	(3216)		42.73	(46)		48.69	(493)		48.71	(487)	
	4 / 0	Before	49.66	(10322)	-	49.85	(8050)	-	49.90	(7960)	-	46.06	(60)	0	49.02	(1554)	0	49.04	(1536)	0
		After	49.36	(3938)		49.41	(3242)		49.50	(3190)		44.38	(43)		49.07	(498)		49.08	(492)	
12	1 / 600	Before	49.98	(10804)	0	50.21	(9136)	-	50.26	(9050)	-	45.41	(61)	-	48.46	(1080)	0	48.50	(1072)	0
		After	49.81	(3883)		49.95	(3412)		50.04	(3368)		41.30	(31)		48.35	(318)		48.37	(314)	
	2 / 400	Before	49.73	(10869)	+	49.95	(9184)	+	49.99	(9098)	+	46.02	(61)	-	48.16	(1090)	0	48.20	(1082)	0
		After	50.18	(3895)		50.35	(318)		50.46	(3379)		42.05	(31)		48.50	(318)		48.52	(314)	
	3 / 200	Before	51.08	(10831)	+	51.30	(9160)	+	51.33	(9078)	+	48.46	(58)	-	49.46	(1077)	0	49.49	(1069)	0
		After	51.60	(3895)		51.75	(3420)		51.86	(3373)		43.14	(32)		50.07	(316)		50.08	(312)	
	4 / 0	Before	51.51	(10877)	+	51.74	(9190)	0	51.78	(9170)	+	49.53	(60)	-	49.73	(1091)	0	49.75	(1083)	0
		After	51.73	(3883)		51.88	(3411)		52.00	(3367)		42.25	(31)		50.30	(319)		50.30	(315)	
21	1 / 904	Before	49.46	(2365)	0	49.51	(1821)	0	49.64	(1771)	0	45.11	(38)	0	49.14	(413)	0	49.34	(397)	0
		After	49.78	(1296)		49.76	(1081)		49.91	(1050)		46.86	(19)		49.65	(146)		49.63	(145)	
	2 / 600	Before	47.92	(2387)	+	47.92	(1834)	+	48.05	(1783)	+	43.44	(39)	0	47.85	(420)	0	48.04	(404)	0
		After	48.85	(1311)		48.84	(1097)		48.97	(1066)		46.34	(19)		48.56	(145)		48.53	(144)	
	3 / 300	Before	46.30	(2346)	-	46.18	(1814)	+	46.31	(1766)	+	41.55	(36)	+	46.51	(403)	0	46.66	(388)	0
		After	47.60	(1308)		47.64	(1096)		47.76	(1065)		45.37	(19)		47.20	(143)		47.16	(142)	
	4 / 0	Before	44.73	(2335)	+	44.49	(1802)	+	44.63	(1751)	+	40.01	(39)	+	45.42	(402)	+	45.57	(386)	+
		After	46.40	(1288)		46.27	(1073)		46.39	(1043)		43.87	(18)		47.14	(146)		47.10	(145)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

Table 14. Summary of t-test analysis of individual vehicle speed at each tapeswitch deployment (10 percent significance level) (continued).

Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	All Time Periods and Vehicle Types Combined: Mean Speed (mi/h) No. Veh.	S.D. (1)	Day, All Vehicle Types: Mean Speed (mi/h) No. Veh.	S.D. (1)	Day, Autos, Vans, Pickups: Mean Speed (mi/h) No. Veh.	S.D. (1)	Day, Trucks and Buses: Mean Speed (mi/h) No. Veh.	S.D. (1)	Night, All Vehicle Types: Mean Speed (mi/h) No. Veh.	S.D. (1)	Night, Autos, Vans, Pickups: Mean Speed (mi/h) No. Veh.	S.D. (1)
22	1 / 900	Before	48.99 (1988)	+	48.88(1467)	+	49.01(1409)	+	45.49 (40)	0	49.32 (391)	+	49.37 (380)	+
		After	50.05 (1127)		49.82 (917)		49.99 (880)		46.37 (29)		51.57 (128)		51.57 (128)	
	2 / 604	Before	47.01 (2038)	+	46.90(1504)	+	47.01(1442)	+	43.90 (41)	0	47.44 (402)	+	47.60 (390)	+
		After	48.54 (1170)		48.28 (955)		48.45 (914)		44.98 (32)		50.18 (132)		50.18 (132)	
	3 / 300	Before	46.06 (2083)	+	45.98(1540)	+	46.09(1477)	+	43.08 (41)	0	46.13 (411)	+	46.22 (399)	+
		After	47.28 (1194)		47.01 (977)		47.17 (934)		43.95 (32)		48.76 (134)		48.76 (134)	
	4 / 0	Before	47.62 (1995)	+	47.50(1468)	0	47.65(1407)	0	43.56 (39)	0	47.82 (401)	+	47.93 (389)	+
		After	48.19 (1160)		47.94 (952)		48.08 (912)		45.47 (29)		49.94 (129)		49.94 (129)	
31	1 / 600	Before	42.35 (3767)	+	42.39(3177)	+	42.42(3160)	0	Insufficient	-	42.53 (407)	0	42.53 (407)	0
		After	42.65 (2216)		42.64(1731)		42.67(1722)		sample size		43.08 (316)		43.08 (316)	
	2 / 400	Before	42.06 (3833)	+	42.08(3241)	+	42.10(3224)	+	Insufficient	-	42.53 (406)	0	42.53 (406)	0
		After	42.56 (2227)		42.51(1740)		42.53(1731)		sample size		43.15 (318)		43.15 (318)	
	3 / 200	Before	43.54 (3850)	+	43.48(3259)	0	43.51(3242)	0	Insufficient	-	44.56 (405)	0	44.56 (405)	0
		After	43.84 (2236)		43.75(1746)		43.77(1737)		sample size		44.62 (321)		44.62 (321)	
	4 / 0	Before	43.86 (3753)	-	43.83(3180)	0	43.85(3163)	0	Insufficient	-	44.56 (398)	0	44.56 (398)	0
		After	43.56 (2148)		43.57(1699)		43.60(1661)		sample size		44.06 (314)		44.06 (314)	
32	1 / 935	Before	43.37 (4195)	+	43.47(3506)	+	43.49(3483)	+	40.56 (16)	0	43.36 (447)	+	43.36 (447)	+
		After	44.01 (2530)		43.81(1888)		43.82(1875)		41.97 (11)		44.29 (330)		44.29 (328)	
	2 / 600	Before	45.80 (4215)	+	45.86(3524)	0	45.88(3501)	0	43.06 (16)	0	46.12 (446)	0	46.12 (446)	0
		After	46.11 (2537)		45.91(1894)		45.92(1881)		43.84 (11)		46.49 (331)		46.51 (329)	
	3 / 300	Before	45.47 (4078)	+	45.50(3414)	+	45.53(3391)	+	42.06 (16)	0	45.81 (435)	0	45.81 (435)	0
		After	46.29 (2495)		46.11(1858)		46.12(1845)		44.19 (11)		46.45 (329)		46.47 (327)	
	4 / 0	Before	47.48 (3675)	0	47.52(3044)	0	47.55(3028)	0	Insufficient		47.73 (409)	0	47.73 (409)	0
		After	47.60 (2353)		47.31(1766)		47.31(1757)		sample size		48.31 (311)		48.33 (309)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

Table 14. Summary of t-test analysis of individual vehicle speed at each tapeswitch deployment (10 percent significance level) (continued).

			All Time Periods and Vehicle Types Combined			Day									Night					
						All Vehicle Types			Autos, Vans, Pickups			Trucks and Buses			All Vehicle Types			Autos, Vans, Pickups		
Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)	Mean Speed (mi/h)	No. Veh.	S.D. (1)
41	1 / 321	Before	36.33	(15604)	+	36.02	(12588)	+	36.07	(12410)	+	33.00	(121)	0	38.06	(1985)	+	38.08	(1976)	+
		After	37.22	(6234)		36.87	(4619)		36.93	(4563)		32.29	(39)		38.81	(1042)		38.83	(1035)	
	2 / 214	Before	35.90	(12883)	+	35.67	(10775)	+	35.72	(10603)	+	32.96	(117)	0	37.50	(1289)	0	37.54	(1284)	0
		After	37.02	(5013)		36.89	(3915)		36.95	(3859)		32.61	(39)		37.79	(659)		37.81	(653)	
	3 / 107	Before	36.98	(15962)	+	36.71	(12831)	+	36.76	(12652)	+	33.86	(121)	0	38.37	(2089)	+	38.39	(2079)	+
		After	38.15	(6370)		37.95	(4689)		38.00	(4632)		33.55	(39)		39.01	(1096)		39.04	(1089)	
	4 / 0	Before	37.23	(15949)	+	37.02	(12815)	+	37.07	(12635)	+	34.05	(123)	0	38.30	(2000)	+	38.33	(2080)	+
		After	38.56	(6367)		38.36	(4682)		38.41	(4626)		33.81	(39)		39.44	(1100)		39.46	(1093)	
42	1 / 525	Before	43.08	(15228)	-	43.02	(12596)	-	43.06	(12435)	-	40.77	(104)	0	44.25	(1353)	0	44.29	(1346)	0
		After	42.79	(6272)		42.55	(4539)		42.70	(4496)		39.28	(29)		44.34	(867)		44.34	(866)	
	2 / 350	Before	43.36	(15204)	-	43.27	(12583)	-	43.31	(12420)	-	40.89	(104)	0	44.53	(1344)	0	44.57	(1337)	0
		After	42.94	(6261)		42.66	(4539)		42.70	(4496)		39.28	(29)		44.32	(816)		44.33	(860)	
	3 / 175	Before	43.25	(15009)	-	43.15	(12467)	-	43.18	(12308)	-	40.79	(102)	0	44.48	(1297)	0	44.52	(1291)	0
		After	43.07	(6204)		42.86	(4515)		42.89	(4471)		40.22	(29)		44.10	(838)		44.10	(837)	
	4 / 4	Before	42.08	(15322)	-	42.00	(12673)	-	42.03	(12510)	-	39.79	(104)	0	43.06	(1366)	-	43.09	(1359)	-
		After	41.66	(6288)		41.50	(4555)		41.53	(4512)		39.59	(29)		42.42	(868)		42.43	(867)	
51	1 / 920	Before	51.99	(400)	0	54.07	(15)	0	54.07	(15)	0	Insufficient			51.78	(322)	+	51.94	(317)	+
		After	52.42	(1829)		52.13	(873)		52.37	(833)		sample size			52.78	(669)		52.77	(662)	
	2 / 600	Before	50.88	(418)	0	52.77	(15)	0	52.77	(15)	0	Insufficient			50.50	(340)	+	50.73	(334)	+
		After	51.55	(1830)		51.10	(868)		51.48	(833)		sample size			51.94	(678)		51.93	(671)	
	3 / 300	Before	50.91	(381)	0	54.00	(12)	0	54.01	(12)	0	Insufficient			50.56	(310)	0	50.79	(304)	0
		After	50.26	(1634)		49.84	(744)		50.18	(734)		sample size			50.71	(500)		50.71	(574)	
	4 / 0	Before	50.19	(417)	0	52.32	(15)	0	52.32	(15)	0	Insufficient			49.77	(342)	+	50.00	(336)	+
		After	50.52	(1883)		49.98	(890)		50.36	(846)		sample size			51.26	(693)		51.27	(686)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

Table 14. Summary of t-test analysis of individual vehicle speed at each tapeswitch deployment (10 percent significance level) (continued).

Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	All Time Periods and Vehicle Types Combined: Mean Speed (mi/h) No. Veh.	S.D. (1)	Day – All Vehicle Types: Mean Speed (mi/h) No. Veh.	S.D. (1)	Day – Autos, Vans, Pickups: Mean Speed (mi/h) No. Veh.	S.D. (1)	Day – Trucks and Buses: Mean Speed (mi/h) No. Veh.	S.D. (1)	Night – All Vehicle Types: Mean Speed (mi/h) No. Veh.	S.D. (1)	Night – Autos, Vans, Pickups: Mean Speed (mi/h) No. Veh.	S.D. (1)
52	1 / 900	Before	52.71 (702)	0	53.86 (23)	0	53.86 (23)	0	Insufficient		52.51 (575)	0	52.66 (565)	0
		After	52.91 (1864)		53.17 (948)		53.47 (893)		sample size		52.76 (730)		52.78 (728)	
	2 / 600	Before	52.73 (673)	0	54.19 (24)	0	54.19 (24)	0	Insufficient		52.44 (545)	0	52.62 (535)	0
		After	52.29 (1769)		52.41 (907)		52.67 (858)		sample size		52.29 (674)		52.30 (669)	
	3 / 300	Before	52.49 (704)	-	53.18 (24)	0	53.18((24)	0	Insufficient		52.30 (577)	0	52.51 (566)	0
		After	51.87 (1880)		51.95 (975)		52.26 (921)		sample size		51.89 (715)		51.89 (710)	
	4 / 0	Before	49.05 (710)	0	49.08 (24)	0	49.08 (24)	0	Insufficient		48.92 (580	0	49.05 (571)	0
		After	48.79 (1899)		48.55 (967)		48.91 (912)		sample size		49.19 (745)		49.19 (740)	
61	1 / 900	Before	53.81 (1935)	+	53.76 (1371)	+	54.06 (1288)	+	48.52 (52)	0	54.07 (404)	0	54.18 (394)	0
		After	54.42 (1402)		54.56 (971)		54.90 (914)		48.79 (45)		54.15 (288)		54.44 (274)	
	2 / 600	Before	52.51 (1936)	+	52.40 (1377)	+	52.65 (1294)	+	48.35 (52)	0	53.02 (399)	0	53.11 (389)	0
		After	53.79 (1397)		53.94 (971)		54.24 (915)		48.82 (45)		53.64 (283)		53.89 (270)	
	3 / 300	Before	51.63 (1629)	+	51.59 (1175)	+	51.84 (1104)	+	48.41 (48)	0	51.97 (321)	+	51.99 (314)	0
		After	53.41 (1288)		53.44 (888)		53.71 (833)		49.48 (43)		53.44 (266)		53.62 (253)	
	4 / 0	Before	50.31 (1827)	+	50.34 (1297)	+	50.57 (1237)	-	45.57 (33)	0	50.53 (381)	+	50.59 (371)	+
		After	52.54 (1405)		52.56 (963)		52.81 (905)		48.49 (45)		52.62 (298)		52.84 (284)	
62	1 / 900	Before	53.99 (2067)	+	53.03 (1212)	0	53.53 (1124)	0	46.06 (63)	0	55.11 (576)	+	55.17 (568)	0
		After	54.61 (1499)		53.67 (759)		54.16 (697)		47.97 (50)		55.76 (512)		55.88 (500)	
	2 / 600	Before	53.29 (2062)	+	52.28 (1212)	+	52.71 (1125)	+	46.41 (63)	0	54.61 (572)	+	54.67 (564)	+
		After	54.50 (1517)		53.34 (770)		53.83 (707)		47.70 (51)		55.81 (518)		55.91 (506)	
	3 / 300	Before	52.85 (2070)	+	51.79 (1227)	+	52.10 (1141)	+	47.48 (61)	0	54.19 (567)	+	54.24 (559)	+
		After	53.80 (1473)		52.49 (760)		52.86 (699)		47.91 (50)		55.38 (489)		55.44 (479)	
	4 / 0	Before	53.40 (2034)	+	52.47 (1197)	0	52.73 (1114)	0	49.29 (58)	0	54.41 (565)	+	54.45 (558)	+
		After	54.55 (1484)		52.88 (750)		53.29 (689)		48.00 (49)		56.55 (511)		56.63 (500)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

Table 14. Summary of t-test analysis of individual vehicle speed at each tapeswitch deployment (10 percent significance level) (continued).

Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	All Time Periods and Vehicle Types Combined: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – All Vehicle Types: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – Autos, Vans, Pickups: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – Trucks and Buses: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Night – All Vehicle Types: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Night – Autos, Vans, Pickups: Mean Speed (mi/h)	No. Veh.	S.D. (1)
71	1 / 900	Before	54.07	(1285)	0	54.45	(768)	0	54.90	(674)	-	52.01	(67)	0	52.91	(403)	0	52.83	(390)	0
		After	53.98	(1741)		53.93	(1256)		54.14	(1189)		49.37	(43)		53.16	(327)		53.18	(315)	
	2 / 600	Before	53.44	(1287)	0	53.58	(771)	0	54.07	(676)	-	50.89	(68)	-	52.71	(403)	0	52.66	(391)	0
		After	53.37	(1781)		53.13	(1292)		53.42	(1221)		46.70	(45)		53.17	(332)		53.20	(320)	
	3 / 300	Before	52.97	(1285)	0	52.77	(768)	0	53.22	(676)	0	50.28	(68)	0	52.72	(402)	0	52.63	(389)	0
		After	53.25	(1766)		52.92	(1276)		53.23	(1207)		47.16	(43)		53.39	(332)		53.39	(320)	
	4 / 0	Before	53.44	(1230)	-	53.26	(732)	-	53.68	(646)	-	50.41	(61)	-	53.17	(389)	0	53.05	(377)	0
		After	52.68	(1771)		52.34	(1280)		52.61	(1213)		46.78	(42)		52.91	(334)		52.84	(322)	
72	1 / 900	Before	53.81	(1400)	-	54.15	(961)	-	54.33	(893)	-	52.49	(47)	0	52.79	(340)	0	52.96	(316)	0
		After	53.08	(1830)		53.12	(1426)		53.23	(1352)		50.60	(46)		53.18	(312)		53.32	(295)	
	2 / 600	Before	53.57	(1420)	-	53.90	(975)	-	54.11	(905)	-	52.01	(47)	0	52.52	(346)	0	52.70	(322)	0
		After	52.64	(1874)		52.63	(1459)		52.72	(1385)		50.69	(46)		52.88	(321)		53.00	(304)	
	3 / 300	Before	52.97	(1419)	-	53.30	(970)	-	53.51	(902)	-	51.07	(45)	0	51.92	(350)	-	52.05	(325)	0
		After	52.28	(1867)		52.19	(1456)		52.28	(1380)		50.33	(47)		52.88	(316)		53.02	(301)	
	4 / 0	Before	52.60	(1392)	-	53.00	(946)	-	53.19	(881)	-	51.06	(44)	0	51.46	(348)	-	51.55	(323)	-
		After	51.92	(1864)		51.78	(1452)		51.86	(1376)		49.91	(47)		52.73	(319)		52.75	(303)	
81	1 / 950	Before	49.70	(1784)	+	49.91	(628)	0	50.02	(608)	0	48.19	(15)	0	49.12	(76)	0	49.35	(75)	0
		After	50.41	(1319)		50.29	(1045)		50.40	(1003)		48.31	(31)		50.69	(203)		50.83	(200)	
	2 / 500	Before	39.40	(1784)	+	40.05	(1330)	0	40.06	(1291)	0	42.85	(25)	0	38.07	(313)	0	38.06	(305)	0
		After	40.61	(2071)		40.86	(1625)		40.81	(1570)		45.36	(36)		39.33	(332)		39.34	(328)	
	3 / 250	Before	44.57	(1840)	+	44.94	(1351)	+	44.99	(1313)	+	44.41	(24)	0	44.16	(349)	0	44.24	(340)	0
		After	45.60	(2367)		45.93	(1848)		45.95	(1788)		46.17	(39)		43.81	(391)		43.92	(383)	
	4 / 0	Before	45.68	(1911)	+	46.02	(1406)	+	46.08	(1366)	+	45.17	(25)	0	45.31	(358)	0	45.40	(349)	0
		After	46.85	(2396)		47.08	(1863)		47.11	(1801)		47.13	(40)		45.55	(401)		45.69	(393)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

Table 14. Summary of t-test analysis of individual vehicle speed at each tapeswitch deployment (10 percent significance level) (continued).

Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	All Time Periods and Vehicle Types Combined: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – All Vehicle Types: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – Autos, Vans, Pickups: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Day – Trucks and Buses: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Night – All Vehicle Types: Mean Speed (mi/h)	No. Veh.	S.D. (1)	Night – Autos, Vans, Pickups: Mean Speed (mi/h)	No. Veh.	S.D. (1)
82	1 / 900	Before	45.95	(1160)	0	45.28	(690)	+	45.33	(675)	+	Insufficient			47.49	(351)	-	47.53	(348)	-
		After	46.33	(520)		46.36	(389)		46.45	(379)		sample size			45.59	(93)		45.59	(93)	
	2 / 600	Before	42.96	(1218)	-	42.63	(716)	+	42.68	(701)	+	Insufficient			44.01	(10370)	-	44.04	(367)	-
		After	41.38	(531)		45.59	(398)		41.48	(388)		sample size			41.06	(95)		41.00	(94)	
	3 / 300	Before	40.88	(1830)	+	40.48	(1052)	+	40.66	(1022)	+	34.11	(16)	+	41.93	(564)	-	41.99	(558)	0
		After	42.70	(1822)		43.01	(1333)		43.16	(1285)		41.06	(29)		40.86	(304)		41.04	(299)	
	4 / 0	Before	44.95	(1813)	+	44.44	(1045)	+	44.56	(1015)	+	39.40	(16)	+	46.45	(558)	-	46.51	(522)	-
		After	46.18	(1816)		46.29	(1329)		46.41	(1282)		44.21	(29)		45.10	(302)		45.27	(297)	
91	1 / 900	Before	54.25	(706)	-	54.17	(493)	0	54.18	(478)	0	Insufficient			54.36	(160)	-	54.34	(159)	-
		After	53.45	(2362)		54.18	(1842)		54.27	(1795)		sample size			50.55	(408)		50.71	(396)	
	2 / 600	Before	54.32	(710)	-	54.28	(497)	0	54.25	(482)	0	Insufficinet			54.55	(159)	-	54.53	(158)	-
		After	52.86	(2360)		53.59	(1841)		53.67	(1794)		sample size			49.97	(406)		50.11	(394)	
	3 / 300	Before	53.82	(711)	0	53.45	(494)	0	53.39	(479)	0	Insufficient			54.68	(164)	-	54.65	(163)	-
		After	53.36	(2379)		54.10	(1861)		54.17	(1814)		sample size			50.41	(405)		50.50	(395)	
	4 / 0	Before	51.71	(706)	0	51.24	(488)	0	51.14	(474)	+	Insufficient			52.87	(164)	-	52.85	(163)	-
		After	51.30	(2367)		51.87	(1847)		51.96	(1800)		sample size			49.04	(408)		49.20	(397)	
92	1 / 900	Before	53.44	(829)	-	53.84	(590)	-	54.01	(575)	-	Insufficient			52.74	(178)	-	52.60	(173)	-
		After	51.44	(2089)		51.91	(1587)		51.97	(1553)		sample size			49.93	(433)		49.93	(433)	
	2 / 600	Before	53.64	(834)	-	53.94	(595)	-	54.26	(577)	-	Insufficient			53.12	(178)	-	52.98	(173)	-
		After	51.59	(2097)		52.04	(1591)		52.16	(1555)		sample size			50.27	(436)		50.27	(436)	
	3 / 300	Before	52.49	(847)	-	52.66	(610)	-	52.91	(594)	-	Insufficient			52.19	(176)	-	52.04	(171)	-
		After	51.16	(2089)		51.49	(1586)		51.61	(1553)		sample size			50.21	(433)		50.21	(433)	
	4 / 0	Before	53.06	(825)	-	52.98	(595)	-	53.18	(579)	-	Insufficient			53.25	(172)	-	53.15	(167)	-
		After	50.86	(2063)		51.00	(1568)		51.09	(1532)		sample size			50.51	(426)		50.51	(426)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 mi/h = 1.6 km/h

4. Right Hand Lateral Position at Tapeswitch Deployments

The analyses of right hand lateral position at tapeswitch deployments were conducted to determine if the countermeasures caused lateral position variations within each site and where on the approach these variations occurred. The lateral placement measures were obtained by measuring the distance from the right edge of the paved roadway surface to the outside edge of the right front tire. Table 16 contains a summary of the right hand lateral placement by tapeswitch location.

The data were measured in feet with a positive sign indicating either placement to the left of, or direction away from, the right hand roadway edge. Positive signs associated with the placement measures indicate that the average vehicle position occurred with the right front tire totally on the paved surface. Positive signs in the significant difference column indicate that the average direction of movement between the before and after time periods were to the left away from the right hand road edge.

Inspecting the signs associated with the lateral position measures of table 16 reveals that approach sites 11, 21, 22, 32, 42, 52, 61, 62, 91 and 92 experienced average movements to the right at the traps closest to the bridge after countermeasure installation. Approach sites 31, 41, 71, 72, 81 and 82 experienced average movements to the left at the traps closest to the bridge after countermeasure installation. The way in which the directional movements are distributed among the approach sites results in difficulty associating the direction of movement with the types of countermeasures installed. Approach sites 11, 12, 41 and 42 received eight inch (20.3 cm) edgelines installed as part of the countermeasure. Approach sites 11 and 42 resulted in average movements to the left, site 41 except for the category of trucks and buses resulted in movements to the right and site 12 experienced no significant changes in any analysis category. There are, therefore, no evident directions of movement that can be associated with the implemented countermeasures.

Paired t analyses were performed on the tapeswitch deployments to ascertain if the differences experienced at each tapeswitch deployment were sufficiently large to be significant. These analyses were performed by considering the data from different time periods for each trap as being

Table 16. Summary of t-test analysis of right hand lateral placement for individual vehicle observations (10 percent significance level).

			All Time Periods and Vehicle Types Combined			Day									Night					
						All Vehicle Types			Autos, Vans, Pickups			Trucks and Buses			All Vehicle Types			Autos, Vans, Pickups		
Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)
11	1/900	Before	3.86	(10145)	-	3.78	(7952)	-	3.79	(7867)	-	3.42	(60)	-	4.19	(1507)	-	4.19	(1490)	-
		After	3.22	(3949)		3.16	(3254)		3.17	(3196)		2.55	(45)		3.59	(494)		3.58	(488)	
	2/600	Before	3.81	(10146)	-	3.75	(7925)	-	3.76	(7838)	-	3.28	(60)	-	4.03	(1518)	-	4.04	(1501)	-
		After	3.47	(3956)		3.41	(3270)		3.45	(3211)		2.75	(46)		3.82	(486)		3.82	(480)	
	3/300	Before	4.37	(9931)	+	4.36	(7773)	+	4.37	(7684)	+	3.93	(59)	+	4.34	(1475)	+	4.35	(1459)	+
		After	4.49	(3788)		4.49	(3123)		4.50	(3064)		3.93	(46)		4.49	(474)		4.48	(469)	
	4/0	Before	2.83	(10163)	-	2.82	(7920)	-	2.82	(7830)	-	2.82	(60)	0	2.92	(1537)	-	2.92	(1519)	-
		After	2.62	(3411)		2.59	(2726)		2.59	(2685)		2.47	(32)		2.76	(489)		2.75	(483)	
12	1/600	Before	4.44	(10346)	-	4.42	(8745)	-	4.42	(8661)	-	4.20	(59)	-	4.55	(1039)	-	4.55	(1031)	-
		After	4.05	(3865)		4.01	(3395)		4.02	(3351)		3.66	(31)		4.39	(317)		4.39	(313)	
	2/400	Before	3.90	(10767)	-	3.88	(9099)	-	3.88	(9014)	-	3.59	(60)	0	4.08	(1078)	-	4.09	(1070)	-
		After	3.65	(3885)		3.62	(3416)		3.63	(3372)		3.38	(30)		3.83	(316)		3.84	(312)	
	3/200	Before	3.95	(10605)	-	3.91	(9004)	-	3.91	(8923)	-	3.86	(57)	0	4.28	(1022)	-	4.28	(1014)	-
		After	3.83	(3844)		3.80	(3400)		3.81	(3354)		3.56	(31)		3.96	(309)		3.96	(305)	
	4/0	Before	3.14	(10791)	0	3.10	(9119)	0	3.09	(9036)	0	3.15	(60)	0	3.49	(1080)	0	3.49	(1072)	0
		After	3.12	(3849)		3.10	(3387)		3.10	(3394)		2.91	(30)		3.35	(310)		3.35	(306)	
21	1/904	Before	3.21	(2334)	+	3.16	(1800)	+	3.16	(1751)	+	3.04	(37)	0	3.39	(404)	+	3.39	(388)	+
		After	3.41	(1282)		3.37	(1071)		3.38	(1041)		3.02	(18)		3.60	(142)		3.60	(141)	
	2/600	Before	3.01	(2361)	+	2.98	(1814)	+	2.99	(1763)	+	2.91	(39)	0	3.09	(415)	+	3.09	(399)	+
		After	3.35	(1293)		3.33	(1083)		3.34	(1053)		3.04	(19)		3.44	(143)		3.44	(142)	
	3/300	Before	4.69	(2226)	-	4.65	(1731)	-	4.65	(1686)	-	4.51	(34)	-	4.85	(375)	0	4.84	(361)	0
		After	4.46	(1214)		4.41	(1017)		4.43	(988)		3.80	(17)		4.75	(133)		4.75	(132)	
	4/0	Before	4.64	(2180)	-	4.59	(1695)	-	4.59	(1649)	-	4.77	(34)	-	4.79	(368)	-	4.79	(355)	-
		After	4.23	(1260)		4.19	(1053)		4.19	(1023)		4.25	(18)		4.50	(143)		4.49	(142)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 ft = 0.31 m

Table 16. Summary of t-test analysis of right hand lateral placement for individual vehicle observations (10 percent significance level) (continued).

Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	All Time Periods and Vehicle Types Combined			Day									Night					
						All Vehicle Types			Autos, Vans, Pickups			Trucks and Buses			All Vehicle Types			Autos, Vans, Pickups		
			Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)
22	1 / 900	Before	3.75	(1958)	+	3.70	(1447)	+	3.71	(1390)	+	3.46	(39)	0	3.94	(384)	+	3.93	(373)	+
		After	4.00	(1104)		3.94	(900)		3.95	(863)		3.62	(29)		4.26	(124)		4.26	(124)	
	2 / 604	Before	2.61	(2026)	0	2.58	(1495)	0	2.59	(1433)	0	2.40	(41)	0	2.72	(399)	0	2.72	(387)	0
		After	2.59	(1165)		2.55	(950)		2.57	(909)		2.11	(32)		2.74	(132)		2.74	(132)	
	3 / 300	Before	4.49	(947)	-	4.48	(744)	-	4.49	(716)	-	4.50	(17)	-	4.43	(137)	-	4.44	(130)	-
		After	3.92	(1120)		3.38	(931)		3.89	(889)		3.78	(31)		4.20	(113)		4.20	(113)	
	4 / 0	Before	3.73	(1960)	-	3.69	(1441)	-	3.68	(1381)	-	3.72	(38)	-	3.87	(393)	-	3.88	(381)	-
		After	3.06	(1138)		2.99	(935)		2.99	(896)		3.05	(28)		3.42	(128)		3.42	(128)	
31	1 / 600	Before	3.19	(3734)	+	3.15	(3152)	+	3.15	(3135)	+	Insufficient sample size			3.46	(401)	+	3.46	(401)	+
		After	3.51	(2205)		3.48	(1723)		3.48	(1714)					3.71	(314)		3.71	(314)	
	2 / 400	Before	3.46	(3789)	+	3.41	(3200)	+	3.41	(3183)	+	Insufficient sample size			3.85	(403)	+	3.85	(403)	+
		After	3.89	(2217)		3.85	(1732)		3.85	(1723)					4.15	(316)		4.15	(316)	
	3 / 200	Before	3.66	(3790)	+	3.62	(3208)	+	3.62	(3191)	+	Insufficient sample size			3.99	(400)	+	3.99	(400)	+
		After	3.75	(2161)		3.68	(1684)		3.68	(1676)					4.16	(311)		4.16	(311)	
	4 / 0	Before	3.30	(3708)	+	3.28	(3145)	+	3.28	(3128)	+	Insufficient sample size			3.49	(391)	+	3.49	(391)	+
		After	3.59	(2102)		3.56	(1638)		3.56	(1630)					3.75	(304)		3.75	(304)	
32	1 / 935	Before	4.48	(4055)	+	4.46	(3397)	+	4.46	(3375)	+	4.31	(15)	0	4.65	(420)	+	4.65	(420)	+
		After	4.65	(2512)		4.61	(1876)		4.62	(1863)		4.13	(11)		4.74	(326)		4.74	(324)	
	2 / 600	Before	4.00	(4180)	+	3.97	(3498)	+	3.97	(3475)	+	3.76	(16)	0	4.20	(442)	+	4.20	(442)	+
		After	4.25	(2580)		4.17	(1871)		4.18	(1858)		3.55	(11)		4.48	(329)		4.49	(327)	
	3 / 300	Before	4.43	(3873)	+	4.40	(3267)	+	4.39	(3244)	+	4.98	(16)	0	4.62	(397)	+	4.62	(397)	+
		After	4.77	(2358)		4.72	(1762)		4.71	(1749)		5.36	(11)		4.89	(316)		4.90	(314)	
	4 / 0	Before	4.08	(3322)	-	4.06	(2760)	-	4.05	(2746)	-	Insufficient sample size			4.24	(358)	-	4.24	(358)	-
		After	3.70	(2219)		3.64	(1665)		3.65	(1656)					3.85	(302)		3.85	(300)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 ft = 0.31 m

Table 16. Summary of t-test analysis of right hand lateral placement for individual vehicle observations (10 percent significance level) (continued).

Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	All Time Periods and Vehicle Types Combined: Distance (ft) (No. Veh.)	All Time Periods and Vehicle Types Combined: S.D. (1)	Day – All Vehicle Types: Distance (ft) (No. Veh.)	Day – All Vehicle Types: S.D. (1)	Day – Autos, Vans, Pickups: Distance (ft) (No. Veh.)	Day – Autos, Vans, Pickups: S.D. (1)	Day – Trucks and Buses: Distance (ft) (No. Veh.)	Day – Trucks and Buses: S.D. (1)	Night – All Vehicle Types: Distance (ft) (No. Veh.)	Night – All Vehicle Types: S.D. (1)	Night – Autos, Vans, Pickups: Distance (ft) (No. Veh.)	Night – Autos, Vans, Pickups: S.D. (1)
41	1 / 321	Before	4.18(14949)	-	4.11(12180)	-	4.12(12007)	-	3.48 (118)	-	4.66 (1771)	-	4.67 (1763)	-
		After	3.87 (6001)		3.75 (4590)		3.76 (4454)		2.99 (38)		4.53 (941)		4.45 (934)	
	2 / 214	Before	5.12 (8008)	-	5.11 (6923)	-	5.12 (1770)	-	4.89 (104)	-	5.19 (613)	-	5.19 (609)	-
		After	4.88 (3597)		4.86 (2894)		4.87 (2843)		4.46 (36)		5.03 (402)		5.02 (398)	
	3 / 107	Before	3.84(15158)	+	3.82(12146)	0	3.83(11975)	0	3.27 (116)	0	3.93 (2003)	+	3.93 (1993)	+
		After	3.90 (6142)		3.84 (4583)		3.84 (4526)		3.36 (39)		4.23 (1003)		4.22 (996)	
	4 / 0	Before	2.68(15366)	+	2.65(12583)	+	2.65(12406)	+	2.23 (122)	0	2.85 (1883)	+	2.85 (1875)	+
		After	2.83 (6348)		2.79 (4669)		2.79 (4613)		2.45 (39)		3.06 (1097)		3.07 (1090)	
42	1 / 525	Before	3.52(14813)	-	3.46(12399)	-	3.46(12241)	-	3.36 (104)	-	4.06 (1188)	+	4.06 (1181)	-
		After	3.42 (6203)		3.29 (4503)		3.29 (4462)		3.04 (28)		3.93 (850)		3.93 (849)	
	2 / 350	Before	3.84(14748)	-	3.80(12276)	-	3.80(12115)	-	3.89 (103)	0	4.14 (1242)	+	4.14 (1236)	+
		After	3.78 (6080)		3.69 (4466)		3.69 (4424)		3.80 (28)		4.24 (811)		4.24 (810)	
	3 / 175	Before	4.01(13940)	0	3.97(11725)	0	3.97(11574)	0	3.87 (98)	0	4.27 (1082)	0	4.26 (1076)	0
		After	4.01 (5903)		3.95 (4326)		3.95 (4285)		3.83 (27)		4.28 (771)		4.28 (770)	
	4 / 0	Before	3.74(15173)	-	3.68(12577)	-	3.69(12414)	-	3.58 (104)	-	4.21 (1324)	-	4.21 (1317)	-
		After	3.36 (6200)		3.28 (4487)		3.28 (4446)		3.01 (28)		3.68 (856)		3.68 (855)	
51	1 / 920	Before	3.09 (390)	+	3.38 (15)	0	3.39 (15)	0	Insufficient sample size		3.06 (313)	-	3.07 (309)	-
		After	3.30 (1805)		3.31 (865)		3.34 (826)				3.26 (653)		3.27 (646)	
	2 / 600	Before	3.71 (406)	+	3.58 (15)	0	3.58 (15)	0	Insufficient sample size		3.78 (330)	-	3.79 (324)	-
		After	3.98 (1767)		3.79 (842)		3.82 (800)				4.22 (651)		4.23 (644)	
	3 / 300	Before	4.67 (350)	+	Insufficient sample size		Insufficient sample size		Insufficient sample size		4.75 (289)	0	4.75 (283)	0
		After	4.53 (1424)								4.76 (518)		4.77 (512)	
	4 / 0	Before	3.13 (403)	0	3.36 (13)	0	3.36 (13)	0	Insufficient sample size		3.19 (332)	+	3.17 (326)	+
		After	3.18 (1769)		2.99 (840)		2.99 (799)				3.48 (642)		3.49 (636)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 ft = 0.31 m

Table 16. Summary of t-test analysis of right hand lateral placement for individual vehicle observations (10 percent significance level) (continued).

			All Time Periods and Vehicle Types Combined			Day									Night					
						All Vehicle Types			Autos, Vans, Pickups			Trucks and Buses			All Vehicle Types			Autos, Vans, Pickups		
Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)
52	1 / 900	Before	4.18	(699)	0	3.98	(22)	0	3.98	(22)	0	Insufficient sample size			4.22	(546)	0	4.23	(536)	0
		After	4.17	(1816)		4.09	(923)		4.12	(869)					4.29	(710)		4.30	(705)	
	2 / 600	Before	4.42	(605)	0	3.79	(22)	+	3.79	(24)	+	Insufficient sample size			4.50	(481)	+	4.50	(472)	+
		After	4.37	(1473)		4.22	(731)		4.24	(689)					4.62	(564)		4.62	(559)	
	3 / 300	Before	4.08	(660)	0	3.49	(24)	+	3.49	(24)	+	Insufficient sample size			4.13	(539)	+	4.13	(528)	+
		After	4.03	(1775)		3.89	(937)		3.93	(888)					4.26	(652)		4.26	(647)	
	4 / 0	Before	3.55	(684)	-	3.25	(24)	-	3.25	(24)	-	Insufficient sample size			3.58	(560)	-	3.59	(552)	-
		After	2.44	(1870)		2.35	(960)		2.35	(905)					2.58	(725)		2.58	(720)	
61	1 / 900	Before	3.69	(1910)	-	3.60	(1357)	-	3.63	(1274)	-	2.97	(52)	0	4.07	(396)	-	4.08	(386)	-
		After	3.46	(1378)		3.39	(961)		3.43	(904)		2.75	(45)		3.71	(278)		3.76	(264)	
	2 / 600	Before	3.97	(1840)	-	3.87	(1328)	-	3.90	(1245)	-	3.28	(52)	0	4.36	(358)	-	4.39	(349)	0
		After	3.89	(1336)		3.79	(939)		3.82	(883)		3.31	(45)		4.24	(256)		4.30	(243)	
	3 / 300	Before	4.66	(1381)	-	4.63	(1006)	-	4.64	(942)	-	4.42	(44)	-	4.82	(260)	0	4.83	(254)	0
		After	4.49	(1106)		4.43	(779)		4.46	(731)		4.07	(39)		4.70	(209)		4.76	(197)	
	4 / 0	Before	3.87	(1641)	-	3.88	(1169)	-	3.88	(1114)	-	4.02	(30)	-	3.82	(341)	-	3.81	(331)	-
		After	3.26	(1372)		3.22	(934)		3.23	(877)		2.96	(45)		3.39	(294)		3.41	(280)	
62	1 / 900	Before	3.02	(2053)	+	2.90	(1203)	+	2.94	(1115)	+	2.25	(63)	0	3.30	(572)	+	3.30	(564)	+
		After	3.17	(1487)		2.97	(754)		3.03	(692)		2.24	(50)		3.47	(508)		3.47	(496)	
	2 / 600	Before	3.04	(2041)	+	2.78	(1201)	0	2.82	(1115)	0	2.25	(62)	0	3.56	(564)	0	3.57	(556)	0
		After	3.15	(1502)		2.84	(763)		2.88	(700)		2.18	(51)		3.63	(513)		3.63	(501)	
	3 / 300	Before	3.56	(2011)	+	3.35	(1123)	+	3.37	(1117)	+	2.95	(61)	+	3.98	(538)	+	3.98	(530)	+
		After	4.19	(1388)		3.91	(734)		3.94	(675)		3.59	(49)		4.61	(436)		4.60	(426)	
	4 / 0	Before	3.90	(1875)	0	3.86	(1123)	-	3.83	(1042)	-	4.13	(57)	-	4.00	(509)	0	4.00	(503)	0
		After	3.67	(1443)		3.50	(734)		3.50	(675)		3.35	(48)		4.01	(492)		4.01	(481)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 ft = 0.31 m

Table 16. Summary of t-test analysis of right hand lateral placement for individual vehicle observations (10 percent significance level) (continued).

Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	All Time Periods and Vehicle Types Combined: Distance (ft)	No. Veh.	S.D. (1)	Day – All Vehicle Types: Distance (ft)	No. Veh.	S.D. (1)	Day – Autos, Vans, Pickups: Distance (ft)	No. Veh.	S.D. (1)	Day – Trucks and Buses: Distance (ft)	No. Veh.	S.D. (1)	Night – All Vehicle Types: Distance (ft)	No. Veh.	S.D. (1)	Night – Autos, Vans, Pickups: Distance (ft)	No. Veh.	S.D. (1)
71	1/900	Before	4.25	(1257)	-	4.10	(758)	-	4.20	(664)	-	3.40	(67)	0	4.47	(383)	-	4.48	(376)	-
		After	4.07	(1626)		3.97	(1158)		3.98	(1098)		3.69	(37)		4.30	(313)		4.32	(302)	
	2/600	Before	3.98	(1269)	0	3.90	(761)	0	3.99	(666)	0	3.28	(68)	0	4.09	(396)	0	4.09	(384)	0
		After	3.99	(1744)		3.92	(1267)		3.94	(1199)		3.55	(44)		4.14	(324)		4.15	(314)	
	3/300	Before	4.05	(1257)	0	4.02	(749)	0	4.09	(658)	-	3.63	(67)	0	4.04	(394)	+	4.04	(384)	+
		After	4.08	(1722)		4.00	(1245)		4.00	(1181)		4.02	(40)		4.32	(319)		4.31	(310)	
	4/0	Before	4.32	(1153)	+	4.41	(673)	+	4.39	(593)	+	4.45	(57)	+	4.17	(374)	+	4.15	(365)	+
		After	4.50	(1721)		4.53	(1237)		4.50	(1171)		4.98	(41)		4.44	(327)		4.40	(316)	
72	1/900	Before	3.45	(1386)	-	3.30	(952)	+	3.33	(885)	-	2.84	(46)	0	3.85	(336)	+	3.90	(312)	+
		After	3.69	(1810)		3.60	(1419)		3.61	(1345)		3.09	(46)		4.04	(308)		4.04	(292)	
	2/600	Before	3.49	(1407)	+	3.31	(965)	+	3.34	(897)	+	2.79	(45)	+	3.91	(344)	+	3.94	(321)	+
		After	3.84	(1847)		3.77	(1442)		3.80	(1368)		3.12	(46)		4.17	(313)		4.18	(297)	
	3/300	Before	3.93	(1392)	+	3.84	(950)	+	3.89	(885)	+	3.19	(44)	+	4.19	(345)	+	4.20	(321)	+
		After	4.09	(1732)		4.00	(1336)		4.01	(1267)		3.59	(43)		4.40	(302)		4.40	(288)	
	4/0	Before	3.93	(1357)	+	4.04	(918)	+	4.04	(858)	+	4.12	(41)	+	3.64	(342)	+	3.61	(318)	+
		After	4.48	(1835)		4.51	(1428)		4.50	(1353)		4.83	(47)		4.37	(315)		4.35	(301)	
81	1/950	Before	4.88	(624)	+	4.84	(546)	+	4.85	(530)	+	4.32	(11)	+	5.21	(42)	0	5.21	(42)	0
		After	5.12	(1307)		5.10	(1038)		5.10	(996)		4.82	(31)		5.27	(199)		5.27	(196)	
	2/500	Before	4.52	(1682)	+	4.48	(1262)	+	4.49	(1224)	+	4.45	(24)	0	4.81	(288)	+	4.82	(280)	+
		After	4.88	(1805)		4.82	(1436)		4.82	(1385)		4.82	(33)		5.17	(276)		5.15	(272)	
	3/250	Before	4.47	(1713)	+	4.47	(1265)	0	4.48	(1229)	0	3.80	(22)	+	4.50	(317)	0	4.50	(309)	+
		After	4.55	(2246)		4.47	(1761)		4.47	(1704)		4.28	(37)		4.92	(359)		4.92	(352)	
	4/0	Before	3.29	(1750)	+	3.30	(1272)	+	3.31	(1232)	+	3.49	(25)	+	3.21	(343)	+	3.21	(334)	+
		After	4.33	(2345)		4.38	(1822)		4.38	(1760)		4.28	(40)		4.20	(393)		4.20	(385)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 ft = 0.31 m

Table 16. Summary of t-test analysis of right hand lateral placement for individual vehicle observations (10 percent significance level) (continued).

			All Time Periods and Vehicle Types Combined			Day									Night					
						All Vehicle Types			Autos, Vans, Pickups			Trucks and Buses			All Vehicle Types			Autos, Vans, Pickups		
Approach	Trap Designation / Distance From Bridge (Feet)	Time Period	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)	Distance (ft)	No. Veh.	S.D. (1)
82	1/900	Before	4.74	(1091)	+	4.70	(647)	-	4.70	(632)	-	Insufficient			4.82	(332)	-	4.82	(329)	-
		After	4.47	(501)		4.45	(376)		4.45	(366)		sample size			4.53	(88)		4.54	(88)	
	2/600	Before	4.25	(1115)	-	4.24	(682)	-	4.28	(667)	-	Insufficient			4.25	(391)	-	4.25	(307)	-
		After	3.50	(524)		3.51	(391)		3.51	(381)		sample size			3.59	(310)		3.58	(94)	
	3/300	Before	4.48	(1771)	+	4.37	(1022)	+	4.38	(993)	+	3.71	(16)	+	4.63	(544)	+	4.63	(538)	+
		After	5.32	(1658)		5.30	(1219)		5.32	(1173)		4.91	(28)		5.42	(278)		5.43	(274)	
	4/0	Before	3.02	(1800)	+	2.92	(1039)	+	2.92	(1009)	+	2.61	(16)	+	3.11	(554)	+	3.11	(548)	+
		After	4.07	(1799)		4.10	(1317)		4.10	(1270)		4.10	(29)		3.81	(299)		3.81	(294)	
91	1/900	Before	3.11	(698)	-	3.06	(489)	-	3.08	(475)	-	Insufficient			3.20	(157)	0	3.20	(156)	0
		After	2.93	(2358)		2.89	(1839)		2.90	(1792)		sample size			3.08	(407)		3.09	(395)	
	2/600	Before	2.84	(705)	-	2.76	(494)	-	2.77	(480)	+	Insufficient			3.10	(157)	0	3.11	(156)	0
		After	2.95	(2338)		2.86	(1839)		2.89	(1778)		sample size			3.21	(400)		3.21	(389)	
	3/300	Before	3.12	(694)	-	3.08	(481)	-	3.07	(466)	-	Insufficient			3.30	(160)	-	3.30	(159)	-
		After	2.88	(2344)		2.85	(1836)		2.85	(1789)		sample size			3.03	(396)		3.03	(386)	
	4/0	Before	3.52	(696)	-	3.54	(478)	-	3.52	(464)	-	Insufficient			3.48	(164)	-	3.48	(163)	-
		After	3.15	(2347)		3.14	(1830)		3.14	(1783)		sample size			3.21	(407)		3.19	(396)	
92	1/900	Before	2.93	(807)	-	2.28	(569)	-	2.88	(555)	-	Insufficient			3.07	(177)	-	3.07	(172)	-
		After	2.53	(2070)		2.45	(1571)		2.45	(1537)		sample size			2.83	(430)		2.83	(430)	
	2/600	Before	3.15	(827)	0	3.09	(589)	0	3.09	(572)	0	Insufficient			3.31	(177)	0	3.31	(172)	0
		After	3.12	(2088)		3.05	(1583)		3.05	(1547)		sample size			3.34	(435)		3.34	(435)	
	3/300	Before	3.17	(832)	0	3.15	(598)	0	3.15	(583)	0	Insufficient			3.14	(173)	0	3.13	(168)	0
		After	3.12	(2043)		3.09	(1548)		3.09	(1515)		sample size			3.20	(426)		3.20	(426)	
	4/0	Before	2.95	(815)	-	2.93	(587)	-	2.92	(573)	-	Insufficient			2.95	(170)	-	2.95	(165)	-
		After	2.53	(2054)		2.52	(1560)		2.51	(1524)		sample size			2.56	(425)		2.56	(425)	

(1) - S.D. = Significant difference; (+) = significant increase, (-) = significant decrease, (0) = no significant difference
1 ft = 0.31 m

paired observations. The paired t analyses compensated for the differences in trap distance from the bridges. The results of the paired t analysis, performed separately for day and night conditions on the category of vehicle types, are summarized in table 17. There were no significant differences, at a significance level of 10 percent, indicated by either the day or night data. It cannot be concluded, therefore, at a 90 percent level of confidence that the low-cost countermeasures resulted in significant changes in right-hand lateral placement between tapeswitch deployments.

Table 17. Summary of paired t analysis of right-hand lateral position at tapeswitch deployment (feet).

	Day		Night	
	Before	After	Before	After
mean	3.71	3.69	3.95	3.97
standard deviation	0.60	0.67	0.60	0.67
t value	0.38		-0.58	
degrees of freedom	70		71	
probability	0.71		0.56	

1 ft = 0.31 m

5. <u>Deviations in Right-Hand Lateral Placement Between Tapeswitch Deployments</u>

Analyses were performed on the average variation that occurred between adjacent tapeswitch deployments and between deployments that were the furthest apart. The purpose of these analyses was to determine if the low-cost countermeasures were effective in providing increased motorist guidance resulting in a more uniform vehicle path. The data for these analyses were obtained by determining the difference in the right-hand lateral placement, from table 16, for the appropriate trap pairs.

Inspection of the resultant differences in table 18 reveals that the type of movements between adjacent trap pairs remains relatively constant, between the before and after time periods. Those pairs that exhibited average movements to the right (minus sign) between the traps in the before period usually exhibited movements to the right in the after period.

Table 18. Difference in lateral placement between adjacent tapeswitch deployments (feet).

Approach Site Designation	Change in Lateral Placement Between Traps	All Vehicle Types and all Time Periods Combined	Day: All Vehicle Types Combined	Day: Autos, Vans and Pickups	Day: Trucks/Buses	Night: All Vehicle Types Combined	Night: Autos, Vans and Pickups
11	1-2	-0.05 0.25	-0.03 0.25	-0.03 0.28	-0.14 0.20	-0.16 0.23	0.15 0.24
	2-3	0.56 1.02	0.61 1.08	0.61 1.05	0.65 1.18	0.31 0.67	0.31 0.66
	3-4	-1.54 -1.87	-1.54 -1.90	-1.55 -1.91	-1.11 -1.46	-1.42 -1.73	-1.43 -1.73
12	1-2	-0.54 -0.40	-0.54 -0.39	-0.54 -0.39	-0.61 -0.28	-0.47 -0.56	-0.46 -0.55
	2-3	0.05 0.18	0.03 0.18	0.03 0.18	0.27 0.18	0.20 0.13	0.19 0.12
	3-4	-0.81 -0.02	-0.81 -0.70	-0.82 -0.71	-0.71 -0.65	-0.79 -0.61	-0.79 -0.61
21	1-2	-0.20 -0.06	-0.18 -0.04	-0.17 -0.04	-0.13 0.02	-0.30 -0.16	-0.30 -0.16
	2-3	1.68 1.11	1.67 1.08	1.66 1.09	1.60 0.76	1.76 1.31	1.75 1.31
	3-4	-0.05 -0.23	-0.06 -0.22	-0.06 -0.24	0.26 0.45	-0.06 -0.25	-0.05 -0.26

1 ft. = 0.31 m

Table 18. Difference in lateral placement between adjacent tapeswitch deployments (feet)(continued).

Approach Site Designation	Change in Lateral Placement Between Traps	All Vehicle Types and all Time Periods Combined	Day			Night	
			All Vehicle Types Combined	Autos, Vans and Pickups	Trucks/Buses	All Vehicle Types Combined	Autos, Vans and Pickups
22	1-2	-1.14 -1.41	-1.12 -1.39	-1.12 -1.38	-1.06 -1.51	-1.22 -1.52	-1.21 -1.52
	2-3	1.88 1.33	1.90 1.33	1.90 1.32	2.10 1.67	1.71 1.46	1.72 1.46
	3-4	-0.76 -0.86	-0.79 -0.89	-0.81 -0.90	-0.78 -0.73	-0.56 -0.78	-0.56 0.78
31	1-2	0.27 0.38	0.26 0.37	0.26 0.37	Insufficient Sample Size	0.39 0.44	0.39 0.44
	2-3	0.20 -0.14	0.21 -0.17	0.21 -0.17	Insufficient Sample Size	0.14 0.01	0.14 0.01
	3-4	-0.36 -0.16	-0.34 -0.12	-0.34 -0.12	Insufficient Sample Size	-0.50 -0.41	-0.50 -0.41
32	1-2	-0.48 -0.40	-0.49 -0.44	-0.49 -0.44	-0.55 -0.58	-0.45 -0.26	-0.45 -0.25
	2-3	0.43 0.52	0.43 0.55	0.42 0.53	1.22 1.81	0.42 0.41	0.42 0.41
	3-4	-0.35 -1.07	-0.34 -1.08	-0.34 -1.06	Insufficient Sample Size	-0.38 -1.04	-0.38 -1.05

1 ft. = 0.31 m

Table 18. Difference in lateral placement between adjacent tapeswitch deployments (feet)(continued).

Approach Site Designation	Change in Lateral Placement Between Traps	All Vehicle Types and all Time Periods Combined	Day: All Vehicle Types Combined	Day: Autos, Vans and Pickups	Day: Trucks/Buses	Night: All Vehicle Types Combined	Night: Autos, Vans and Pickups
41	1-2	0.94 1.01	1.00 1.11	1.00 1.11	1.41 1.47	0.53 0.50	0.52 0.57
	2-3	-1.28 -0.98	-1.29 -1.02	-1.29 -1.03	-1.62 -1.10	-1.26 -0.80	-1.26 -0.80
	3-4	-1.16 -1.07	-1.17 -1.05	-1.18 -1.05	-1.04 -0.91	-1.08 -1.17	-1.08 -1.15
42	1-2	0.32 0.36	0.34 0.40	0.34 0.40	0.53 0.76	0.08 0.31	0.08 0.31
	2-3	0.17 0.23	0.17 0.26	0.17 0.26	-0.02 0.03	0.13 0.04	0.12 0.04
	3-4	-0.27 -0.65	-0.29 -0.67	-0.28 -0.67	-0.29 -0.82	-0.06 -0.60	-0.05 -0.60
51	1-2	0.62 0.68	0.20 0.48	0.19 0.48	Insufficient Sample Size	0.72 0.96	0.72 0.96
	2-3	0.96 0.55	Insufficient Sample Size	Insufficient Sampel Size	Insufficient Sample Size	0.97 0.54	0.96 0.54
	3-4	-1.54 -1.35	Insufficient Sampel Size	Insufficient Sample Size	Insufficient Sample Size	-1.56 -1.28	-1.58 -1.28

1 ft. = 0.31 m

Table 18. Difference in lateral placement between adjacent tapeswitch deployments (feet)(continued).

Approach Site Designation	Change in Lateral Placement Between Traps	All Vehicle Types and all Time Periods Combined	Day			Night	
			All Vehicle Types Combined	Autos, Vans and Pickups	Trucks/Buses	All Vehicle Types Combined	Autos, Vans and Pickups
52	1-2	0.24 0.20	-0.19 0.13	-0.19 0.12	Insufficient Sample Size	0.28 0.33	0.27 0.32
	2-3	-0.34 -0.34	-0.30 -0.33	-0.30 -0.31	Insufficient Sample Size	-0.37 -0.36	-0.37 -0.36
	3-4	-0.53 -1.59	-0.24 -1.54	-0.24 -1.58	Insufficient Sample Size	-0.55 -1.68	-0.54 -1.68
61	1-2	0.28 0.43	0.27 0.40	0.27 0.39	0.31 0.56	0.29 0.53	0.31 0.54
	2-3	0.69 0.60	0.76 0.64	0.74 0.64	1.14 0.76	0.46 0.46	0.44 0.46
	3-4	-0.79 -1.23	-0.75 -1.21	-0.76 -1.23	-0.40 -1.11	-1.00 -1.31	-1.02 -1.35
62	1-2	0.02 -0.02	-0.12 -0.13	-0.12 -0.15	0.00 -0.06	0.26 0.16	0.27 0.16
	2-3	0.52 1.04	0.57 1.07	0.55 1.06	0.70 1.41	0.42 0.98	0.41 0.97
	3-4	0.34 -0.52	0.51 -0.41	0.46 -0.44	1.18 -0.24	0.02 -0.60	0.02 -0.59

1 ft. = 0.31 m

Table 18. Difference in lateral placement between adjacent tapeswitch deployments (feet)(continued).

Approach Site Designation	Change in Lateral Placement Between Traps	All Vehicle Types and all Time Periods Combined	Day			Night	
			All Vehicle Types Combined	Autos, Vans and Pickups	Trucks/Buses	All Vehicle Types Combined	Autos, Vans and Pickups
71	1-2	-0.27 -0.08	-0.20 -0.05	-0.21 -0.04	-0.12 -0.06	-0.38 -0.16	-0.39 -0.17
	2-3	0.07 0.09	0.12 0.08	0.10 0.06	0.35 0.47	-0.05 0.18	-0.05 0.16
	3-4	0.27 0.42	0.39 0.53	0.30 0.50	0.82 0.96	0.13 0.12	0.11 0.09
72	1-2	0.05 0.15	0.01 0.17	0.01 0.19	-0.05 0.03	0.06 0.13	0.04 0.14
	2-3	0.44 0.25	0.53 0.23	0.55 0.21	0.40 0.47	0.28 0.23	0.26 0.22
	3-4	0.00 0.39	0.20 0.51	0.15 0.49	0.93 1.24	-0.55 -0.03	-0.59 -0.05
81	1-2	-0.36 -0.24	-0.36 -0.28	-0.36 -0.28	0.13 0.00	-0.40 -0.10	-0.39 -0.12
	2-3	-0.05 -0.33	-0.01 -0.35	-0.01 -0.35	-0.65 -0.54	-0.31 -0.25	-0.32 -0.23
	3-4	-1.18 -0.22	-1.17 -0.09	-1.17 -0.09	-0.31 -0.04	-1.29 -0.72	-1.29 -0.72

1 ft. = 0.31 m

Table 18. Difference in lateral placement between adjacent tapeswitch deployments (feet)(continued).

Approach Site Designation	Change in Lateral Placement Between Traps	All Vehicle Types and all Time Periods Combined	Day		Night		
			All Vehicle Types Combined	Autos, Vans and Pickups	Trucks/Buses	All Vehicle Types Combined	Autos, Vans and Pickups
82	1-2	-0.49 -0.97	-0.46 -0.94	-0.42 -0.94	Insufficient Sample Size	-0.57 -0.94	-0.57 -0.96
	2-3	0.23 1.82	0.13 1.79	0.10 1.81	Insufficient Sample Size	0.38 1.83	0.38 1.85
	3-4	-1.46 -1.25	-1.45 -1.20	-1.46 -1.22	-1.10 -0.81	-1.52 -1.62	-1.52 -1.62
91	1-2	-0.27 0.02	-0.03 -0.03	-0.31 -0.01	Insufficient Sample Size	-0.10 0.13	-0.09 0.12
	2-3	0.28 -0.07	0.32 -0.01	0.30 -0.04	Insufficient Sample Size	0.20 -0.18	0.19 -0.18
	3-4	0.40 0.27	0.46 0.29	0.45 0.29	Insufficient Sample Size	0.18 0.18	0.18 0.16
92	1-2	0.22 0.59	0.21 0.60	0.21 0.60	Insufficient Sample Size	0.24 0.51	0.24 0.51
	2-3	0.02 0.00	0.06 0.04	0.06 0.04	Insufficient Sample Size	-0.17 -0.14	-0.18 -0.14
	3-4	-0.22 -0.59	-0.22 -0.57	-0.23 -0.58	Insufficient Sample Size	-0.19 -0.64	-0.18 -0.64

1ft. = 0.31 m

This observation is supported by the results of the paired t analyses that are summarized in table 19. There were no significant differences, at the 10 percent significance level, between the lateral movements exhibited by adjacent pairs in the before and after time periods.

Table 19. Summary of paired t analyses on lateral position changes between adjacent tapeswitch deployments (feet).

	Day		Night	
	Before	After	Before	After
mean	-0.06	-0.07	-0.13	0.69
standard deviation	0.68	0.77	-0.13	0.78
t value	0.16		-0.01	
degrees of freedom	51		53	
probability	0.87		0.99	

1 ft = 0.31 m

Paired t analyses performed on the differences in lateral movement between the furthest trap pairs (i.e., tapeswitch deployments 1 and 4) are summarized in table 20. This analysis did not display any significant differences, at the 10 percent significance level, between the lateral movements of the furthest trap pairs in the before and after time periods.

Table 20. Summary of paired t analysis on overall difference in right hand lateral placement (feet).

Approach Designation	Day Before	Day After	Night Before	Night After
11	-0.96	-0.57	-1.27	-0.83
12	-1.32	-0.91	-1.06	-1.04
21	1.43	0.82	1.40	0.90
22	-0.01	-0.95	-0.07	-0.84
31	0.13	0.08	0.03	0.04
32	-0.40	-0.97	-0.41	-0.89
41	-1.46	-0.96	-1.81	-1.47
42	0.22	-0.01	0.15	-0.25
51	-0.02	-0.32	0.13	0.22
52	-0.73	-1.74	-0.64	-1.71
61	0.28	-0.17	-0.25	-0.32
62	0.96	0.53	0.70	0.54
71	0.31	0.56	-0.30	0.14
72	0.74	0.91	-0.21	0.33
81	-1.54	-0.72	-2.00	-1.07
82	-1.78	-0.35	-1.71	-0.72
91	0.48	0.25	0.28	0.13
92	0.05	0.07	-0.12	-0.27
Mean	-0.20	-0.25	-0.40	-0.40
Standard Deviation	0.92	0.72	0.89	0.72
t value	0.32		-0.02	
degrees of freedom	17		17	
probability	0.76		0.983	

1 ft = 0.31 m

CONCLUSIONS

The conclusions presented below are based on the results of the project analysis, observations made during the study and the literature review.

1. Analysis of individual vehicle speeds indicated that the effect of the low-cost countermeasures were essentially the same for day and night conditions. Three sites during the day and four during the night experienced a significant decrease in speed. When both day and night conditions were analyzed together eight sites experienced a significant increase, four a significant decrease and six no significant difference in mean speeds between the before and after time periods. These results did not establish a sufficient difference in the mean speed increases or decreases to attribute the effects to the low-cost countermeasures. The low-cost countermeasures cannot, therefore, be assumed to result in significant changes in mean speeds.

2. An inspection of the mean individual vehicle speed at each tapeswitch deployment was performed to determine if the speed profile of motorists changed due to the installation of the low-cost countermeasures. Inspection of the mean speeds at each trap deployment revealed that trends that were present in the before time period continued to the after period. Those sites which exhibited peak speeds at the trap located closest to the bridge during the before period also exhibited peak speeds at the bridge during the after period. It cannot be concluded, at a 10 percent significance level, that the low-cost countermeasures resulted in significant changes in mean speed between tapeswitch deployments.

3. Estimates of vehicle lateral placement were obtained by measuring the distance from the right road edge to the outside of the right front tire. Inspecting the manner in which the directional movements were distributed among the approach sites resulted in difficulty associating the direction of movement with the types of countermeasures installed. For example, four approach sites received eight inch (20.3 cm) edgelines as part of their physical

upgrade. Two of these sites resulted in average movements to the right, one site experienced movements to the left and one site experienced no change in any direction. It could not be concluded that the low-cost countermeasures resulted in significant changes in right hand lateral placement between tapeswitch deployments.

4. Analyses were performed on the average variation that occurred between adjacent tapeswitch deployments and between deployments that were the furthest apart. The purpose of these analyses was to determine if the low-cost countermeasures resulted in a more uniform vehicle path. Inspection of the differences indicated that the type of movement between adjacent trap pairs remained relatively constant between the before and after time periods. Those pairs that exhibited average movements to the right between the traps in the before period usually exhibited movements to the right in the after period. There were no significant differences, at the 10 percent significance level, between the lateral movements exhibited by either adjacent pairs, or between the furthest trap pairs, in the before and after time periods.

5. Estimates of the maximum speed variation were obtained by measuring the greatest difference in speed exhibited by individual vehicles as they progressed through the trap array. This maximum speed variation was averaged over all the observations to obtain the analysis value. The intuitive logic in the selection of this MOE was that a reduction in speed variation denotes increased safety due to more uniform speeds. This effect was expected to be more pronounced during the nighttime and periods of low visibility when the delineators, edge lines and hazard markers provide maximum conspicuity. Analyzing data obtained by combining the day and night observations into one group revealed that a significant number of analysis sites, at the 10 percent level of significance, experienced a reduction in speed variability after countermeasure implementation. When the average speed variation was analyzed separately for day and night conditions, however, there were no significant differences between the before and after time periods.

6. The inability of the measures of effectiveness to exhibit significant differences between the before and after time periods can be interpreted in two ways. The first way is that the operational measures of effectiveness related to vehicle speed and position are not appropriate measures for narrow bridge sites. The literature review indicated that these measures had been used successfully in prior studies at narrow bridge sites. The use of the Traffic Evaluator System (TES), however, resulted in much larger data bases and greater accuracy than those studies that relied primarily on manual data collection techniques. In addition, since the narrow bridges studied existed on low volume rural roadways the majority of roadway users can be expected to be local motorists who are familiar with the roadway geometrics. These motorists know the presence of the narrow bridge and have developed driving patterns to safely negogiate the hazardous roadway feature prior to the installation of the low-cost countermeasures. Their driving characteristics may not, therefore, be altered by the installation of low-cost countermeasures.

The second possible interpretation is that the countermeasures are not effective in influencing driver behavior. However, the inability of the operational measures of effectiveness to identify changes in driving behavior does not necessarily imply that the low-cost countermeasures are ineffective. Accidents are relatively rare events that result from circumstances related to the driver, vehicle, roadway and environment. The low-cost countermeasures provide increased delineation and driver information. The impact of these enhancements on potential accidents involving unfamiliar drivers, impaired drivers and unfavorable environmental conditions (such as restricted visibility, wet and slippery road conditions) cannot be ascertained by analyzing average operational measures. A determination on the actual effectiveness of low-cost countermeasures, therefore, requires a proper accident-based evaluation.

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