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Ramp Signing for Trucks

Research and Development
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FOREWORD

This report presents the results of a research study addressing methods for treating interchange ramps that are prone to cause high center of gravity vehicles to lose control and overturn. Laboratory tests were conducted to identify specific sign elements and to format the various sign elements into a meaningful message. The most promising sign formats were then tested for understanding, preference, and relative visibility by truckers. Field tests of the "best" sign were conducted at two interchange ramp sites, one at the clover leaf interchange ramp at I-95/US 17 in Virginia and the other at the interchange ramp at Interstates I-70/I-81 in Maryland.

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Lyle Saxton, Director
Office of Safety and Traffic
Operations Research and
Development

NOTICE

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16. Abstract

This report describes a study of ramp signing for trucks. The research addressed methods for treating interchange ramps that are prone to cause high center of gravity vehicles to lose control and overturn.

A critical review of the pertinent literature on interchange ramp design, signing, and overturning truck accidents was conducted. A state-of-the-practice review was also conducted in 12 States. This review determined the nature and extent of the truck rollover accident problem, determined problem ramp identification procedures, and identified active and passive treatments currently being used at problem ramps. A "design-a-sign" study was conducted using 61 professional truck drivers. This study attempted to identify critical ramp characteristics and to develop innovative procedures for effectively communicating this information to approaching drivers.

A series of laboratory studies were conducted to identify the specific sign elements and the specific sign format that most effectively warn truck drivers about potentially dangerous ramps. Two of the lab studies, using 117 trucker subjects, determined which sign elements, either words or symbols, were most effective. A third lab study, involving 44 truckers, determined the most effective format of the various sign elements. A fourth lab study, using 60 truckers and 27 non-truckers, involved meaning and preference testing of the most promising sign formats. The final laboratory procedure examined the relative visibility of the final sign formats. Seventy-two truckers were tested in that procedure.

A field test was conducted at two interchange ramps in Virginia and Maryland that had high incidences of truck rollover accidents. A truck tipping sign with activated flashing beacons was installed at the ramp and an advance warning sign was installed prior to the ramp. Control sites received no treatment. Analysis indicated that the speeds of tractor trailers, in general, and top-heavy tractor trailers, in particular, were not affected by the experimental treatments. Speeds of automobiles showed a small but statistically significant speed reduction.

The project concludes that truckers have a relatively high level of understanding regarding the truck rollover problem and the meaning of the truck tipping sign. Unfortunately, the field test results failed to show an operational effect to support this cognitive awareness. Nevertheless, the high level of understanding associated with the signs suggests that their use at high accident locations may be appropriate.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

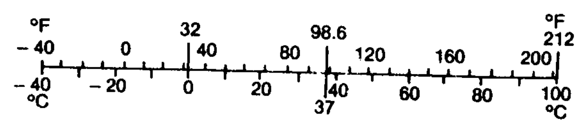
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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I. INTRODUCTION AND BACKGROUND

This project developed and evaluated various active and passive traffic control systems to warn truck drivers about interchange ramps with geometric characteristics that can cause trucks to overturn. A series of laboratory experiments was conducted to identify the traffic control systems with the highest levels of truck driver understanding. A field study was conducted to determine the operational effectiveness of the most promising candidate systems.

This report is organized into chapters documenting the various aspects of the study. The remainder of this chapter provides background information derived from the state-of-the-art review, the literature review, the state-of-the-practice review, and the "design-a-sign" experiment. Chapter II describes five separate laboratory studies designed to identify specific sign elements (words and/or symbols) and the specific sign format (layout of the elements) that most effectively inform truckers about a ramp with a truck rollover hazard. Sign preference, comprehension, and legibility was tested. Chapter III summarizes the procedures and results of the field study. Chapter IV summarizes the research and provides conclusions and recommendations.

STATE-OF-THE-ART REVIEW

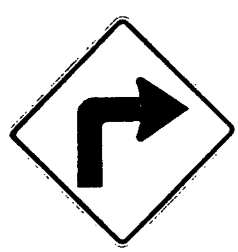
This section includes pertinent excerpts that deal with interchange ramp signing and ramp design from the Manual of Uniform Traffic Control Devices (MUTCD), the Traffic Control Devices Handbook (TCDH), and A Policy on Geometric Design of Highways and Streets (AASHTO Green Book).[1,2,3]

The Manual of Uniform Traffic Control Devices (MUTCD) specifies a variety of warning signs to be used to warn traffic of existing or potentially hazardous conditions on a highway or street.[1] The manual suggests that hazardous conditions are "in varying degrees" common to all highways and that existing standards for warning signs are generally applicable to expressways. Warning signs are used to advise traffic of locations and hazards such as intersections, converging roadways, railroad crossings, entrances, and exits. Generally, warning signs are diamond-shaped (square, but installed with one diagonal perpendicular) with block lettering and/or figures and a yellow background. Warning signs at least 36 by 36 in (92 by 92 cm) are recommended on expressways.

There are two signs used to warn drivers of approaching changes in horizontal alignment, the turn sign (W1-1) and the curve sign (W1-2). These signs are described in sections 2C-4 and 2C-5 of the MUTCD. Those sections also indicate that additional protection may also be provided by using an Advisory Speed Plate as described in section 2C-35. Sections 2C-4, 2C-5, and 2C-35 are shown as figure 1.

2C-4 Turn Sign (W1-1)

The Turn sign (W1-1R or 1L) is intended for use where engineering investigations of roadway, geometric, and operating conditions show the recommended speed on a turn to be 30 MPH or less, and this recommended speed is equal to or less than the speed limit established by law or by regulation for that section of highway. Where a Turn sign is warranted, a Large Arrow sign (sec. 2C-9) may be used on the outside of the turn. Additional protection may be provided by use of the Advisory Speed plate (sec. 2C-35).



W1-1R
30" x 30"

W1-2R
30" x 30"

2C-5 Curve Sign (W1-2)

The Curve sign (W1-2R or 2L) may be used where engineering investigations of roadway, geometric, and operating conditions show the recommended speed on the curve to be greater than 30 miles per hour and equal to or less than the speed limit established by law or by regulation for that section of highway. Additional protection may be provided by use of the Advisory Speed plate (sec. 2C-35).

Editorial Change Rev. 4

Figure 1. Sections 2C-4, 2C-5, and 2C-35 of the MUTCD.

2C-35 Advisory Speed Plate (W13-1)

The advisory speed plate is intended for use to supplement warning signs. The standard size of the Advisory Speed plate shall be 18 × 18 inches. Advisory Speed plates used with 36-inch and larger warning signs shall be 24 × 24 inches.

The plate shall carry the message (35) MPH in black on a yellow background except for construction and maintenance signs (sec. 6B-34). The speed shown shall be a multiple of 5 miles per hour. The plate may be used in conjunction with any standard yellow warning sign to indicate the maximum recommended speed around a curve or through a hazardous location. It shall not be used in conjunction with any sign other than a warning sign, nor shall it be used alone. When used, it shall be mounted on the same assembly and normally below the standard warning sign (fig. 2-1, page 2A-9).

Except in emergencies, or at construction or maintenance sites, where the situation calling for an advisory speed is temporary, an Advisory Speed plate shall not be erected until the recommended speed has been determined by accepted traffic engineering procedures. Because changes in surface characteristics, sight distance, etc., may alter the recommended speed, each location should be periodically checked and the speed plate corrected if necessary.

W13-1
18" x 18"
24" x 24"

Figure 1. Sections 2C-4, 2C-5, and 2C-35 of the MUTCD (continued).

The MUTCD specifies that the large arrow sign (W1-6) can be used to warn of especially sharp changes in alignment. That sign is described in section 2C-9, which is shown here as figure 2.

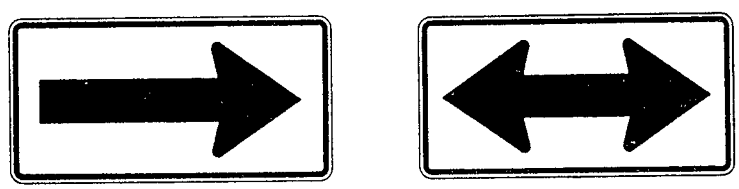
2C-9 Large Arrow Sign (W1-6, W1-7)

The Large Arrow sign shall be a horizontal rectangle with a standard size of 48 × 24 inches, having a large arrow (W1-6) or a double head arrow (W1-7). It shall have a yellow background with symbol in black.

A Large Arrow sign is intended to be used to give notice of a sharp change of alignment in the direction of travel. It is not to be used where there is no change in the direction of travel (ends of medians, center piers, etc.).

The Large Arrow sign, when used, shall be erected on the outside of a curve or on the far side of an intersection, in line with, and at right angles to, approaching traffic.

To be effective the Large Arrow sign should be visible for at least 500 feet and trial runs by day and night may be desirable to determine final positioning.



W1-6
48" x 24"

W1-7
48" x 24"

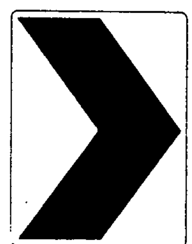
Figure 2. Section 2C-9 of the MUTCD.

The MUTCD further specifies that the chevron alignment sign (W1-8) can be used instead of or as a supplement to standard delineators and the large arrow sign. That sign is described in section 2C-10, which is shown here as figure 3.

2C-10 Chevron Alignment Sign (W1-8)

The Chevron Alignment sign shall be a vertical rectangle with a minimum size of 12 inches by 18 inches. It shall have a yellow background with chevron symbol in black. The size of sign used will be determined by an engineering investigation.

A Chevron Alignment sign may be used as an alternate or supplement to standard delineators and to the Large Arrow sign. The Chevron Alignment sign is intended to be used to give notice of a sharp change of alignment with the direction of travel. Chevron Alignment sign is intended to provide additional emphasis and guidance for vehicle operators as to changes in horizontal alignment of the roadway.



W1-8
18" × 24"

Chevron Alignment signs, when used, are erected on the outside of a curve, sharp turn, or on the far side of an intersection, in line with and at right angles to approaching traffic. Spacing of the signs should be such that the motorists always have two in view, until the change in alignment eliminates the need for the signs. To be effective, Chevron Alignment signs should be visible for at least 500 feet; trial runs by day and night may be desirable to determine final positioning.

Figure 3. Section 2C-10 of the MUTCD.

The MUTCD discussion of the entire W-1 family of signs (curves and turns) covers all applications, regardless of highway type. There is no distinction made between the use of curve or turn signs on twisting secondary roadways or freeway exit ramps. The type of roadway is specifically addressed only in terms of sign placement and sign size. The MUTCD does, however, specify specific versions of the standard advisory speed plate (W13-1) to be used on ramps and exits. These advisory speed plates are described in section 2C-36, which is shown here as figure 4.

2C-36 Advisory Exit Speed Signs (W13-2, W13-3)

The Exit Speed or Ramp Speed signs are intended for use where engineering investigations of roadway, geometric, or operating conditions show the necessity of advising drivers of the maximum recommended speed on a ramp.

The sign should be posted along the deceleration lane or along the ramp so that it is visible in time for the driver to make a safe slowing and exiting maneuver. Where additional advisory speed indication is needed on the ramp well beyond the gore, a standard warning sign with an Advisory Speed plate (W13-1) is to be used.

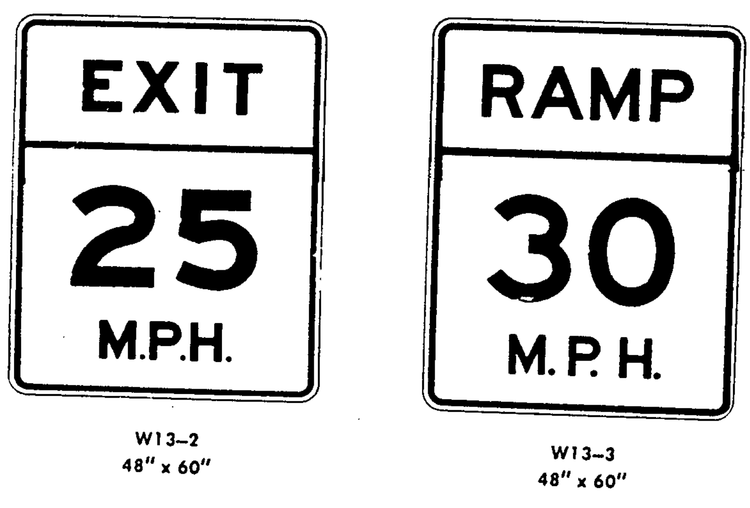


Figure 4. Section 2C-36 of the MUTCD.

The MUTCD specifies that the speed plate not be erected until the recommended speed can be determined "by accepted traffic engineering procedures." The manual further states, "Because changes in surface characteristics, sight distances, etc., may alter the recommended speed, each location should be periodically checked and the advisory speed plate corrected if necessary." The MUTCD does not specifically indicate that hazards unique to certain vehicle types (i.e., trucks) should be considered when selecting either curve/turn signing or advisory speed plates.

The Traffic Control Devices Handbook (TCDH) is intended to augment the MUTCD and to serve an interpretative function.(2) The TCDH offers guidelines for implementing the standards and applications contained in the manual. The TCDH does specify three procedures that can be used to determine the recommended speed in a curve or turn. The methods involve interpolating the speed from a graph (when the curve radius is known), the use of a ball-bank indicator, and the use of a mathematical computation.

A Policy on Geometric Design of Highways and Streets (AASHTO "Green Book") is a comprehensive reference manual based on established practices and supplemented by recent research.(3) It is intended for use by highway designers and highway engineers. Chapter III of the Green Book covers elements of design including sight distance, vertical alignment, and horizontal alignment. The section on horizontal alignment begins with a discussion of the theoretical considerations for a vehicle operating through a curve. The basic point mass formula is given:

$$\frac{e + f}{1 - ef} = \frac{0.067V^2}{R} = \frac{V^2}{15R} \qquad (1)$$

where:
- e = rate of roadway superelevation, ft/ft;
- f = side friction factor;
- V = vehicle speed, mph; and
- R = radius of curve, ft.

Since the value of ef is always small, the term $(1 - ef)$ is typically omitted in highway designs.

The Green Book then provides a more detailed discussion of superelevation and side friction factor. There are practical limits to the amount of superelevation that can be used. In areas of ice and snow, the rate cannot exceed that which vehicles can <u>slowly</u> travel without sliding down the cross slope. Other factors related to limiting the amount of superelevation include:

> Such a high rate of superelevation is undesirable on high-volume roads, as in urban and suburban areas, where there are numerous occasions when vehicle speeds are reduced considerably because of highway traffic volume or other conditions. Also some trucks have high centers of gravity and some cars are loosely suspended on the axles. When these vehicles travel slowly on steep cross slopes, a high percentage of the weight is carried by the inner tires. (page 164)

This is the only reference in the discussion of curve design that specifies center of gravity height as a factor to be considered.

The coefficient of friction **f** is the friction force divided by the weight perpendicular to the pavement. The side friction factor (i.e., lateral ratio; cornering ratio; or friction factor) is expressed as the following simplified curve formula:

$$\mathbf{f} = \frac{\mathbf{V_2}}{15\mathbf{R}} - \mathbf{e} \qquad (2)$$

The upper limit of the side friction factor is the point of skidding or the point of impending skid. The Green Book further explains:

> Because highway curves are designed to avoid skidding conditions with a margin of safety, the **f** values should be substantially less than the coefficient of friction of impending skid.
>
> The side friction factor at which side skidding is imminent depends on a number of factors, among which the most important are the speed of the vehicle, the type and condition of the roadway surface, and the type and condition of the tires. (page 165)

Thus, the AASHTO discussion of vehicle speeds on curves indicates that studies have shown that the maximum side friction factor developed between new tires and wet concrete ranges from 0.5 at 20 mi/h (32 km/h) to about 0.35 at 60 mi/h (97 km/h). For normal wet concrete pavement and smooth tires, the value is about 0.35 at 45 mi/h (72 km/h). Friction values decrease as speed increases. Yet curves should not be designed on the basis of the maximum available side friction factor. The portion of the side friction factor that can be used with comfort and safety by the vast majority of drivers should be the maximum allowable value for design. The Green Book provides a discussion of how the ball-bank indicator has been used to quantify side friction factors associated with driver discomfort:

> In selecting maximum allowable side friction factors for use in design, one criterion is the point at which the centrifugal force is sufficient to cause the driver to experience a feeling of discomfort and cause him to react instinctively to avoid higher speed. The speed on a curve, at which discomfort due to the centrifugal force is evident to the driver, can be accepted as a design control for maximum allowable amount of side friction. At lower nonuniform running speeds, which are typical in urban areas, drivers are more tolerant of discomfort, thus permitting employment of an increased amount of side friction for use in design of horizontal curves.
>
> The ball-bank indicator has been widely used by research groups, local agencies, and highway departments as a uniform measure for the point of discomfort to set safe speeds on curves. It consists of a steel ball in a sealed glass tube. The ball is free to roll except for the damping effect of the liquid in the tube. Its simplicity of construction and operation has led to widespread acceptance as a guide for determination of safe speeds. With such a device mounted in a vehicle in motion, the ball-bank reading at any time is indicative of the combined effect of the body roll angle, the centrifugal force angle, and the superelevation angle ...
>
> The centrifugal force developed as a vehicle travels at uniform speed on a curve causes the ball to roll out to a fixed angle position ... A correction must be made for that portion of the force taken up in the small body roll angle. The indicated side force perceived by the vehicle occupants is thus on the order of F=tan (a-p).
>
> In a series of definitive tests (20) it was concluded that safe speeds on curves were indicative by ball-bank readings of 14° for speeds of 20 mph or less, 12° for speeds of 25 and 30 mph, and 10° for speeds of 35 through 50 mph. These ball-bank readings are indicative of side friction factors of 0.21, 0.18,

and 0.15, respectively, for the test body roll angles and provide ample margin of safety against skidding. (page 166)

The AASHTO Green Book concludes the discussion of side friction force with the following: "When practical, the maximum factors selected should be conservative for dry pavements and provide a margin of safety for operating on pavements that are wet as well as ice or snow covered ..." (page 167)

The AASHTO Green Book (page 169) describes five methods for counteracting centrifugal force on curves by use of **e** or **f**, or both:

1. Superelevation and side friction are directly proportional to the degree of curve, i.e., a straight-line relation exists between D = O and D = D_{max}.
2. Side friction is such that a vehicle traveling at design speed has all centrifugal force counteracted in direct proportion by side friction on curves up to those requiring f_{max}. For sharper curves, f remains at f_{max} and e is then used in direct proportion to the continued increase in curvature until e reaches e_{max}.
3. Superelevation is such that a vehicle traveling at design speed has all centrifugal force counteracted in direct proportion by superelevation on curves up to that requiring e_{max}. For sharper curves, e remains at e_{max} and f is then used in direct proportion to the continued increase in curvature until f reaches f_{max}.
4. Method 4 is the same as method 3, except that it is based on average running speed instead of design speed.
5. Superelevation and side friction are in a curvilinear relation with degree of curve, with values between those of methods 1 and 3.

The remaining discussion of curve design in the Green Book involves a detailed discussion of these five methods for counteracting centrifugal force on a curve and includes detailed charts and graphs illustrating design elements, design speed, and horizontal curvature. The entire AASHTO discussion of design speed for curves involves addressing efforts to counteract centrifugal force; i.e., increase superelevation, decrease degree of curvature, increase coefficient of friction. Thus, the design process involves interactions between the superelevation, degree and curvature, and design speed so that only side friction factors are considered. The design elements are balanced to avoid the hazards associated with skidding with a margin of safety. There is no reference in the AASHTO Green Book to hazards associated with overturning vehicles in general, or to the hazards associated with top-heavy trucks in particular.

LITERATURE REVIEW

A review of the Transportation Research Information Service (TRIS) data base was conducted covering the identification and signing of interchange ramps that represent a rollover hazard to trucks. Few relevant items were uncovered. They are summarized below.

Ervin, Barnes, MacAdam, and Scott examined the impact of specific geometric features on truck operations and safety at interchanges.(4) The first phase of the project involved an analysis of accident data. Since computerized accident files (BMCS, FARS, NASS) did not contain sufficient detail, hard copy accident reports were examined. The accident analysis had two objectives: (1) identify a number of individual ramps for use in later simulation work and (2) study the causes of truck accidents on ramps to guide the simulation work and suggest avenues for development of possible countermeasuring. Although study sites for simulation work were developed, no detailed data on the causes of truck accidents were reported.

The second phase of the study consisted of collecting information on the geometric features of 15 specific ramps for use in the computer simulation. The ramps were each examined and analyzed relative to conformance with the design policies of AASHTO. They were grouped to identify primary features that may lead to truck accidents. Six sets of primary characteristics were identified:

1. Poor transition of superelevation.
2. Abrupt changes in compound curve.
3. Short deceleration lane preceding a tight-radius exit.
4. Curb placed on the outside of a ramp curve.
5. Substantial downgrade leading to a tight ramp curve.
6. Reduced friction level on a high speed ramp.

The first five of these situations involved a substantial number of truck rollover accidents.

The last phase of the project involved the simulation of specific truck configurations in each of the 15 selected ramps. The UMTRI "phase 4" simulation model was used to represent the dynamic response of the "baseline tractor trailer." The phase 4 model is a nonlinear, time-domain simulation capable of representing commercial vehicles ranging from straight trucks to triple combinations. Five vehicle types were simulated including three trailers with different load distributions and two different tankers. The payload center of gravity (CG) varied from 83.5 to 105.0 in (214 to 269 cm). Not all vehicle configurations were run at each site. The high CG configuration was conducted at selected sites to determine if rollover would occur at or near the posted speed. Ervin et al. summarized the results of their analyses of the accident data, the geometric data, and the computer simulations as follows:(4)

> 1) Truck loss-of-control accidents on interchange ramps are predominantly by rollover and jackknife events ...
>
> 2) Jackknife accidents predominate at sites where inadequate pavement friction levels prevail during wet weather ...
>
> 3) Rollover accidents are precipitated at sites having high levels of side friction demand ...
>
> 4) The AASHTO policy for the geometric design of curves provides for virtually no margin of safety against rollover for certain trucks ... The trucks of critical interest lie at the low end of the roll stability spectrum, primarily as a result of high payload centers of gravity, but exist in substantial numbers. Curves designed to suitably accommodate such trucks would have side friction factor values limited to approximately 50 percent of the current AASHTO-prescribed limits.
>
> 5) The AASHTO policy for the length of deceleration lanes does not provide for the deceleration of truck combinations in a manner analogous to the treatment for passenger cars. For trucks to decelerate safely within the AASHTO-prescribed lengths, the vehicle must apply service brakes over the full length of the deceleration lane--rather than being allowed an initial 3-second period for coasting in gear upon entering the lane, as is assumed in the AASHTO calculations. Deceleration lanes which would realistically reflect the braking constraints of trucks would be 30 percent to 50 percent longer than AASHTO guidelines suggest.
>
> 6) The tremendous mismatch between the provided lengths of acceleration lanes and the acceleration length demands of loaded trucks may be prompting the truck driver to speed in the later portions of many interchange ramps in order to mitigate the inevitable conflicts associated with merging. For ramps which entail a final sharp curve before the exit terminal, the increased-speed strategy threatens loss-of-control in this curve.

> 7) The AASHTO policy of accepting ramp downgrades as high as 8 percent may be ill-advised at sites on which a relatively sharp curve remains to be negotiated toward the bottom of the grade.
>
> 8) Curve warning signs were observed to be improperly selected or, in certain cases, placed an insufficient distance ahead of the curve, considering the guidelines of the Manual on Uniform Traffic Control Devices ...

Glines provides a review of the Ervin et al. report.(5) Although he did little more than summarize the report, it is noteworthy that publication in a large trade journal undoubtedly increased public awareness of and interest in the truck rollover problem.

Merritt provides a historical perspective of the use of the ball-bank indicator.(6) In 1935, maximum safe speed was defined as the minimum speed that drivers or passengers would feel a "side pitch outward" when negotiating a curve. This was later known as "driver judgment of incipient instability." In an effort to correlate this subjective opinion with physical factors, the Bureau of Public Roads requested experimental data. About 900 road tests involving "several hundred" volunteer drivers were submitted by "various" States and analyzed:(6)

> ... Using the basis side friction formula $e + f = 0.67V^2/R$, in which **e** represents the superelevation slope, **f** the side friction factor, **V** the velocity of the vehicle in miles per hour, and **R** the radius in feet, a side friction factor was calculated. The results of these tests were plotted and reported by Barnett. The range of side friction factors varied from a low of 0.07 to a high of 0.20, with an average of 0.16 for speeds between 20 and 60 miles per hour.
>
> There was no attempt to account for the differences in size, model, and weight of the vehicles used, variation in the condition of the tires, differences in pavement surfaces, or varying environmental and geographical factors at the test sites.
>
> Although no driver descriptions were reported, it is presumed that the drivers represented a cross-section of all ages, driving experiences, and capabilities. The general conclusion from the tests was that a side friction factor of 0.16 was considered to be an acceptable limit based on the judgment of the drivers that participated in the testing program. Still, there was no relationship of side friction with speeds or curves and driver discomfort that could be easily measured.

In 1937, tests indicated that a ball-bank instrument originally developed for aircraft use provided a means of quantifying side friction forces. It was found that a ball-bank reading of 10 degrees corresponded approximately to a side friction factor of 0.14 to 0.15.

Merritt continues his historical account of the use of the ball-bank indicator by reporting several additional 1940 studies which concluded that vehicle characteristics due to body roll were not considered significant. These tests were conducted on 1937 to 1940 model vehicles.

Merritt conducted his own survey of ball-bank usage during 1986 and 1987. Although all of the 36 States responding had established criteria for using the ball-bank indicator, a number of States indicated that they did not routinely use the ball-bank indicator for determining the maximum safe speed signing on curves.

In a 1940 TRB presentation, Mayer and Berry (in Merritt (6)) recommended ball-bank readings dependent on the operating speed. Table 1 presents their recommendations.

Table 1. Recommended ball-bank readings.

Speed	Recommended Ball-Bank Reading
20 mi/h (32 km/h) or less	14
30 mi/h (48 km/h) or less	12
Up to 50 mi/h (80 km/h)	10

Council and Hall report on large truck safety in North Carolina.(7) This is one of the only published accident studies reviewed that provides details on accident location and accident dynamics (i.e., rollover, jackknife):

> The results of this analysis indicated that twins and mobile home combinations were over-represented on Interstate, U.S., and when both classes were combined. The proportion of twins in ramp accidents was 1.7 times their proportion in the total Interstate accident sample. The "other semis" group were slightly over-represented on U.S. ramps. Neither type was over-represented when the classes were combined.

They looked at the percentage of ramp accidents which resulted in rollovers for each truck type. Twins were over-represented in rollovers on Interstates, where 30 percent of their accidents were rollovers. This is compared to 22 percent of all twin accidents in the total data sample. Flatbeds were in rollover accidents in 32.7 percent of the cases vs. 12 percent in all flatbed accidents and 4 of the 6 house trailer accidents on U.S. ramps resulted in rollovers.

In terms of the accident types which were most prevalent in these ramp accidents, the most prevalent types on both Interstate roads and U.S. roads were rear-end accidents involving a vehicle slowing down. Somewhat surprising at first glance was the fact that the percentage of multi-vehicle accidents on ramps was higher than the percentage of single-vehicle crashes. Close examination revealed that this resulted from the fact that many ramp-related accidents are occurring at the ends of the ramps where vehicles are interacting with other vehicles either at the stop sign at the end of a diamond interchange ramp, at the end or beginning of the ramp where the vehicle is leaving or trying to enter a line of traffic, or in the weaving section. In fact, it may well be that the major "ramp accident problem" is not related to the geometry of the ramp itself, but to the terminals.

This analysis was carried one step further when we looked at the type of accidents in which a given trailer was over-represented. Here, the analysis indicated that tankers appear to be over-represented in ran-off-road left and ran-off-road right accidents (meaning that their accidents do indeed occur on the ramp proper), flatbeds and twins are over-represented in overturn accidents, mobile homes are over-represented in rear-end slow and sideswipe accidents, and twins are also over-represented in angle crashes ...

STATE-OF-THE-PRACTICE REVIEW

This section reports on contacts made with State transportation officials to determine how they handle the truck rollover accident problem. The purpose of contacting State officials was to:

1. Determine the nature and extent of the truck rollover accident problem by examining accident data and hard copy accident reports.
2. Determine problem ramp identification procedures.
3. Identify active and passive treatments currently being used.
4. Identify potential sites to conduct the field studies.

Accident Data Analysis

Fifteen States were contacted to obtain data for truck rollover accidents occurring at ramps. Some of these States were not able to identify either the specific accident dynamic (i.e., rollovers) or the specific accident location (i.e., ramps) in their automated files and, therefore, could not provide the required information. Those States that could identify accident location and accident dynamics in their automated data bases were able to identify the entire population of truck rollover accidents at ramps statewide so that a sample could be selected. Other States identified applicable hard copy reports by selecting accidents from ramps with a known truck rollover accident problem. Since the sampling procedure necessarily varied from State to State, the subset of truck rollover accident reports is not a nationally representative sample and projections and/or extrapolations are not appropriate. The information extracted from the hard copy accident reports and other data obtained from the various States is described in the narrative that follows. Some of the data are presented in table 2.

State No. 1. This mid-Atlantic State provided a Staff Memorandum describing all overturned tractor trailer accidents that occurred from 1985 to 1987. There were 379 accidents, or about 126 annually. About one-sixth of these overturning accidents (23 per year) occur at ramps. This represents 5.7 percent of all tractor trailer accidents. About one out of seven of the reports had the type of cargo listed in the narrative but no patterns were apparent. There was no indication of a problem attributable to cargo shifting. The State highway personnel contacted did not know if cargo shifting was a major problem. Of the 379 accidents occurring over 3 years, 49 occurred at interchanges that had 2 or more accidents. Eleven interchanges had 2 or more accidents in 3 years.

State No. 2. This New England State provided a printout describing the overturned truck accidents that occurred during 1986. There were 223 overturning truck accidents; including 3 fatal, 84 injury, and 136 PDO accidents. Nearly half (46%) occurred during daylight while 32 percent occurred when it was dark with no overhead lighting. Most (99%) occurred when the weather was either clear or cloudy. State officials tentatively indicated that 35 of the 223 accidents may have occurred at ramps with potential

Table 2. Accident characteristics: truck rollover accidents at ramps.

	States								
	1	2	3	4	5	6	7	8	9
Approximate Number of Overturning Truck Accidents Occurring at Ramps (Annually)	23	35	88	24			11		
Percentage:									
Truck Type									
Straight Truck			40	38		0	11	18	0
Single Trailer			42	62		100	56	82	86
Double Trailer			10			0	33	0	14
Injury Severity									
Fatal	3	0	1	0		0	0	10	0
Injury	62	43	59	62		55	65	40	43
PDO	35	57	40	38		45	35	50	57
Light Condition									
Daylight		46	70	85		70	67	70	82
Dark-Lights		9	3	0		10	0	30	9
Dark-No Lights		43	23	15		20	33	0	9
Weather									
Clear		77	79	85		100	67	90	66
Rain		20	11	15		0	33	10	25
Snow		3	9	0		0	0	0	9
Road Surface									
Dry		69	72	83		95	76	90	66
Wet		29	16	7		5	24	10	25
Snow/Ice		3	12	0		0	0	0	9
Load Shifting			12	35		55	66	60	43
Struck Curb or Island		37	1	0		0	0	10	0

rollover problems. An interesting element available in this State's data is the category "hit curbing" as a vehicle action. Over one-third of the accidents involved the truck hitting a curb. It is not known if this was the cause of the overturning (i.e., the "off-tracking" problem reported by Ervin et al.[4]) or if an out-of-control truck merely "tripped" on the curb and overturned.

State No. 3. This mid-Western State provided printouts and a formatted diskette of a file of 396 large truck rollover accidents that occurred in freeway interchange areas from 1985 through 1987. The file contained 396 records representing about 88 truck overturning accidents annually at ramps. About 60 percent of the vehicles were tractor trailers while 40 percent were straight trucks. One-fifth of the tractor trailers were doubles. Most accidents occurred when it was daylight (70%) and when the roadway was dry (72%). The accidents were rarely fatal (1%) and typically involved personal injury (59%) or property damage only (40%). About 12 percent of the accidents involved a shifting cargo. In this State, shifting cargo is a coded data item so it was not necessary to rely on the accident narrative for this information. The 396 accidents occurred at 275 different locations, and 31 interchanges were identified that had at least 3 accidents during the 3-year period.

State No. 4. The Highway Patrol for this mid-Western State provided 24 hard copy accident reports for truck rollover accidents occurring within their jurisdiction during 1987. It was determined that only 11 of these accidents occurred on actual expressway ramps in situations that might be considered addressable by the treatments being developed in this project. The accidents were found to be mostly a daylight, clear weather, dry pavement phenomenon. In one-third of the cases, there was a specific mention in the accident narrative of cargo or load shifting being a probable cause of the accident.

State No. 5. This mid-Atlantic State compiled a list of accident locations from the 1986 accident data files where five or more accidents involved trucks. This list was used as a starting point to search for truck rollover problem locations. Detailed summaries of the accidents occurring at each location were scanned by accident type and type of vehicle involved to see if any of the accidents involved overturned trucks or other oversize vehicles. There was only one location that had overturned truck accidents and at this location there was only one accident. While one accident does not seem significant, the location itself, near a brewery, aroused suspicions based on experiences in other beer-producing areas relating to load shifting. Accident summaries were retrieved from the 1984 and 1985 data files and four other accidents in the vicinity involved the overturning of oversized vehicles. The hard copy accident reports were analyzed further.

State No. 6. This east coast State provided 27 accident reports representing truck rollover accidents from 1985, 1986, and 1987 from seven possible problem ramp locations. As shown in table 2, these accidents are also a clear weather, dry roadway phenomenon. It is especially interesting that over half of the accidents had cargo or load shifting mentioned in the narrative.

State No. 7. This Northern Pacific State provided a printout describing trucks overturning on ramps accidents. There were 17 accidents that occurred during 1987 and the first half of 1988. Most occurred when the roadway was dry (76%) and during daylight (65%). Two-thirds of the narratives in the hard copy accident reports specifically mention a load or cargo shift, frequently the load was logs or wood products.

State No. 8. This North Central State provided hard copy accident reports and summary data for 32 tractor trailer tipping accidents occurring at 6 major interchanges from 1973 to 1983. The vast majority (90%) occurred on dry pavement, none occurred on snow covered or icy roadways. Load shifting, especially pallets of beer, was frequently mentioned in the narrative.

State No. 9. This Western State provided a printout of the truck accident experience of a single interchange. In 9 years, the location experienced over 60 truck accidents. Seven were determined to be rollover accidents and subjected to further analysis. Again, the accident problem is predominantly a fair weather one and a relatively large percentage of the accidents involved a cargo shift (43%).

An additional analysis of the location of the rollover on the ramp was conducted. In those accident reports where an adequate site diagram was available, the point where the truck rolled over was estimated. The data are presented in table 3.

Table 3. Location of rollover accidents.

Location of Rollover	Percent of Accidents
First Quarter of Ramp	35
Second Quarter of Ramp	31
Third Quarter of Ramp	17
Fourth Quarter of Ramp	17

It appears that most trucks are experiencing problems upon entering the ramp or shortly thereafter.

An in-depth accident data analysis was done to obtain some additional insights into the nature of the truck rollover accident problem at ramps. The following conclusions appear reasonable:

1. Accidents appear to occur mostly during daylight hours. Since exposure data were not available for the accident locations, no general conclusions are appropriate. However, this factor should be considered when treatment characteristics, such as sign size, sign retroreflectivity characteristics, and flashing light size are being evaluated.

2. The accident problem appears to be predominantly a clear weather, dry roadway situation. This is not at all surprising since it is much more difficult to generate enough lateral g forces to roll a truck on a wet road than a dry one (depending on such factors as pavement coefficient of friction and superelevation).

3. Some State accident reports indicate that the truck rollovers are striking curbs. Whether this is resulting in tripping and rolling or if it is the result of off-tracking is not known.

4. Load/cargo shifting appears to be a problem in a large number of the accidents.

Problem Ramp Identification

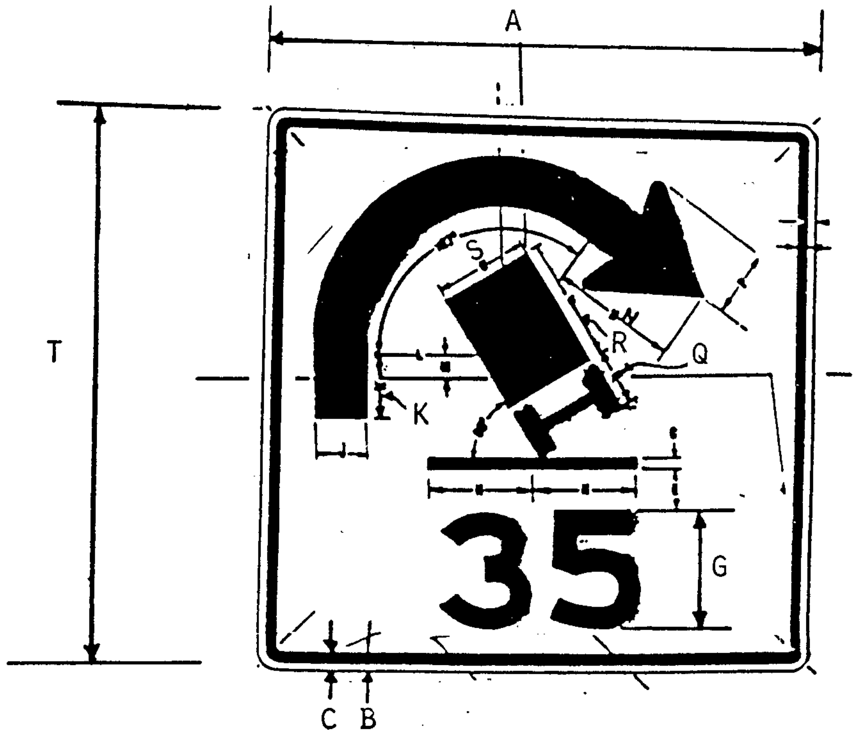
Although many of the States contacted have developed specific treatments for locations with truck rollover problems, none of the States has specific procedures or methods to identify the potential for a truck rollover accident problem. Although at least two States (Maryland and Pennsylvania) have standard drawings for signs, there are no known procedures for identifying problem locations except waiting for truck rollover accidents to occur. Since ramps with a serious truck rollover problem are relatively rare, this approach is not as irresponsible as it may first appear.

Current Treatment Approaches

Fifteen States were contacted to identify traffic control devices currently used at interchange ramps with histories of truck rollover accidents. Many of the States use variations of the standard MUTCD-specified traffic control devices discussed in the first section of this report. Some of the States indicate that they use larger than required signs or use additional chevrons, additional arrow signs, and/or additional delineators. Several of the States have tried innovative approaches at known problem locations. Although many of the individuals contacted felt that their innovative approaches were successful, none of the various systems was tested in a formal evaluation. The traffic control devices used by each of the States contacted are presented in table 4.

Table 4. Supplemental ramp signing used by 15 States.

State	Supplemental Ramp Signing
No. 1	• Rear silhouette of tipping truck, installed as 8 by 8 ft (2.44 by 2.44 m) square--not as a diamond. Text on sign - "Slow to ___"
No. 2	• "Trucks - Curve Tightens" (black on white--for mainline locations)
	• "Trucks Watch - Ramp Tightens" (black on yellow for interchange locations)
	• Rear silhouette of tipping truck, flashing "25" sign mounted overhead, black on yellow--one especially hazardous location
No. 3	• Rear silhouette of tipping truck with diagrammatic arrow and advisory speed (see figure 5)
	• "Trucks - Caution Ramp Tightens" word sign



TIPPING TRUCK

	DIMENSIONS (INCHES)																	
	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T
MD STANDARD	96	1¼	2¼	-	7	19½	29E	18	9	6	25	4	22	12	18	21	17	108

COLORS
LEGEND - BLACK
BACKGROUND - YELLOW (REFL)

MAY BE ORDERED FOR ANY SPEED.
MAY BE ORDERED WITH LEFT TURNING ARROW AND RIGHT TIPPING TRUCK.
MAY BE ORDERED IN EITHER DIAMOND OR RECTANGULAR SHAPE.
SEE W4 FOR ARROWHEAD DETAIL.

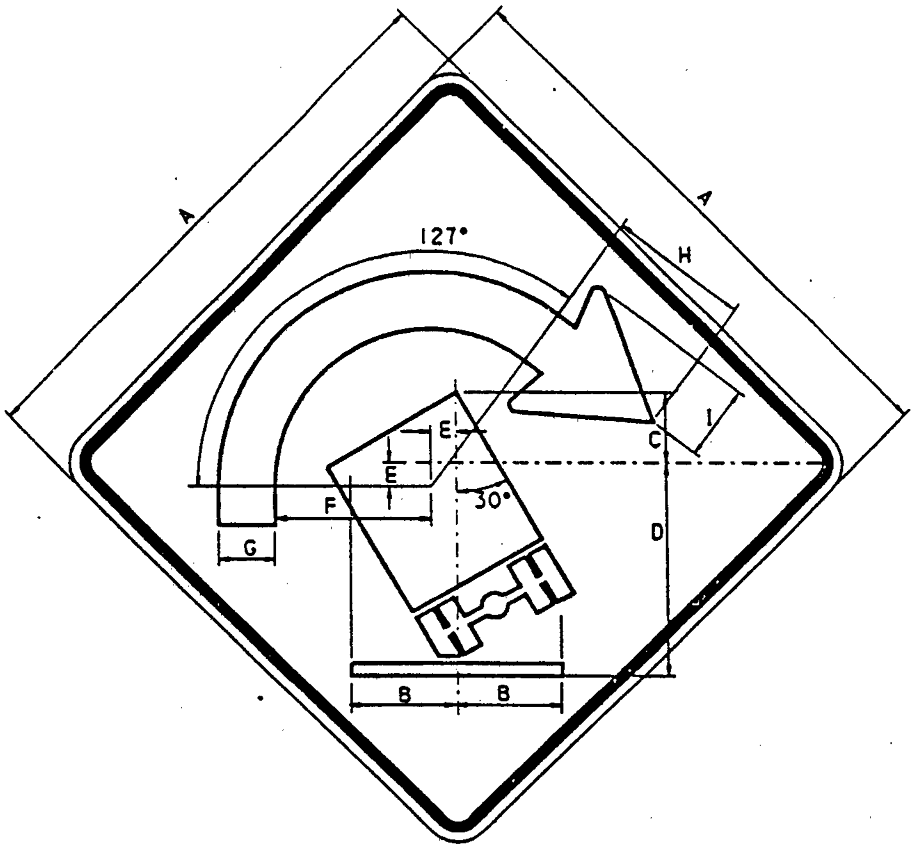
Figure 5. Maryland's truck ramp signing.

Table 4. Supplemental ramp signing used by 15 States (continued).

State	Supplemental Ramp Signing
No. 4	• Chevrons • Overhead (street) lighting at interchange • Scored concrete rumble strips • Flashing arrow panels
No. 5	• Chevrons • Additional delineations
No. 6	• Chevrons • Rear silhouette of tipping truck (48 by 48 in [1.22 by 1.22 m] mounted as diamond); no diagrammatic arrow showing ramp geometry and no advisory speed. Truck always shown tilting to the right (left wheels off ground) regardless of direction of curve
No. 7	• Larger advisory speed signs • Move advisory signing upstream
No. 8	• Additional ramp signing consisting of: - "Ramp Exit" speed signing, - chevrons, - horizontal alignment arrows, - diagrammatic signs, and - double turn warning signs. • Rumble strips • Amber flashers on advisory speed signs • Constructed 10-ft (3.05-m) outside paved shoulders, and cross-hatched with paint to improve visibility • "Trucks Too Fast When Flashing" - activated (by trucks) flashers used at accident location 10 years ago - site since redesigned • "Too Fast For Curve When Flashing" - (not truck specific) on sharp mainline curve

Table 4. Supplemental ramp signing used by 15 States (continued).

State	Supplemental Ramp Signing
No. 9	• Large chevrons
	• Large arrows
	• Ramp speed signs with diagrammatic arrows
	• Transverse lane striping
	• Additional delineators
No. 10	• Chevrons (W1-8)
	• Diagrammatic arrow of ramp with advisory speed inside arrow (black on yellow); no outline of truck
No. 11	• Rear silhouette of tipping truck with diagrammatic arrow (see figure 6)
	• "Trucks Caution Load May Shift"
	• Rumble strips
No. 12	• Rear silhouette of tipping truck with diagrammatic arrow and advisory speed - see Maryland
No. 13	• Chevrons
	• Large arrows
	• Large arrows with imbedded speed advisory
	• Rear silhouette of tipping truck (no diagrammatic arrow or advisory arrow)
No. 14	• "Ramp ___ MPH"
	• Rear silhouette of tipping truck (no diagrammatic arrow or advisory speed)
	• Large arrow sign (W1-6)
No. 15	• Large (5 by 5 ft [1.52 by 1.52 m]) 90^{o} turn arrows
	• "20 mph" with flashing yellow lights



COLOR: LEGEND AND BORDER — BLACK
BACKGROUND — YELLOW (REFLECTORIZED)

SIGN SIZE	DIMENSIONS									MAR-GIN	BOR-DER	BLANK STD.
	A	B	C	D	E	F	G	H	I			
48X48	48	9	5 15/16	18	2	13 1/2	5	11 3/4	6 3/8	3/4	1 1/4	B3-48

Figure 6. Pennsylvania's truck ramp signing.

THE "DESIGN-A-SIGN" EXPERIMENT

The "design-a-sign" experiment solicited opinions from more than 60 professional truck drivers about the use of special signs to warn them about ramps with rollover accident potential. The activity involved three specific components. First, we attempted to isolate those factors that truckers consider to be most relevant to identifying hazardous ramps; i.e., vertical curvature, superelevation (or absence of), compound curvature, roadway surface, lighting, and/or roadway width. Second, we asked the subjects to indicate how these ramp critical characteristics can be most effectively communicated to the approaching driver. Finally, we asked truck drivers to design a sign to warn of vehicle tipping hazards. More than 60 professional truck drivers were contacted at two truck stops, Truckers City located on I-70 in Frederick, Maryland and Speed Briscoe on I-95 just north of Richmond, Virginia.

Procedure

The interviewer approached groups of two to four drivers (and occasionally lone drivers) seated at tables in the cafeteria-dining area of the facility. Care was taken not to interrupt the subjects during a meal. The interviewer introduced herself, determined that the subjects were professional truck drivers, and explained the purpose of her visit. The interviewer explained that the purpose of the study was to develop/design a sign that would warn drivers of top heavy loads of potential rollover on dangerous ramps. She further explained that one of the approaches was to gain input from professional drivers because of their experience and possible expertise. The truckers were paid for their participation. The interviewer then presented a photo of a truck tilting sign currently located at Exit 54 on I-70 westbound in Frederick, Maryland. This was done to further focus on the type of problems being studied. Generally, the photo prompted comments, criticisms, and group discussion. Notes were made of any insightful or informative remarks.

The truckers were then asked to provide written responses to three specific questions and given a chance to indicate, by drawing, what they thought the truck tipping sign should look like. After completing the form, subjects joined the interviewer for a debriefing. Occasionally, the interviewer returned to the subjects at their table if it appeared everyone was finished at the same time. The debriefing interviews took a variety of formats, depending on the group dynamics. The interviewer encouraged the subjects to amplify their ideas with examples from their experience, stimulated group discussion, and probed for more information. Because not all of the subjects were comfortable verbalizing their thoughts, the debriefing was not an effective source of information from all of the subjects.

Results

A total of 61 truck drivers participated in the design-a-sign study. Table 5 presents biographical information provided by the subjects.

Table 5. Professional truck driving experience.

Years of Professional Truck Driving Experience:

1	1
1 - 2	8
3 - 5	8
6 - 10	8
11 - 20	21
Over 20	14
No Response	1
Total	61

Type of Trailer Being Pulled:

Enclosed	34
Flatbed	7
Car Carrier	3
Double	1
Tanker	1
Other, Not Specified	15

Personal Driving Experience With a Top Heavy Load:

Yes	58
No	2
No Response	1

Question one asked subjects to identify features that would warn drivers of top heavy loads of a dangerous ramp. They were also asked to rank order their responses. Recommended speed on the ramp, degree of sharpness to the ramp curve, and superelevation of the ramp were of prime importance. Additionally, many of the truckers wanted a general description of the ramp, to include lane width and weather effects (rain, snow, wind). The responses that appeared with some frequency were: direction of curve on ramp, curve length and/or degree, and knowledge of what existed at end of ramp; i.e., stop sign, yield, major or minor roadway.

Question two asked subjects how to make signs about rollover potential more understandable. One or more suggestions were recorded per driver. Twenty-one of the responses included using flashing lights (usually amber) on the road signs. Another 17 responses were for multiple signs with considerable advanced placement. Twelve subjects thought a symbol or illustration of a truck rolling over would be most understandable. Conversely, nine drivers thought large printed words of warning would best communicate the idea. Another five responses asked that much larger (than standard size) signs be used.

Question three dealt with making a sign believable to drivers, especially those not familiar with the roadway. Flashing lights topped the list with 12 responses. Six subjects thought that stating the number of accidents on the ramp that year would be most effective; four subjects wanted the sign to graphically show the consequences of load shifts or rollovers. Placing signs on both sides of the roadway and/or over the roadway, large signs, and activated warning lights for vehicles traveling too fast each received three votes. The following suggestions, while only mentioned by one or two subjects, were interesting:

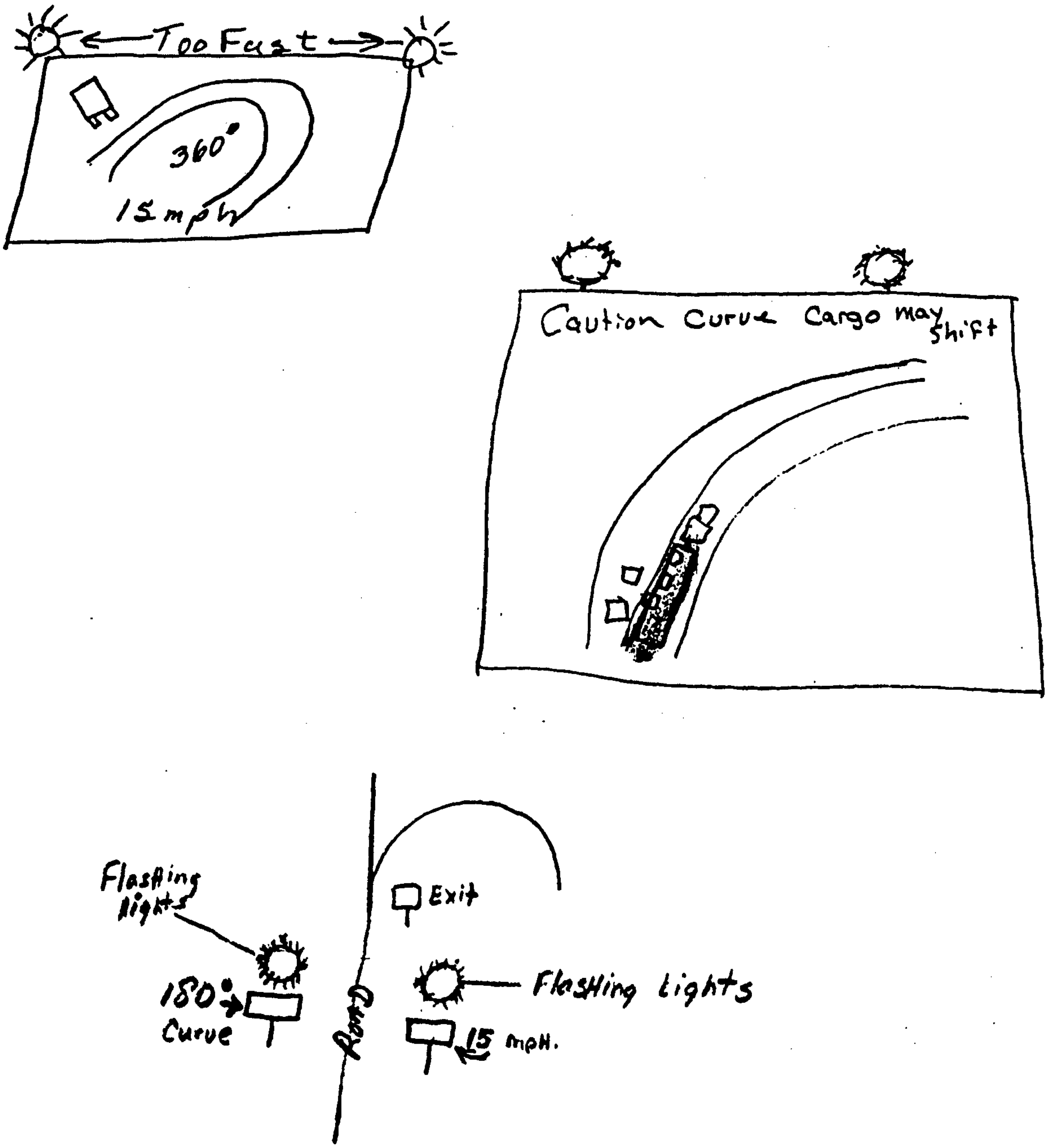
- State fines in dollar amounts for rollover citation.
- Stationary radar gun and camera.
- Rumble strip in deceleration lane.
- Video displays placed at truck stop and rest areas showing road hazards and potential dangerous ramps in the local area.

The last question asked subjects to draw/design their own sign. The majority of drawings incorporated some or all of the responses to the first three questions. Samples of these designs are shown in figure 7.

Because most of the participants often haul top heavy loads or loads that shift easily, they were very interested in the study. During the debriefing interviews, a pattern developed regarding the subjects' views. Multiple signs with sufficient advanced placement (1 mi [1.6 km]) were most important for their specific driving needs. Many emphasized their inability to slow down in preparation for difficult ramps. A number of drivers recommended an activated sign that would inform them if they were going too fast.

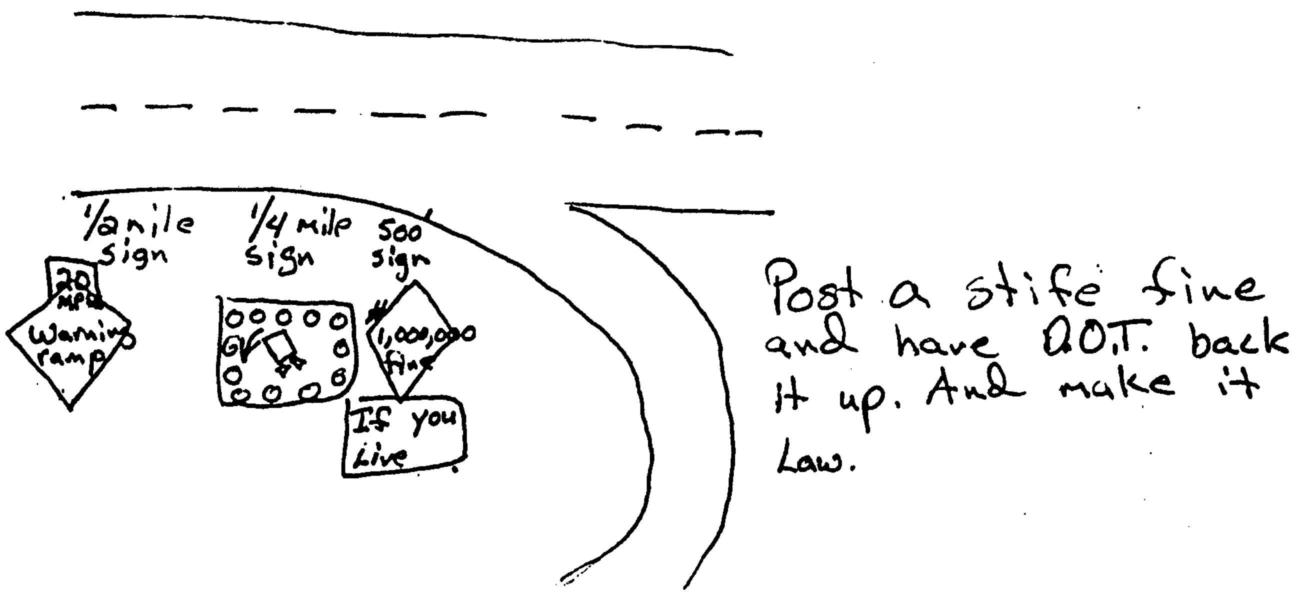
Well-lit signs, preferably with flashing amber lights, were regarded as of great importance in order to alert them. However, the lights should not be placed at "truck drivers eye-height" like lane closure arrow boards because they produce temporary night blindness. Subjects also noted that outer curbs often catch the rear tires and set a rollover in motion.

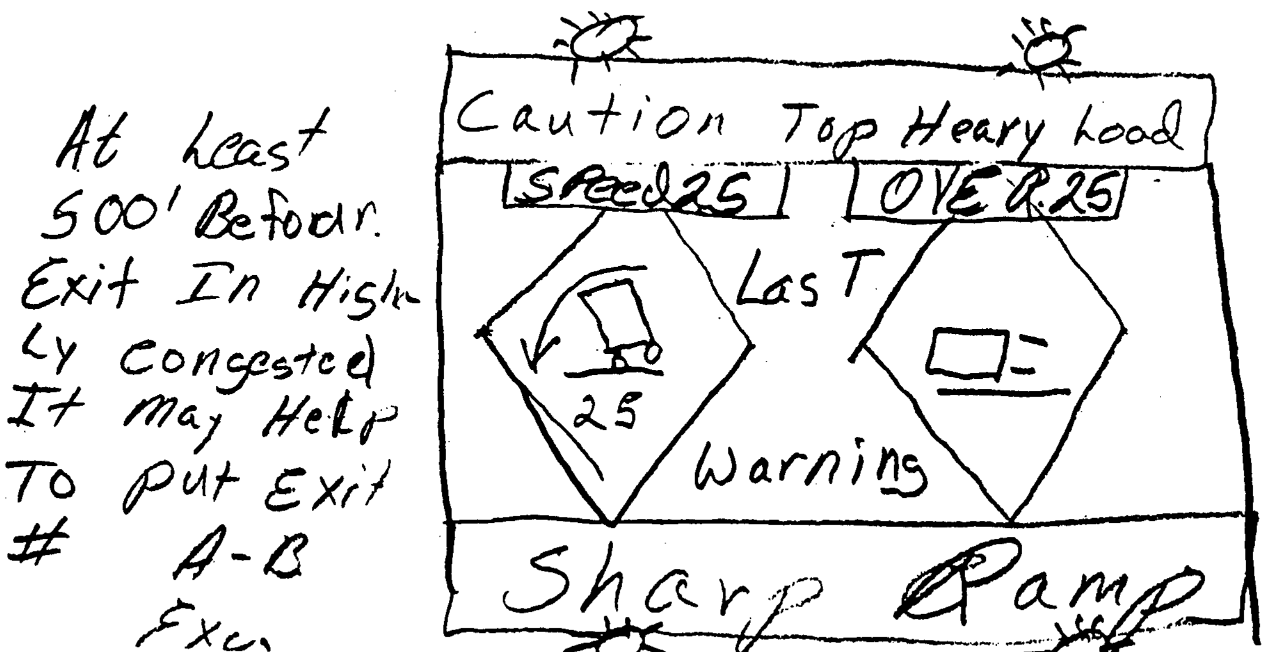
Mixed reviews came in regarding the use of symbols versus words to communicate on the sign itself. A truck tipping over and an illustration of the curve itself were the two most requested symbols. Words such as "caution," "warning," and "hazard" along with advisory speeds were also recommended.



Flashing lights; designs showing trucks rolling, tipping, or shifting loads: and degree of curvature were features frequently used by the subjects.

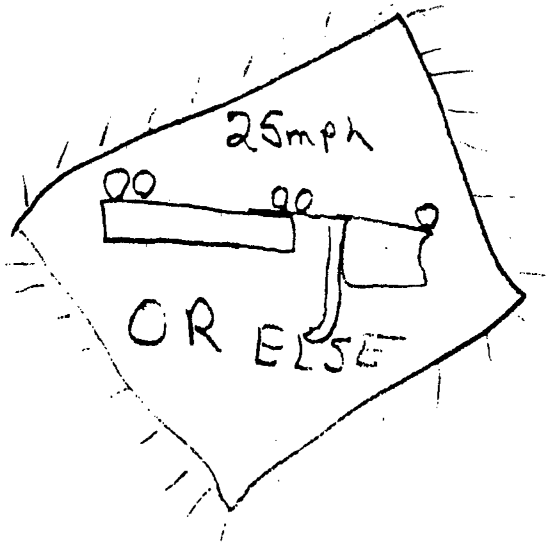
Figure 7. Samples of sign designs drawn by subjects.

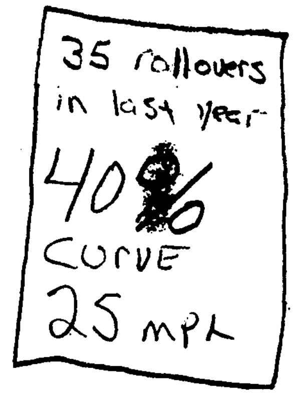




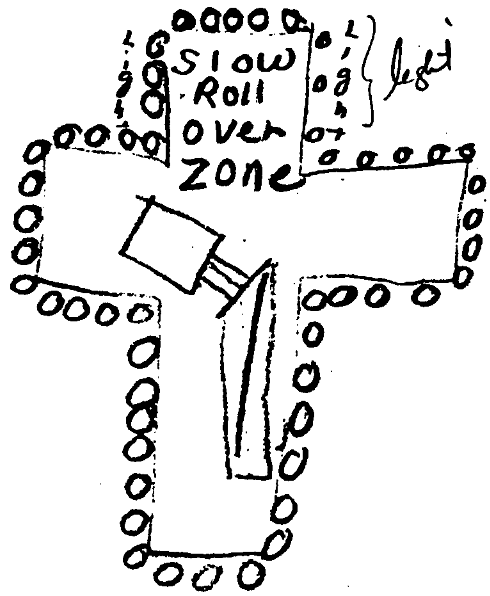
Specific advance warning locations and multiple messages were recommended.

Figure 7. Samples of sign designs drawn by subjects (continued).





Consequences, both graphically and statistically, were popular themes.



Our subjects were serious!

Figure 7. Samples of sign designs drawn by subjects (continued).

II. LABORATORY STUDIES

In the previous chapter, we noted that some States use word signs, some use symbol signs, and still others use hybrid signs to identify an interchange ramp with a truck rollover hazard. We also found that some of the truck drivers we talked to thought word messages were better while other truckers believed symbol signs should be used. The laboratory studies were five separate research efforts designed to identify the specific sign elements (i.e., words and/or symbols) and the specific sign format (layout of the specific sign elements) that can most effectively be used to warn truck drivers of such ramps.

This chapter addresses the following:

1. Should word signs be used to identify locations with actual or potential truck rollover problems? If so, what words are most effective at relating this message?

2. Should symbol signs be used to identify locations with actual or potential truck rollover problems? If so, what symbols are most effective at relating this message?

3. Should combinations of words and symbols be used? If so, what words and symbols are the most effective?

4. Should a rectangular or a diamond-shaped sign be used?

5. Where should the sign(s) be placed?

The laboratory studies identified the words and symbols to relate two critical sign message elements:

1. Target Group. The warning sign should target drivers of trucks with a high center of gravity/tendency to overturn.

2. Ramp Characteristics. The warning sign should provide information about the geometric characteristics of the location (superelevation, degree, direction, and/or length of curvature and perhaps information relative to an advisory speed).

LABORATORY STUDY NO. 1: ELEMENT IDENTIFICATION

Procedures

A paper-and-pencil test procedure was developed to provide ratings of specific sign elements, both words and symbols. Sign elements were tested that (1) helped identify the target group (top-heavy trucks), (2) warned truck drivers of the nature of the hazard (ramp characteristics), and (3) informed truck drivers of the potential consequences (rollover).

Truckers used a five-point rating scale to indicate how well the various signs/sign elements warn drivers about a dangerous ramp and, more specifically, how well they warn drivers of top-heavy trucks about a potential rollover hazard at a particular ramp. In addition, the test subjects indicated which signs they preferred and provided their recommendations for sign placement. Thirty-one sign formats consisting of various sign elements were tested. These included:

- 13 symbol signs.
- 10 word signs.
- 8 hybrid signs (both words and symbols).

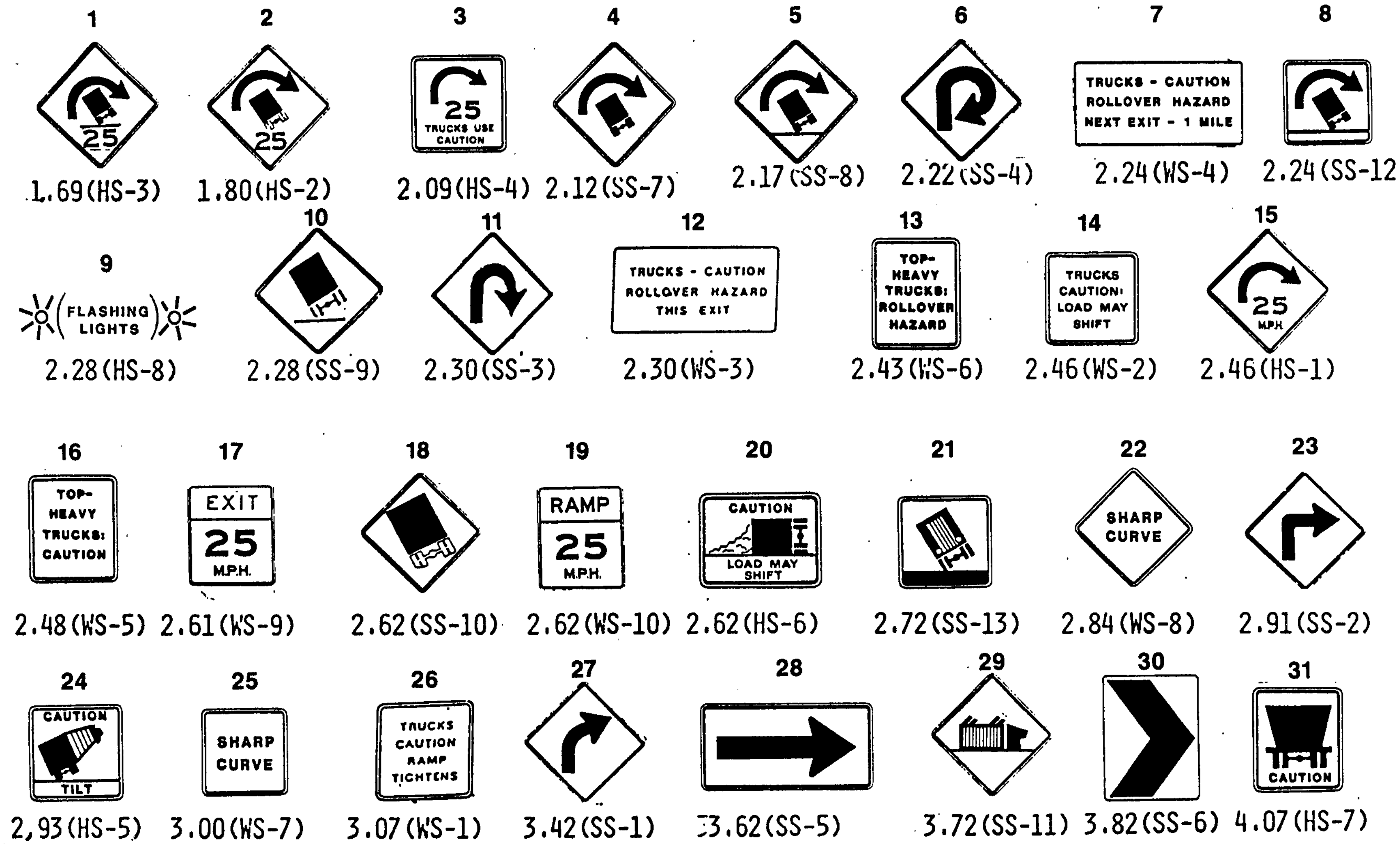
The test signs were developed from:

- Current State standard signs, with and without a horizon line and an advisory speed.
- Exit ramp, chevron, arrows, and curve signs from the MUTCD.
- Inputs from the trucker design-a-sign study.
- Combinations from the state-of-the-art and the state-of-the-practice reviews.

Ninety-five truckers served as subjects. Of these, 30 were from the Speed Briscoe Truck Stop near Richmond, Virginia and 65 were from the I-70 Truckers Inn near Frederick, Maryland. A total of 87 usable responses were completed.

Results

Figure 8 shows the truckers' ratings of how well each sign warns drivers of top-heavy trucks about a rollover hazard at a ramp. The candidate signs are listed in rank order and the mean rating for each sign using a five-point



Listed in rank order. Mean rating score shown below sign. Number in parentheses refers to each sign's code number.

Figure 8. Rating of how well each sign warns drivers of top-heavy trucks about a rollover hazard at a ramp (N = 89).

scale is shown (1=very good, 5=very bad). Hybrid sign HS-3 is the Maryland standard truck tipping sign consisting of the tipping truck symbol, a horizon line, a curve arrow, and the advisory speed. It was ranked first with a mean rating of 1.69. HS-2, the same sign without the horizon line, was ranked second with a mean rating of 1.80. HS-4, consisting of a curve arrow, an advisory speed, and the words "TRUCKS USE CAUTION," was ranked third. SS-7, the Pennsylvania standard sign without the horizon line, was ranked fourth, and the Pennsylvania standard sign (SS-8) was fifth.

An all-word advance warning sign (WS-4), "TRUCKS - CAUTION ROLLOVER HAZARD NEXT EXIT - 1 MILE," was ranked seventh and the all-word sign, "TRUCKS - CAUTION ROLLOVER HAZARD THIS EXIT" (WS-3), was ranked twelfth. The subjects also gave flashing lights a high rating.

It is possible that the subjects familiarity with the existing Maryland and Pennsylvania signs may have affected their ranking of the various signs. However, several reasonable conclusions are still possible. The tipping rear truck silhouette, a diagrammatic exit arrow, and an advisory speed appear to be preferred sign elements. None of the innovative design elements faired very well. The next laboratory study involved an effort to identify more innovative sign elements.

LABORATORY STUDY NO. 2: ADDITIONAL ELEMENT IDENTIFICATION

Procedures

In laboratory study no. 1, signs and sign elements were tested that were developed from current State standard signs, the MUTCD, and the trucker design-a-sign activity. Unfortunately, none of the sign elements being considered was particularly innovative. In an effort to identify innovative approaches, an "art" contest was conducted concurrently with laboratory study no. 1. Contest flyers and attention-getting posters were displayed in art supply stores, store windows, and on art department bulletin boards at several college campuses in Virginia, Maryland, and Michigan. Despite the cash incentives, the response rate was disappointing. Fewer than 20 entries were submitted. The most promising of these new design concepts were selected for additional testing.

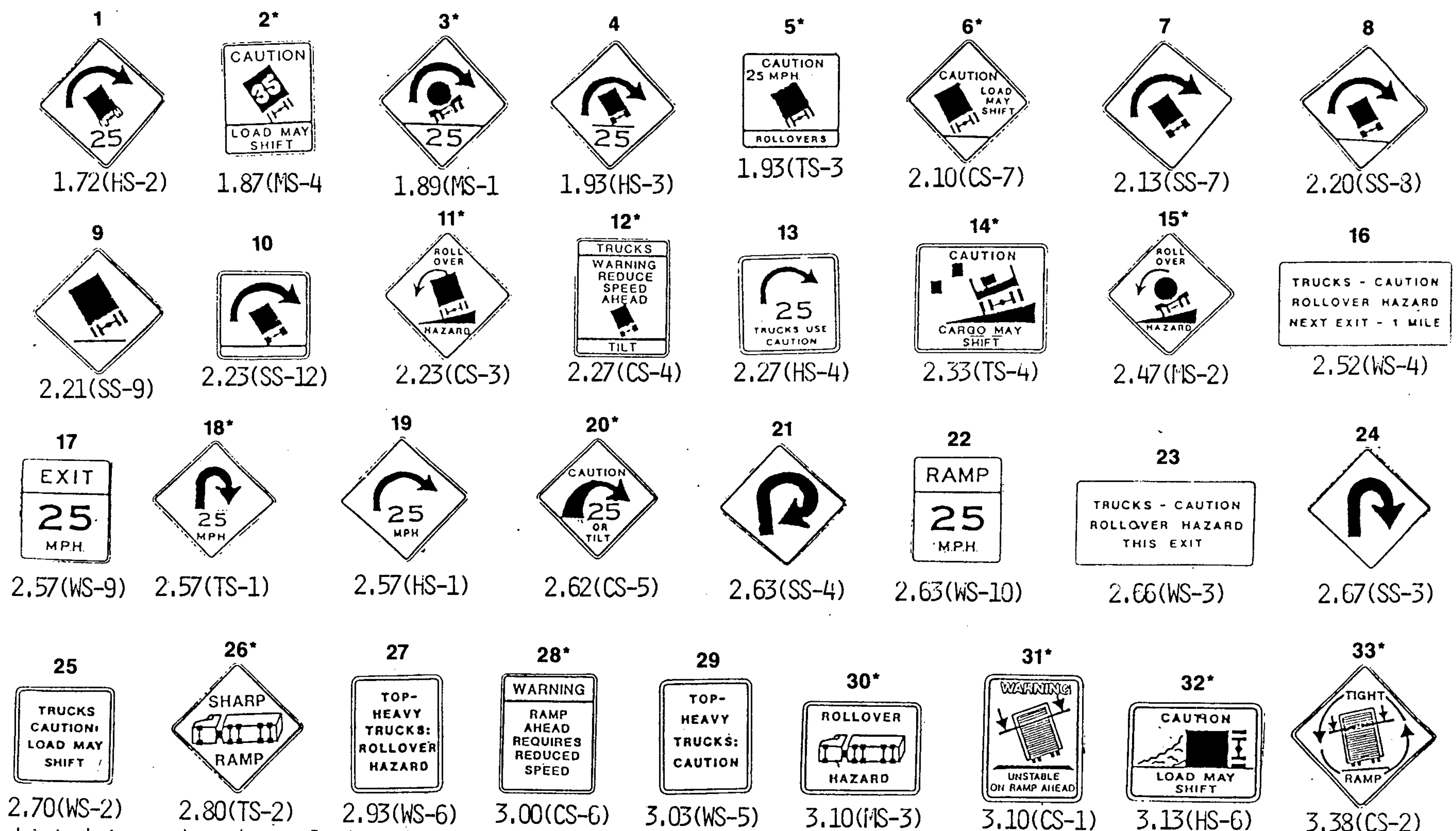
Thirty truckers used the same five-point rating scale used in laboratory study no. 1 to indicate how well the various signs/sign elements warn drivers about a dangerous ramp. Thirty-three sign formats were tested. They included 18 signs that rated highly in laboratory study no. 1 and 15 new designs and formats.

Results

Figure 9 shows the truckers' ratings of how well each sign warns drivers of top-heavy trucks about a rollover hazard at a ramp. The candidate signs are listed in rank order and the mean rating is shown for each sign using a five-point scale (1=very good, 5=very bad). Hybrid sign HS-2, consisting of a tipping truck, a diagrammatic arrow, and the advisory speed was ranked first. A new design (MS-4), containing a tipping truck with the advisory speed on the truck and the words "CAUTION" "LOAD MAY SHIFT" was ranked second. Another new design (MS-1), consisting of a tipping tanker, a diagrammatic arrow, a horizon line, and the advisory speed, was ranked third. The fourth-ranked sign was the Maryland truck tipping sign (HS-3) that was ranked first in laboratory study no. 1. The relative performance of the various sign formats in laboratory study no. 1 and laboratory study no. 2 is shown in table 6. Most of the more highly rated signs in laboratory study no. 1 also rated highly in laboratory study no. 2. Eight of the top 16 signs tested were new formats not tested in laboratory study no. 1. The strong performance of these new hybrid formats supports the use of such word messages as "CAUTION," "ROLLOVER HAZARD," and "LOAD MAY SHIFT," as well as the use of tipping trucks, advisory speeds, and diagrammatic arrows.

Table 6. Relative performance of candidate sign formats.

Sign Format	Laboratory Study No. 1 (N = 89)	Laboratory Study No. 2 (N = 30)
HS-2	2	1
MS-4	Not tested	2
MS-1	Not tested	3
HS-3	1	4
TS-3	Not tested	5



Listed in rank order. Rank order shown above sign. Mean rating score shown below sign. Number in parentheses refers to each sign's code number.

*Indicates sign formats not listed in laboratory study no. 1.

Figure 9. Rating of how well each sign warns drivers of top-heavy trucks about a rollover hazard at a ramp (N = 30).

Table 6. Relative performance of candidate sign formats (continued).

Sign Format	Laboratory Study No. 1 (N = 89)	Laboratory Study No. 2 (N = 30)
CS-7	Not tested	6
SS-7	4	7
SS-8	5	8
SS-9	10	9
SS-12	8	10
CS-3	Not tested	11
CS-4	Not tested	12
HS-4	3	13
TS-4	Not tested	14
MS-2	Not tested	15
WS-4	7	16

LABORATORY STUDY NO. 3: SIGN FORMAT

Procedures

Similar signs with certain common elements performed comparably in laboratory study no. 1 and laboratory study no. 2. What was not known is how important each specific element is to the overall performance of the sign. Also unknown was whether the actual layout of the various elements was the most effective layout possible.

Laboratory study no. 3 was conducted to determine the specific sign elements that make up the most effective sign format. An innovative unstructured response scenario was developed to allow subjects to select specific sign elements and create the format of their own sign. The sign elements were made from a sticky-backed paper material and could be applied and reapplied. Subjects selected the sign elements they preferred and arranged the elements on a blank sign in whatever position they wished. The 21 sign elements included in the test were taken from the most highly rated signs in laboratory study no. 1 and laboratory study no. 2. Subjects were 44 truckers from truck stops in Maryland and Virginia; 43 of the subjects (98%) claimed to have experience pulling top-heavy loads.

Results

The following general conclusions were suggested by the truckers we tested:

- An advisory speed should be provided (98%).
- Signs should be located at the exit ramp <u>and</u> before the exit (98%).
- Both words and symbols should be used (93%).
- An arrow indicating roadway curvature should be provided (89%).
- The signs should be yellow with black lettering (73%).
- The signs should be diamond shaped (55%).

Figure 10 shows the percentage of truckers selecting each sign element for use on a sign located <u>at the exit ramp</u>. The sign elements are listed in order, with the most frequently selected elements first. The first two-digit number is the identifying code for each element and the second number indicates the percentage of truckers selecting that element. The elements selected most frequently were the word legends "ROLLOVER HAZARD" and "TRUCKS CAUTION," selected by 75 percent and 57 percent of the truckers, respectively. All of the truckers (100%) selected one of the truck rearview silhouettes (codes 13 through 21) and 66 percent selected one of the diagrammatic arrows (codes 10, 11, or 12). The word legend "TRUCKS CAUTION" was used by 57 percent and "THIS EXIT" was used by 55 percent of the truckers.

Figure 11 shows the percentage of truckers selecting each sign element for use on an advance warning sign located <u>before the hazardous exit ramp</u>. Again, the words "ROLLOVER HAZARD" (73%) and "TRUCKS CAUTION" (61%) were the most frequently selected elements. However, for the advance warning sign, the legends "1 MILE" (60%) and "NEXT EXIT" (50%) were used more than either the advisory speed (30%) or the most popular diagrammatic arrow (23%). Most of the truckers (93%) used one of the truck rearview silhouettes (codes 13 through 21) in their advance warning signs.

LABORATORY STUDY NO. 4: MEANING/PREFERENCE TESTING

Procedures

In laboratory studies no. 1 and no. 2, subjects used rating scales to identify a traffic sign that would relate a specific message; i.e., warn drivers of top-heavy trucks about a potentially hazardous ramp. In each test, we explained the sign message we wanted to convey and asked for assistance.

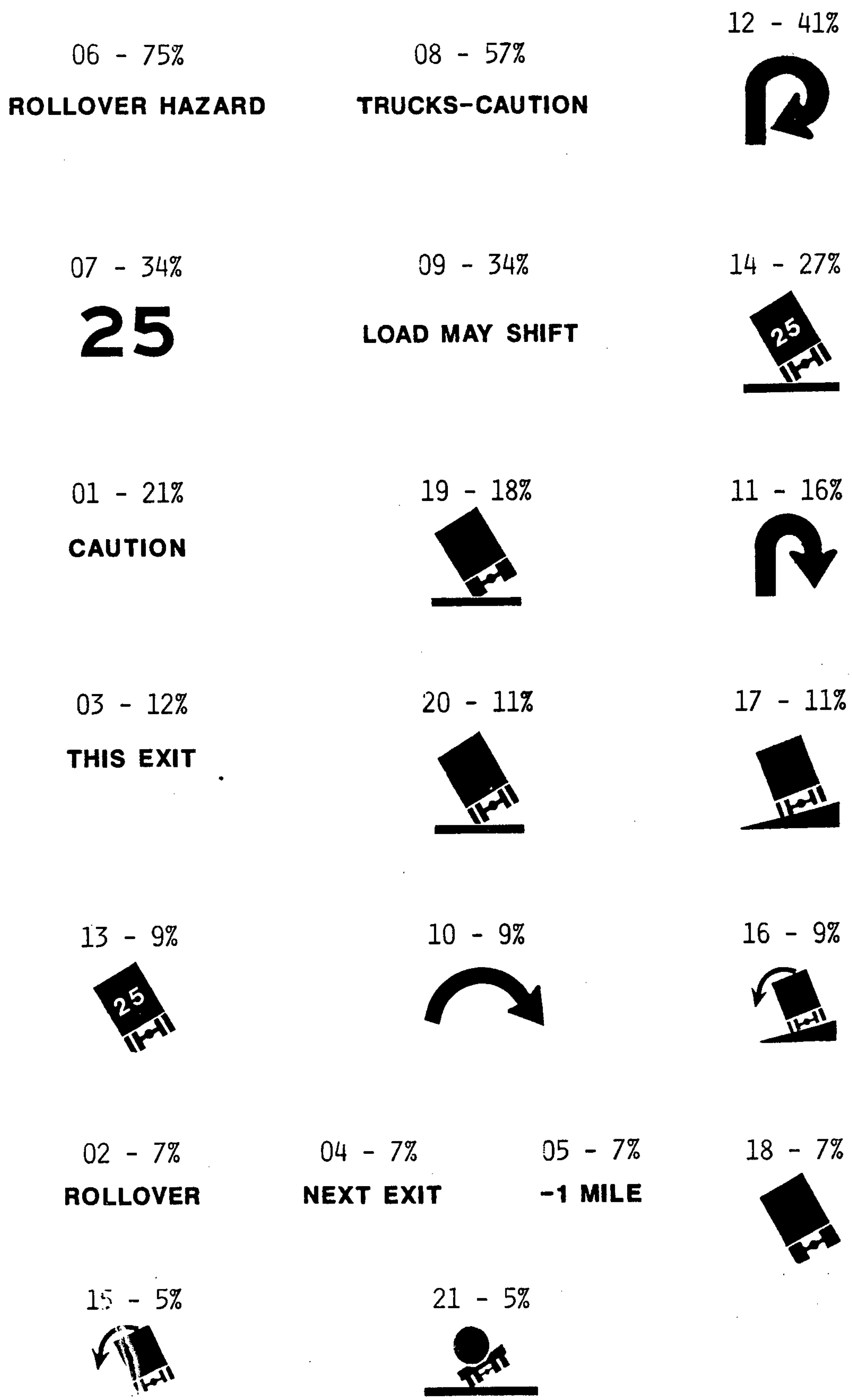


Figure 10. Laboratory study no. 3 – Sign elements selected for use at the ramp (in order by percentage).

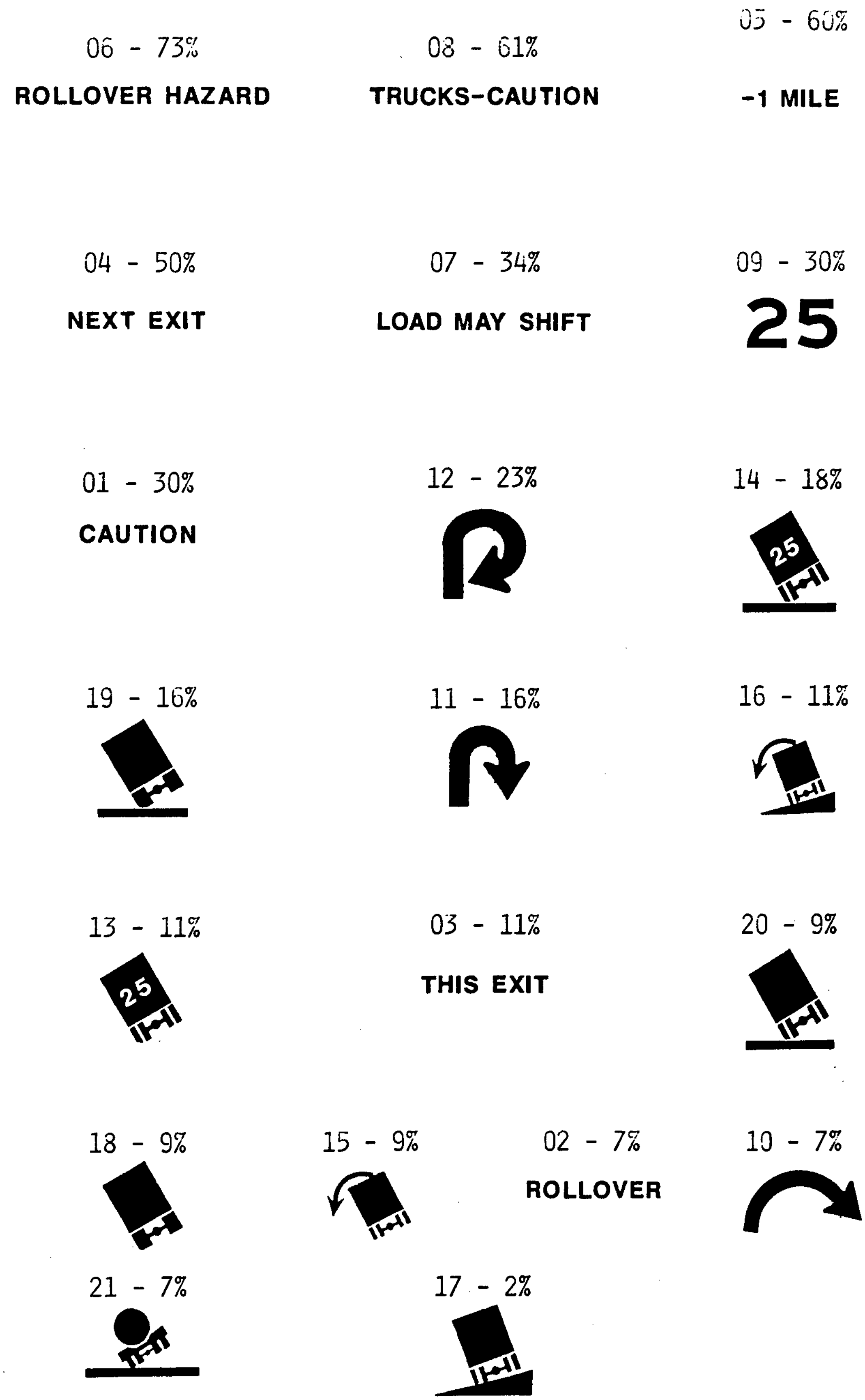


Figure 11. Laboratory study no. 3 – Sign elements selected for use on advance warning sign (in order by percentage).

In laboratory study no. 4, we asked subjects what they thought a sign meant and provided for an open-ended response.

A 15-page test pamphlet was prepared depicting candidate signs in an artist's rendition of a freeway exit (or an advance location). To control for any potential ordering effects, the 16 test signs and 8 distractor signs were divided into two separate tests with two different random orders for each test. The test signs were selected based on the results of the previous laboratory studies. The signs tested included the following sign elements:

- A tipping truck.
- A diagrammatic arrow.
- The words "ROLLOVER HAZARD."
- Advisory speed limits.

In addition, several advance placement sign formats were tested. For each sign, subjects were asked to provide:

- Sign meaning - an open-ended response.
- A rating of sign effectiveness - a subjective rating of how well the sign works.
- Action response - what would you do if you saw the sign while hauling a regular load.
- Action response - what would you do if you saw the sign while hauling a top-heavy load.

Sixty truckers and 27 nontruckers were tested at Maryland and Virginia truck stops.

Results

Figure 12 shows the truckers' responses to the experimental question - What does this sign mean? The responses were categorized into those related to rollover hazard (second column) and those related to slowing down or reducing speed (third column). The last column shows the combined percentage of responses related to both rollover hazards and slowing down. The sign formats tested are listed in rank order based on the last column percentage. The results indicate that the first 10 signs listed conveyed the intended message

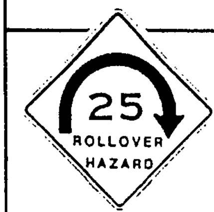
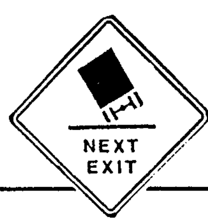
SIGN	SIGN CODE	PERCENT OF SUBJECT RESPONSES RELATING TO		
		ROLLOVER HAZARD	SLOWING DOWN	BOTH ROLLOVER OR SPEED RELATED
	T-3	30%	57%	87%
	T-21	33%	50%	83%
	T-19	30%	53%	83%
	T-16	43%	37%	80%
	T-6	37%	43%	80%
	T-7	37%	43%	80%
	T-12	23%	57%	80%
	T-1	50%	27%	77%
	T-24	43%	33%	76%
	T-4	30%	43%	73%
	T-10	23%	43%	66%
	T-9	33%	33%	66%

Figure 12. Sign meaning study: what the sign means.

quite well. It is also apparent that truckers understand that the tipping truck symbol means a rollover hazard is present.

Figure 13 shows the truckers' reported action responses to two important questions:

- What would you do if you saw this sign when you were hauling a regular load?
- What would you do if you saw this sign when you were hauling a top-heavy load?

The truckers' written responses were categorized into three general groups:

1. Slow to a "safe" speed.
2. Slow to the advisory speed.
3. Slow to less than the advisory speed.

The signs are listed in the same order as they were in figure 12. It is apparent that truckers believe that signs which combine an advisory speed with a tipping truck (and/or the words "ROLLOVER HAZARD") and a diagrammatic curve mean that drivers of top-heavy loads should slow to less than the advisory speed. The truckers generally indicate they would comply with the advisory speed if driving a regular load and would slow to less than the advisory speed if driving a top-heavy load. Sign codes T-3, T-19, T-16, T-12, and T-1 had the highest percentage responses combining these two categories.

Figure 14 shows the truckers' ratings of sign effectiveness. Subjects were asked to rate the signs on a five-point scale (1=very good, 5=very bad). Truckers gave the highest mean ratings (1.90) to the two signs with an arrow, a tipping truck, and the advisory speed (T-19 and T-16). The next highest score (2.24) went to T-12, which combined the truck, the arrow, the advisory speed, and the legend "ROLLOVER HAZARD."

To determine how well nontruckers understand the various signs, we tested 27 drivers who were not professional truck drivers. We hoped that nontruckers would realize the signs were intended specifically for drivers of top-heavy trucks that might roll over and that they, as drivers of cars or vans, do not necessarily need to heed the warning. Figure 15 shows the responses for the nontruckers tested. A relatively high percentage of the subjects indicated

SIGN CODE	Hauling TOP-HEAVY Load			Hauling REGULAR Load		
	Slow to "Safe" Speed	Slow to Advisory Speed	Slow to less than Advisory Speed	Slow to "Safe" Speed	Slow to Advisory Speed	Slow to less than Advisory Speed
T-3	13	20	50	17	47	17
T-21	53	0	30	57	3	6
T-19	27	3	60	33	37	23
T-16	23	0	60	40	27	23
T-6	53	10	17	73	13	3
T-7	53	3	27	73	3	6
T-12	20	17	50	27	40	20
T-1	23	6	53	33	30	23
T-24	53	0	17	53	3	3
T-4	23	20	33	27	40	10
T-10	40	0	20	67	3	0
T-9	47	0	23	67	6	3

Figure 13. Sign meaning study: percentage of truckers reporting specific "action" responses.

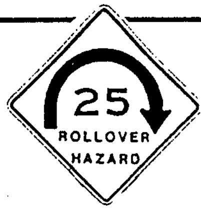
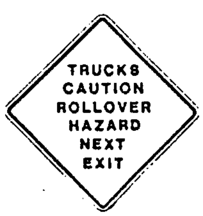
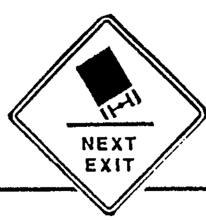
SIGN	SIGN CODE	Percent of Subjects Rating Sign					Mean	Std. Dev.
		Very Good (1)	Good (2)	Fair (3)	Poor (4)	Very Poor (5)		
	T-3	28	35	24	10	3	2.28	1.10
	T-21	17	38	41	3	0	2.31	.81
	T-19	27	60	10	3	0	1.90	.71
	T-16	30	50	20	0	0	1.90	.71
	T-6	23	37	30	7	3	2.30	1.02
	T-7	17	38	31	14	0	2.41	.95
	T-12	28	45	10	10	7	2.24	1.19
	T-1	25	43	14	4	14	2.39	1.32
	T-24	24	38	24	14	0	2.28	1.00
	T-4	7	37	22	7	26	3.07	1.36
	T-10	24	21	31	10	14	2.69	1.34
	T-9	23	40	20	13	3	2.33	1.09

Figure 14. Sign meaning study: ratings of sign effectiveness.

SIGN CODE	Responses With "roll," "overturn" "cargo shift,"etc.	Action Responses "slow down" "reduce speed,"etc.
T-3	23%	84%
T-21	54%	69%
T-19	46%	85%
T-16	54%	92%
T-6	23%	85%
T-7	46%	61%
T-12	31%	69%
T-1	31%	54%
T-24	69%	85%
T-4	39%	62%
T-10	46%	54%
T-9	23%	54%

Figure 15. Sign meaning study: nontruckers' responses.

responses with "roll," "overturn," or "cargo shift," in some of the sign formats (T-24=69%, T-16 and T-21=54%). However, when asked how they would react when they saw each sign, most of the nontruckers indicated they would slow down or reduce their speed. This response could produce the undesirable effect of having all traffic slow excessively at ramps that represent a rollover hazard only to top-heavy trucks.

LABORATORY STUDY NO. 5: LEGIBILITY TESTING

Procedures

It was concluded that several of the candidate signs performed equally well in terms of subject understanding and preference. The test signs that performed best include the following elements:

- Rear silhouette of a tipping truck.
- Diagrammatic curve arrow.
- Advisory speed limit.
- Word legend - "ROLLOVER HAZARD."
- Word legend - "TRUCK CAUTION."

However, there was concern that some of the candidate signs were "too busy" and might be difficult to see at a distance. The sign legibility testing was designed to determine the relative detection distances of the at ramp test signs, the advance test signs, and a selection of standard symbol and word signs from the MUTCD. The standard signs served as "distractor" stimuli as well as a gauge to determine the relative performance of the new test signs.

The Visual Acuity Tester (VAT) was designed and fabricated to test the various signs on a sample of truck drivers recruited in truck stops. The VAT is similar to a testing instrument previously used by Dewart and Ells to test the legibility distance of various highway signs.[8,9] The VAT is a light, portable box made of 0.0625 aluminum sheet. The box is 8 in (20.5 cm) wide by 8 in (20.5 cm) high by 72 in (184.6 cm) long. A viewing hole 2-1/4 in (57.7 cm) in diameter was provided in one end. A headrest was provided to restrict the subject from getting closer than 14 in (35.9 cm) from the viewing hole. Stimulus materials consisted of reduced color photographic prints of the candidate signs. During pilot testing, it was found that the 36 by 36 in (92.3 by 92/3 cm) signs needed to be reduced to a stimulus size of 0.250 by

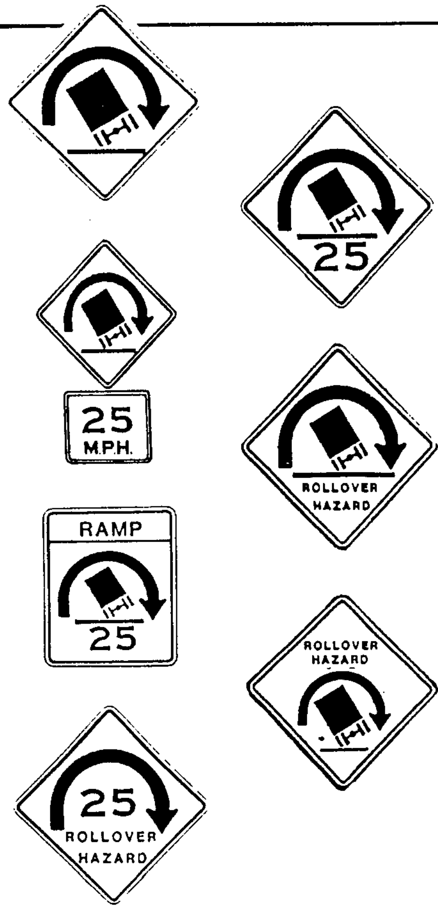
0.250 in (9.4 by 9.4 cm) to be barely perceptible at the longest distance available by those subjects with the best visual acuity. Other size signs, i.e., 24- by 24-in (61- by 61-cm) placards, were reduced proportionally to maintain the same relative scale. Distractor stimuli were similarly prepared from other commonly used symbol signs. The stimuli were placed, one at a time, on a lighted, movable platform at the far end of the VAT. Illumination was provided by a 12-volt, 18-watt bulb with an integral reflector that was placed 7 in (180 cm) in front of the stimulus. The subjects were instructed to turn a handle, which brought the sign closer. They were instructed to stop when they could clearly see any portion of the sign. After reporting this information, they were instructed to proceed until they could see more of the sign. In each instance, the subjects were asked to report what they could see and what they thought the sign meant. The experimenter recorded each response and the distance between the subject and the stimulus when each response was made.

A total of 33 professional truck drivers were tested at two truck stops, one near Hagerstown, Maryland and another north of Richmond, Virginia. They had an average of 15.4 years of professional truck driving experience. They were paid to participate in the study. Each subject was shown a total of 30 signs; 7 at ramp test signs, 3 advance test signs, and 20 distractor signs.

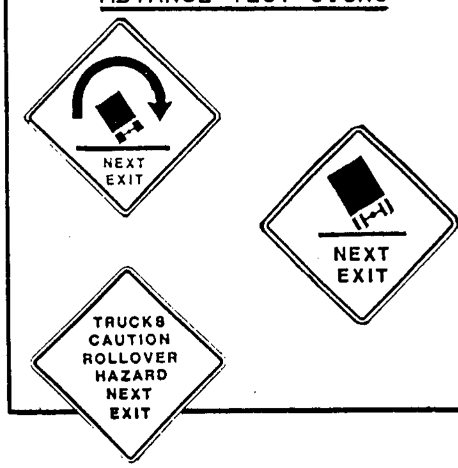
Results

The relative detection distances for the 7 at ramp signs, the 3 advance test signs, and the 7 selected distractor signs are given in figure 16. The sign detection distances are shown in the two columns on the right side of the figure. The column labeled "meaning" shows the average distance at which the subjects were able to identify the meaning of the sign. The column labeled "read" shows the average distance at which the subjects were able to read the word signs or read a word component of a hybrid sign. Test sign T-21 had the best meaning detection distance (58 in [148.7 cm]). Test sign T-16, the Maryland tipping truck sign, had a nearly identical meaning detection distance, but the advisory speed was not readable until a distance of 29 in (74.3 cm). Test sign T-25 also had a very good meaning detection distance (50 in [128.2 cm]), but the larger number on the separate advisory speed plate

AT RAMP TEST SIGNS



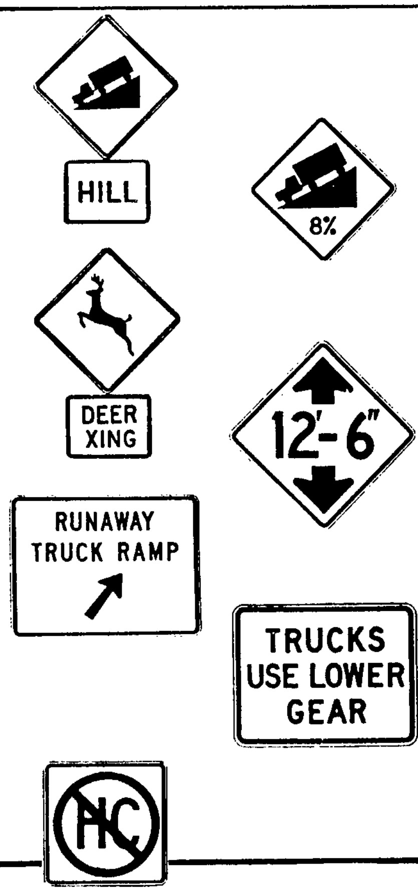
ADVANCE TEST SIGNS



	SIGN CODE	SIGN DETECTION DISTANCE	
		MEANING	READ
AT RAMP TEST SIGNS	T-21	58"	N/A
	T-16	56"	29"
	T-25	50"	46"
	T-24	45"	No
	T-26	40"	35"
	T-7	32"	No
	T-3	No	No
ADVANCE TEST SIGNS			
	T-6	36"	No
	T-9	28"	14"
	T-10	No	No

*Metric conversion: 1 in = 2.54 cm

Figure 16. Relative sign detection distances.



SELECTED DISTRACTORS	SIGN CODE	SIGN DETECTION DISTANCE	
		MEANING	READ
	D-11	65"	37"
	D-2	53"	No
	D-10	51"	39"
	D-3	50"	46"
	D-15	47"	44"
	D-18	25"	25"
	D-21	14"	16"

*Metric conversion: 1 in = 2.54 cm

Figure 16. Relative sign detection distances (continued).

could be read at 46 in (117.9 cm). Thus, it appears that T-25 is the best overall at ramp test sign.

The T-6 advance test sign had the best meaning detection distance (36 in [92.3 cm]). Sign T-9, the same sign without the diagrammatic arrow, had a very similar meaning detection distance (28 in [71.8 cm]). The T-10 word sign performed very poorly. Because of concerns involving placing a diagrammatic arrow on a tangent section well in advance of the exit ramp, it appears that T-9 is the most promising candidate for the advance sign position.

The data on some of the distractor signs are also given in table 7. Note that only one of the standard symbol signs, the hill sign (W7-1), had a slightly better detection distance (65 in [166.7 cm]) than the best two truck tipping signs. Two very highly detectable standard symbol signs, the low clearance sign (D-3) and the deer crossing sign (D-10), performed slightly worse than the best two new signs.

SUMMARY OF LABORATORY RESULTS

The laboratory tests indicate several different sign formats perform equally well in terms of subject understanding and performance. The test signs that perform best include the following elements:

- Rear silhouette of a tipping truck.
- Diagrammatic curve arrow.
- Advisory speed limit.
- Word legend - "ROLLOVER HAZARD."
- Word legend - "TRUCK CAUTION."

However, the legibility testing strongly supports the use of symbolic signs using the rear silhouette of a tipping truck, a diagrammatic curve arrow, and an advisory speed placard.

The laboratory studies also clearly indicate the desirability of using advance signing located well before the ramp and the desirability of using flashing lights in combination with these signs.

III. FIELD TESTS

This chapter describes the results of three field studies conducted to test the most promising sign elements and formats to identify interchange ramps that are prone to cause a vehicle with a higher center of gravity to lose control and overturn.

The basic experimental paradigm was that of a Before/After with control group design. The experimental devices were deployed at one ramp while there was no treatment at a similar nearby ramp. Before and after speed data were collected at both ramps. One testing location was at the I-70/I-81 interchange near Frederick, Maryland, and the other was at the I-95/US-17 interchange near Fredericksburg, Virginia.

The three field studies involved the following signing conditions:

- FIELD STUDY I: Change in advisory speed signing, replacement of existing curve warning sign with truck tipping sign, and replacement of standard gore sign with a diagrammatic arrow (Maryland).
- FIELD STUDY II: Replacement of existing curve warning sign with truck tipping sign, addition of flashing beacons, addition of advance warning sign (Virginia).
- FIELD STUDY III: Addition of flashing beacons to existing truck warning sign, addition of advance warning sign (Maryland).

Before proceeding with a discussion of each of the three field studies, the following topics will be addressed:

- Data collection locations.
- Collection of speed data.
- Collection of truck weight and load data.

DATA COLLECTION LOCATIONS

The I-70/I-81 interchange in Maryland is a full cloverleaf design with collector distributor roadways. There were high accident rates at two of the four cloverleaf ramps. Figure 17 shows accidents that occurred at the site from 1985 through 1987.

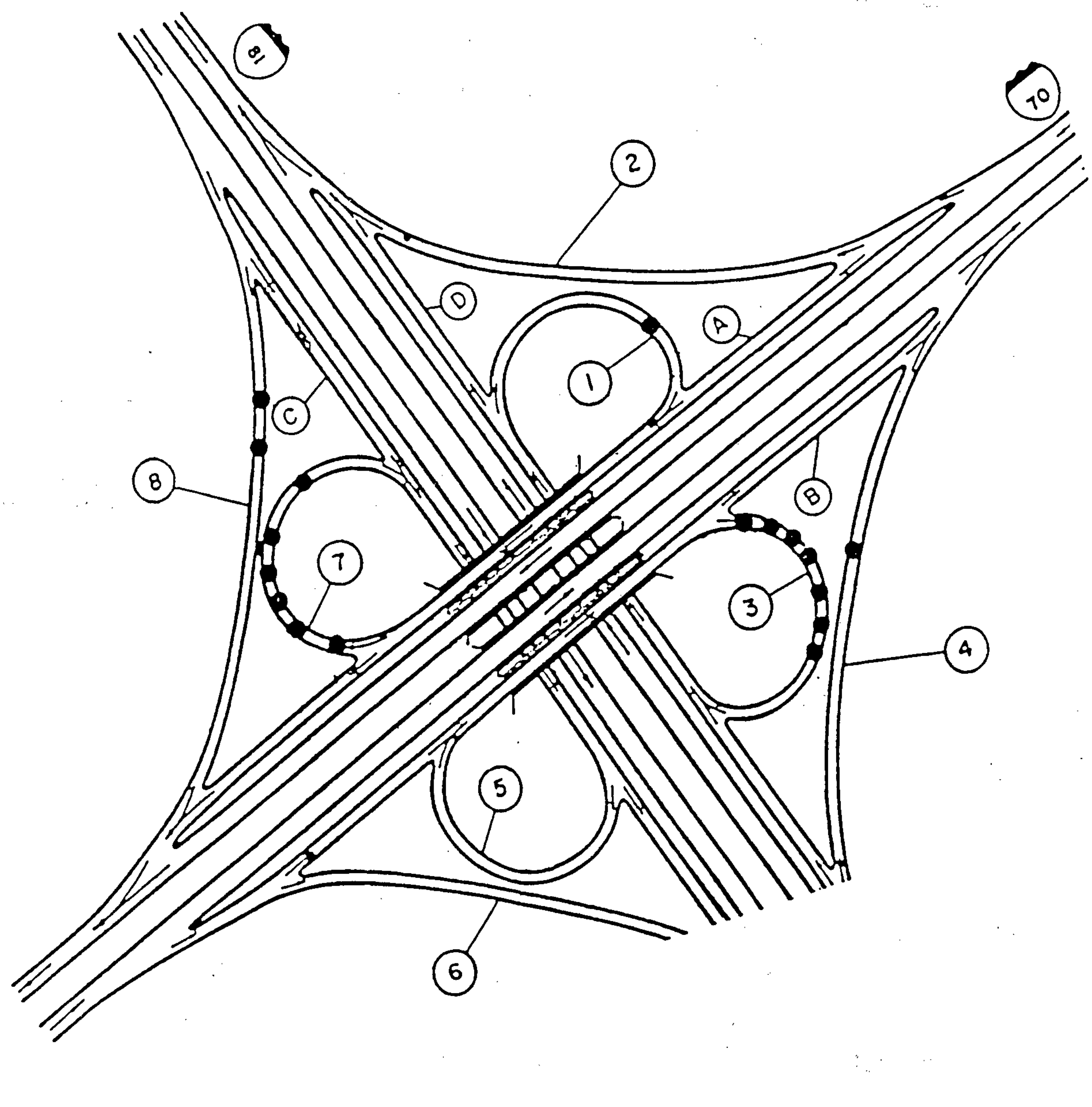


Figure 17. Overturned tractor trailer accidents.

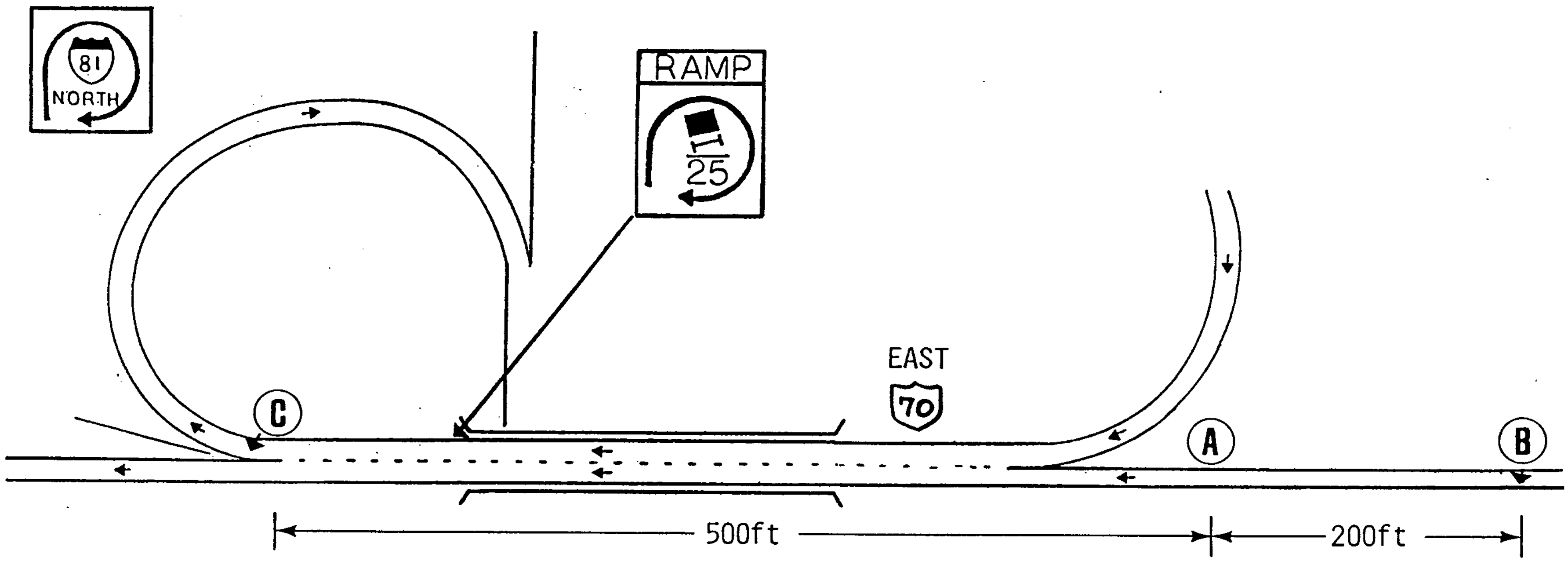
The I-95/US-17 interchange in Virginia is also a full cloverleaf design but there is a collector distributor roadway only on the Northbound side of I-95. Two truck rollover accidents had occurred at the cloverleaf leading from Northbound I-95 to Westbound US-17 from 1987 through 1989.

COLLECTION OF SPEED DATA

The data collection procedure for the Maryland location is shown in figure 18 and for the Virginia location in figure 19. A data collection vehicle was located off the shoulder at a point 500 ft (152 m) from the exit gore of the ramp being evaluated. The vehicle was equipped with two nondetectable radar units, one facing forward toward the exit gore and one facing rearward. As a lone vehicle or a lead vehicle in a platoon approached, its speed was taken at a point of the collector/distributor 200 ft (61 m) behind the observer's vehicle. The target vehicle was observed as it passed the data collection vehicle and entered the deceleration lane. If the target vehicle was not influenced by another vehicle entering the collector/distributor from the entrance ramp, the vehicle's speed was taken again (using the forward-facing radar) as the target vehicle turned into the ramp.

Target vehicles were free flow or first in a platoon of vehicles. All vehicle types were observed with the exceptions of bobtails and vehicles in tow. Day and night observations were made on dry road surfaces. Trucks were grouped as either straight or articulated and by number of axles. Additionally, truck description was observed (van, tanker, flatbed, etc.). Where possible, notation was made as to whether the trucks were national, independent, or local.

Observations were made using a tape recorder. Volume counts were made continuously and broken down into groups by vehicle type. Data were collected for 45 minutes per hour. A Citizens Band (CB) radio was used to monitor for any unusual conditions. There was no indication on the CB that the truckers suspected the observer's vehicle was involved in a speed-monitoring study.



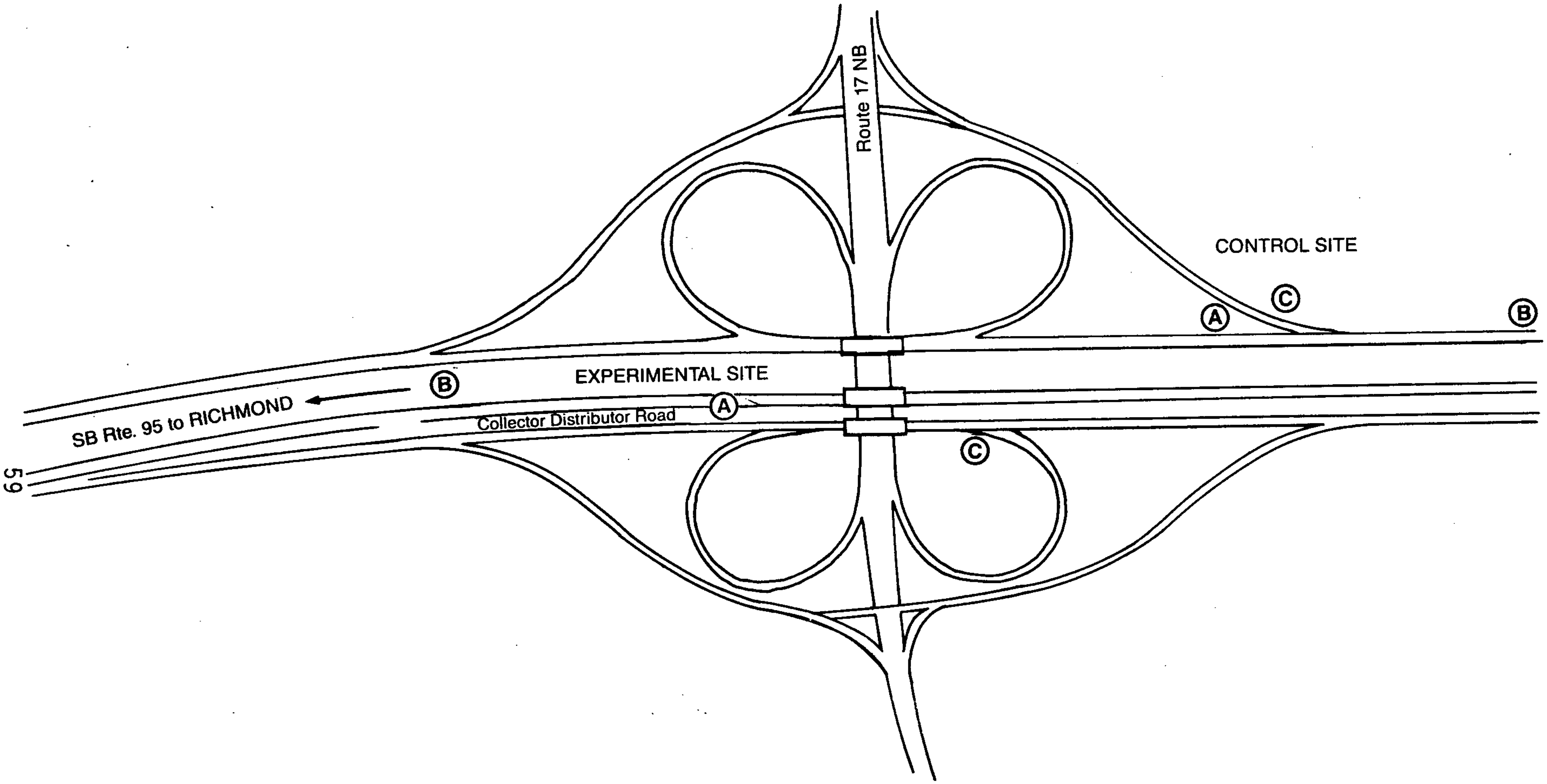
(A) Location of data collection vehicle equipped with rearward-facing and forward-facing nondetectable radar.

(B) Point where approach speeds were measured.

(C) Point where ramp entry speeds were measured.

1 ft = 0.3048m

Figure 18. Maryland I-70/I-81 data collection procedure.



A Location of data collection vehicle equipped with rearward-facing and forward-facing nondetectable radar.

B Point where approach speeds were measured (350 ft [107 m] for Point A).

C Point where ramp entry speeds were measured.

Figure 19. Virginia data collection procedure.

COLLECTION OF TRUCK WEIGHT AND LOAD DATA

After the completion of Field Test I, it became apparent that it would be difficult to detect a significant change in the speeds of all the trucks passing through the experimental site. The truck tipping sign is specifically targeted at loaded trucks whose cargo is such (i.e., relatively low density) that they have a high risk of rollover. In the laboratory studies, the majority of the truckers (60%) indicated that they would slow to less than the advisory speed if they were hauling a top-heavy load, but only less than a quarter (23%) indicated they would slow to less than the advisory speed if they were hauling a regular load. Thus, it was determined that it would be highly desirable to attempt to identify a target vehicle population consisting of loaded trucks carrying a potentially top-heavy cargo. Since none of the potential study sites were in the vicinity of a weigh-station and because portable weigh-in-motion equipment was prohibitively expensive, an alternative procedure was developed.

Early in the project, it was found that truckers were very willing to disclose their weight and cargo in response to an inquiry on the CB radio. What was not known was the reliability of this report. A procedure was developed to verify the CB-reported weights provided by the truckers. One weigh-station on I-81 Northbound near Stevens City, Virginia and a second one on I-70 Westbound near West Friendship, Maryland were used. One researcher was stationed at the weigh-station. This individual recorded the weight and specific identifying colors/markings on each tractor-trailer passing over the scales. A second researcher was stationed on an overpass 15 to 20 mi (24 to 32 km) from the weigh-station. (The procedure was tested by talking to truckers both before and after they were weighed. No differences were found.) The second researcher hailed approaching truckers on the CB-radio and asked what they were hauling and how much they weighed. This information, as well as specific identifying colors/markings for each truck, was recorded. The information on each truck was matched on the basis of anticipated arrival time and the specific identifying colors/markings.

The mean reported weight of the trucks successfully "matched" (N=86) was 55,058 lb (24,970 kg), while the actual weight was 59,453 lb (26,963 kg). The difference between actual and reported weight was 4,395 lb (1,993 kg), which represents 7 percent of the actual weight. The tabulated data are shown in table 7. Trucks weighing less than 30,000 lb (13,605 kg) reported their correct weight 92 percent (79 out of 86) of the time. A reported weight that was within 10 percent (3,000 lb [1,361 kg]) was considered a "match." Using this criterion, seven truckers underreported their weight, while only one overreported. When data were tabulated for 60,000 lb (27,211 kg) loads, 73 (36 plus 37) of the truckers reported correct (within 3,000 lb [1,361 kg]) weights. Nine underreported, while four overreported. The correlation between reported and actual weight was 0.91. This procedure provided a reasonably valid method for determining truck weights. The information on type of cargo also provided another means of identifying the target population of high center of gravity trucks. In fact, the actual population at risk may be truckers who are carrying much more weight than they believe they are carrying. However, since only four truckers who were actually carrying 60,000 lb (27,211 kg) or more were off by more than 15 percent (9,000 lb [4,082 kg]), this subgroup would be a very small proportion of the trucking population.

For the data collection, a vehicle was located off the shoulder of the collector/distributor 500 ft (152 m) from the exit gore of the ramp being evaluated. The vehicle was equipped with two nondetectable radar units, one facing forward toward the exit gore and one facing rearward. As a lone vehicle or a lead vehicle in a platoon approached, its speed was taken at a point on the collector/distributor 200 ft (61 m) behind the observer's vehicle. The target vehicle was observed as it passed the data collection vehicle and entered the deceleration lane. If the target vehicle was not influenced by another vehicle entering the collector/distributor from the entrance ramp, its speed was taken again (using the forward-facing radar) as it turned into the ramp. In Field Studies II and III, after the data collector obtained an approach speed and ramp speed on target vehicles that were trucks, a CB radio was used to provide a second data collector, several miles downstream from the ramp, with a description of the vehicle. The second data collector used a CB radio to contact the target vehicle and determine the vehicle's gross weight and type of cargo. Truck weight and cargo was determined for about 60 percent of the target vehicles. Data were collected on dry roads, during daylight, on weekdays only.

Table 7. Tabulation of reported versus actual truck weights, within ± 3,000 lb (1,361 kg).

Reported Weight	Actual Weight: Less than 30,000 lb	Actual Weight: More than 30,000 lb	Total
Less than 30,000 lb	1	7	8
More than 30,000 lb	0	78	78
Total	1	85	86

Reported Weight	Actual Weight: Less than 40,000 lb	Actual Weight: More than 40,000 lb	Total
Less than 40,000 lb	12	9	21
More than 40,000 lb	1	64	65
Total	13	73	86

Reported Weight	Actual Weight: Less than 50,000 lb	Actual Weight: More than 50,000 lb	Total
Less than 50,000 lb	24	15	39
More than 50,000 lb	2	45	47
Total	26	60	86

Reported Weight	Actual Weight: Less than 60,000 lb	Actual Weight: More than 60,000 lb	Total
Less than 60,000 lb	36	9	45
More than 60,000 lb	4	37	41
Total	40	46	86

Note: 30,000 lb = 13,605 kg
40,000 lb = 18,141 kg
50,000 lb = 22,676 kg
60,000 lb = 27,211 kg

FIELD STUDY I

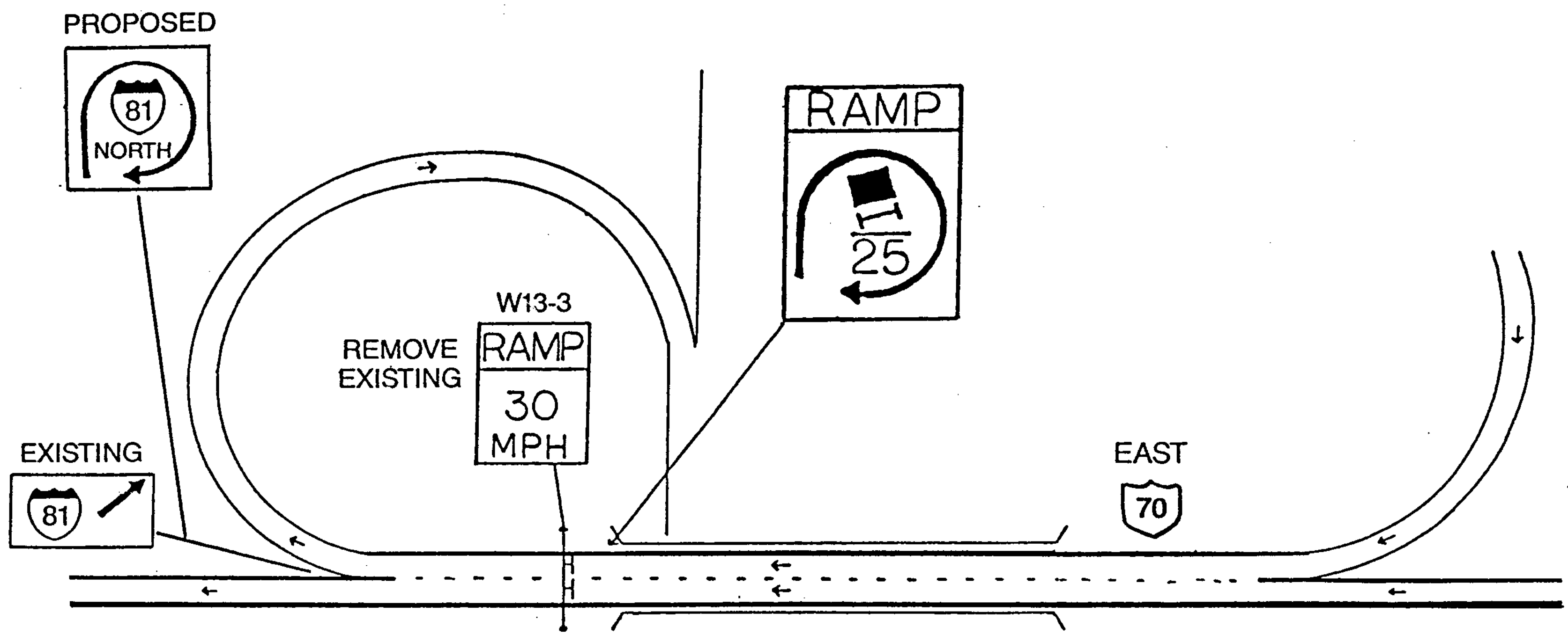
Background

Maryland DOT identified two interchange ramps with a high frequency of truck rollover accidents. It was decided to install several signing treatments in an effort to reduce the number of truck rollover accidents at those ramps.

The treatments were installed at two of the four cloverleaf ramps at the I-70/I-81 interchange. No changes were made at the other two cloverleaf ramps. The high accident locations (experimental sites) were downhill ramps and the low accident locations (control sites) were uphill ramps. This must be considered when making experimental-control comparisons.

Maryland DOT decided to improve ramp signing at the two high accident locations, as shown in figure 20. As a concession to our experimental design, they agreed to first lower the speed limit on the existing advisory sign (W13-3) from 30 to 25 mi/h (48 km/h to 40 km/h), allowing us to separate any effects of the speed limit change from the effects of the new, larger warning sign. Although it was not expected that simply lowering the posted advisory speed by 5 mi/h would produce a measurable effect, this step does eliminate the speed limit change as a possible confound. Next, they replaced the W13-3 sign with a very large (8-ft by 11-ft [2.49 m by 3.35 m]) sign with a tipping truck, a diagrammatic arrow, and a 25 mi/h (40 km/h) advisory speed. Third, they replaced the existing gore sign with a new gore sign that had a diagrammatic arrow. The changes were scheduled so that speed measures could be taken to determine the effect of each sign condition.

Speed data on 4,000 vehicles were recorded during a total of 202 hours of field data collection effort.



Stage 1: Replace existing W13-3 (30 mi/h) with W13-3 (25 mi/h).

Stage 2: Remove W13-3 (25 mi/h). Install large (8-ft by 11-ft [2.49-m by 3.35-m]) tipping truck sign between the end of the bridge and the existing overhead sign structure. Remove existing ramp speed sign from overhead sign structure pole.

Stage 3: Replace existing gore sign with new gore sign with a diagrammatic arrow.

Figure 20. I-70/I-81 signing changes.

Results

Although speed data were collected on a wide variety of vehicles, the major emphasis of the analysis focuses on articulated trucks (18-wheelers) since they are most frequently involved in rollover accidents and therefore the target population for the various treatments being tested. Data on other types of vehicles will be presented to determine if the treatments are having an adverse effect on the speeds of non-target vehicle populations. The Kolmogoroff-Smirnoff test was used to test the speed data for normality. Since it was found that much of the ramp speed data were not normally distributed, only non-parametric methods were used to analyze the data.

Tables 8, 9, 10 and 11 present a data summary for the two experimental sites and the two control sites used in Field Test I. The tables show the sample size, mean, standard deviation, and the 75th, 85th, 90th, and 95th percentile speeds for each of five time periods. The five time periods were arranged to evaluate the signing changes illustrated in figure 20. The five time periods covered the following conditions:

Period 1 - Before data
Period 2 - Post Speed: after changed in posted advisory speed only
Period 3 - Post Tip: after installation of tipping truck sign
Period 4 - Post All: after tipping truck sign and diagrammatic exit sign
Period 5 - Final: collected two months after installation to allow for any acclimatization effects

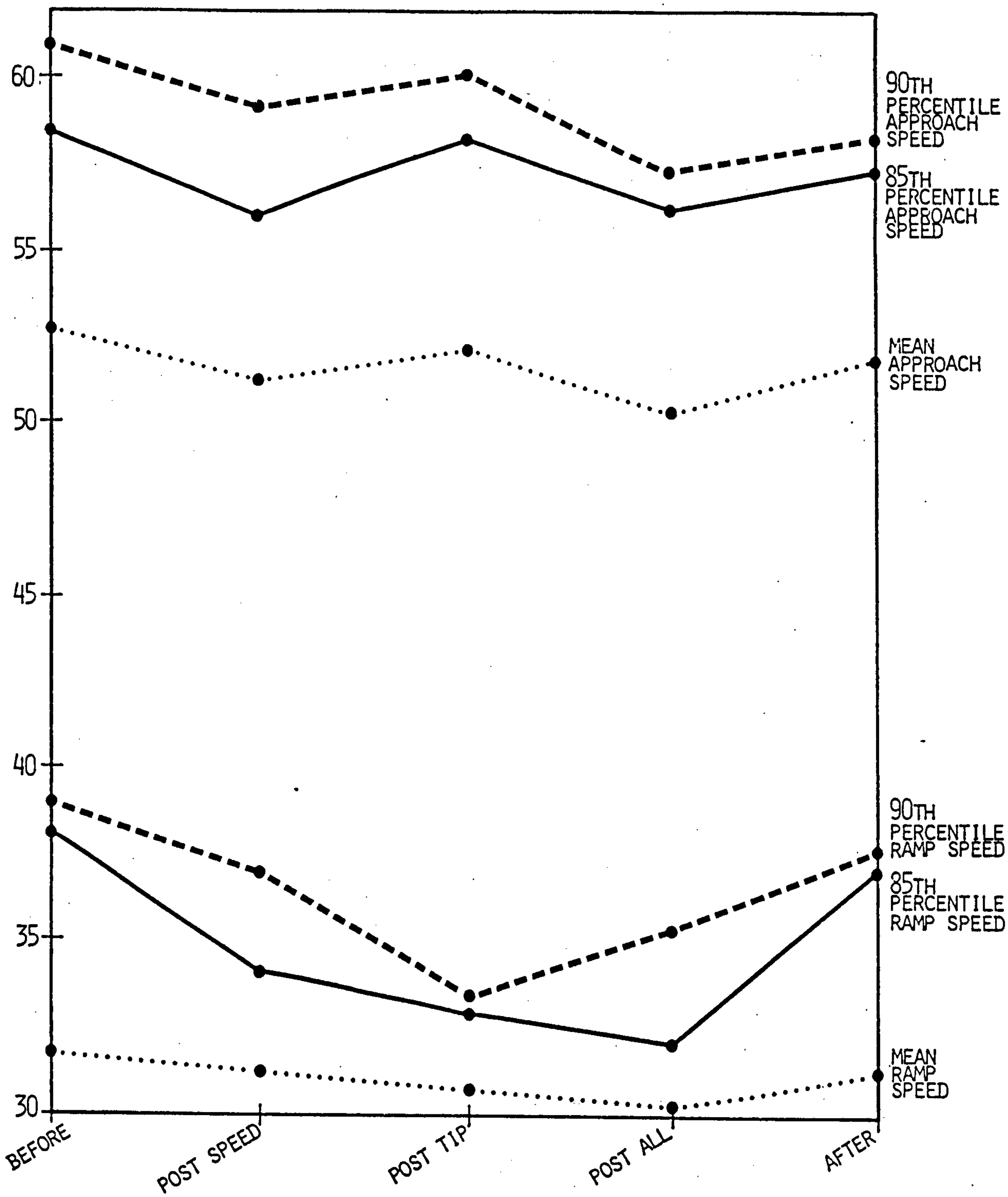
All of the data to be discussed in this section describe the speeds of articulated trucks through the study sites. Articulated trucks included all tractor trailer combinations but did not include doubles, triples, or bobtails.

Besides these four tables, some data are presented in graphical form to illustrate the effect of the experimental treatments. Figures 21 through 25 plot the means, 85th and 90th percentiles of both the ramp speeds and the approach speeds for each of the four sites. Table 8 and figures 21 and 22 contain data for the 70E ramp, an experimental site. Table 9 and figure 23 contain the data for the 70W ramp, the second experimental site. Table 10 and figure 24 contain the data for the 81N ramp, a control site. Table 11 and figure 25 present the data for the 81S ramp, the second control site.

Table 8. Mean, standard deviation and percentile data for articulated trucks at 70E (experimental): Field Study I.

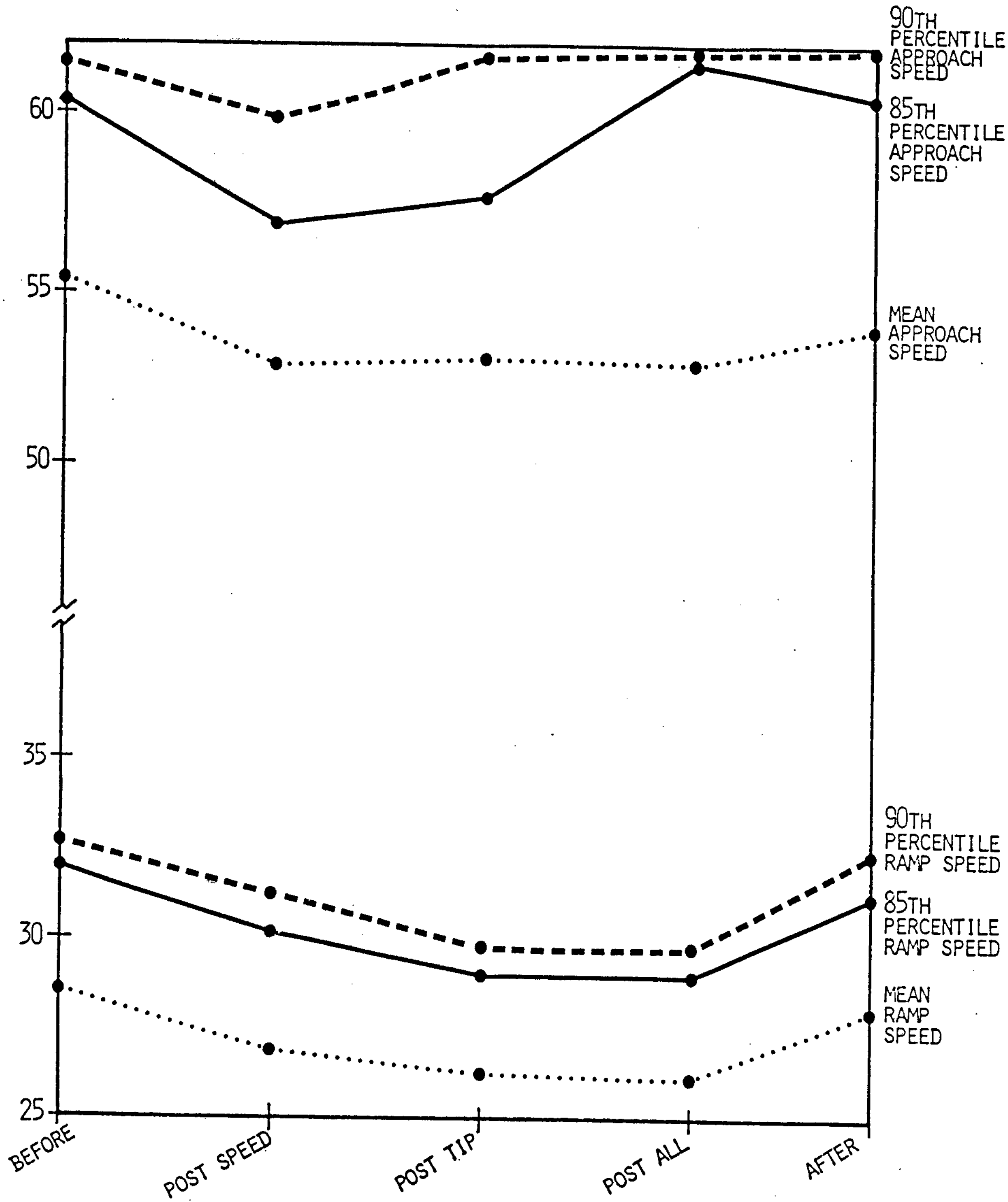
	PERIOD				
	1 Before	2 Post-Speed	3 Post Tip	4 Post All	5 Final
Approach Speeds, Daylight					
Sample Size	89	39	30	56	57
Mean	53	51	52	50	52
Standard Deviation	5.7	5.1	4.9	5.4	5.4
75th Percentile	57	55	55	54	55
85th Percentile	59	56	58	56	57
90th Percentile	61	59	59	57	58
95th Percentile	63	61	61	61	62
Ramp Speeds, Daylight					
Sample Size	89	39	30	56	57
Mean	32	31	31	29	31
Standard Deviation	4.6	3.6	2.3	3.9	5.0
75th Percentile	34	34	32	31	35
85th Percentile	38	34	33	33	37
90th Percentile	39	37	34	35	38
95th Percentile	42	38	35	37	41
Approach Speeds, Night					
Sample Size	44	31	21	51	66
Mean	50	48	48	48	49
Standard Deviation	5.0	4.5	5.6	6.2	5.4
75th Percentile	54	51	51	52	53
85th Percentile	56	52	53	56	55
90th Percentile	58	55	58	57	56
95th Percentile	60	56	61	59	58
Ramp Speeds, Night					
Sample Size	44	31	21	51	66
Mean	29	27	26	26	28
Standard Deviation	3.4	3.7	3.2	3.7	4.1
75th Percentile	30	29	28	28	30
85th Percentile	32	30	29	29	31
90th Percentile	33	32	30	30	32
95th Percentile	37	36	34	33	39

1 mi/h = 1.61 km/h
* = Insufficient data



1 mi/h = 1.61 km/h

Figure 21. Mean, 85th and 90th percentile speeds of site 3: 70E - experimental (daytime).



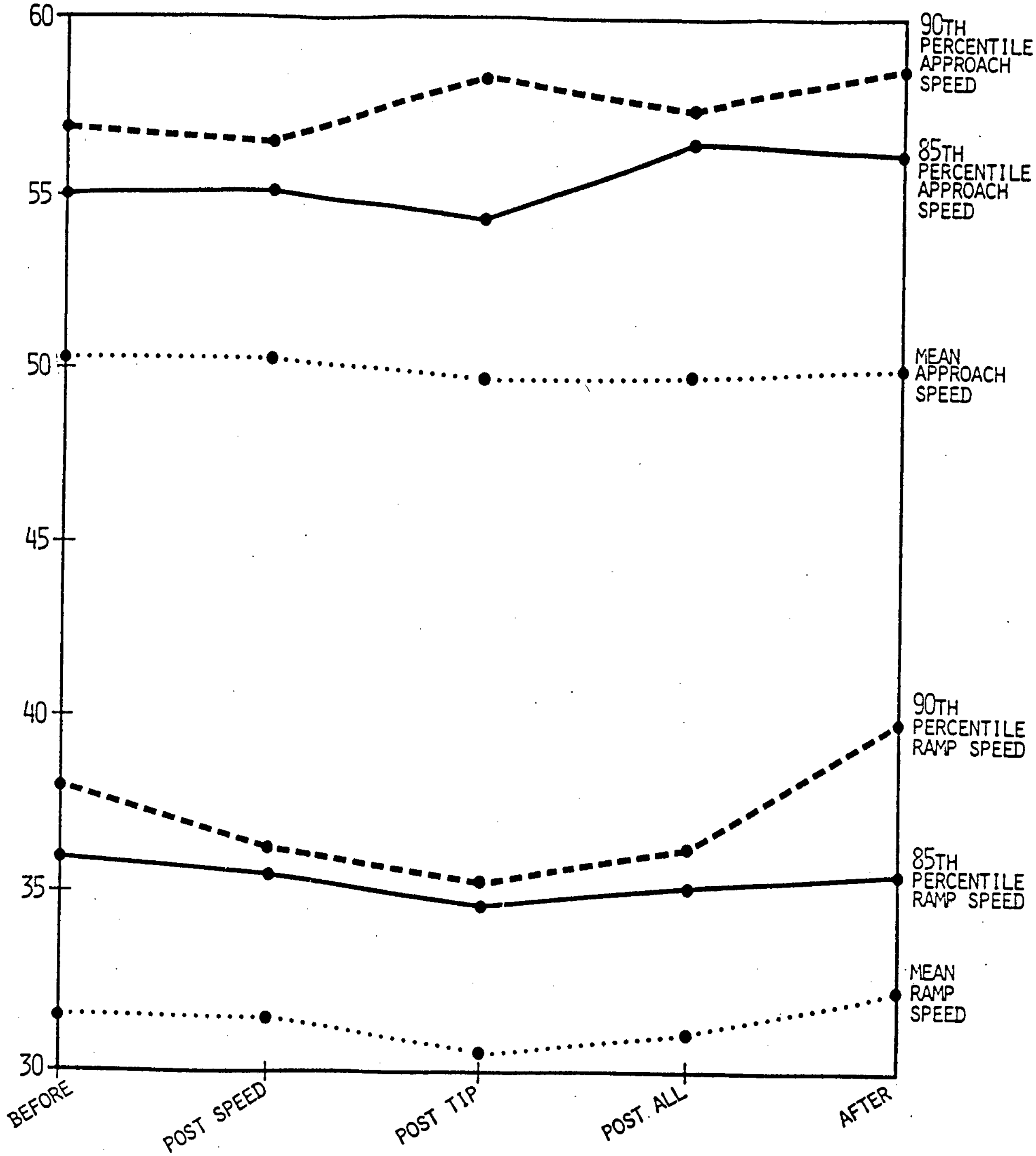
1 mi/h = 1.61 km/h

Figure 22. Mean, 85th and 90th percentile speeds at 70E - experimental (night).

Table 9. Mean, standard deviation and percentile data for articulated trucks at 70W (experimental): Field Study I.

	PERIOD				
	1 Before	2 Post-Speed	3 Post Tip	4 Post All	5 Final
Approach Speeds, Daylight					
Sample Size	123	56	14	49	51
Mean	50	50	50	50	50
Standard Deviation	5.3	5.5	5.7	6.1	5.5
75th Percentile	53	53	53	55	53
85th Percentile	55	55	54	56	55
90th Percentile	57	56	58	57	58
95th Percentile	59	58	*	57	58
Ramp Speeds, Daylight					
Sample Size	123	56	14	49	51
Mean	32	32	30	31	32
Standard Deviation	4.1	3.4	3.3	3.7	3.9
75th Percentile	34	33	33	34	34
85th Percentile	36	36	35	35	35
90th Percentile	38	36	35	36	35
95th Percentile	39	38	*	37	42
Approach Speeds, Night					
Sample Size	21	41	8	27	22
Mean	49	48	48	48	48
Standard Deviation	4.7	4.7	4.0	6.9	6.5
75th Percentile	52	54	51	51	52
85th Percentile	54	54	53	54	55
90th Percentile	56	56	*	54	57
95th Percentile	59	56	*	58	61
Ramp Speeds, Night					
Sample Size	21	41	8	27	22
Mean	29	29	29	28	29
Standard Deviation	3.5	4.0	3.3	3.6	5.6
75th Percentile	31	32	33	31	32
85th Percentile	33	35	34	32	34
90th Percentile	35	36	*	33	39
95th Percentile	37	37	*	34	42

1 mi/h = 1.61 km/h
* = Insufficient data



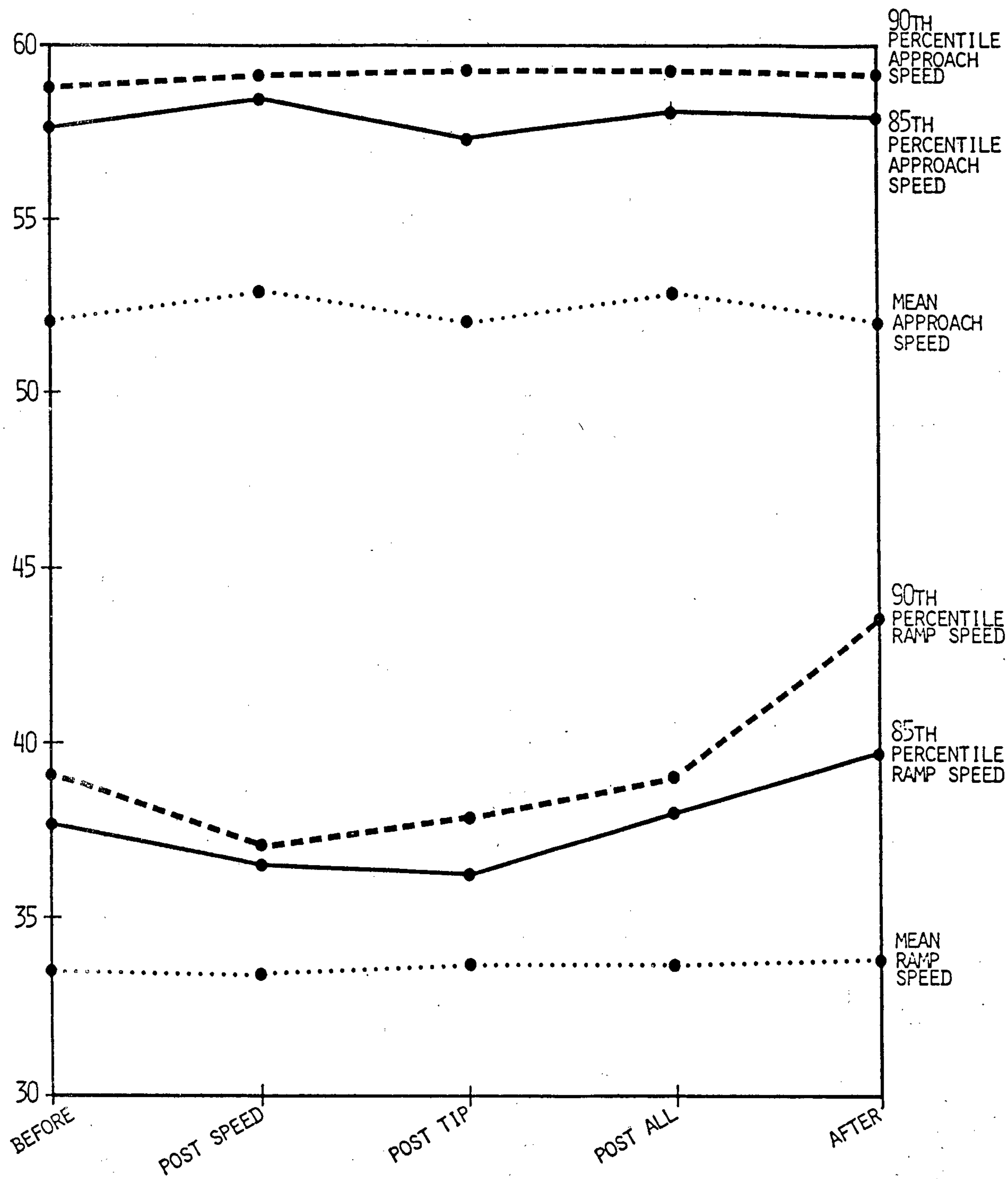
1 mi/h = 1.61 km/h

Figure 23. Mean, 85th and 90th percentile speeds at 70W - experimental (daytime).

Table 10. Mean, standard deviation and percentile data for articulated trucks at 81N (control): Field Study I.

	PERIOD				
	1 Before	2 Post-Speed	3 Post Tip	4 Post All	5 Final
Approach Speeds, Daylight					
Sample Size	100	49	18	58	40
Mean	52	53	52	53	51
Standard Deviation	5.2	5.5	5.1	4.4	5.9
75th Percentile	55	58	56	57	56
85th Percentile	58	59	57	58	58
90th Percentile	59	59	58	58	58
95th Percentile	61	63	*	60	62
Ramp Speeds, Daylight					
Sample Size	100	49	18	58	40
Mean	33	33	35	34	34
Standard Deviation	3.9	3.3	2.6	3.5	5.9
75th Percentile	36	36	35	36	36
85th Percentile	38	37	36	38	40
90th Percentile	39	37	38	39	44
95th Percentile	41	39	*	39	46
Approach Speeds, Night					
Sample Size	40	30	11	20	21
Mean	49	49	49	49	49
Standard Deviation	6.7	5.3	3.2	5.1	5.5
75th Percentile	54	52	50	53	54
85th Percentile	55	55	53	55	54
90th Percentile	56	58	53	55	56
95th Percentile	57	60	*	56	56
Ramp Speeds, Night					
Sample Size	40	30	11	20	21
Mean	30	31	31	30	32
Standard Deviation	3.6	3.5	2.0	3.9	4.4
75th Percentile	32	34	32	32	34
85th Percentile	34	34	33	35	34
90th Percentile	36	36	35	35	36
95th Percentile	37	39	*	42	45

1 mi/h = 1.61 km/h
* = Insufficient data



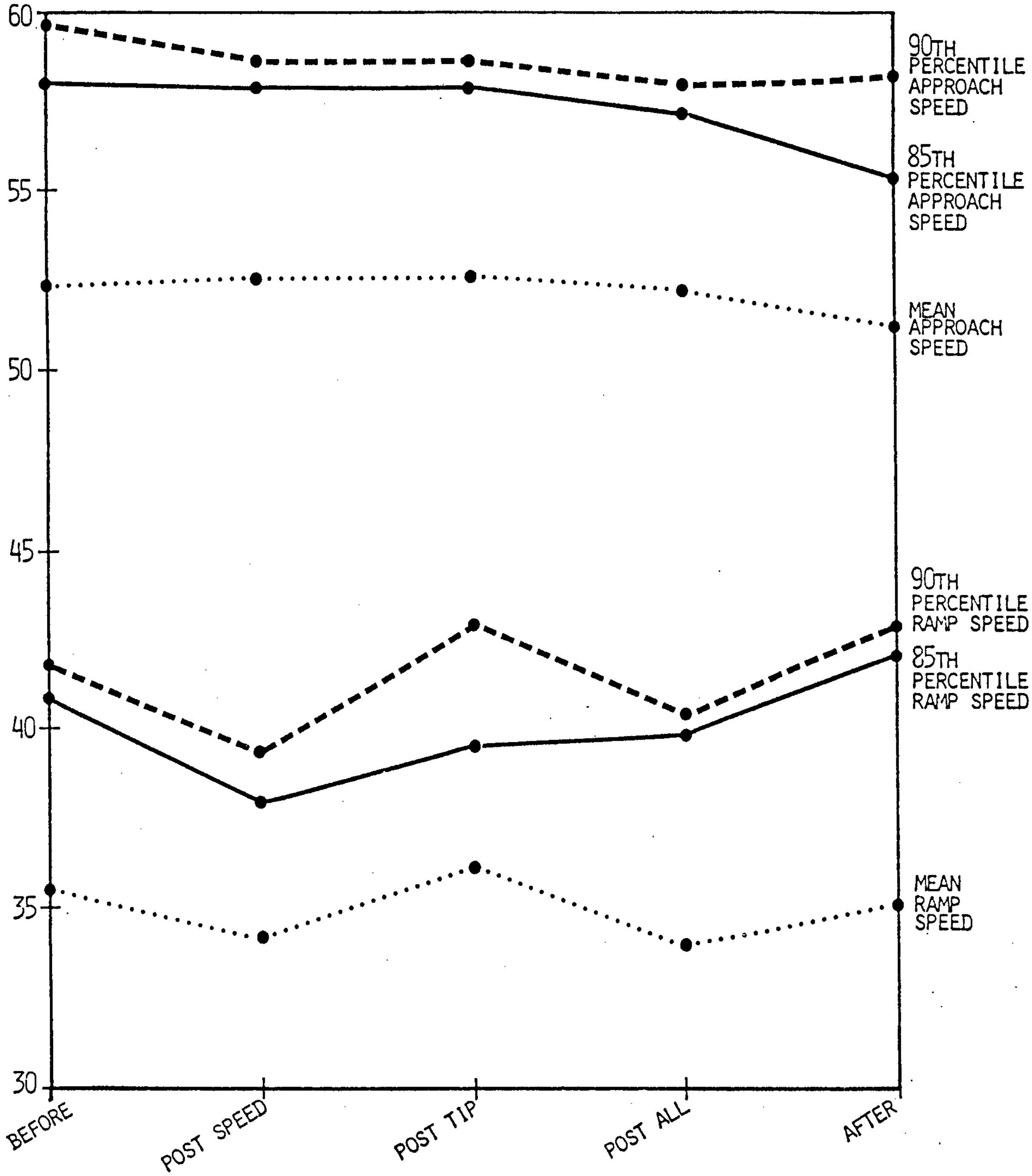
1 mi/h = 1.61 km/h

Figure 24. Mean, 85th and 90th percentile speeds at 81N - control (daytime).

Table 11. Mean, standard deviation and percentile data for articulated trucks at 81S (control): Field Study I.

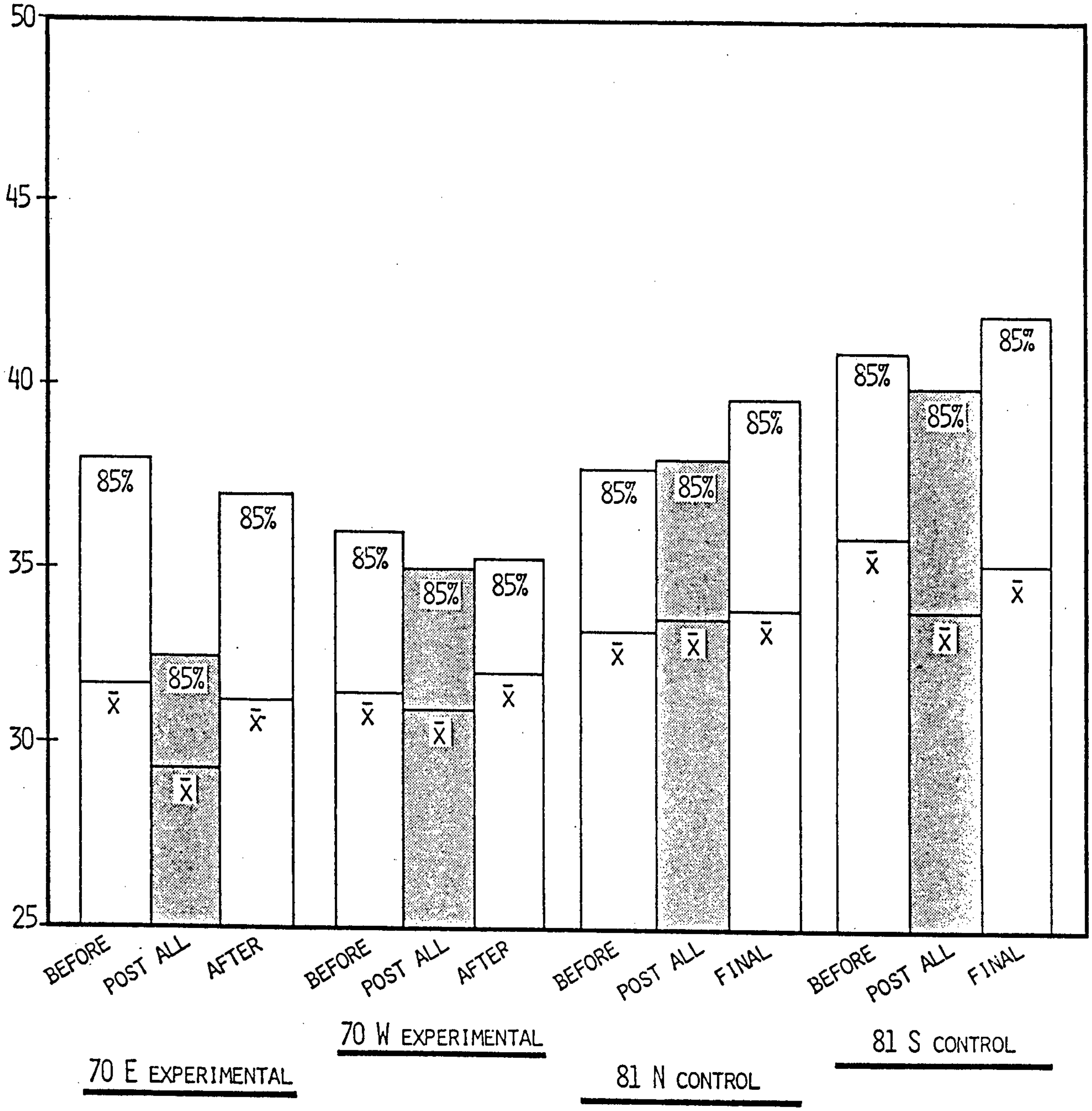
	PERIOD				
	1 Before	2 Post-Speed	3 Post Tip	4 Post All	5 Final
Approach Speeds, Daylight					
Sample Size	70	33	16	24	38
Mean	52	53	53	52	51
Standard Deviation	6.2	5.5	4.3	3.9	5.0
75th Percentile	56	57	57	55	53
85th Percentile	58	58	58	58	58
90th Percentile	60	59	59	58	58
95th Percentile	63	64	*	59	62
Ramp Speeds, Daylight					
Sample Size	70	33	16	24	38
Mean	36	34	36	34	35
Standard Deviation	4.6	3.6	3.8	3.9	4.7
75th Percentile	39	37	37	37	37
85th Percentile	41	38	40	39	37
90th Percentile	42	39	44	40	43
95th Percentile	43	41	*	41	45
Approach Speeds, Night					
Sample Size	42	35	7	23	13
Mean	50	50	51	51	49
Standard Deviation	5.0	5.2	5.4	6.3	5.5
75th Percentile	53	54	57	57	53
85th Percentile	55	55	53	55	54
90th Percentile	56	57	*	59	55
95th Percentile	59	59	*	59	*
Ramp Speeds, Night					
Sample Size	42	35	7	23	13
Mean	31	31	32	31	31
Standard Deviation	3.7	4.5	3.0	3.7	3.1
75th Percentile	34	33	34	34	33
85th Percentile	35	36	36	35	34
90th Percentile	37	37	*	37	36
95th Percentile	39	40	*	38	*

1 mi/h = 1.61 km/h
* = Insufficient data



1 mi/h = 1.61 km/h

Figure 25. Mean, 85th and 90th percentile speeds at 81S - control (daytime).



1 mi/h = 1.61 km/h

Figure 26. Ramp speeds for articulated trucks by initial and second final stages (daytime).

populations. Table 12 summarizes the results given by the analysis. The observations for a particular period are regarded as a sample. Thus there are five samples for each site/vehicle type combination. As a first test, all the periods are included to see if there was some difference over the five periods.

Table 12. Kruskal-Wallis analysis of variance - ramp speeds for articulated trucks, changes across all five time periods: Field Study I.

Site	Time	K-W Statistic	Significant (5% Level)
81N	Day	0.95	No
	Night	2.62	No
70E	Day	20.28	Yes
	Night	20.21	Yes
81S	Day	5.98	No
	Night	0.26	No
70W	Day	1.85	No
	Night	1.18	No

Further, if the data are dichotomized so that all periods for which there were interventions are classified as After, the conclusions are not affected; i.e., 70E shows definite changes. Similar results occurred when automobiles were examined.

It was then decided to see which of the experimental periods was significantly different from the Before period. This was also accomplished using the Kruskal-Wallis statistic and the results are presented in table 13.

Table 13. Kruskal-Wallis analysis of variance - significant differences in ramp speeds for articulated trucks between Before and subsequent conditions (0.05 level): Field Study I.

Site	Time	Post Speed	Post Tip	Post All	Final
81N	Day	No	No	No	No
	Night	No	No	No	No
70E	Day	No	No	Yes	No
	Night	Yes*	Yes	Yes	No
81S	Day	No	No	No	No
	Night	No	No	No	No
70W	Day	No	No	No	No
	Night	No	No	No	No

*There is a significant difference in approach speed also.

The top of table 8 shows the daylight approach speeds at one of the experimental sites (I-70E). It can be seen that between 30 and 89 articulated trucks were observed during each of the five experimental conditions, a total of 271 trucks. Since there were no treatments that would have affected approach speed, it was expected that approach speed would not change very much across the five conditions. And, in fact, that was the case. The mean approach speed fluctuated between 50 and 53 mi/h while the various percentile scores showed a similar stability and lack of systematic effect. The various treatments being evaluated in Field Study I were intended to improve ramp safety by lowering the ramp speeds of articulated vehicles.

One would hypothesize that the speed limit change might produce a small speed reduction while the large tipping truck sign and the diagrammatic exit arrow would produce additional incremental reductions. An examination of table 8 suggests that such is the case. Daylight ramp speeds were reduced from an average of 32 mi/h from the before period until immediately after the installation of all of the signing treatments. The mean night ramp speeds showed a similar reduction from 29 mi/h to 26 mi/h. The ramp percentile speeds showed reductions between 2 and 5 mi/h for the same period. Unfortunately, this slight apparent effect does not last long. When additional data were collected 2 months after the installation of the signs, it was found that the mean and percentile scores had returned to within 1 mi/h of the Before values. This slight decrease and final return to near Before values is seen in the mean, 85th and 90th percentile ramp speed plots shown in figure 22.

The nighttime approach and ramp speeds are presented in the bottom half of table 8 and depicted graphically in figure 22. Like the daylight speeds, there is an initial reduction in speeds that returns to the Before values in the final After period.

Table 9 presents the data for the second experimental ramp at 70W. The results are strikingly similar. The mean approach speeds, as expected, show no change whatsoever. The ramp speeds showed a slight (2 mi/h) reduction in mean speed after the installation of the large tipping truck sign, but speeds returned to exactly the Before values when measures 2 months later. These data are shown graphically in figure 23.

The data for the two control sites from Field Study I are presented in tables 10 and 11. The data are depicted in figures 24 and 25. At both control sites all of the approach speed measures as well as the mean ramp speed showed no major fluctuation during the testing. The various percentile speeds showed some variation over time with the 90th and 95th percentile speeds of 81N showing a 5 mi/h increase from Post All to After. The cause for this change is unknown, yet both experimental sites also showed a similar change in percentile speeds during the same time period.

Figure 26 summarizes the means and 85th percentile for all four sites for the three periods: Before, Post All, and After. The graph shows that the 85th percentile speeds at the experimental sites showed a slight decrease while the comparable values at the control sites showed an increase. These increased values at the control site might be interpreted as an indication that the decrease at the experimental sites is effectively larger than observed. However, the observed differences between the experimental and control raise some questions about the appropriateness of experimental-control comparisons. Although the experimental and control ramps were located at the same interchange and had identical radii and superelevations, there are apparently some differences, possibly related to the accident experience of the experimental locations or to the fact that they were downhill ramps (although the superelevation was equal). The differences in the Before mean and 85th percentile scores between the experimental and control locations is apparent in figure 26.

It is of great importance to determine if the characteristics, such as ramp speed (SPEEDRAM), changes over time. Ordinary tests to detect differences were suspect as ramp speed was suspected of not being normally distributed. Thus, for each vehicle type (auto, articulated truck, and other truck) both ramp speed (SPEEDRAM) and approach speed (SPEEDAPP) were subjected to the Kruskal-Wallis one-way analysis of variance, a nonparametric test so that violations of distributional considerations are not an issue. The Kruskal-Wallis test is generalization of the Wilcoxin rank sum test to k groups. The null hypothesis is that the k independent samples are from the same population. To apply the test, all observations are ranked. The sum of the ranks for each of the samples is calculated. If all samples are from the same population, then the expected mean sample rank will be the same for each group. If this is not so, then one concludes that the different samples were from different

In addition to the significant changes shown in table 13, the following incremental changes were noted for 70E:

(1) Post Tip to Post All - Day.

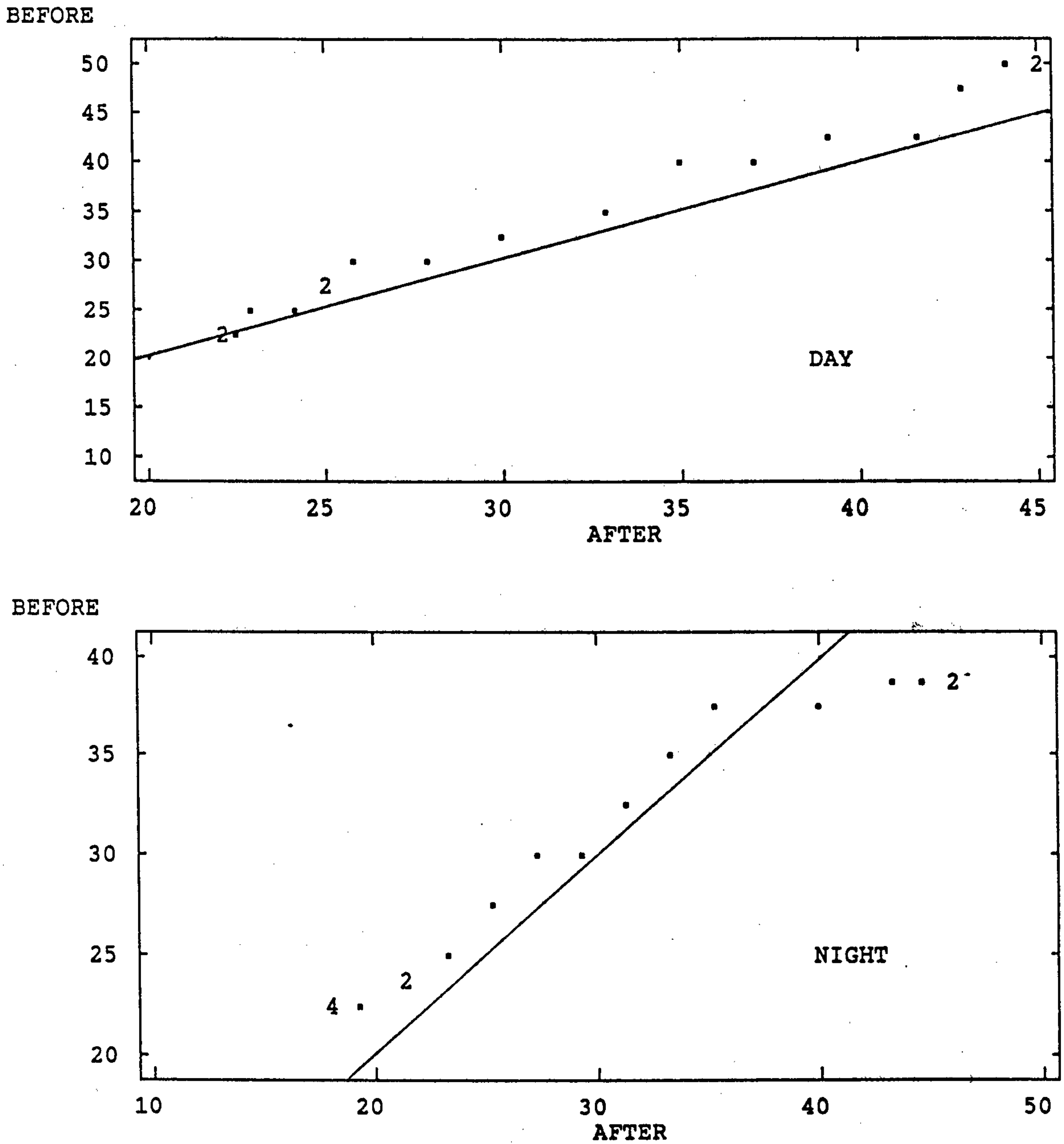
(2) Post All to Final - Day (the significance level is 0.053).

(3) Post All to Final - Night.

An examination of quantile-quantile plots of the Before data plotted against the After data is revealing. A quantile-quantile plot is simple a scatter plot of the identical percentiles. For example, if Before is the vertical axis (y-axis) and After is the horizontal (x-axis), then when a plot lies above the 45 degree line (y=x), it indicates that the corresponding percentile was greater in the Before period that in the After period. This would indicate a speed decrease. The converse is also true; i.e., points lying below the line indicate a speed increase.

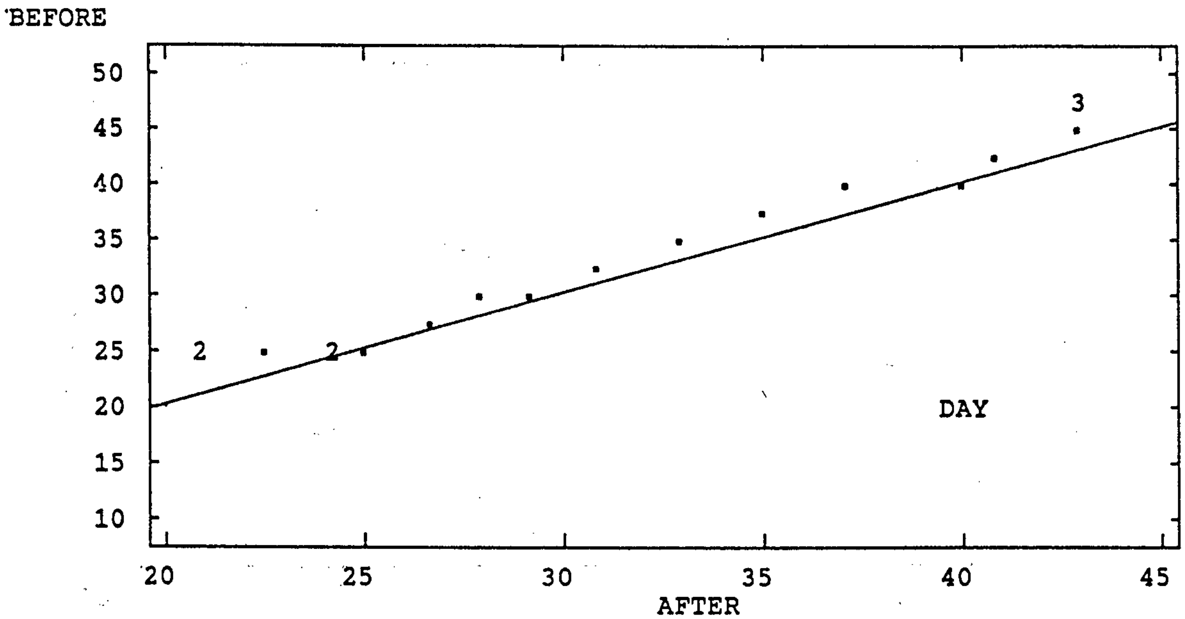
Figures 27 through 30 present the quantile plots of articulated truck ramp speeds at the two experimental and the two control sites. Figure 27 shows the plots for the 70E experimental site. Figure 28 shows the plots for the 70W experimental site. Figures 29 and 30 display the data for the two control sites, 81N and 81S, respectively. As show in figures 27 and 28, nearly all of the quantile values for the daytime testing at both experimental sites are above the 45 degree (y=x) line. For the nighttime testing (at the bottom of the same figures), it is shown that some of the points plotted are below the 45 degree line, indicating that some of the speeds actually increased in the After period, especially in the higher percentiles. The control site plots (figures 29 and 30) show the points generally much closer to the 45 degree line while some of the higher percentiles indicate a slight increase in speeds. The quantile-quantile plots generally indicate very few differences between the Before and After conditions and are generally supportive of the Kruskal-Wallis analysis of variance results.

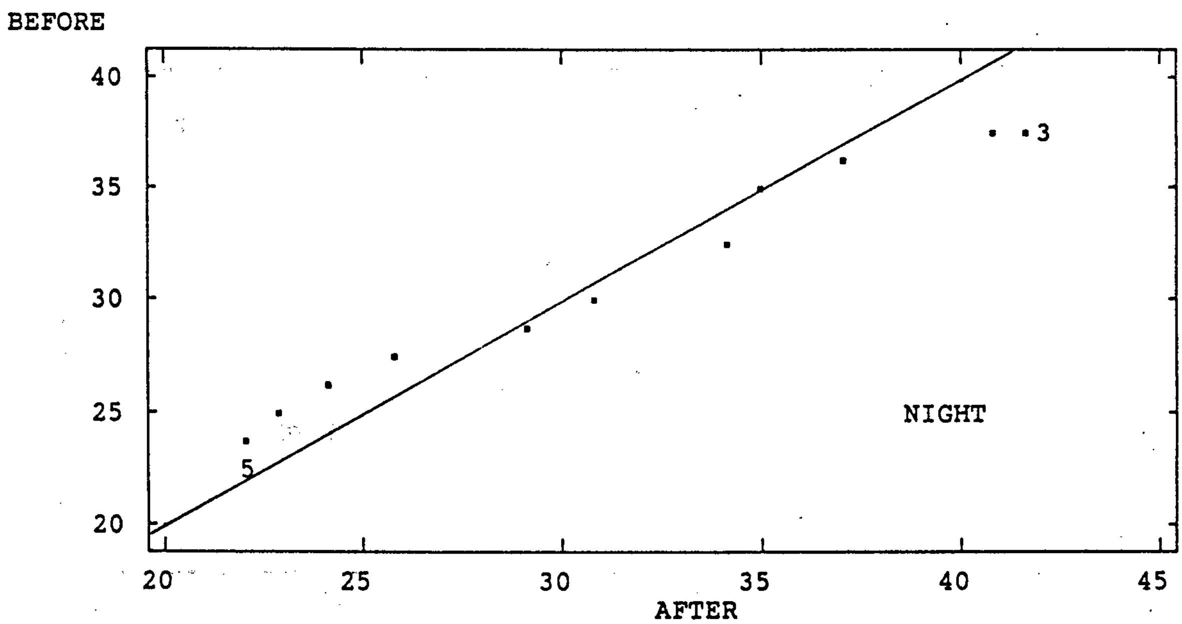
The results suggest that there was a small, short-term change in ramp speed in response to each of the three signing changes at one of the two experimental sites, i.e., 70E. However, since there were no measurable differences during the final data collection period, it is apparent that any speed reduction effects were short-lived. This raises some questions about the suitability of the experimental site in terms of repeat drivers and acclimatization effects. The purpose of the tipping truck sign is to warn an unfamiliar driver about the potential rollover hazard associated with a given ramp. Drivers familiar with a particular ramp may not rely on signing for that kind of information. The apparent lack of experimental effect may, in fact, be due to a high proportion of familiar truck drivers at the test sites. Such drivers, because they are familiar with the study ramps, would not be expected to slow down in response to the various signing changes.



1 mi/h = 1.61 km/h

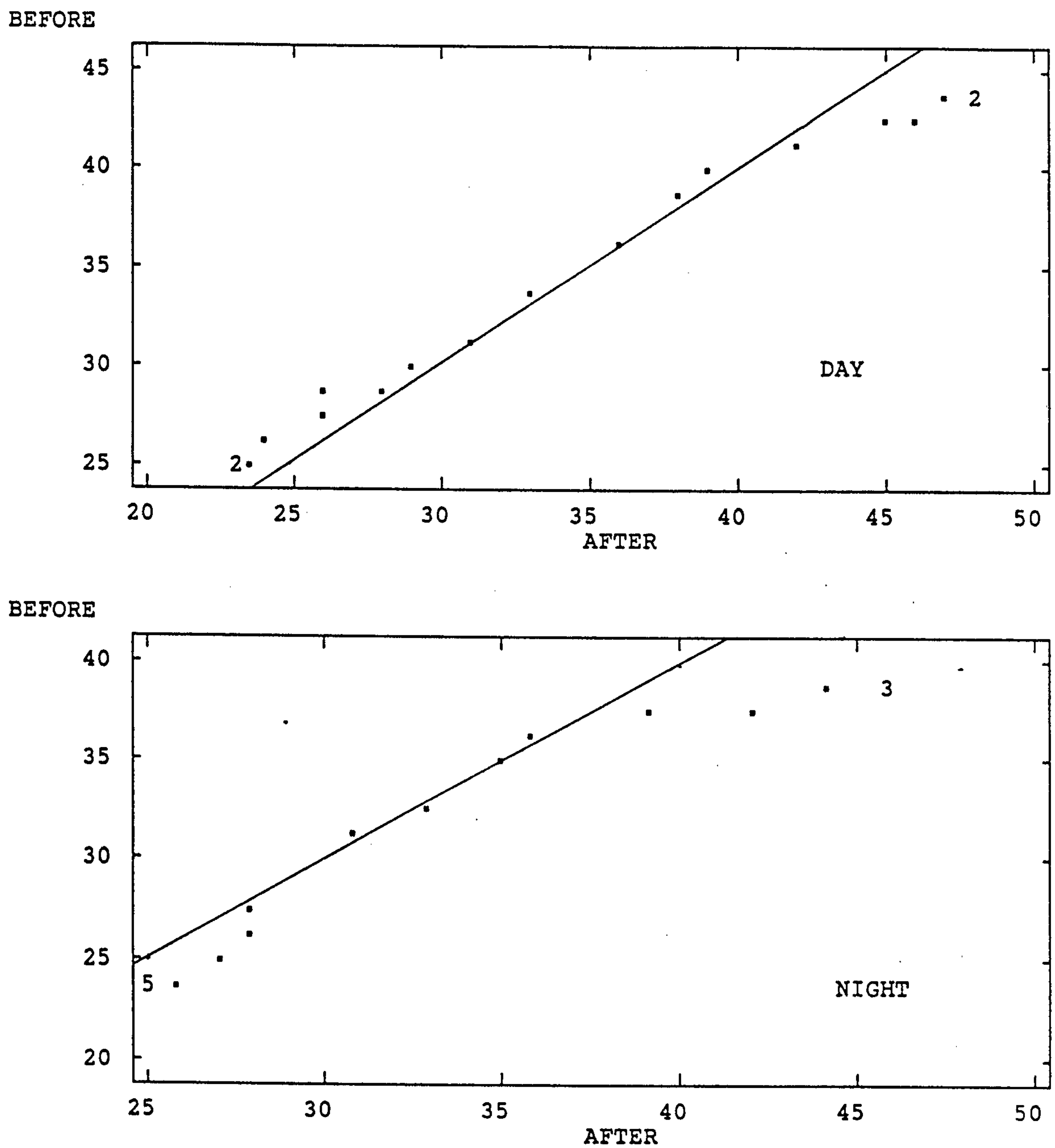
Figure 27. Quantile plots for experimental site 70E.





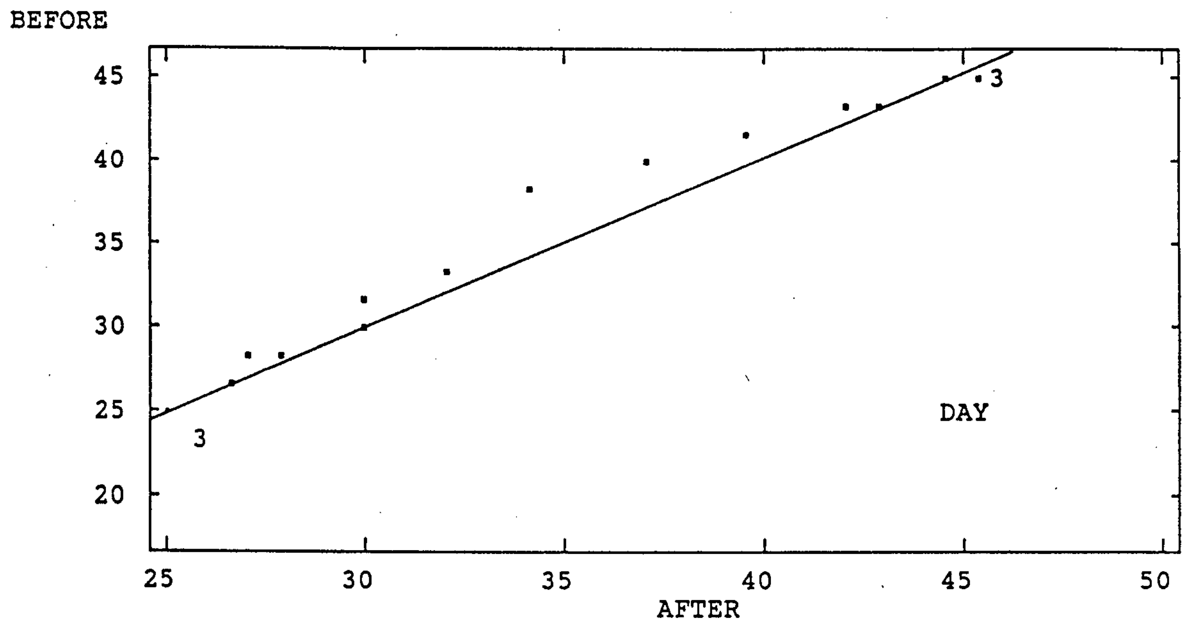
1 mi/h = 1.61 km/h

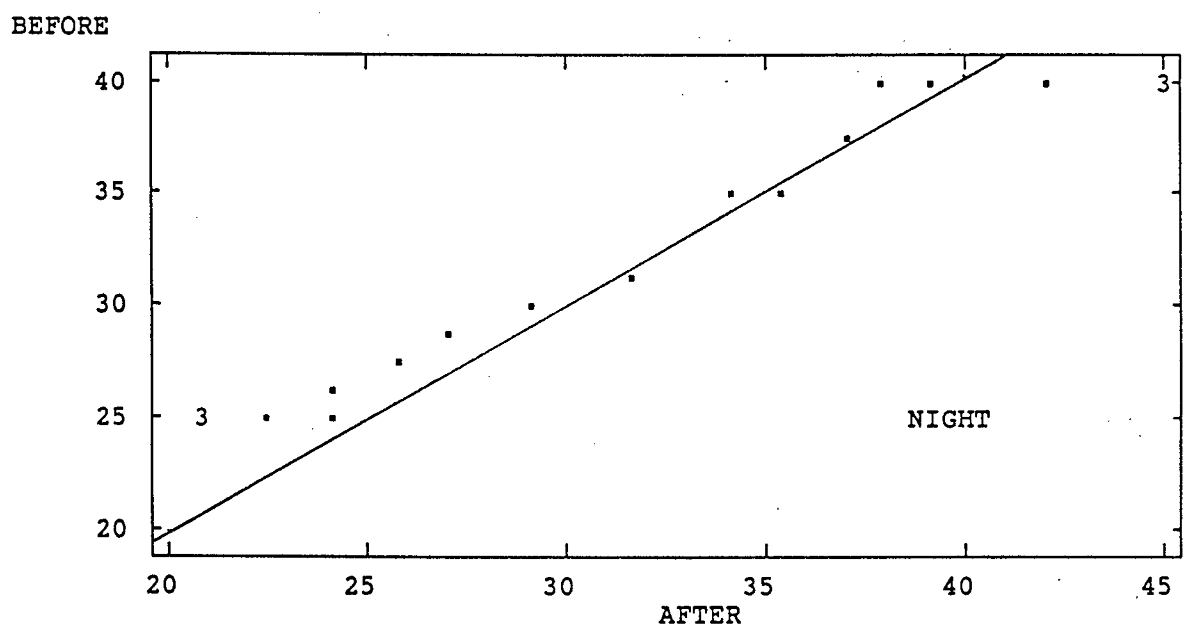
Figure 28. Quantile plots for experimental site 70W.



1 mi/h = 1.61 km/h

Figure 29. Quantile plots for control site 81N.





1 mi/h = 1.61 km/h

Figure 30. Quantile plots for control site 81S.

FIELD STUDY II

Virginia DOT identified one interchange ramp with a history of truck rollover accidents and allowed us to install and evaluate several signing treatments. The treatments were installed at one cloverleaf ramp at the I-95/US 17 interchange (see figure 19). Very low truck volumes at the other three interchange ramps prevented their use as a control location. Unfortunately, no other suitable control location was found so the evaluation consists of a Before/After design. The signing changes are shown in figure 31. The flashing beacons were powered by a small portable generator and were activated by a remote switch operated by the data collector (see figure 18). The flashers were activated, for randomly selected trucks, as soon as the approach speed was taken, approximately 500 ft (152 m) from the ramp.

Because the preliminary analysis of the Field Study I data indicated minimal effects from the tipping truck sign, it was decided to concentrate the field effort on the "full treatment." This consisted of the tipping truck sign with flashers activated and an advance warning sign. Because speeds on automobiles were taken while waiting for trucks, some automobile speed data were taken when the flashers were not activated. A total of 546 automobiles and 2,120 trucks were observed during 120 hours of field data collection.

Results

The data collected for the Before and After conditions for automobiles, articulated trucks and top-heavy trucks are presented as tables 14, 15, and 16, respectively. The tables, like those used in Field Study I, show the sample size, mean, standard deviation, and the 75th, 85th, 90th, and 95th percentile speeds for the various experimental condition. In the case of automobiles the conditions were Before, Ramp Sign and Advance Warning Sign, and Ramp Sign with Flashers and Advance Warning Sign. For articulated trucks and top-heavy trucks, the conditions were Before and Ramp Sign with Flashers and Advance Warning Sign.

The data for automobiles in table 16 show essentially no change in approach speeds, either means or percentiles, across the three conditions. The mean ramp speeds, however, do drop 1 mi/h in response to the two signs and another 1 mi/h in response to the signs and flashers. The percentile scores drop 3 to 4 mi/h in

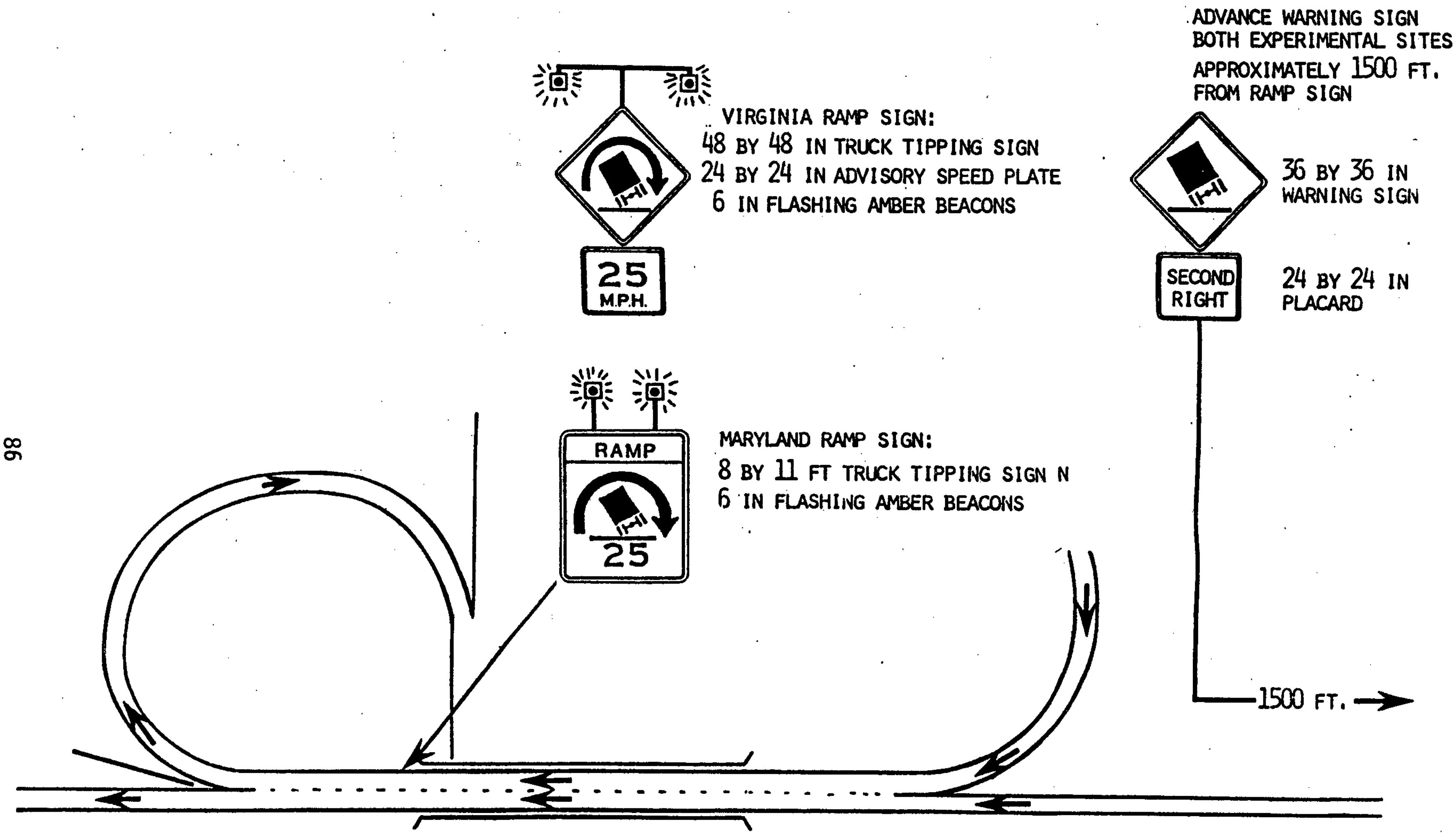


Figure 31. Field study II and field study III signing changes.

Table 14. Mean, standard deviation and percentile data for automobiles: Field Study II.

	Before	Ramp Sign and Advance Warning Sign	Flashers on at Ramp and Advance Warning Sign
Approach Speeds, Experimental Site			
Sample Size	302	149	108
Mean	59	58	59
Standard Deviation	6.1	5.3	5.7
75th Percentile	62	62	63
85th Percentile	64	64	65
90th Percentile	66	66	66
95th Percentile	68	68	69
Ramp Speeds, Exp. Site			
Sample Size	302	149	108
Mean	42	41	40
Standard Deviation	4.7	3.9	4.0
75th Percentile	46	43	43
85th Percentile	47	45	44
90th Percentile	48	46	45
95th Percentile	50	48	46

Table 15. Mean, standard deviation and percentile data for articulated trucks: Field Study II.

	Before	Flashers on at Ramp Sign and Advanced Warning Sign
Approach Speeds, Experimental Site		
Sample Size	755	600
Mean	50	51
Standard Deviation	5.1	5.2
75th Percentile	54	54
85th Percentile	55	56
90th Percentile	57	57
95th Percentile	58	59
Ramp Speeds, Exp. Site		
Sample Size	755	600
Mean	34	34
Standard Deviation	4.2	4.1
75th Percentile	37	37
85th Percentile	38	38
90th Percentile	40	40
95th Percentile	42	41

1 mi/h = 1.61 km/h

Table 16. Mean, standard deviation and percentile data for top-heavy trucks: Field Study II.

	Before	Flashers on at Ramp Sign and Advance Warning Sign
Approach Speeds, Experimental Site		
Sample Size	26	60
Mean	50	50
Standard Deviation	4.7	5.1
75th Percentile	53	53
85th Percentile	56	55
90th Percentile	57	56
95th Percentile	58	60
Ramp Speeds, Exp. Site		
Sample Size	26	60
Mean	34	33
Standard Deviation	4.6	3.7
75th Percentile	36	34
85th Percentile	37	37
90th Percentile	42	38
95th Percentile	45	41

1 mi/h = 1.61 km/h

response to the lights and flashers. However, the Kruskal-Wallis analysis of variance test indicated that this was not a statistically significant difference. Table 14 contains the data for a subsample of all articulated trucks that were identified as top-heavy. Using the procedures described on page 60, the weight and cargo of some of the articulated trucks was determined. Trucks weighing at least 60,000 lb (27,240 kg) and carrying a low- or medium-density load (i.e., paper products) were defined as top-heavy. These trucks have the highest center of gravity and are most likely to roll over in the ramp. They are the true target population for the truck rollover warning signs. The approach speeds show no change in response to the advance warning sign. The ramp speeds do, however, show some small but consistent changes. Mean ramp speeds were reduced 1 mi/h (1.61 km/h). Both the 90th and the 95th percentile ramp speeds showed a 4 mi/h (6.4 km/h) reduction. These vehicles, the fastest of the top-heavy trucks, are the prime target group and the ones who need to slow down the most. Unfortunately, the Kruskal-Wallis analysis of variance indicated that this speed reduction was not quite significant ($p=0.108$).

FIELD STUDY III

At the conclusion of Field Studies I and II, it was apparent that neither the signing or the flashing lights had a very great effect on truck speeds in the interchange ramps. It was decided to use the Field Study I locations to evaluate the effect of a flashing light warning system as well as an advance warning sign.

The treatments were installed at the I-70 Eastbound to I-81 Southbound ramp, one of the two experimental ramps used in Field Study I. The treatments were shown in figure 31. The other experimental ramp for Field Study I was used as the control ramp. Thus, experimental comparisons focus on the effect of flashing beacons and advance warning signing as a supplement to a truck tipping sign installed at the interchange ramp. As was the case in Field Study II, the flashing beacons were powered by a small portable generator and were activated when the approaching truck was approximately 500 ft (152 m) from the ramp. Speed data for automobiles were taken for both the flashers-on and the flashers-off conditions in order to determine if the flashers themselves had an adverse effect on automobile speeds. A total of 280 automobiles and 684 trucks were observed during 81 hours of data collection.

Results

Table 17 presents the descriptive data for automobiles collected at both the experimental and control sites. Table 18 presents the descriptive data for articulated trucks, while table 19 presents the data for top-heavy trucks.

As shown in table 17 the mean approach speeds and percentile approach speeds for automobiles show no consistent effect. The advance warning sign apparently has no effect on approach speeds, as was anticipated. The approach speeds at the control site also showed no changes. The ramp speeds, however, show some differences. Flashers at the ramp sign reduced the mean speed from 43 mi/h (69 km/h) to 38 mi/h (61 km/h). Combined with the advance warning sign, the effect of the flashers was somewhat less. There was also a 4 mi/h (6.4 km/h) to 6 mi/h (9.7 km/h) reduction in the various percentile scores. The mean and percentile ramp speeds at the control site actually increased slightly between the Before and After testing. The Kruskal-Wallis test indicated that any changes observed were not statistically significant at the 0.05 level.

Table 17. Mean, standard deviation and percentile data for automobiles: Field Study III.

	Before Ramp Sign Only	Flashers on at Ramp Sign	Ramp Sign & Advance Warning Sign	Flashers on at Ramp Sign and Advance Warning Sign
Approach Speeds, Experimental Site				
Sample Size	28	83	22	45
Mean	59	57	59	57
Standard Deviation	3.4	5.5	7.0	5.5
75th Percentile	62	60	64	59
85th Percentile	62	63	66	62
90th Percentile	62	65	67	65
95th Percentile	65	66	76	69
Ramp Speeds, Experimental Site				
Sample Size	28	83	22	45
Mean	43	38	41	39
Standard Deviation	4.7	4.3	5.7	5.3
75th Percentile	46	41	44	43
85th Percentile	49	43	47	44
90th Percentile	49	45	51	47
95th Percentile	50	46	56	50

	Before Ramp Sign Only	After Ramp Sign Only
Approach Speeds, Control Site		
Sample Size	114	51
Mean	55	55
Standard Deviation	5.3	4.4
75th Percentile	59	59
85th Percentile	61	61
90th Percentile	62	62
95th Percentile	65	62
Ramp Speeds, Control Site		
Sample Size	114	51
Mean	38	40
Standard Deviation	3.6	5.6
75th Percentile	40	43
85th Percentile	42	46
90th Percentile	43	47
95th Percentile	43	48

1 mi/h = 1.61 km/h

Table 18. Mean, standard deviation and percentile data for articulated trucks: Field Study III.

	Before Ramp Sign Only	Flashers on at Ramp Sign	Flashers on at Ramp Sign and Advance Warning Sign
Approach Speeds, Experimental Site			
Sample Size	133	91	183
Mean	54	54	53
Standard Deviation	5.7	5.0	5.1
75th Percentile	57	58	57
85th Percentile	59	60	59
90th Percentile	61	60	60
95th Percentile	63	62	62
Ramp Speeds, Experimental Site			
Sample Size	133	91	183
Mean	32	32	32
Standard Deviation	4.3	4.1	3.8
75th Percentile	34	34	34
85th Percentile	36	36	35
90th Percentile	38	37	36
95th Percentile	40	40	38

	Before Ramp Sign Only	After Ramp Sign Only
Approach Speeds, Control Site		
Sample Size	191	177
Mean	50	50
Standard Deviation	5.7	5.2
75th Percentile	54	53
85th Percentile	56	55
90th Percentile	57	56
95th Percentile	59	58
Ramp Speeds, Control Site		
Sample Size	191	177
Mean	33	32
Standard Deviation	4.2	3.9
75th Percentile	35	34
85th Percentile	36	36
90th Percentile	37	37
95th Percentile	39	39

1 mi/h = 1.61 km/h

Table 19. Mean, standard deviation and percentile data for top-heavy trucks: Field Study III.

	Before Ramp Sign Only	Flashers on at Ramp Sign	Flashers on at Ramp Sign and Advance Warning Sign
Approach Speeds, Experimental Site			
Sample Size	15	16	18
Mean	55	53	53
Standard Deviation	5.3	4.4	5.1
75th Percentile	59	57	56
85th Percentile	60	59	59
90th Percentile	62	60	60
95th Percentile	64	60	63
Ramp Speeds, Experimental Site			
Sample Size	15	16	18
Mean	30	32	30
Standard Deviation	2.8	3.9	3.6
75th Percentile	32	35	32
85th Percentile	33	35	34
90th Percentile	33	37	35
95th Percentile	34	40	39
Approach Speeds, Control Site	Before Ramp Sign Only	After Ramp Sign Only	
Sample Size	13	15	
Mean	49	49	
Standard Deviation	6.4	6.4	
75th Percentile	52	52	
85th Percentile	56	56	
90th Percentile	56	59	
95th Percentile	56	61	
Ramp Speeds, Control Site			
Sample Size	13	15	
Mean	32	32	
Standard Deviation	3.6	6.8	
75th Percentile	35	34	
85th Percentile	37	34	
90th Percentile	37	35	
95th Percentile	37	36	

1 mi/h = 1.61 km/h

The data for articulated trucks in table 16 indicate a 1 mi/h (1.61 km/h) reduction in mean approach speed as well as 90th and 95th percentile speeds when the advance warning sign was in place. Although there was no change in the mean ramp speed when the flashers were activated, the percentile speeds were reduced 1 to 2 mi/h (1.6 to 3.2 km/h). At the control site, however, the mean ramp speed was down 1 mi/h (1.61 km/h) while the percentile ramp speeds were unchanged. Again, the Kruskal-Wallis test indicated no significant differences.

The data for top-heavy trucks are shown in table 19. The criteria for identifying top-heavy trucks was described under Field Study II. The approach speeds again indicate that the advance warning sign may be having a small effect on mean and percentile approach speeds. However, there does not appear to be any speed reduction in ramp speeds in response to the flashers. The speeds at the control site were remarkably consistent between the Before and After conditions. Testing at the Maryland site indicates that the advance warning sign has a slight, but insignificant effect on top-heavy trucks while the use of flashers has no consistent effect.

IV. SUMMARY AND CONCLUSIONS

BACKGROUND

Truck rollover accidents represent a serious national problem. A search of the accident records in a sample of 15 States found that between 11 and 88 accidents occur annually in each State. The accidents typically occur on interchange ramps in clear weather, on dry roads, during daylight hours. Load shifting was identified as a possible contributing factor in about half of the accidents. At the local level, a number of States have tried a number of traffic control devices to warn truckers of potentially dangerous interchange ramps. Various traffic control devices listed in the Manual of Uniform Traffic Control Devices (MUTCD) have been used at such locations. These devices include: Turn Sign (W1-1), Curve Sign (W1-2), Advisory Speed Plates (W13-1), Large Arrow Sign (W1-6), Chevrons (W1-8) and Advisory Exit Speed Signs (W13-2, W13-3).

In addition, several States have installed special tipping truck signs at certain high accident locations. These special signs have typically included a rear silhouette of a tipping truck, often combined with a diagrammatic arrow and an advisory speed. Until this project, the effectiveness of these signs had not been evaluated.

LABORATORY TESTING

As part of this project, an effort was made to develop new and innovative signing for problem ramps. A series of open-ended and structured interview techniques were used to identify sign elements and combinations of sign elements (sign formats) that most effectively warn truckers. The most promising candidate sign formats were then tested, using open-ended response procedures to identify the formats which evoked the highest level of understanding and which were most preferred by professional truckers. The sign formats that had the highest levels of understanding consisted of the rear silhouette of a tipping truck, a diagrammatic arrow, and an advisory speed indication. Signs with these elements were also the most preferred. The truckers also indicated that they preferred the use of advance warning signs located well in advance of the ramp and the use of flashing lights or beacons to identify particularly hazardous locations.

The majority of the truckers tested indicated an understanding that the sign indicated they had to be more careful when they were hauling a top-heavy load, then when they were hauling a regular load. Unfortunately, a majority of the nontruckers tested also indicated that they, too, would slow down in response to the sign. This raised a concern that the tipping truck sign may have an adverse effect on nontruck operating speeds, a concern that was addressed in subsequent field testing. A final series of laboratory tests were conducted to test the legibility distance of the sign formats that did best in the cognitive testing. It was found that the new signs were as "visible" as many commonly used warning signs.

FIELD TESTING

Two of the most promising sign formats were subjected to a series of three field tests. In the first field test, the tipping truck sign produced a slight short-term reduction in truck ramp speeds at one of two experimental sites. However, the effect was gone within 3 months after the signs were installed. In the second field study, the tipping truck sign with flashing beacons (that were activated when the truck approached the ramp) combined with an advance warning sign approximately 1,500 ft (457 m) upstream from the ramp produced no statistically significant change in truck speeds. The speeds of all trucks, of all articulated trucks and of a special sample of top-heavy trucks were analyzed with no effects apparent. There was, however, a 4-mi/h (6.4-km/h) reduction in the 90th and 95th percentile speeds of top-heavy trucks. Although not statistically significant, this suggests that the truck tipping sign with flashers may be having an effect on the real target group - fast moving, top-heavy trucks. In the third field test, the addition of flashing beacons to an existing tipping truck sign and an advance warning sign had no effect on the approach or ramp speeds of all articulated trucks or a subset of articulated trucks that were identified as carrying top-heavy loads. Again there was a slight reduction in the 85th, 90th and 95th percentile ramp speeds of all articulated trucks. In none of the three field tests was an effect on automobile speed observed. Thus, although the tipping truck sign may not be having a measurable effect on the drivers of top-heavy loads, at least it is not producing an undesired effect on the rest of the traffic stream.

CONCLUSIONS

The laboratory testing clearly indicates that the majority of truckers understand the meaning of the truck tipping signs. They understand that the sign is specifically intended for drivers of top-heavy loads and they further indicated that they would respond appropriately to the sign <u>if</u> they were hauling a top-heavy load. In addition, the vast majority indicated that advisory signing should include a ramp warning sign as well as an advance warning sign.

Unfortunately, the field testing failed to demonstrate a statistically significant change in truck ramp speeds. However, there was a fairly consistent reduction in the ramp speeds of the fastest trucks (85th, 90th and 95th percentile) at several of the test sites. It is also important that mean ramp speeds are 7 to 8 mi/h (11.3 to 12.9 km/h) more than the advisory speed and more than 10 percent of the trucks are exceeding the advisory speed by more than 10 mi/h (24.2 km/h). This suggests that many truckers are traveling at or near potentially dangerous speeds and that some signing is appropriate. Although the field tests failed to demonstrate a favorable effect on the population observed, the high levels of understanding associated with the truck tipping sign suggests that the continued use of the sign may be appropriate. It may be that the real target population is such a small percentage of the trucking population that obtaining a field validation is very difficult.

Presumably the real target population is those truckers who are not familiar with the handling characteristics of the particular load they are carrying and who are <u>also</u> not familiar with the characteristics (degree of curvature, superelevation, etc.) of rhe ramp they are approaching. It is not known what percentage of the truck driving population, in general, or of the truck driving population at our study sites, in particular, fall into that category. Alshough the study sites were selected because they were high-accident locations, the percentage of the drivers who are truly unfamiliar with the ramp and with the characteristics of their load may still be very small.

Historically, tipping truck signs have been used at locations that have experienced truck rollover accidents. Ideally we would prefer to be able to identify potentially hazardous locations before they experience a series of rollover accidents. In an effort to quantify the differences between ramps that are potentially hazardous and those that are not, some limited field measurements were made (see appendix A). Two devices, a ball-bank indicator and an electronic tri-axial accelerometer ("the g-analyst"), were used to measure lateral acceleration at two ramps with high-accident rates and at two ramps with very few or no accidents. Measurements were taken with two different vehicles at a variety of operating speeds. Analysis of the resulting measurements indicated that neither device was able to differentiate the hazardous ramps from the non-hazardous ramps.

Since there do not appear to be measurable differences between ramps with a high propensity for truck rollover accidents and those with less propensity, perhaps driver familiarity with vehicle handling characteristics may play a greater role in the occurrence of rollover accidents than the physical characteristics of a particular ramp. To examine these factors, the relationship between rollover thresholds and cornering speeds was addressed (see appendix B).

It was found that the density of the load being carried has a very dramatic effect on the rollover threshold of a tractor-trailer. A seemingly small change in the Center of Gravity Height (CGH) of only 12 in. (31 cm) changes the rollover threshold by 3 mi/h (4.8 km/h). Thus, while a trucker may have previously negotiated a ramp successfully at 34 mi/h (55 km/h), the truck will roll if the driver enters that same ramp with a slightly less dense load (with a CGH 12 in [31 cm] higher) and the truck speed exceeds 31 mi/h (50 km/h). The difference between a load of spaghetti sauce and a load of spaghetti noodles is all it takes to separate a successful ramp passage from a rollover accident. From a human factors standpoint, this may be a very difficult distinction for the average truck driver to make.

The laboratory studies indicate that the meaning of the tipping truck sign is well understood by truckers. Although the field studies failed to confirm this high level of understanding, the potential utility of the tipping truck sign should not be underestimated. Truck drivers are being asked to make a very difficult discrimination each time they enter an interchange ramp. They must select an exit speed that is compatible with the characteristics of the curve and the characteristics of their load, as well as one that permits them to safely and efficiently enter the ramp and subsequently exit the ramp and successfully merge with the traffic stream. The truck tipping sign may be an effective way to remind truckers that they should consider the characteristics of their load when deciding how fast they should enter an oncoming interchange ramp. Although this project was unable to identify an effective way to identify potentially hazardous locations, it does support the use of the tipping truck sign at high-accident locations.

APPENDIX A

FACTORS RELATED TO DEVELOPING GUIDELINES FOR THE PLACEMENT OF TRUCK ROLLOVER WARNING SIGNS

One purpose of this project was the development of guidelines for the placement of the truck rollover warning signs that were developed and subjected to extensive laboratory and field testing.

There should be two objectives in the development of guidelines for the placement of warning signs on a ramp. The guidelines should direct the engineer to place the signs where they are necessary. Overuse of these signs will lead to a complacency on the part of the target vehicle operator. The guidelines should also be easy to apply or they will not be applied at all. Keeping that in mind, the following discussion should serve as a starting point for the development of useful guidelines.

There is quite a bit of recent literature on the subject of rollover accidents. This body of work is the principal reason for this study. Ervin et al. (1986) in their analysis of interchange geometric features on the operation and safety of trucks conclude that rollover accidents occur at locations where side friction demand is high[4]. This is particularly true if:

- The superelevation is largely undeveloped at the point of curvature.
- There is a curb on the outside of the curve close to the roadway.
- A sharp curve is placed at the end of a considerable downgrade.
- The curve is placed near the beginning of the ramp with only a short deceleration lane before the ramp curve.
- A sharp curve is encountered after traversing a sharp-flat set of curves on the ramp.

Cases where the acceleration and deceleration lanes are insufficient to allow high center of gravity (CG) vehicles to enter horizontal curves at appropriate speeds can also cause high side friction demands.

From these findings, they recommend that highway curves be examined to look for the design elements that can cause rollover accidents. The authors state that the examination should include an evaluation of the following factors germane to this discussion:

- Continuous side friction demand through all curves on the ramp.
- The sequence and magnitude of radius changes along compound curves.
- Length of deceleration lanes and their relationship to sharp curves (this should also apply to acceleration lanes).
- Downgrade slope and length prior to sharp curves.

This set of examinations can be used as a starting point for the development of a set of guidelines for the placement of signs to warn high CG vehicles can be formulated. However, the actual guidelines need to include specific methodologies that are easy and inexpensive to perform these examinations.

MEASURING LATERAL ACCELERATION IN CURVES

It can be argued that by examining curve sequence, acceleration and deceleration lane lengths, and length and slopes of downgrades a good evaluation of the potential for high CG vehicle rollover accidents can be obtained. These factors can also indicate placement locations for warning signs. However a definitive answer as to whether rollover accidents will actually happen can only be achieved through an analysis of continuous side friction demand. Ervin et al. and Harwood et al. use a measure of side friction demand to establish high CG vehicle rollover threshold levels.[10]

To analyze continuous side friction demand, it would be necessary to calculate the side friction demand at a series of closely spaced points on the curve from the point of curvature of the first curve (PC) to the point of tangency of the last curve (PT). This would be done by calculating a value for f in the equation $f = V^2 / 15 R - e$ (f is side friction demand, V is speed in miles per hour, R is the radius of the curve in feet, and e is the superelevation in feet per foot) at enough points along the ramp curve to be sensitive to the changes in superelevation. While this would meet the recommendation, it would be a very labor intensive task. However, since f is equal to the lateral acceleration of the vehicle, use of a device that continually monitors lateral acceleration would also fulfill this requirement.

Two devices that continually monitor lateral acceleration are available. The ball-bank indicator has long been used to determine appropriate advisory speeds for curves (see page 9 of this report). The "g-analyst," produced by Valentine Industries, is an electronic tri-axial accelerometer that sells for less than $400 with PC-compatible software.

Both devices can be used to monitor the lateral acceleration experienced by a vehicle while traveling through a curve at various speeds. One might hypothesize that the differences between the lateral acceleration readings found in different curves could be used to target potentially dangerous ramps for treatment. To test this hypothesis, ball-bank and g-analyst data were collected at four Interstate ramps in Western Maryland. Two of these ramps were the sites of many truck accidents involving rollovers and jack-knifing. Two of the ramps had very few such accidents. Lateral acceleration data was recorded at cornering speeds from 20 mi/h (32 km/h) to 40 mi/h (64 km/h) in 5 mi/h (8 km/h) increments. Since the ball-bank indicator readings are somewhat dependent on the amount of body-roll experienced by the test vehicle, it was decided to use two different vehicles to take those readings. A late-model front-wheel drive Dodge minivan and a 1984 rear-drive Oldsmobile Cutlass were selected as test vehicles. Since the g-analyst electronically corrects for body-roll when measuring lateral acceleration, only one test vehicle, the Dodge minivan, was used.

The ball-bank indicator readings were recorded by a passenger in the right front seat. The highest reading obtained in the curve at each speed was recorded. The g-analyst records lateral acceleration readings every second. For analysis purposes, it was decided to examine the peak reading obtained in any 1 second as well as the highest reading obtained for 3 continuous seconds. The data collected at the four Maryland sites are shown in table 20. The van and the Cutlass provided similar ball-bank readings, except that the Cutlass tended to have slightly lower readings, especially at speeds equal to the posted advisory speed of 30 mi/h (48 km/h) and above. This was probably due to the softer suspension and resultant greater body-roll experienced by the minivan. Also, not surprisingly, the 1-second peak readings were typically higher than the 3-second continuous readings recorded by the g-analyst.

Table 20. Ball-bank and g-analyst readings at four interchange ramps in Maryland.

	Accident Site 1 70 W/81 S				Accident Site 2 70 E/81 N				Control Site 1 81 S/70 E				Control Site 2 81 N/70 W			
Speed	Ball-Bank		g-Analyst		Ball-Bank		g-Analyst		Ball-Bank		g-Analyst		Ball-Bank		g-Analyst	
mi/h	Van	Cutlass	Peak	3-Sec	Van	Cutlass	Peak	3-Sec	Van	Cutlass	Peak	3-Sec	Van	Cutlass	Peak	3-Sec
20	6	6	.08	.07	6	3	.09	.09	8	5	.08	.05	6	5	.09	.09
25	11	10	.16	.15	10	12	.17	.16	12	9	.15	.12	11	11	.18	.11
30	16	16	.22	.18	17	15	.26	.22	16	14	.22	.19	18	16	.28	.20
35	22	21	.30	.28	23	20	.33	.33	23	21	.33	.28	22	23	.39	.31
40	28+	--	.49	.46	28+	--	.47	.47	28+	25	.46	.40	28+	28+	.44	.41

Metric Conversions: 1 mi/h = 1.61 km/h
1 lb = 0.454 kg
1 in = 0.0254 m

Several statistical analyses were performed to determine the potential usefulness of these readings for identifying sites with a high potential for truck rollover accidents. Paired t-tests for the data at each site found the following:

Site	Van/Cutlass Comparisons	Peak/3-Second Comparisons
Accident Site 70W	Van = Cutlass	Peak > Continuous
Accident Site 70E	Van = Cutlass	Peak = Continuous
Control Site 81S	Van > Cutlass	Peak > Continuous
Control Site 81N	Van = Cutlass	Peak > Continuous

These tests support the previous discussed observations that the two vehicles provided comparable reading except that at one site, Control Site 81S, the ball-bank readings were significantly higher in the van. And, that the peak readings were significantly higher than the three second continuous readings.

Two 4x2 Analyses of Variance with repeated measures were performed, one for ball-bank readings and one for g-analyst measures. The ball-bank data revealed the following:

Site	Not significant
Ball-bank	Van > Cutlass
Site by ball/bank	Not significant

There was no significant difference between the ball-bank reading of either vehicle recorded at the four sites. The g-analyst data revealed similar results:

Site	Not significant
G-analyst	Peak > Continuous
Site by g-analyst	ACC 70W, CON 81S, CON 81N: Peak > Continuous
	ACC 70E: Peak = Continuous

There were no significant differences between the g-analyst readings, either peak or continuous, recorded at the four sites.

Finally, a One-Way Analysis of Variance between sites was performed. No significant difference between the sites were found in either the van or Cutlass ball-bank readings or in the peak or continuous g-analyst readings.

In conclusion, all of the statistical tests performed failed to show any differences between the ball-bank or g-analyst readings obtained at the high accident locations and the control locations. It appears that neither device provides a method of identifying sites with high accident potential.

APPENDIX B

THE RELATIONSHIP BETWEEN ROLLOVER THRESHOLDS AND CORNERING SPEEDS

Harwood et al. concluded that a rollover threshold of 0.30 g appears to be "appropriate for design" (page 56). In order to illustrate the relationship between lateral acceleration and vehicle speed, it is helpful to make some simplifying assumptions about the nature of the curve; i.e., both the radius and the superelevation. The relationship between vehicle speed and lateral acceleration of the curve itself are shown in the following equation:

$$a = \frac{V^2}{15R} - e \qquad (1)$$

where:
a = lateral acceleration (g)
V = vehicle speed (mi/h)
R = radius of curve (ft)
e = superelevation

If we assume that 0.30 is an appropriate design limit and that we wish to have a 30 mi/h design speed, equation (1) can be used to determine the radius of curve needed.

$$a = \frac{V^2}{15R}$$

where:
a = lateral acceleration limit assumed to be (0.30g)
V = vehicle speed limit assumed to be 30 mi/h
R = radius of curve
e = 0

$$0.30 = \frac{(30)^2}{15R}$$

$$4.5R = 900$$

$$R = 200$$

Given these assumptions and a flat (i.e., no superelevation) curve, a 200-ft (61-m) curve would be needed to generate 0.30 g of lateral acceleration at a vehicle speed of 30 mi/h (48 km/h). If we use this flat 200-ft (61-m) curve as a typical curve, the same equation can be used to determine the effect that small changes in the rollover threshold (g) has on the vehicle speed in that corner.

Ervin et al. prepared an interesting illustration (page 55) of the rollover thresholds for several types of loaded tractor-semitrailers.[4] They showed that the rollover thresholds for loaded trucks varied from 0.24 to 0.34 g. Unfortunately most people have some difficulty relating to the concept of lateral acceleration and the unit of measurement "g." Although we spend our entire lives experiencing one "g" of vertical force -- at times more or less if one is a patron of amusement park rides -- it is difficult to "imagine" one g or a quarter g of lateral acceleration. With several additions/ modifications, Ervin's illustration of rollover thresholds becomes much more understandable. The modified figure is presented here as table 21. The modifications consisted of the following: First, an additional truck configuration (i.e., the high density freight semi) and a standard passenger car were added. Second, columns were added to show the speed in mi/h at rollover on flat curves with 200-ft (61-m) and 355-ft (108-m) radii. As shown above, the 200-ft (61-m) radius would be needed to generate 0.30 g of lateral acceleration at a speed of 30 mi/h (48 km/h). The 355-ft (108-m) radius produces 0.30 g at 40 mi/h (64 km/h). On the 200-ft (61-m) curve, the speed of rollover varies from 27 mi/h (43 km/h) for a semi with a Gross Vehicle Weight (GVW) of 80,000 lb (36,320 kg) and a low-density load to 36 mi/h (58 km/h) to a semi with the same GVW but with a high-density load. On the curve with a 40-mi/h (64-km/h) design speed, there is a 12-mi/h (19-km/h) difference between the rollover speeds of these same two vehicles. Third, the last two columns in table 21 were generated to show the speed at rollover for the project study sites in Maryland. According to the design specifications, all four loops have a 230-ft (70-m) radius and a superelevation of 3.43°. Using equation (1) above, the speed at rollover was computed for each of the seven vehicle configurations. The table shows that, without superelevation, the various truck configurations would roll at speeds between 29 and 39 mi/h (47 and 63 km/h). When the effect of the superelevation is added, the rollover speeds increase by about 3 mi/h (4.8 km/h) for each of the truck configurations.

Converting the rollover thresholds to the speed at rollover for these hypothetical and real-world interchange ramps provides a very interesting perspective to the truck rollover problem. On one trip a trucker with 80,000 lb (36,320 kg) of steel plate can safely negotiate the I-70/I-81 interchange at 42 mi/h (68 km/h); on the next trip with 80,000 lb (36,320 kg) of toilet paper the truck

Table 21. Rollover thresholds and speeds for various vehicles and various curves.

Configuration	Gross Vehicle Weight	Payload Center of Gravity Height (inches)	Rollover Threshold (g's)	Speed in mi/h at Rollover on Flat Curve (on Superelevation): 200-ft Radius 30 mi/h Design Speed	Speed in mi/h at Rollover on Flat Curve (on Superelevation): 355-ft Radius 40 mi/h Design Speed*	Speed in mi/h at Rollover at Maryland Study Sites (I-70/I-81): Without Superelevation	Speed in mi/h at Rollover at Maryland Study Sites (I-70/I-81): With Superelevation
Passenger Car	3,000	21.0	1.20	60	80	64	66
Semi - Full Gross High Density Freight	80,000	63.5	0.44	36	48	39	42
Semi - Full Gross Medium Density Freight	80,000	83.5	0.34	32	43	34	37
Tanker Full Gross Gasoline	80,000	88.6	0.32	31	41	33	36
Semi - "Typical" LTL Freight Load	73,000	95.0	0.28	29	38	31	34
Tanker Full Gross Cryogenic	80,000	100.0	0.26	28	37	30	33
Semi - Full Gross Full Cube	80,000	105.0	0.24	27	36	29	32

*Design speed based on assumed rollover threshold of 0.3 g's.

Metric Conversions: 1 mi/h = 1.61 km/h
1 lb = 0.454 kg
1 in = 0.0254 m

will roll over at speeds over 32 mi/h (52 km/h). It is apparent that truckers have a very difficult discrimination task. Although these two loads weigh the same, they must drive very differently. Since the GVW is the same, the truck accelerates and decelerates similarly. Since tractor-trailers are articulated, the driver is isolated from the increased body roll that may warn of impending disaster. All of these factors no doubt contribute to the problem of being able to demonstrate a sizable operational effect on truck speeds during the field studies. Our target group, in reality, is not all heavily loaded trucks or even all trucks with high Center of Gravity Heights (CGH's). Our target group is actually only those truckers who have a load which has a high rollover potential <u>and</u> who need to be reminded to reduce their speeds accordingly. The relative rarity of rollover accidents would suggest that this group is a relatively small proportion of the trucker population.

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