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FEASIBILITY OF DETERMINING THE INCREMENTAL EFFECTIVENESS OF ACCIDENT COUNTERMEASURES

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101

U.S. Department of Transportation
Federal Highway Administration

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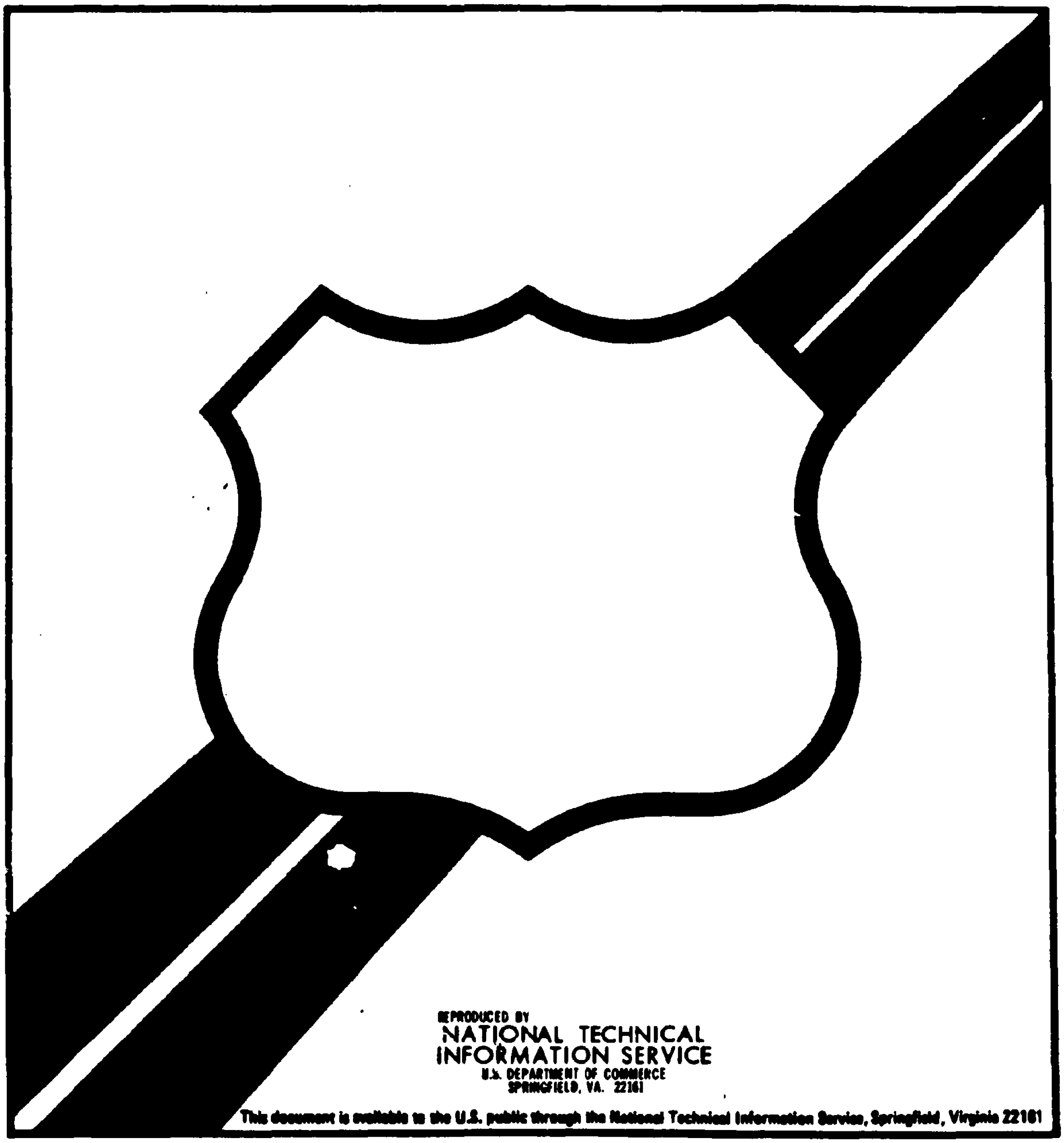

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16. Abstract

This report documents the development of a generalized methodology for determining the incremental effects of accident countermeasures employed individually and in groups. Two basic experimental designs are presented, and each is illustrated in an experimental plan for two groupings of countermeasures in two common highway situations. An assessment is made of the feasibility of implementing the methodology with respect to practicality, reliability, validity, time, cost, and expected benefit.

The study concludes that while the methodology can produce incremental effects for many countermeasure groups in the more common highway situations, there are some serious disadvantages in terms of practicality, time, and cost.

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METRIC (SI*) CONVERSION FACTORS

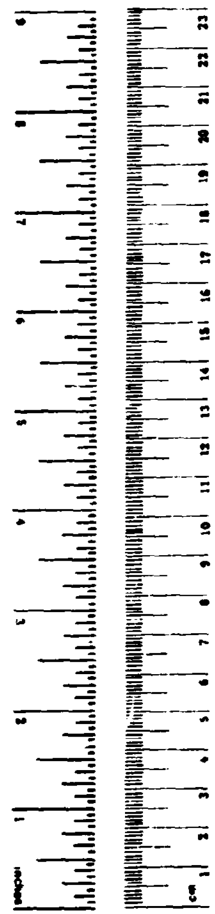
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

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

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



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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
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

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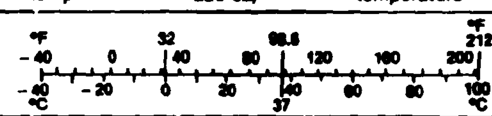

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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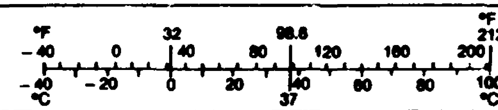

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I. INTRODUCTION

Background

Effective highway safety improvement programs require the identification of the specific roadway, traffic control, and environmental deficiencies of a hazardous location and the implementation of appropriate countermeasures to alleviate the accident problems. A wide range of countermeasures have been applied to address safety deficiencies, but in many cases the expected effectiveness of the countermeasures was based largely on judgment. Traffic and safety engineers have been implementing accident countermeasures for many years using past experience without follow up evaluations. Thus, statistically sound information about the accident reduction capabilities of various countermeasures is still limited. While efforts have been made to alleviate this deficiency, there are several complicating factors which must be addressed. These include:

- A countermeasure may affect both safety and operations making it difficult to interpret any changes in accidents at a site.

- The use of multiple countermeasures at a site increases the difficultly of isolating the effect of a single countermeasure.

These issues are important, because in order to select appropriate and cost-effective countermeasures for a site, it is essential to accurately estimate the resulting safety benefits. This requires the availability of accident reduction factors not only for individual treatments, but also estimates of the incremental benefits for countermeasures which involve multiple treatments. In the absence of quantitative data on such incremental benefits, safety engineers have relied either on subjective judgment or published accident reduction factors for individual countermeasures.

Objectives

The objectives of this study were to develop a methodology for determining the incremental effectiveness of accident countermeasures applied in combination at particular locations, to outline a plan for implementing the methodology, and to assess the expected feasibility of the methodology.

Scope of the Research

This study was primarily a "paper study" in which subjective judgment was applied to the assessment of existing information. No new data were collected. The first step listed accident countermeasures by type of situation or location and by accident pattern. Both individual countermeasures and typical groups of countermeasures were identified. The next step examined several potential methodologies for determining the incremental effectiveness of typical accident countermeasure groups. Experimental plans were outlined for each of the most promising methodologies. The plans included the consideration of consistency with current practices, measures of effectiveness (to include surrogates), specific accident types to be affected and cost to implement. Next, the feasibility of the candidate methodologies was assessed with regard to practicality, reliability, validity, time, cost, and expected benefit.

Finally, conclusions were drawn and recommendations were made with respect to the continuation of research to fully develop and test a methodology for determining the incremental effectiveness of groups of accident countermeasures.

II. ACCIDENT COUNTERMEASURES

The development of a methodology for the investigation of the incremental effectiveness of accident countermeasures requires initially that a comprehensive list of countermeasures be compiled. This list will provide the basis for reviewing:

- o Accident countermeasures and their groupings in practice for different types of highways.
- o Past efforts to evaluate the accident reduction effects of countermeasures and the associated critiques of these efforts.
- o Past research aimed at analyzing incremental effectiveness.

The following subsections describe various approaches to categorizing countermeasures which have been attempted. These lists are intended to provide the background for determining common practices in the application of countermeasures (i.e., their groupings), and assessing the practicality of a plan to conduct a formal study to establish the levels of incremental effectiveness. Each of the following subsections addresses a means to categorize countermeasures.

Locational Influences on Accidents

The frequency and severity of accidents on the highway system vary by location. Thus, accident treatments are often categorized by the type of location. Table 1 provides a summary of typical accident countermeasures which may be applied to types of locations.

Table 1. Countermeasures categorized by location type

- Highway Sections (Roadway)
  - Channelization
  - Delineators
  - Illumination
  - Add Lanes
  - Median Barriers
  - Median Improvements
  - Pavement Markings
  - Raised Pavement Markers
  - Pavement Widening
  - Shoulder Widening/Improvement
  - Rumble Strips
  - Roadway Realignment/Reconstruction
  - Sight Distance Improvements
  - Signing
  - Skid Treatment - Grooving/Overlay
  - Drainage Improvements
  - Speed Zones
  - Truck Escape Lanes
  - Close Median Openings
  - Add Climbing Lanes
  - Add Passing Lanes
  - Improve Superelevation
  - Acceleration/Deceleration Lanes
  - Improve Surface
  - Improve Access Management

- Highway Sections (Roadside)
  - Breakaway Sign Supports
  - Guardrail
  - Obstacle Removal

Table 1. Countermeasures categorized by location type (continued)

- Utility Pole Modification
- Slope Flattening
- Sidewalks/Bicycle Facilities
- Fencing
- Drainage Structure Improvements
- Breakaway Poles

o <u>Highway Sections (Bridges)</u>
- Install Guardrail Transitions
- Construct New Bridges
- Replace/Add bridge Rail
- Replace Bridges
- Widen/Improve Bridges
- Impact Attenuators
- Drainage Improvements
- Deicing Treatments
- Improve Surface

o <u>Highway Sections (Others)</u>
- Minor Structural Improvements
- Overheight Vehicle Detection System

o <u>Rail-Highway Crossings</u>
- Install RR Crossing Gates
- Install RR Crossing Flashing Lights
- Improve Crossing Surface
- Upgrade Crossing Surface
- Reconstruct Vertical Alignment

Table 1. Countermeasures categorized by location type (continued)

- Upgrade Crossing Markings
- Grade Separation
- Illumination

o <u>At-Grade Intersections</u>

- Install Beacons/Flashers
- Channelization
- Illumination
- Add Lanes
- Median Barriers
- Pavement Widening
- Pavement Markings
- Roadway Realignment
- Rumble Strips
- Sight Distance Improvements
- Signing
- Skid Treatment - Overlay/Grooving
- Traffic Signals
- Pedestrian Signals
- Tree Removal
- Turning Lanes
- Grade Separation
- Pedestrian Overpasses
- Drainage Improvements
- Turn Prohibitions
- Reduce Speed Limits
- Increase Turning Radii
- Provide Advance Warning
- Install Ped Barriers
- Eliminate Parking
- Establish One-Way Streets

Table 1. Countermeasures categorized by location type (continued)

- <u>Interchanges</u>
  - Channelization
  - Illumination
  - Add Lanes
  - Median Barriers
  - Pavement Widening
  - Pavement Markings
  - Roadway Realignment
  - Signing
  - Skid Treatment - Overlay/Grooving
  - Drainage Improvements
  - Reduce Speed Limits
  - Increase Turning Radii

Other locational classifications may also be pertinent to the categorization of countermeasures. For example area type classifications may be useful. Certain countermeasures may be classified as urban or rural. Multi-phase traffic signal operation may, for instance, be considered typical of urban situations. Other categories might include road classification (i.e., functional or administrative), or land use.

Addressing Accident Problems

It is imperative to implement the most appropriate countermeasure to remedy the particular safety deficiency at a site. The selection of an inappropriate countermeasure may result in minimal or even adverse impacts upon the safety problem. A number of documents have been published in the last two decades which outline procedures for the systematic selection of countermeasures on the basis of a detailed analysis of accident information. One of the earliest of these was prepared by Midwest Research Institute for the Missouri State Highway Commission with a later adaptation by Datta (2). Tabular summaries of countermeasures were presented in these documents to address the probable cause of accidents. A similar set of tables has been included in the FHWA Highway Safety Engineering Studies (HSES) Procedural Guide (3). Figures 1 and 2 provide a dot matrix summary of the tables provided in this Guide. In Figure 1 the dot in a particular cell indicates the possible causes of accidents associated with observed accident patterns at links and intersections. Once the possible causes are identified, Figure 2 can be reviewed to determine the type of countermeasure appropriate for remedying a specific accident cause.

These tables represent worthwhile attempts to guide highway safety engineers in the selection of appropriate countermeasures based upon addressing the specific accident causes at a location. A notable deficiency of these tables lies in the fact that single countermeasures are proposed in each case. None of the tables provides a systematic scheme for packaging a series of treatments into an improvement project which addresses the unique features of the location.

ACCIDENT PATTERN \ POSSIBLE CAUSES	HIGH VOLUMES OF TRAFFIC	IMPROPER SIGNAL TIMING/PHASING	UNWARRANTED TRAFFIC SIGNAL	LACK OF ADEQUATE GAPS	INADEQUATE PEDESTRIAN FACILITIES	CROSSING PEDESTRIANS	HEAVY TURN VOLUMES	EXCESSIVE SPEEDS	SLIPPERY SURFACE	INADEQUATE LIGHTING	POOR DELINEATION	RESTRICTED SIGHT DISTANCE	POOR VISIBILITY	INADEQUATE ADVANCE WARNING	INADEQUATE OR IMPROPER SIGNING	INADEQUATE CHANNELIZATION	PARKING	INADEQUATE ROAD MAINTENANCE	INADEQUATE SHOULDERS/PAVEMENT	INADEQUATE DRAINAGE	ROADSIDE OBJECTS
LEFT-TURN		●					●	●				●			●						
REAR-END (UNSIGNALIZED INTER)				●		●	●	●	●	●				●	●		●				
REAR-END (SIGNALIZED INTER)		●	●			●	●	●	●	●			●		●		●				
RIGHT-ANGLE (UNSIGNALIZED INTER)	●						●	●		●		●			●	●					
RIGHT-ANGLE (SIGNALIZED INTER)	●	●				●		●		●		●	●	●	●	●					
PEDESTRIAN		●		●	●	●	●	●		●	●	●		●	●						
SIDE-SWIPE/HEAD ON								●	●		●			●		●		●	●		
WET PAVEMENT								●	●		●									●	
NIGHTTIME								●		●	●					●					
RUN-OFF-THE-ROAD								●	●	●	●		●			●		●	●		
FIXED OBJECTS								●	●	●	●			●				●	●		
PARKED VEHICLE								●			●						●		●		●
DRIVEWAY-RELATED							●	●		●		●									
TRAIN-VEHICLE								●	●			●	●	●							

INTERSECTIONS

LINKS

Figure 1. HSES summary of accident patterns and possible causes.

Accident Countermeasures \ Possible Causes	High volumes of traffic	Improper signal timing/phasing	Unwarranted traffic signal	Lack of adequate gaps	Inadequate pedestrian facilities	Crossing pedestrians	Heavy turn volumes	Excessive speeds	Slippery surfaces	Inadequate lighting	Poor delineation	Restricted sight distance	Poor visibility	Inadequate advance warning	Inadequate or improper signing/marking	Inadequate channelization/design	Parking	Roadside objects	Inadequate shoulders/pavement	Inadequate drainage	Inadequate road maintenance	
Remove sight obstructions						●							●		●							
Restrict parking												●	●				●					
Prohibit turns	●																					
Install warning signs					●	●			●		●	●	●	●	●	●			●	●		
Reduce speeds or speed limits								●	●	●		●	●	●		●	●		●			
Channelize or improve geometrics	●				●	●				●	●	●				●						
Install/remove traffic signals			●		●	●																
Upgrade or improve signalization	●	●	●	●	●	●						●	●									
Remove or protect obstacles												●						●				
Improve road surface								●	●										●			
Improve cross section	●										●					●	●	●				
Improve markings											●				●							
Improve drainage									●										●	●		
Reroute traffic	●						●															
Provide illumination						●				●			●	●								
Add turning lanes	●						●					●				●						
Install yield/stop signs			●	●															●			

Figure 2. HSES summary of accident countermeasures associated with various possible causes.

In August of 1982, the FHWA released a memorandum on the subject of accident reduction levels attainable from various safety improvements (4). This memo provides new data on accident reduction potentials of highway improvements based upon:

- o Data provided annually by States.
- o Data provided by the States in special effectiveness evaluation reports.
- o Data provided by the States as part of the FHWA research project titled, "Implementation of Highway Safety Project Evaluation Procedures."

These accident reduction levels were all based upon before and after studies with adjustments made for exposure and control groups where possible. These are believed to be useful as a starting point for forecasting benefits to be derived from specific highway improvements.

The countermeasures listed in Table 2 represent those for which data were compiled. Other categories were also defined, but no accident reduction data were available for these. It is interesting to note that data were compiled for combinations of some countermeasures. While these data are useful, they are not believed to represent rigorous measures of the incremental effects of various countermeasures. The FHWA tables also provide breakdowns of the accident reductions possible for rural and urban situations and where appropriate for highways of different laneage.

Countermeasure Types

The review of previous efforts and the nature of current practices implies the need to categorize countermeasures by location type. Figure 3 depicts what might be considered the fundamental categorization of highway situations. It is believed that the nature of traffic controls, intensity of

Table 2. Situation and countermeasures for which accident reduction factors were provided by FHWA Memo

- o <u>Intersections</u>
  - Channelization
  - Turning Lanes
  - New Traffic Signals
  - Upgraded Traffic Signals
  - Sight Distance Improvements
  - Signs
  - Pavement Markings
  - Illumination

- o <u>Traffic Control Devices</u>
  - All Combinations of signs
  - Warning and Regulatory Signs
  - Pavement Markings and Delineations
  - Signs, Marking, and Delineation at Narrow Bridges
  - Rumble Strips

- o <u>Structures</u>
  - Bridge Widening
  - Bridge Replacement

- o <u>Roadway Improvement</u>
  - Pavement Widening
  - Lanes Added
  - New Median Strip
  - Shoulder Widening or Improvement
  - Pavement and Shoulder Widening
  - Skid Treatment - Grooving
  - Horizontal Realignment
  - Vertical Realignment

Table 2. Situation and countermeasures for which accident reduction factors were provided by FHWA Memo (continued)

- Horizontal and Vertical Realignment
- Passing Lanes

o <u>Roadside-Improvements</u>

- Guardrail - New and/or Improved
- Median Barrier
- Roadway Lighting

o <u>Railroad-Highway Grade Crossing Improvements</u>

- New Flashing Lights
- Upgraded Flashing Lights
- Automatic Gates and New Flashing Lights
- Grade Separation
- Illumination at Crossings
- Signs and Markings at Crossings
- Surface Improvement at Marked Crossing

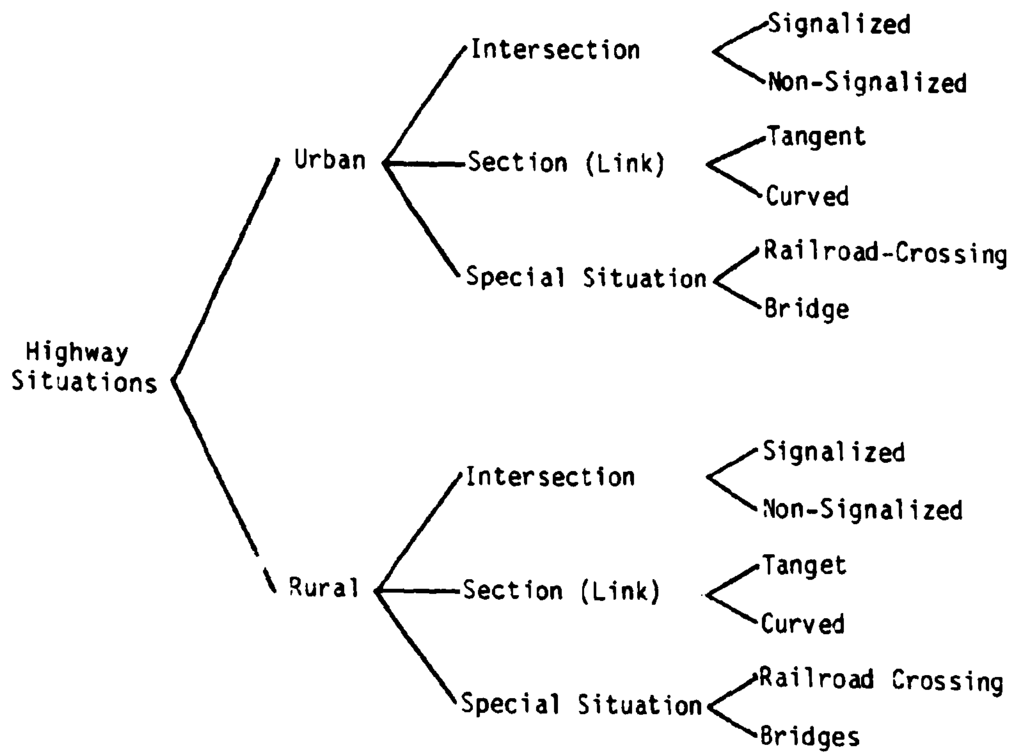

Figure 3. Proposed classification of highway situations.

land use, and volumes of traffic warrant a breakdown by urban and rural situations. A suburban classification may be possible, but it was believed that locations in this transitional area could be effectively treated under one of the basic classifications, depending on its features. Within each area type the highway system can be broken down into intersection, section (link), or special situations where traffic streams cross or merge. Roadway sections may be considered to be those segments between intersections. While some intersecting movements may occur (i.e., at driveways) the major concern is the longitudinal movement of traffic streams. Last, there occur special situations that, while occurring at intersections or on links, have features which often lead to unique accident problems. The treatments associated with these situations differ between urban and rural locations. The treatments will also vary by the nature of the type of intersection, section, or special situation. Hence, intersections were categorized as signalized and non-signalized, sections as tangent or curved, and special situations as railroad crossings or bridges (overpass or underpass).

The causes of accidents at these situations often follow regular patterns. In selecting an appropriate accident countermeasure it is important to consider the nature of the safety deficiency. Therefore, a summary of general countermeasures appropriate for each accident pattern and highway situation was prepared. The dot matrix shown in Figure 4 was synthesized from the various summaries previously presented. Table 3 provides a summary of the specific treatments which may be included under each of the general countermeasure categories. It is important to point out that this summary addresses only highway-oriented countermeasures. Countermeasures such as education or enforcement were not included.

Countermeasure Groups

Traffic and safety personnel have long used countermeasures consisting of multiple treatments at specific highway locations to alleviate safety problems. The determination of the effectiveness of these multiple applications has, however, not been rigorously undertaken. Some data is available relative to the accident reduction capabilities of individual

	GENERAL COUNTERMEASURE / ACCIDENT PATTERN	REMOVE SIGHT OBSTRUCTIONS	RESTRICT PARKING	PROHIBIT TURNING MOVEMENTS	INSTALL STOP/YIELD SIGNS	INSTALL WARNING SIGNS	REDUCE SPEEDS OR SPEED LIMITS	CHANNELIZE/UPGRADE GEOMETRICS	INSTALL SIGNALS	UPGRADE SIGNALS	IMPROVE MOTORIST GUIDANCE	OVERLAY/GROOVE PAVEMENT	PROVIDE ADEQUATE DRAINAGE	PROVIDE PEDESTRIAN FACILITIES	WIDEN PAVEMENT OR SHOULDERS	ADD TURNING LANES OR TURN PHASES	IMPROVE PAVEMENT MARKINGS	IMPROVE SIGNAL TIMING	PROVIDE ILLUMINATION				
SIGNALIZED INTERSECTIONS	LEFT TURN COLLISIONS			●			●	●		●					●	●		●	●				
	REAR END COLLISIONS			●		●	●			●		●	●	●		●		●	●				
	PEDESTRIAN VEHICLE ACCIDENTS	●	●	●			●		●					●			●	●	●				
	RIGHT ANGLE COLLISIONS	●	●			●	●			●								●	●				
	SIDESWIPE COLLISIONS		●			●					●				●	●	●		●				
UNSIGNALIZED INTERSECTIONS	LEFT TURN COLLISIONS			●	●		●	●	●						●	●		●	●				
	REAR END COLLISIONS			●	●	●	●	●				●	●			●			●				
	PEDESTRIAN VEHICLE ACCIDENTS					●								●					●				
	RIGHT ANGLE COLLISIONS	●	●		●	●	●		●			●							●				
	SIDESWIPE COLLISIONS				●	●			●						●	●	●						

Figure 4. Summary of accident countermeasures by highway situation and accident pattern.

	General Countermeasure / Accident Pattern	Remove Sight Obstructions	Restrict Parking	Prohibit Driveway Movements	Improve Access Management	Install Warning Signs/ Signals	Reduce Speeds or Speed Limits	Improve Driver Guidance	Overlay/Groove Pavement	Provide Adequate Drainage	Improve Alignment/ Superelevation	Remove/Protect Obstacles	Provide Pedestrian Facilities	Widen Pavement/Shoulders	Add Turning/Passing Lanes	Improve Pavement Markings	Install Median Barrier	Provide Illumination	Relocate Parking	Channelize	Improve Passing Zones	Provide Roadway/Shoulder Maintenance	
Highway Sections	Run-off-the-Road					●		●	●	●	●			●	●	●		●			●	●	
	Head-on Collisions	●				●	●		●		●			●	●	●	●				●		
	Pedestrian-Bicycle Accidents	●	●			●	●						●	●				●					
	Parked Vehicle Collisions		●				●							●					●				
	Fixed Object Collisions						●	●			●	●		●								●	
	Sideswipe (Opposite Direction)		●	●	●			●		●	●			●	●	●	●			●	●		
	Sideswipe (Same Direction)		●	●	●		●	●		●	●			●	●					●	●		
	Driveway-Related Accidents	●		●	●		●	●	●						●			●		●			
Special Situations	Narrow Bridge	●				●												●					
	Railroad-Highway Crossings	●				●												●					

Figure 4. Summary of accident countermeasures by highway situation and accident pattern (continued).

Table 3. Detailed summaries of accident countermeasure treatments

- <u>Remove Sight Obstructions</u>
  - Trim Trees and Bushes
  - Remove Unnecessary Signs/Obstacles
  - Remove Other Natural/Man-made Obstacles

- <u>Restrict Parking</u>
  - Reduce Parking Area
  - Limit Parking Area

- <u>Prohibit Turning/Driveway Movements</u>
  - Post Prohibition Signs
  - Channelize to Prevent Prohibited Movements

- <u>Improve Access Management</u>
  - Reduce the Number of Driveways
  - Provide Proper Driveway Channelization

- <u>Install Warning Signs/Signals</u>
  - Install Warning Signs
  - Install Warning Signs with Flashing Signals
  - Install Warning Signs with Activated Flashing Signals

- <u>Reduce Speeds or Speed Limits</u>
  - Use Special Pavement Markings
  - Install Speed Bumps
  - Post Lower Speed Limits
  - Install Rumble Strips

- <u>Channelize/Upgrade Geometrics</u>
  - Improve Turning Radii
  - Provide Special Lanes for Turning Movements

Table 3. Detailed summaries of accident countermeasure treatments (continued)

- Provide Adequate Acceleration/Deceleration Lanes
- Flatten Vertical Alignment
- Reduce Curvature in Horizontal Alignment
- Correct or Add Superelevation
- Add Climbing Lanes

o <u>Install Signals</u>
  - Install Traffic Signals
  - Install Pedestrian Signals
  - Install Railroad Crossing Signals
  - Install Flashing Beacons

o <u>Upgrade Signals</u>
  - Add Signal Heads
  - Install Larger Signal Lenses
  - Install Traffic Actuated Equipment
  - Install Railroad Crossing Gate

o <u>Improve Motorist Guidance</u>
  - Install Additional Signing/Markings
  - Provide Overhead Signing
  - Install Delineators
  - Install Raised Pavement Markers

o <u>Improve Roadway Surface</u>
  - Provide Skid Resistance Overlay
  - Provide Pavement Grooving
  - Install Deicing Equipment
  - Stabilize Shoulders
  - Improve Bridge/Railroad Crossing surface

Table 3. Detailed summaries of accident countermeasure treatments (continued)

- <u>Provide Adequate Drainage</u>
  - Install Larger Culverts
  - Clean Drainage Courses
  - Install Additional Catch Basins

- <u>Improved Roadside</u>
  - Flatten Side Slopes
  - Remove Trees/Obstacles
  - Install Breakaway Poles/Sign Supports
  - Install Guardrail
  - Install Impact Attenuators
  - Provide Adequate Clear Zone

- <u>Provide Pedestrian Facilities</u>
  - Install Sidewalks/Crosswalks
  - Add Pedestrian Signals
  - Provide Pedestrian Overpasses/Underpasses
  - Install Pedestrian Barriers (i.e., fences)
  - Provide Pedestrian Refuge Areas

- <u>Widen Pavement or Shoulders</u>
  - Widen Lanes
  - Increase Shoulder Width
  - Widen Bridges

- <u>Add Turning Lanes or Turn Phases</u>
  - Add Left Turn Lanes
  - Add Left Turn Phases
  - Add Right Turn Lanes

Table 3. Detailed summaries of accident countermeasure treatments (continued)

- Add Right Turn Phases
- Permit Right Turn on Red

o <u>Improve Pavement Markings</u>
- Use Longer Lasting Marking Materials
- Add Edgelines
- Use Raised Pavement Markers

o <u>Improve Medians</u>
- Install Median Barriers
- Widen Medians
- Reduce Crossing Points

o <u>Improve Signal Timing</u>
- Increase Number of Phases
- Alter Signal Splits
- Increase Amber Phase
- Add All-Red Clearance Phase

o <u>Provide Illumination</u>
- Add Street Lighting
- Improve Street Lighting
- Add Sign Illumination/Case Signs

o <u>Improve Passing Zones</u>
- Increase Delineations
- Lengthen Passing Zones
- Provide Passing Lanes

Table 3. Detailed summaries of accident countermeasure treatments (continued)

- Provide Roadway/Shoulder Maintenance
  - Resurface Roadway
  - Stabilize Shoulders

treatments, or very common groups of treatments. Little, if any, quantitative information on the incremental effects of multiple treatments have been developed. The overall accident reduction expectations for multiple treatments have generally been determined by using the additive model formulated by Jorgensen (5). This model treats each successive treatment over and above the previous one as a function of the balance of accidents not reduced in the previous step:

$$P_t = P_1 + \left(\frac{100 - P_1}{100}\right) P_2 + \left(\frac{100 - P_1}{100}\right)\left(\frac{100 - P_2}{100}\right) P_3$$

$$+ \left(\frac{100 - P_1}{100}\right)\left(\frac{100 - P_2}{100}\right)\left(\frac{100 - P_3}{100}\right) P_4 + \ldots + \left[\prod_n \left(\frac{100 - P_{n-1}}{100}\right)\right] P_n$$

Where: P_t = Total percent reduction in accidents.

P_1 = Largest percent reduction in accidents of any one of the countermeasures.

P_n = Smallest percent reduction in accidents of any one of the countermeasures.

n = Number of countermeasures used in treating a specific situation.

While there seems to be a certain degree of plausibility of this approach, it fails to account for the incremental effects of individual countermeasures when used in combination and the overall interaction effect of two or more treatments working together. This model also requires that viable accident reduction data exist. It also fails to account for the possibility that additional or subsequent countermeasures may not be as effective in reducing the numbers of accidents, i.e., the most tractable portion of the accident problem may have been eliminated by earlier countermeasures.

Various approaches can be employed to establish groups of safety countermeasures. These include:

- o Actual Practice - Review projects and determine the accident patterns and the frequency of countermeasures use application.

- o Accident Problem Combinations - Analyze countermeasure needs on the basis of commonly occurring combinations of accident patterns.

- o Past Research Relative to Accident Reduction Capabilities - Establish groups on the basis of what is known about the interactions of countermeasures from previous research efforts.

- o Highway Situation - Establish groupings to reflect the available options by highway situation.

- o Highway Design Practice - Review State standards to determine countermeasure recommendations and the criteria for their use.

The use of any of these approaches is complicated by the differences in traffic, roadway, accident, and environmental conditions across the country. The lack of convenient sources of data relative to highway safety expenditures, rates of accident occurrence, and so on further limit the applicability of any one of the above approaches.

A combination of these approaches was used to develop various groupings of countermeasures. Appendix A contains listings of typical countermeasures and groupings of countermeasures for each of the highway situations from Figure 3 by the typical accident patterns for these locations (from Figures 4 and 5). It should also be noted that while the countermeasure groups are shown in pairs, groups of three or more countermeasures may be derived by combining pairs containing a common countermeasure. Of course, the engineer reviewing a situation would focus upon the major accident patterns at a location and usually select only some of these countermeasures as candidates.

Countermeasure Cost Categorization

A review of completed safety improvement projects (Ref. 6) in 21 States provided a summary of data that included:

- o Types of Safety Improvements
- o Total Before Period Accidents
- o Accident Reduction Percentages
- o Number of Projects by Type
- o Total Expenditures by Type
- o Average Project Costs

It is critical to recognize that these data were based upon reports submitted to the FHWA by individual States. Differences in definitions of projects, design standards, accounting practices, contracting procedures, regional costs, and other factors may have influenced the accuracy of these numbers and thus bias any comparisons. Further, the data were limited to a single year.

Based on these data, judgment was exercised to classify countermeasures into a low, medium, or high cost category. Appendix B contains a listing of the countermeasures by highway situation and cost category. Generally, the stratification followed the following cost ranges:

- o Low Cost $ 0 - $ 5,000
- o Medium Cost $ 5,000 - $50,000
- o High Cost $50,000 +

It is believed that the engineer would begin considering the low cost countermeasures and progressively consider more expensive countermeasures or groups until the project objectives could be met (e.g., reduce all fatal accidents, reduce 50% of the injury accidents).

Candidate Groups for Subsequent Research

The success of any effort to identify the incremental effectiveness of highway safety countermeasures is dependent upon the selection of appropriate candidate groups for further research analysis. Table 4 provides a summary of commonly used countermeasure groups summarized by highway situation. The groupings are based upon rational combinations of countermeasures. Not all combinations are represented, nor are mandatory groupings indicated. For example, at a signalized intersection if a pavement overlay is put in place, it is necessary to replace the pavement markings.

Table 4. Summary of commonly used countermeasure groups

Urban Signalized Intersections

- o Adjust signal timing - add warning signs
- o Adjust signal timing - improve pavement markings
- o Improve pavement markings - add warning signs
- o Adjust signal timing - install lane use signing
- o Adjust signal timing - overlay pavement
- o Improve pavement markings - upgrade signals
- o Upgrade signals - install lane use signs
- o Upgrade signals - overlay pavement
- o Upgrade signals - add turning lanes
- o Overlay pavement - add turning lanes
- o Overlay pavement - install actuated signals
- o Add turning lanes - install actuated signals

Urban Non-Signalized Intersections

- o Install warning signs - install stop/yield signs
- o Install warning signs - reduce speed limits
- o Install stop/yield signs - improve pavement markings
- o Prohibit turning movements - improve pavement markings
- o Install warning signs - install signals
- o Install signals - improve pavement markings
- o Install stop/yield signs - widen pavement
- o Install warning signs - overlay pavement
- o Install warning signs - provide illumination
- o Install stop/yield signs - add turning lanes
- o Overlay pavement - install signals
- o Provide illumination - overlay pavement
- o Install signals - add turning lanes
- o Overlay pavement - install actuated signal controllers
- o Channelize - install actuated signal controllers

Table 4. Summary of commonly used countermeasure groups (continued)

Urban Tangent Roadway Sections

- Reduce speeds - improve pavement markings
- Restrict parking - install warning signs/signals
- Improve pavement markings - install warning signs/signals
- Improve pavement markings - improve access management
- Install warning signs/signals - improve alignment
- Add passing/turning lanes - overlay pavement
- Improve access management - add passing/turning lanes
- Remove/protect roadside obstacles - widen lanes
- Add passing/turning lanes - improve alignment
- Improve alignment - install median barriers

Urban Curved Roadway Sections

- Install warning signs/signals - improve pavement markings
- Install warning signs/signals - restrict parking
- Install warning signs/signals - restrict turning movements to/from driveways
- Install warning signs/signals - overlay/groove pavement
- Install warning signs/signals - widen pavement/shoulders
- Install warning signs/signals - install guardrail
- Improve pavement markings - install guardrail
- Overlay/groove pavement - install guardrail
- Provide illumination - widen pavement/shoulders
- Install guardrail - widen pavement/shoulders
- Overlay pavement - install median barriers

Urban/Rural Railroad - Highway Crossings

- Install crossing signs - install advance warning signs
- Install crossing signs - reduce sight obstructions
- Reduce sight obstructions - provide illumination
- Install warning signs - install crossing flashers

Table 4. Summary of commonly used countermeasure groups (continued)

- o Install warning signs - install crossing gates w/flashers
- o Improve crossing surface - install crossing flashers
- o Provide illumination - install crossing gates w/flashers
- o Improve crossing surface - improve approach alignment
- o Install crossing gates - improve approach alignment

Urban/Rural Bridges

- o Install warning signs - improve pavement markings
- o Improve pavement markings - install delineators
- o Install warning signs - install delineators
- o Reduce sight obstructions - provide illumination
- o Install delineators - install guardrails
- o Improve pavement markings - install guardrails
- o Improve pavement markings - reconstruct/relocate bridge
- o Install delineators - realign bridge approaches
- o Remove sight obstructions - provide illumination
- o Install guardrails - improve shoulders
- o Install guardrails - widen roadway
- o Install guardrails - reconstruct/relocate bridge
- o Widen roadway - reconstruct/relocate bridge
- o Reconstruct/relocate bridge - realign bridge approaches

Rural Signalized Intersections

- o Adjust signal timing - add warning signs
- o Adjust signal timing - improve pavement markings
- o Improve pavement markings - add warning signs
- o Add warning signs - reduce sight obstructions
- o Upgrade signals - overlay pavement
- o Upgrade signals - widen pavement/shoulders
- o Upgrade signals (visibility) - install actuated signals
- o Upgrade signals - channelize intersection

Table 4. Summary of commonly used countermeasure groups (continued)

Rural Non-Signalized Intersections

- Install stop/yield signs - install warning signs
- Install stop/yield signs - improve pavement markings
- Install warning signs - reduce sight obstructions
- Install warning signs - install signals
- Improve pavement markings - install signals
- Install stop/yield signs - widen pavement/shoulders
- Install warning signs - provide illumination
- Install stop/yield signs - add turning lanes
- Improve pavement markings - add turning lanes
- Overlay pavement - install signals
- Install signals - channelize

Rural Tangent Roadway Sections

- Improve pavement markings - reduce speeds
- Improve pavement markings - add passing/turning lanes
- Install warning signs/signals - add passing/turning lanes
- Install warning signs/signals - remove/protect obstacles
- Improve pavement/shoulder maintenance - remove/protect obstacles
- Add passing/turning lanes - overlay pavement
- Remove/protect obstacles - widen pavement

Rural Curved Roadway Sections

- Install warning signs/signals - improve pavement markings
- Reduce speeds - improve pavement markings
- Install warning signs/signals - overlay/groove pavement
- Improve pavement markings - provide illumination
- Install warning signs/signals - widen pavement/shoulders
- Install warning signs/signals - install guardrail
- Overlay/groove pavement - install guardrail

Table 4. Summary of commonly used countermeasure groups (continued)

- o Widen pavement/shoulders - Install guardrail
- o Widen pavement/shoulders - provide illumination
- o Remove sight obstructions - provide illumination

III. METHODOLOGY FOR DETERMINING THE INCREMENTAL EFFECTIVENESS OF COUNTERMEASURES

The development of a generalized methodology for determining the incremental effectiveness of countermeasures used in combination to alleviate specific accident problems centers on the selection of the most appropriate experimental design. In the following sections the methodology is discussed in terms of the assumptions made, the basic approaches to the experimental design that were considered, the measures of effectiveness selected, the treatment of confounding factors, and the data requirements.

Assumptions

It is critical that the ramifications of assumptions made in the development of the generalized methodology be clearly understood. These assumptions often provided the basis for decisions made in selecting the experimental design and other components of the methodology. Key assumptions included the following:

- The change in accident experience at a site over time is a viable measure of the effectiveness of a treatment or group of treatments when other factors have been controlled.

- Accident data represent the best Measure of Effectiveness (MOE) for the assessment of treatment effectiveness. Surrogate measures, while useful in some cases, do not (at this time) represent a viable means to determine the incremental accident reduction potential for highway safety countermeasures.

- Ultimately, a comprehensive set of incremental effectiveness data for all types and groups of countermeasures will be required to fully validate the methodology. Initially, however, the methodology development is based on experimental plans for two of the more common groupings of countermeasures.

- Before/After with Controls - This design involves the comparison of MOE's recorded in both a "before" and "after" time period at sites where a treatment has been implemented (a treatment may consist of one countermeasure or a group of countermeasures). In addition, control sites having characteristics similar to the test sites are selected to monitor (or control for) the impact of confounding factors on the MOE's. The control sites may be selected on a random basis (randomized controls) or a non-random basis (comparison groups). While the latter design makes it possible to choose a comparison group even after implementation of the treatment, it is crucial that the characteristics of the control sites be almost identical to those of the test sites; otherwise, the design becomes very weak.

- Comparative Parallel - This design involves the comparison of MOE's at test sites and control sites in the "after" treatment period only. The degree of impact of an improvement is indicated by the difference between the levels of the MOE's at the test sites and the average performance of the control sites in the same time period. This design is particularly suited to the situation where insufficient data exist for the "before" period.

Measures of Effectiveness (MOE's)

MOE's must be defined for each experimental design to provide quantifiable units of measurement by which the research question can be answered. The research question in this study is "do countermeasures employed in groups have discernable incremental effects on reducing accidents?" As stated earlier, it was assumed that accident data represented the best MOE for the assessment of safety countermeasure effectiveness. Traffic accidents may be expressed in terms of frequency or rate. An excellent discussion of using either frequency or rate may be found in the Accident Research Manual (8), which concludes that exposure (from which accident rates are developed) should be treated as an independent variable. Thus, accident frequency is generally the preferred MOE as long as exposure is accounted for.

In addition to total accidents, other subsets representing crash severity (i.e., fatal, injury, property damage only) or accident type (i.e., head-on, right angle, sideswipe, rear-end, pedestrian, run-off-road) may provide appropriate MOE's.

Confounding Factors

One of the major obstacles to determining the incremental effectiveness of safety countermeasures applied in groups is the question of how to account for or control the influences of confounding factors. Such factors may be categorized as geometric factors (e.g., intersection type, number of traffic lanes, type of alignment), traffic factors (e.g., volumes, vehicle mix, peaking characteristics, type of traffic control), roadway user factors (e.g., drivers, pedestrians; land-use), and environmental factors (weather, lighting, road surface condition). Confounding factors must be dealt with in the experimental design by (1) carefully controlling the selection of sites to ensure that a near-perfect matching of control sites to test sites is achieved, or (2) treating the important factors as independent variables in the statistical analysis such that the impact of the factors may either be calculated or blocked, or (3) some combination of both (1) and (2). The two experimental designs identified, Before/After with Controls and the Comparative Parallel, rely on careful site selection to control for confounding factors.

Data Requirements

The other major obstacle to determining the incremental effectiveness of countermeasures is the availability of data both in terms of quantity and type. The use of accident data as an MOE relies on the existence of complete and consistent accidents records, a sufficient accident history at the sites of interest, and a sufficient number of sites with the requisite characteristics.

Finding sites with the same characteristics is perhaps the greatest stumbling block to the development of a successful methodology. None of the experimental designs will solve this problem, and many experienced highway data users will support the notion that no two sites are exactly alike. The key question is, "can enough sites be found that are sufficiently similar such that one or more of the experimental designs can be properly executed to provide reliable results?" To answer this question one must first define the highway situation and countermeasure grouping of interest. In other words, it is unlikely that enough sites exist to determine the incremental effectiveness of all common groupings of countermeasures for all highway situations.

The number of sites required is dependent on the manner in which treatments (consisting of two or more countermeasures) are to be applied. Two basic approaches may be taken. The first approach is called phased (or sequential) implementation in which each individual countermeasure in the group is installed at a given site one after the other with data being collected for some period of time between installations. While this approach requires fewer sites and involves a simpler experimental design, the obvious practical and political ramifications of "experimenting" with safety far outweigh the advantages of the method. Thus, the use of this approach was not only minimized as suggested in the scope of the contract, but was eliminated from further consideration.

The second approach involves either finding locations with the appropriate groupings of countermeasures in place or installing the entire grouping at the same time. For in-place countermeasure groups, there must exist sufficient "before" data. If good "before" data are available and the countermeasure group has been in place a sufficient length of time, "after" data collection may not be required. Obviously if the countermeasure group is to be installed, "before" data must either exist or be collected before installation. This approach requires a significantly larger number of sites than the phased implementation approach as well as a much more controlled site selection process to ensure that confounding factors among sites are accounted for.

The number of sites required is also dependent on the accident history of the population of sites to be sampled. The selection of test and control sites must account for differences in levels of accident experience to avoid a bias in the data.

Finally, the accident data available at each site must have some minimum degree of homogeneity in terms of commonly defined data elements, uniform reporting procedures, and similar reporting thresholds in order to serve as an MOE across sites.

Based on the information reviewed in this study, it appears that a sufficient number of sites should exist to meet the requirements of the methodology for certain highway situations and groupings of countermeasures.

IV. EXPERIMENTAL PLANS FOR TWO COUNTERMEASURE GROUPS

In order to illustrate the generalized methodology and to provide a basis for determining its feasibility, two specific countermeasure groups were identified for two different highway situations and two experimental plans were developed. The two groups were selected from the groups of countermeasures commonly used together that were identified in Task B of the study. The selection was based on the combined judgment of the key staff using the principal criterion that a sufficient number of sites with the requisite characteristics should exist to permit the use of the methodology. The assumption was made that the accident data record requirements could also be met at the sample of sites.

Each experimental plan includes the countermeasure groups of interest; experimental design; MOE's; site requirements; data requirements; sample size; analysis plan; and estimates of time and cost.

Urban Signalized Intersections

This particular highway situation was selected because it is a very common situation. It has been estimated that there are approximately 250,000 signalized intersections in the United States. Since not all signalized intersections are comparable, the population from which a sample of sites is being drawn would be narrowed to the most common type, i.e., four approximately 90 degree approaches with traffic operating two-ways on all approaches.

Countermeasure Groupings: Two safety countermeasures were chosen, each representing a different relative cost level. The addition of turn lanes represented high cost and the installation of warning signs, low cost. It is recognized that turn lanes could also be considered an operational improvement. In the judgment of the staff, these two countermeasures may be found both individually and in combination at numerous sites.

Experimental Design: As mentioned previously, two designs were deemed suitable for use with the methodology. The Before/After with controls was deemed to be the strongest design for the urban signalized intersection situation. Four treatments were selected for comparison to determine incremental effects as follows:

- Treatment 1 - added turn lanes (CM#1)
- Treatment 2 - added warning signs (CM#2)
- Treatment 3 - added turn lanes and warning signs (CM#1 and #2)
- Treatment 4 (Control) - no new countermeasures

Three important confounding factors were selected for inclusion in the experimental design: peak vs. off-peak periods (representing traffic demand variations), day vs. night (representing the environmental condition of lighting), and four traffic volume levels (chosen to control for exposure). The selection of specific volume levels would be made after an examination of the characteristics of the population of sites from which the sample is to be drawn.

Measures of Effectiveness: Total accidents were selected as the primary MOE. Two subsets, right-angle and rear-end, were also selected to provide for a more in-depth examination of incremental effects.

Site Requirements: All sites sampled must be right-angle, four-leg, two-way, two-way urban intersections. Intersections with each of the treatments must be found for each of the volume levels. Preferably, intersections that meet these requirements should be selected from the same jurisdiction or region to control for the effects of local design standards and operating practices, driver characteristics, weather, accident reporting thresholds and other regional differences. In order to make the proper site selection, records containing information on the above characteristics must be available.

Data Requirements: The source of data for this study will be police reported accident records. Such records must be identifiable with the particular sites sampled and must, as a minimum, contain the date of the accidents, time of day, lighting condition (day or night), and type of accident (e.g., angle or rear-end).

Sample Size: It was not possible to determine a precise sample size for this particular experiment due to the lack of available data on which to base estimates of population variance for the parameters of interest. However, a procedure for estimating sample size was developed and several sample sizes were calculated for different sets of assumed values.

The simplest method for calculating sample size when the population variance is either unknown or difficult to calculate is to assume that the number of accidents at the sites to be studied can be considered to have a Poisson distribution. If an estimate can then be made of the mean accident frequency in the control group or "before" period (for before/after with controls) or the comparison group (for comparative parallel), an approximate sample size can be estimated due to the fact that the mean of a Poisson variable is equal to the variance.

Calculate the sample size, N, as follows:

- Determine or estimate the mean accident frequency λ for sites in the control group or "before" period.
- Specify the percentage change in mean accident frequency thought to be important (C, where C is expressed as a proportion from 0 to 1.0).

o Calculate $N = \dfrac{2(Z_\alpha + Z_\beta)^2}{C^2 \lambda}$

Where:

N = the number of accidents required per data cell.

Z_α = the critical value of Z which leaves in the upper tail of the standard normal distribution.

Z_β = the critical value of Z which leaves in the upper tail of the standard normal distribution.

Table 5 contains sample sizes for various values of α, β, C, and λ calculated using the formula above. For example, if the α-level is assumed to be .10 and the desired power of the test $(1-\beta)$ is .90 and the percent change in accidents felt to be important is 20 percent and the mean accident frequency at the "before" or control sites is 10, the required sample size for each data cell would be 33 accidents.

The number of data cells required by the experimental design would include the matrix of four treatments, two traffic demand levels (peak and off-peak), two lighting conditions (day and night), and four volume levels, or a total of 4 x 2 x 2 x 4 = 64 data cells.

The number of sites is a function of treatments and volume levels since both the traffic demand factors and lighting conditions are present at all sites. Therefore, 16 sites (4 x 4) would be required to produce the 64 data cells. As mentioned earlier, it is important to account for confounding factors caused by regional differences; therefore, it is recommended that a sample of 16 sites be drawn from at least five regions. Thus, a total of 80 sites (5 x 16) would be required for this experiment. In other words, the experimental design would be replicated five times to control for regional differences.

Table 5. Number of accidents required per data cell for various assumed values (urban signalized intersections)

α = .10	$1-\beta$ = .90		α = .20	$1-\beta$ = .80	
% Change (C)	Mean Accident Frequency (λ)	Sample Size (N)	% Change (C)	Mean Accident Frequency (λ)	Sample Size (N)
10	10	132	10	10	57
	20	66		20	29
	30	44		30	19
	40	33		40	15
20	10	33	20	10	15
	20	17		20	7
	30	11		30	5
	40	9		40	4

The total sample sizes can be calculated by multiplying the number of data cells times the number of replications times the number of accidents required per cell. For example, five replications of 64 data cells times 33 accidents per cell (from the previous example) produces a required sample size of 10,560 accidents for the "before" period. For data collected at 80 sites, the average number of accidents per site would be 132. If the mean accident frequency is 40 accidents per year, it would require three to four years of "before" data and a similar period for "after" data to meet the sample size requirements. Other total samples may be calculated as above using the data cell sample requirements from Table 5.

Analysis Plan: The analysis for this experiment follows the statistical tests recommended in the Accident Research Manual (8). The analysis question is "Are the accident frequencies for one group (before) significantly different from that of another (after)?" The ^{2} test for Poisson frequencies would be used to analyze the four treatments to compare the "before" to the "after" accidents. If significant differences were found to exist, t-tests would be used to determine which groups were significantly different. The incremental effects of each countermeasure applied individually and the two countermeasures applied together would be calculated by comparing each treatment to the no treatment group.

Time and Cost Estimates: Assuming a design with 64 data cells and five replications requiring 80 sites and using the sample size data from Table 5, the range of time and cost estimates is considerable. Therefore, estimates have been prepared for two representative values of data cell sample size, i.e., 33 and 15 accidents per data cell. The assumptions for these two values are shown in Table 5 and as can be seen represent a total of four different conditions.

The time estimates for collecting "before" data for each cell sample size is presented in Table 6. For the Before/After with Controls design, this time should be doubled to allow for a suitable "after" data collection period.

Table 6. Time estimates for "Before" data collection

Data Cell Sample Size*	Sample of "Before" Accident**	Time to Collect "Before" Data (yrs.)***
33	10,560	3.3
15	4,800	1.5

* Taken from Table 5.

** Data cell sample size x 64 data cells x 5 replications.

***Based on a mean of 40 accidents per year per site.

Total estimated study time duration and costs are presented by task in Table 7 for each of the two situations just described. All assumptions are noted in the table. As shown in the table, the time duration for a study of this nature ranges from four to 7 1/2 years and costs from $95,000 to $145,000 to conduct.

The above time and cost estimates are based on a large number of assumptions. Many of these assumptions could be reasonably changed to bring about a concomitant change in the time and/or cost estimates. Therefore, the estimates presented above are, in the judgment of the principal staff, thought to be representative of the application of the generalized methodology for determining the incremental effectiveness of three safety countermeasure treatments in the urban signalized intersection situation.

Rural Curved Highway Sections

This highway situation was selected because it is a common situation, and over one in four fatalities (30.1 percent) occurred on a curve in 1982 (12). Of the 11,715 fatal curve accidents, 33 percent occurred on undivided roadways. In order to identify comparable sites, the population of curved sections to be sampled was narrowed to these curves on undivided rural roads with no more than two lanes in each direction.

Countermeasure Groupings: Three safety countermeasures were chosen for this study, each representing a different cost level. Cross section improvements such as widening, adding superelevation, overlaying or grooving represented high cost, installing guardrail, medium cost, and improving pavement markings, low cost. In the judgment of the staff, these three countermeasures way be found in combination at numerous sites.

Experimental Design: For this study the comparative parallel design was chosen to illustrate the generalized methodology. Five treatments were selected for comparison to determine incremental effects as follows:

Table 7. Time and cost estimates to conduct the urban signalized intersections study

Task	Situation A Time (Months)	Situation A Costs ($)	Situation B Time (Months)	Situation B Costs ($)
A - Plan Study	2	5,000	2	5,000
B - Select Sites	2	20,000	2	20,000
C - Collect & Code Data	80	98,500	40	49,200
D - Analyze & Report Results	6	21,000	4	21,000
TOTALS	90 (7.5 yrs.)	144,500	48 (4 yrs.)	95,200

NOTES:

1. Situation A is for a data cell sample size of 33 (see Table 6).
2. Situation B is for a data cell sample size of 15 (see Table 6).
3. Both situations assume 64 data cells, five replications, and 80 sites.
4. Assume travel will cost $10,000 in Task B for both situations.
5. Assume that police accident reports will cost $2,500 (Situation A) and $1,200 (Situation B) in Task C.
6. Assume miscellaneous costs of $1,000 in Task D for both situations.
7. Assume labor and overhead is $5,000/staff-month for Tasks A, B, and D and $3,000/staff-month for Task C.
8. The cost estimate for each task consists of labor and overhead plus any of the costs indicated in Notes 4, 5 and 6.

- o Treatment 1 - Cross section improvements and added guardrail (CM #1 and CM #2)

- o Treatment 2 - Added guardrail and improved pavement markings (CM #2 and CM #3).

- o Treatment 3 - Cross section improvements and improved pavement markings (CM #1 and CM #3).

- o Treatment 4 - CM #1, CM #2, and CM #3.

- o Treatment 5 (Control) - No new countermeasures or comparison.

Note that the treatments consist of countermeasure groups to illustrate how incremental effects of two or more groupings of countermeasures may be determined. Again three important confounding factors were selected for inclusion in the experimental design: three vehicle mixes (0-5 percent, 6 to 15 percent, and over 15 percent trucks), two pavement conditions (wet and dry), and three volume levels (again to control for exposure). The selection of specific volume levels would be made after an examination of the characteristics of the population of sites from which the sample is to be drawn, with the exception that roadways below 4,000 ADT would not be included due to the low accident frequency on these roads.

Measures of Effectiveness: Total accidents were again selected as the primary MOE. Although several subsets of total curve accidents could have been selected as supplementary MOE's, none were chosen due to the low accident frequency generally found at any given site. Should a sufficient number of accidents be collected, injury severity could be considered as a supplementary MOE.

Site Requirements: All sites sampled must be rural, undivided, curved section with no more than two lanes in each direction. Sites with each of the five treatments must be found for each of the vehicle mixes and volume levels.

Preferably, sites should be selected from the same jurisdiction or region to control for the effects of local design standards and operating practices, driver characteristics, weather, accident reporting thresholds, and other regional differences. In order to make the proper site selection, records containing information on the above characteristics must be available.

Data Requirements: The source of data for this study will be police reported accident records. Such records must be identifiable with the particular sites sampled and must contain, as a minimum, the date of the accident, condition of the pavement, and possibly the level of injury.

Sample Size: The same procedure used in the first experimental plan was followed to estimate representative sample sizes for the rural highway curve experimental plan. Again it was assumed that the number of accidents at the sites to be studied would have a Poisson distribution. Since the Comparative Parallel design does not require "before" data per se, estimates of the mean accident frequency would be made from the comparison group of sites.

Table 8 contains sample sizes for various values of α, β, C, and λ calculated using the formula from the first experimental plan. Comparing Table 8 to Table 5, it is obvious that when sites experience a low mean accident frequency, many more sites are needed to detect significant differences.

The number of data cells required by the experimental design include five treatments, three vehicle mixes, two pavement conditions, and three volume levels for a total of 5 x 3 x 2 x 3 = 90 data cells.

The number of sites is a function of treatments, vehicle mixes, and volume levels; therefore, 45 sites (5 x 3 x 3) would be required to produce the 90 data cells. Since design standards for rural roads are generally more uniform from region to region than for urban intersections, only three regions are recommended for inclusion in the study. Thus, a total of 135 sites (3 x 45) would be required for this experiment.

Table 8. Number of accidents required per data cell for various assumed values (rural curved highway section)

$\alpha = .10$	$1-\beta = .90$		$\alpha = .20$	$1-\beta = .80$	
% Change (C)	Mean Accident Frequency (λ)	Sample Size (N)	% Change (C)	Mean Accident Frequency (λ)	Sample Size (N)
10	1	1,311	10	1	565
	3	437		3	189
	5	262		5	113
20	1	328	20	1	142
	3	110		3	47
	5	66		5	29

The total sample size is calculated by multiplying the number of data cells times the number of replications times the number of accidents required per cell. It is obvious from Table 8 that in order to avoid large (and thus impractical) sample sizes, the α-level and % change felt important must be as large as possible, and the power of the test ($1-\beta$) must be as small as possible. In the judgment of the principal staff, the following values are reasonable: $\alpha = .20$, $1-\beta = .80$, and C = 20. If then the mean accident frequency was three accidents per year, the required sample size for the study would be 90 data cells times three replications times 47 accidents per cell for a total of 12,690 accidents.

The average number of accidents for the 135 sites would be 94 accidents per site. If the mean accident frequency per site is three accidents per year, it would require 31 years of data to meet the sample size requirements. Since this is an unreasonable time period to consider, adjustments must be made to arrive at a reasonable sample size. This can be done by increasing the number of sites. For example, if the number of sites is increased to 1,350, the data collection period for the above situation would be reduced from 31 years to just over three years.

Analysis Plan: The same analysis plan for the urban signalized intersection study applies to the rural highway curved section study.

Time and Cost Estimates: As in the first study, estimates have been prepared for two representative values of data cell sample size, i.e., one and five accidents per data cell. The basis for these two values is shown in Table 8. Also the number of sites has been substantially increased in order to achieve a reasonable data collection period.

Estimates for the number of sites and time to collect the required sample data are shown in Table 9. For the Comparative Parallel design only one data collection period is required.

Table 9. Site and time estimates for comparative parallel data collection

Data Cell Sample Size[1]	Total Sample of Accidents[2]	Number of Sites[3]	Time to Collect Data (yrs.)[4]
142	38,340	6,750	5.7
29	7,830	540	2.9

[1]Taken from Table 8.

[2]Data cell sample size x 90 data cells x 3 replications.

[3]Based on 4 x number of sites required by the design.

[4]Based on a mean of 1 and 5 accidents per year per site, respectively.

Total estimated study time duration and costs are presented by tasks in Table 10 for each of the two situations just described. All assumptions are noted in the table. As shown in the table, the study times range from four to eight years and cost from $124,000 to $460,000 to conduct.

Again these estimates represent the best judgment of the principal staff and are thought to be representative of the application of the generalized methodology for determining the incremental effectiveness of four safety countermeasures groupings in the rural curved highway section situation.

Table 10. Time and cost estimates to conduct the rural curved highway section study

	Situation A		Situation B	
Task	Time (Months)	Costs ($)	Time (Months)	Costs ($)
A - Plan Study	6	15,000	2	10,000
B - Select Sites	8	210,000	4	50,000
C - Collect & Code Data	72	172,800	36	43,000
D - Analyze & Report Results	10	62,000	6	21,000
TOTALS	96 (8 yrs.)	459,800	48 (4 yrs.)	124,000

NOTES:

1. Situation A is for a data cell sample size of 142 (see Table 9).
2. Situation B is for a data cell sample size of 29 (see Talbe 9).
3. Assume travel in Task B will cost $40,000 (Situation A) and $20,000 (Situation B).
4. Assume police accident report in Task C will cost $4,800 (Situation A) and $1,000 (Situation B).
5. Assume miscellaneous costs in Task D $2,000 (Situation A) and $1,000 (Situation B).
6. Assume labor and overhead is $5,000/staff month for Tasks A, B, and D and $3,000/staff month for Task C.
7. The cost estimate for each task consists of labor and overhead plus any of the costs indicated in Notes 3, 4, and 5.

V. ASSESSMENT OF FEASIBILITY

As the final step in the development of a generalized methodology to determine the incremental effectiveness of safety countermeasures, an assessment of the feasibility of the method was performed by examining the characteristics, advantages, and disadvantages of the method with respect to the following criteria:

- o Is the method practical?
- o Will the method produce reliable and valid results?
- o Can the method be implemented within a reasonable time and acceptable cost?
- o Will the expected benefit justify the costs?

Each question is briefly discussed below.

Practicality

This is perhaps the most critical test of the method. In order to develop the incremental effects, local jurisdictions must be willing to allow sites with similar characteristics to operate at different levels of countermeasure treatments for extended periods of time. While there are large number of sites presently operating in a manner, many agencies may be reluctant to continue such an operation once they know (and sooner or later the public could know) that potentially unsafe sites exist that have no treatment, or at best, only a partial treatment of the known safety countermeasure available. It does not matter how well intended the experiments are or how much long term benefit might result. Public agencies are generally unwilling to knowingly allow any situation to exist for which they could be held liable.

With the exception of the concern described above, the methodology was found to be very practical in terms of ease of implementation, understandability, and simplicity.

Reliability and Validity

Both the reliability and validity of the two experimental designs are thoroughly discussed in the Accident Research Manual (8) and will not be repeated here. The key to meeting these criteria lies in the ability of the researcher to select and properly match appropriate sites. While care may be taken in designing the experiment to control for the most important confounding factors, site selection remains the most critical step in successfully applying the methodology. Properly implemented, the method will produce reliable and valid results.

Time and Cost

As illustrated in the two experimental plans, the time to conduct these studies ranges from four to eight years. While other countermeasure groupings and/or certain modifications to the experimental design may require less time, the time estimates given, while optimistic perhaps, are considered to be representative, and do not deviate substantially from the time required to conduct other types of safety research involving the collection and analysis of accident data.

The question of reasonableness with respect to time is not the issue of concern for any given study. It is a major concern in terms of the number of studies that would be required to produce the incremental effects of even a small number of the most common countermeasure groupings. From Table 4 over 250 different combinations of common countermeasure groups may be derived. While a number of these groupings may be reduced by eliminating those highway situations with relatively low accident frequencies and/or rates (e.g., bridges and railroad grade crossings), there would still remain a large number of groupings for which the determination of incremental effectiveness would be desired.

The feasibility with respect to cost is similar to that presented above for time. Single studies to determine incremental effects for certain groups of countermeasures could be performed at a reasonable cost, using today's standard for the cost of accident research. However, the cost of determining the incremental effects of numerous groupings of countermeasures would be astronomical. For example, assuming an average cost of $200,000 per study, determining the incremental effects on only 70 of the most common groupings would cost more than the $14 million spent on all safety research projects (FCP Category 1) by Federal Highway Administration in 1983.

Expected Benefit

The intent of developing incremental effectiveness factors for groupings of safety countermeasures is to provide a more effective and efficient means of addressing highway safety needs related to the roadway and its environment. Conceivably, many dollars and lives could be saved by putting the "right" groups of countermeasures in the "right" place. Reliable estimates of these benefits could not be made within the scope of this study due to the non-availability of appropriate data.

VI. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the results of analysis, the assessment of feasibility, and the best informed judgment of the principal staff:

1. The generalized methodology as developed and described in the previous sections is a practical research methodology. However, the concern expressed over the ability to gain the cooperation of local agencies in implementing the methodology on a scale sufficient to assure success poses a serious limitation to the overall practicality of the methodology.

2. The methodology will produce reliable and valid results when properly implemented.

3. The time and cost to conduct single studies of incremental effectiveness appear reasonable. At present, the overall time and costs to develop the incremental effects for a useful set of countermeasure groupings appear to be too long and too high, respectively.

4. The expected benefit could not be determined within the scope of this study due to the unavailability of appropriate data.

Based on these conclusions, it is recommended that the methodology developed herein not be implemented until further advances are made in accident data collection, more reliable accident reduction factors for single countermeasures are developed, and more effective and efficient means are found to implement the generalized methodology developed in this study. The question remaining then is, "How can the prerequisites for successful implementation of the methodology best be met in a timely and cost effective fashion?" At present, the single largest obstacle to implementation is the ability to obtain (at low cost) large amounts of accident data that can be easily linked to roadway and traffic characteristics data. Current efforts to build computerized accident data files which can be integrated with traffic volumes and roadway inventories should be accelerated. It is estimated that the availability of such data bases could reduce the costs to collect and code data for determining incremental effectiveness by 30 to 40 percent. These improved files would have the secondary benefit of increasing the efficiency of site selection by eliminating much of the requirement for on-site inspection prior to site selection.

Thus, the recommended approach to the eventual determination of the incremental effectiveness of accident countermeasures is to establish or improve the data files required to support the generalized methodology.

VII. REFERENCES

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APPENDIX A

Commonly used countermeasures and groupings by traffic situation and accident pattern.

Situation: Signalized Intersections

Accident Pattern: Rear End Collisions

Countermeasures:

- o Prohibit turns (U)*
- o Install warning signs (i.e., "Signal Ahead" at intersections with restricted view) (U & R)
- o Increase signal lens size (U & R)
- o Increase clearance interval (U & R)
- o Provide skid treatment (U & R)
- o Provide adequate drainage (U & R)
- o Add turning lane (U)

Countermeasure Groups:

- o Adjust signal timing and add warning signs
- o Adjust signal timing and install lane use signing
- o Adjust signal timing and provide skid treatment
- o Add turning lanes and add warning signs
- o Add turning lanes and upgrade signals
- o Provide skid treatment and upgrade signals
- o Provide skid treatment and add turning lanes

*NOTE: (U) is urban,
(R) is rural.

Situation: Signalized Intersections

Accident Pattern: Left Turn Collisions

Countermeasures:

- o Prohibit turns (U)
- o Add left turn lane (U & R)
- o Add protective left turn signal phase (U)
- o Increase clearance interval (U & R)
- o Upgrade signals (U & R)
- o Install lane use signs (U & R)

Countermeasure Groups:

- o Add turning lanes and add protected left turn signal phasing
- o Add turning lanes and increase clearance interval
- o Upgrade signal and add protective left turn phase
- o Add left turn lane, add protective left turn signal phase, and upgrade signals
- o Add left turn lane, increase clearance interval, and upgrade signals
- o Add left turn lane and install lane use sign

Situation: Signalized Intersections

Accident Pattern: Pedestrian Accidents

Countermeasures:

- Remove sight obstructions (U)
- Restrict parking (U)
- Prohibit turning movements (U)
- Install pedestrian signals (U)
- Provide grade separation (U)
- Improve pavement marking (U)
- Improve signal timing (U)
- Provide illumination (U)

Countermeasure Groups:

- Restrict parking and prohibit turning movements
- Provide pedestrian facilities and install pedestrian signals

Situation: Signalized Intersections

Accident Pattern: Right Angle Collisions

Countermeasures:

- o Remove sight obstructions (U & R)
- o Restrict parking (U)
- o Increase signal visibility (U & R)
- o Increase clearance interval (U & R)
- o Provide all-red phase (U & R)

Countermeasure Groups:

- o Adjust signal timing and add warning signs
- o Adjust signal timing and provide skid treatment
- o Upgrade signals and overlay pavement
- o Provide skid treatment and install actuated signals

Situation: Signalized Intersections

Accident Pattern: Sideswipe Collisions

Countermeasures:

- o Restrict parking
- o Install lane use signs
- o Widen pavement or shoulders
- o Add turning lanes or turn phases
- o Improve pavement markings

Countermeasure Groups:

- o Improve pavement markings and add warning signs
- o Improve pavement markings and upgrade signals
- o Upgrade signals and install lane use signs
- o Add turning lanes and install actuated signals

Situation: Unsignalized Intersections

Accident Pattern: Left Turn Collisions

Countermeasures:

- o Prohibit turns (U)
- o Install stop/yield signs (U & R)
- o Install signasl (U & R)
- o Widen pavement shoulders (U & R)
- o Improve pavement markings (U)

Countermeasure Groups:

- o Install signals and improve pavement markings
- o Install stop/yield signs and widen pavement
- o Install signals and widen pavement

Situation: Unsignalized Intersections

Accident Pattern: Rear End Collisions

Countermeasures:

- o Provide skid treatment (U & R)
- o Provide adequate drainage (U & R)
- o Install signal (U & R)
- o Add stop or yield signs (U & R)

Countermeasure Groups:

- o Provide skid treatment and provide adequate drainage
- o Provide skid treatment and install signal
- o Provide skid treatment and add stop or yield signs

Situation: Unsignalized Intersections

Accident Pattern: Pedestrian Accidents

Countermeasures:

- o Install warning signs
- o Provide pedestrian crosswalks
- o Provide illumination

Countermeasure Groups:

- o Install warning signs and provide pedestrian crosswalks
- o Install warning signs and provide illumination
- o Install warning signs, provide pedestrian crosswalks, and provide illumination

Situation: Unsignalized Intersections

Accident Pattern: Right Angle Collisions

Countermeasures:

- Remove sight obstructions (U & R)
- Restrict parking (U)
- Install stop/yield signs (U & R)
- Install warning signs (U & R)
- Install signals (U & R)

Countermeasure Groups:

- Remove sight obstructions and restrict parking
- Remove sight obstructions, restrict parking and install stop/yield signs
- Remove sight obstructions, restrict parking and install signals
- Install stop/yield signs and install warning signs
- Install stop/yield signs and install signals

Situation: Tangent Roadway Sections

Accident Pattern: Run-off-the-Road

Countermeasures:

- o Provide skid treatment (U & R)
- o Improve alignment (vertical) (U & R)
- o Widen shoulders (U & R)
- o Add turning/passing lanes (U & R)
- o Improve pavement markings (U & R)
- o Improve passing zones (R)
- o Provide roadway/shoulder maintenance (U & R)

Countermeasure Groups:

- o Provide skid treatment and widen shoulders
- o Provide skid treatment and add turning/passing lanes
- o Add turning/passing lanes and improve pavement markings
- o Improve pavement markings and improve passing zones
- o Improve pavement markings and provide roadway/shoulder maintenance
- o Provide skid treatment and improve alignment
- o Provide skid treatment, widen shoulders and add turning/passing lanes

Situation: Tangent Roadway Sections

Accident Pattern: Head-on Collision

Countermeasures:

- o Improve pavement markings (U & R)
- o Improve vertical alignment (U & R)
- o Install median barriers (U)
- o Improve passing zones (R)

Countermeasure Groups:

- o Improve pavement markings and improve passing zones
- o Improve pavement markings and improve vertical alignment

Situation: Tangent Roadway Sections

Accident Pattern: Pedestrian-Bicycle Accidents

Countermeasures:

- Channelize pedestrian/bicycle traffic (U)
- Install illumination (U)
- Install warning signs (U & R)
- Improve pavement markings (i.e., crosswalks) (U & R)
- Install actuated pedestrian signals (U)

Countermeasure Groups:

- Channelize pedestrian/bicycle traffic and install illumination
- Channelize pedestrian/bicycle traffic and install warning signs
- Channelize pedestrian/bicycle traffic, install illumination and install warning signs
- Install warning signs and improve pavement markings (i.e. crosswalks)
- Channelize pedestrian/bicycle traffic, install warning signs and improve pavement markings (i.e., crosswalks)
- Channelize pedestrian/bicycle traffic and install actuated pedestrian signals
- Install warning signs, improve pavement markings, (i.e., crosswalks) and install actuated pedestrian signals

Situation: Tangent Roadway Sections

Accident Pattern: Parked Vehicle Collisons

Countermeasures:

- o Restrict parking (U)
- o Widen pavement (U & R)
- o Reduce speeds (U & R)

Countermeasure Groups:

- o Restrict parking and reduce speeds

Situation: Tangent Roadway Sections

Accident Pattern: Fixed Object Collisions

Countermeasures:

- o Install protection devices (i.e., guardrail) (U & R)
- o Widen shoulders (U & R)
- o Improve shoulder maintenance (U & R)

Countermeasure Groups:

- o Install protection devices (i.e., guardrails) and widen shoulders
- o Widen shoulders and improve shoulder maintenance
- o Install protection devices (i.e., guardrails) and improve shoulder maintenance

Situation: Tangent Roadway Sections

Accident Pattern: Sideswipe Collisions

Countermeasures:

- o Restrict parking (U & R)
- o Reduce speeds (U & R)
- o Install lane use signs (U)
- o Improve pavement markings (U & R)
- o Improve alignment (U & R)
- o Widen pavement (U & R)
- o Add turning/passing lanes (U & R)
- o Install median barrier (U & R)

Countermeasure Groups:

- o Restrict parking and reduce speeds
- o Install lane use signs and improve pavement markings
- o Install lane use signs and improve alignment
- o Restrict parking, reduce speeds and install lane use signs
- o Install lane use signs and widen pavement
- o Install lane use signs and add turning/passing lanes

Situation: Tangent Roadway Sections

Accident Pattern: Driveway-Related Accidents

Countermeasures:

- o Remove sight obstructions (U & R)
- o Prohibit driveway movements (U)
- o Improve access management (i.e., channelize driveways) (U)
- o Provide skid treatment (U & R)
- o Add turning/passing lanes (U & R)
- o Provide illumination (U)
- o Install warning signs (U & R)

Countermeasure Groups:

- o Remove sight obstructions and prohibit driveway movements
- o Remove sight obstructions and install warning signs
- o Remove sight obstructions and provide illumination
- o Remove sight obstructions, provide illumination and install warning signs
- o Improve access management (i.e., channelize driveways) and add turning/passing lanes
- o Add turning/passing lanes and install warning signs

Situation: Curved Roadway Sections

Accident Pattern: Run-off-the-Road

Countermeasures:

- Provide skid treatment (U & R)
- Improve alignment (horizontal) (U & R)
- Widen pavement/shoulders (U & R)
- Add turning/passing lanes (U & R)
- Improve pavement markings (i.e., centerlines & edgelines) (U & R)
- Provide roadway/shoulder maintenance (U & R)
- Install warning signs/signals (i.e., chevrons, arrow boards) (U&R)
- Improve driver guidance (i.e., delineators) (U & R)

Countermeasure Groups:

- Provide skid treatment and widen pavement/shoulders
- Provide skid treatment and add turning/passing lanes
- Add turning/passing lanes and improve pavement markings (i.e., centerlines & edgelines)
- Improve pavement markings (i.e., centerlines & edgelines) and provide roadway/shoulder maintenance
- Provide skid treatment and improve alignment (horizontal)
- Provide skid treatment and widen pavement/shoulders
- Install warning signs/signals (i.e., chevrons, arrow boards) and improve driver guidance (i.e., delineators)
- Improve pavement markings (i.e., centerlines & edgelines) and install warning signs/signals (i.e., chevrons, arrow boards)
- Improve pavement markings (i.e., centerlines & edgelines), install warning signs/signals (i.e., chevrons, arrow boards), and improve driver guidance (i.e., delineators)

Situation: Curved Roadway Sections

Accident Pattern: Head-on-Collision

Countermeasures:

- Improve pavement markings
- Improve horizontal/vertical alignment
- Install median barriers
- Improve passing zones
- Install warning signs

Countermeasure Groups:

- Improve pavement markings and improve passing zones
- Improve pavement markings and improve horizontal/vertical alignment
- Improve pavement markings and install warning signs
- Improve pavement markings, improve passing zones and install warning signs

Situation: Curved Roadway Sections

Accident Pattern: Pedestrian-Bicycle Accidents

Countermeasures:

- o Channelize pedestrian/bicycle traffic (U)
- o Install illumination (U)
- o Install warning signs (U & R)
- o Improve pavement marking (i.e., crosswalks) (U & R)
- o Install actuated pedestrian signals (U)

Countermeasure Groups:

- o Channelize pedestrian/bicycle traffic and install illumination
- o Channelize pedestrian/bicycle traffic and install warning signs
- o Channelize pedestrian/bicycle traffic, install illumination and install warning signs
- o Install warning signs and improve pavement marking (i.e., crosswalks)
- o Channelize pedestrian/bicycle traffic, install warning signs and improve pavement marking (i.e., crosswalks)
- o Channelize pedestrian/bicycle traffic and install actuated pedestrian signals
- o Install warning signs, improve pavement marking (i.e., crosswalks) and install actuated pedestrian signals

Situation: Curved Roadway Sections

Accident Pattern: Parked Vehicle Collisions

Countermeasures:

- o Restrict parking (U)
- o Widen pavement/shoulders (U & R)
- o Reduce speeds (U & R)

Countermeasure Groups:

- o Restrict parking and reduce speeds

Situation: Curved Roadway Sections

Accident Pattern: Fixed Object Collisions

Countermeasures:

- o Install protection devices (i.e., guardrail, crash cushions) (U & R)
- o Widen pavement/shoulders (U & R)
- o Improve shoulder maintenance (U & R)
- o Remove or relocate objects (U & R)
- o Install warning signs

Countermeasure Groups:

- o Install protection devices (i.e., guardrails, crash cushions) and widen pavement/shoulders
- o Widen pavement/shoulders and improve shoulder maintenance
- o Install protection devices (i.e., guardrails, crash cushions) and improve shoulder maintenance
- o Widen pavement/shoulders and remove or relocate objects
- o Install protection devices (i.e., guardrails, crash cushions) and install warning signs
- o Improve shoulder maintenance and install warning signs

Situation: Curved Roadway Sections

Accident Pattern: Sideswipe Collisions

Countermeasures:

- o Restrict parking (U & R)
- o Reduce speeds (U & R)
- o Install lane use signs (U)
- o Improve pavement markings (U & R)
- o Improve alignment (U & R)
- o Widen bridge (U & R)
- o Add turning/passing lanes (U & R)
- o Install median barrier (U & R)

Countermeasure Groups:

- o Restrict parking and reduce speeds
- o Install lane use signs and improve pavement markings
- o Install lane use signs and improve alignment
- o Restrict parking, reduce speeds and install lane use signs
- o Install lane use signs and widen pavement
- o Install lane use signs and add turning lanes

Situation: Curved Roadway Sections

Accident Pattern: Driveway-Related Accidents

Countermeasures:

- Remove sight obstructions (U & R)
- Prohibit driveway movements (U)
- Improve access management (i.e., channelize/close driveways) (U)
- Provide skid treatment (U & R)
- Add turning/passing lanes (U & R)
- Provide illumination (U)
- Install warning signs (U & R)
- Install median barriers (U)

Countermeasure Groups:

- Remove sight obstructions and prohibit driveway movements
- Remove sight obstructions and install warning signs
- Remove sight obstructions and provide illumination
- Remove sight obstructions and provide illumination and install warning signs
- Improve access management (i.e., channelize/close driveways) and add turning/passing lanes
- Add turning/passing lanes and install warning signs
- Improve access management (i.e., channelize/close driveways) and install median barriers

Situation: Highway Sections

Accident Pattern: Bridge-Related

Countermeasures:

- o Remove sight obstructions (U & R)
- o Install advance warning signs/signals (U & R)
- o Improve driver guidance (i.e., delineators) (U & R)
- o Install guardrails (U & R)
- o Provide illumination (U & R)
- o Widen bridge (U & R)
- o Improve pavement markings (U & R)
- o Install crash cushions (U)

Countermeasure Groups:

- o Remove sight obstructions and install warning signs
- o Remove sight obstructions, install warning signs and improve driver guidance (i.e., delineators)
- o Install warning signs and improve driver guidance (i.e., delineators)
- o Install warning signs and improve driver guidance (i.e., delineators)
- o Install warning signs, improve driver guidance (i.e., delineators) and install guardrail
- o Install warning signs, improve driver guidance (i.e., delineators) and improve pavement markings
- o Remove sight obstructions and provide illumination
- o Install guardrails and crash cushions

Situation: Highway Sections

Accident Pattern: Train-Involved Accidents

Countermeasures:

- o Remove sight obstructions (U & R)
- o Install advance warning signs/signals (U & R)
- o Provide illumination (U)
- o Install crossing gates (U)
- o Install crossing flashers (U & R)

Countermeasure Groups:

- o Install advance warning signs/signals and install crossing flashers
- o Install advance warning signs/signals, install crosing gates and install crossing flashers
- o Remove sight obstructions and provide illumination
- o Install crossing gates and install crossing flashers

APPENDIX B

Typical countermeasures by situation and cost category.

Situation	Countermeasures
o **Signalized Intersection** (Urban)	**Low Cost**

Low Cost

- o Adjust signal timing/add all red phase
- o Prohibit turning movements
- o Add Warning signs/signals
- o Restrict parking
- o Improve pavement markings
- o Reduce sight obstructions
- o Install pedestrian barriers
- o Improve turning radii
- o Install lane use signing/markings

Medium Cost

- o Upgrade pavement markings
- o Improve drainage
- o Upgrade signals
- o Overlay pavement
- o Provide illumination
- o Widen pavement
- o Install median barriers
- o Close driveways

High Cost

- o Add turning lanes
- o Channelize
- o Grade separation
- o Install actuated signal system

Situation	Countermeasures
o **Non-Signalized Intersections (Urban)**	**Low Cost** o Prohibit turning movements o Install yield/stop signs o Install warning signs o Reduce speed limits o Improve pavement markings o Provide pedestrian crosswalks o Reduce sight distance obstructions o Restrict parking **Medium Cost** o Install signals o Widen pavement o Provide illumination o Overlay pavement o Remove signt distance obstructions **High Cost** o Channelize o Add turning lanes o Install actuated signal controllers

Situation	Countermeasures
o **Tangent Roadway Section (Urban)**	**Low Cost** o Provide adequate drainage o Improve pavement markings o Reduce speeds o Restrict parking o Install warning signs/signals o Prohibit turns to/from driveways o Provide pedestrian crossings **Medium Cost** o Add passing/turning lanes o Overlay pavement o Widen lanes o Relocate parking o Remove/protect roadside obstacles o Improve access mangement o Channelize traffic o Provide sidewalks **High Cost** o Improve alignment (vertical) o Install median barrier

Situation	Countermeasures
o **Curved Roadway Section (Urban)**	

Low Cost

- o Install warning signs/signals
- o Prohibit adequate drainage
- o Improve pavement markings (edgelines)
- o Improve roadway/shoulder maintenance
- o Reduce speed limits
- o Restrict parking
- o Reduce the number of driveways (access management)
- o Restrict turns

Medium Cost

- o Overlay/groove pavement
- o Remove sight obstructions
- o Channelize driveway traffic
- o Install guardrail
- o Provide illumination
- o Widen pavement/shoulders

High Cost

- o Improve alignment
- o Install median barriers

Situation	Countermeasures
o Railroad Crossing (Urban/Rural)	**Low Cost** o Reduce sight obstructions o Install warning signs/signals o Install crossing signs **Medium Cost** o Provide illumination o Install crossing flashers o Improve crossing surface **High Cost** o Install crossing gates o Improve approach alignment o Grade separate crossing

Situation	Countermeasures
o Bridge Section (Urban/Rural)	

Low Cost

- o Reduce sight obstructions
- o Install warning signs/signals
- o Improve pavement markings (i.e., edge lines)
- o Install delineators
- o Reduce speeds

Medium Cost

- o Remove sight obstructions
- o Provide illumination
- o Install guardrails
- o Improve shoulders
- o Improve bridge railings
- o Widen roadway

High Cost

- o Reconstruct/relocate bridge
- o Realign bridge approaches

Situation	Countermeasures
o Signalized Intersections (Rural)	

Low Cost

- o Adjust signal timing/add all red phase
- o Add Warning signs/signals
- o Improve pavement markings
- o Reduce sight obstructions
- o Improve turning radii
- o Install lane use signing/markings
- o Improve drainage

Medium Cost

- o Remove sight obstructions
- o Widen pavement/shoulders
- o Upgrade signals
- o Overlay pavement
- o Provide illumination
- o Install median barriers
- o Add turning lanes
- o Channelize driveway traffic
- o Install actuated signal system

High Cost

- o Channelize intersection

Situation	**Countermeasures**
o Non-Signalized Intersection **(Rural)**	**Low Cost**
	o Install stop/yield signs
	o Install warning signs
	o Reduce speed limits
	o Improve pavement markings
	o Reduce sight distance obstructions
	Medium Cost
	o Remove sight distance obstructions
	o Widen pavement
	o Provide illumination
	o Overlay pavement
	o Install signals
	o Improve shoulders
	High Cost
	o Channelize
	o Add turning lanes

Situation	Countermeasures
o **Tangent Roadway Sections (Rural)**	**Low Cost**

Low Cost

- o Provide adequate drainage
- o Improve pavement markings
- o Reduce speeds
- o Install warning signs/signals
- o Prohibit turns to/from driveways
- o Provide pedestrian crossings
- o Improve roadway/shoulder maintenance

Medium Cost

- o Add passing/turning lanes
- o Overlay pavement
- o Widen pavement/add turning lanes
- o Remove/protect roadside obstacles
- o Remove sight obstructions

High Cost

- o Improve alignment (vertical)

Situation	**Countermeasures**
o **Curved Roadway Sections (Rural)**	<u>**Low Cost**</u> o Install warning signs/signals o Provide adequate drainage o Improve pavement markings (edgelines) o Improve roadway/shoulder maintenance o Reduce speeds o Reduce sight obstructions <u>**Medium Cost**</u> o Overlay/groove pavement o Remove sight obstructions o Install guardrail o Provide illumination o Widen pavement/shoulders <u>**High Cost**</u> o Improve alignment (vertical)

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH, DEVELOPMENT, AND TECHNOLOGY

The Offices of Research, Development, and Technology (RD&T) of the Federal Highway Administration (FHWA) are responsible for a broad research, development, and technology transfer program. This program is accomplished using numerous methods of funding and management. The efforts include work done in-house by RD&T staff, contracts using administrative funds, and a Federal-aid program conducted by or through State highway or transportation agencies, which include the Highway Planning and Research (HP&R) program, the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board, and the one-half of one percent training program conducted by the National Highway Institute.

The FCP is a carefully selected group of projects, separated into broad categories, formulated to use research, development, and technology transfer resources to obtain solutions to urgent national highway problems.

The diagonal double stripe on the cover of this report represents a highway. It is color-coded to identify the FCP category to which the report's subject pertains. A red stripe indicates category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, and green for category 9.

FCP Category Descriptions

1. Highway Design and Operation for Safety

Safety RD&T addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act. It includes investigation of appropriate design standards, roadside hardware, traffic control devices, and collection or analysis of physical and scientific data for the formulation of improved safety regulations to better protect all motorists, bicycles, and pedestrians.

2. Traffic Control and Management

Traffic RD&T is concerned with increasing the operational efficiency of existing highways by advancing technology and balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, coordinated signal timing, motorist information, and rerouting of traffic.

3. Highway Operations

This category addresses preserving the Nation's highways, natural resources, and community attributes. It includes activities in physical maintenance, traffic services for maintenance zoning, management of human resources and equipment, and identification of highway elements that affect the quality of the human environment. The goals of projects within this category are to maximize operational efficiency and safety to the traveling public while conserving resources and reducing adverse highway and traffic impacts through protections and enhancement of environmental features.

4. Pavement Design, Construction, and Management

Pavement RD&T is concerned with pavement design and rehabilititation methods and procedures, construction technology, recycled highway materials, improved pavement binders, and improved pavement management. The goals will emphasize improvements to highway performance over the network's life cycle, thus extending maintenance-free operation and maximizing benefits. Specific areas of effort will include material characterizations, pavement damage predictions, methods to minimize local pavement defects, quality control specifications, long-term pavement monitoring, and life cycle cost analyses.

5. Structural Design and Hydraulics

Structural RD&T is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highway structures at reasonable costs. This category deals with bridge superstructures, earth structures, foundations, culverts, river mechanics, and hydraulics. In addition, it includes material aspects of structures (metal and concrete) along with their protection from corrosive or degrading environments.

9. RD&T Management and Coordination

Activities in this category include fundamental work for new concepts and system characterization before the investigation reaches a point where it is incorporated within other categories of the FCP. Concepts on the feasibility of new technology for highway safety are included in this category. RD&T reports not within other FCP projects will be published as Category 9 projects.