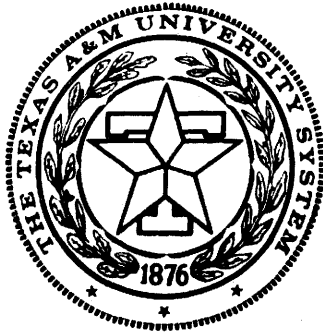


TTI-2-18-78-228-1
TTI-2-18-79-263-1



**TEXAS
TRANSPORTATION
INSTITUTE**

**STATE DEPARTMENT
OF HIGHWAYS AND
PUBLIC TRANSPORTATION**

**COOPERATIVE
RESEARCH**

**MAINTENANCE AND CONSTRUCTION
ZONE: ANNOTATED
BIBLIOGRAPHY**

in cooperation with the
Department of Transportation
Federal Highway Administration

**RESEARCH REPORT 228-1/ 263-1
STUDY 2-18-78-228 AND 2-18-79-263
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16. Abstract This report provides a review of past reports and papers concerned with traffic management and safety in highway maintenance and construction zones. Annotations of literature relevant to the two research projects are categorized and presented in the following areas: <ol style="list-style-type: none"> 1. Work zone safety 2. Accidents 3. Effects of lane closures 4. Maintenance and construction procedures 5. Traffic control plans 6. Traffic management approaches 7. Night work 8. Flagging 9. Barricades, barriers, and crash cushions 10. Signs 11. Tapers and channelizing devices 12. Visibility requirements 13. Arrowboards 14. Warning lights 15. Striping and rumble strips 16. Pavement drop-offs 17. Equipment 					
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Research Study Number 2-18-78-228

Traffic Management During Freeway Reconstruction and in Rural Work Zones
Research Study Number 2-18-79-263

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March 1980



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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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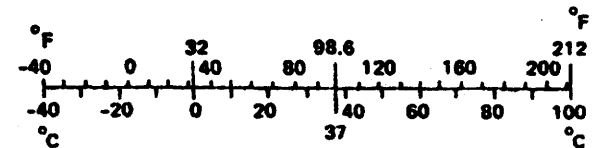
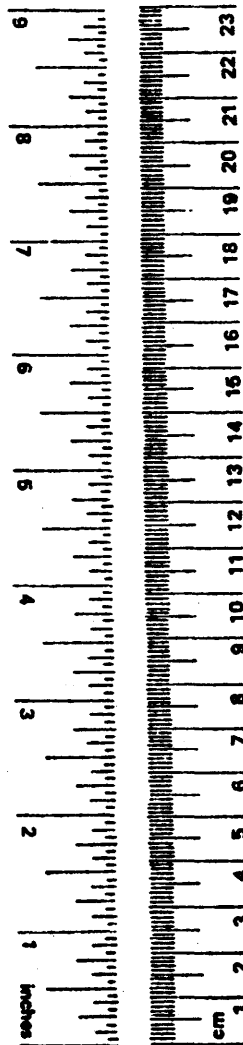
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons	0.9	tonnes	t
	(2000 lb)			
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
^o F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	^o C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
^o C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	^o F



* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10:286.



INTRODUCTION

Over 250 articles were identified and reviewed for their applicability to Study 228, "Traffic Management During Urban Freeway Maintenance Operations," and Study 263, "Traffic Management During Freeway Reconstruction and in Rural Work Zones." Applicable references that were also found to be generally available to interested individuals were annotated and are included in this report. Additional work zone annotations can be found in the NCHRP Report 17-4, "Evaluation of Traffic Controls for Highway Work Zones," Volume II: Appendices," February 1979 (in draft form at the time of this publication), and FHWA Report No. FHWA-RD-79-4, "Identification of Traffic Management Problems in Work Zones," March 1979.

WORK ZONE SAFETY

Adrian, George W. "Work Area Protection on Highways." American Water Works Association Journal. November 1963.

This paper deals with the importance of work area protection to water utility management. The legal requirements as well as the moral responsibilities to protect human life are discussed. To achieve adequate protection of the work area, advanced planning must be stressed. Protection should be given, not only to motorists and pedestrians, but to employees as well.

Good work area protection should be a salient point of water utility policy and is achieved by using the lessons of experience and effective safety rules. Alertness and ingenuity in recognizing and providing for unforeseen and new problems are also important to success.

By establishing a systematic, orderly approach to work area protection, a water utility promotes efficiency and safety while building public confidence in the utility.

McGarry, T. F. "Checklist for Safety at Highway Worksites." Construction. November 1966.

This article discusses the importance of maintaining safe and effective traffic control at worksites and presents several examples of inadequate traffic control and safety practices. Since some worksites constitute a serious hazard to motorists, work zone traffic control is a promising area for significant accident reduction.

The article recognizes the fact that it costs money to manage traffic at worksites and, therefore, each project contract should contain separate pay items for traffic control. Traffic control should not be regarded as incidental to other construction pay items.

For each project, the contracting agency should hold a pre-construction conference. Representatives of the contractor, law enforcement agencies, utility companies, etc., should be encouraged to attend the conference. The project traffic control plan should be explained at the conference and the responsibilities and authority for traffic control at the job site should be established.

"Worksite Protection Requires Timely Communication." Public Works. December 1968.

This article reviews Part VI of the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) which deals with traffic controls for construction and maintenance sites. It stresses the importance of adhering to the standards and guidelines in this document.

No information is introduced in this article that is not already contained in the MUTCD.

Huzvar, J. "Safety on the Job Site." Public Works. March 1970.

This paper discusses the need to provide adequate protection for highway workers, as well as the traveling public, at construction and maintenance work zones. Some methods used by the Pennsylvania Department of Transportation (Penn DOT) to meet these needs are presented.

To supplement the standard warning signs, Penn DOT is using high level plastic warning devices for identifying worksites and "spring-legged" safety markers for channelizing traffic at work zones. Construction vehicles are equipped with emergency warning lights. A "sign truck barricade" is used as a positive barrier to separate traffic and the work crew. The "sign-truck barricade" consists of a 33,000-pound vehicle on which an 8-foot square orange warning sign is mounted. Additionally, all crew members are required to wear red fluorescent vests for day work and high-visibility yellow reflectorized vests for night work.

The effectiveness of the measures used by Penn DOT are documented in the article. No Penn DOT worker has been killed or seriously injured in a work zone-related accident since the measures were implemented.

Jeter, H. "Employee Safety--How a Highway Contractor Does It." Roads and Streets. May 1972.

This article summarizes the work zone safety program developed and used by the Ballenger Corporation. The program includes fundamentals of flagging. Work crews also conduct weekly safety meetings and frequent job inspections are made. Every job site is required to have at least two workers trained in first aid by the Red Cross.

Safety engineers from the company's insurance carrier inspect all jobs and prepare compliance reports, similar to OSHA inspector reports. In addition, a company safety director distributes weekly bulletins to all supervisors informing them of recent changes in OSHA regulations.

"Safety of Maintenance and Construction Personnel in Work Zones - A Special Study." California Department of Transportation. July 1974.

This report presents the findings of a study made to improve the safety of Department construction and maintenance workers at work zones. Specific problem areas are identified and 101 recommendations for solving many of these problems are made. In all, 20 major areas of concern are identified and grouped into the following categories for discussion: problem identification, evaluation of existing procedures, actual maintenance and construction sites, and driver behavior and its effect on construction accidents.

The development of an information system for maintenance and construction zone safety management is recommended. The report also stresses the need for all levels of management to support and accept responsibility for work zone safety. It also recognizes that the attitude and safety consciousness of workmen are probably the most critical factors in the success or failure of any safety program. Training needs at all levels are identified. The importance of visible and uniform traffic control devices at all worksites is also addressed and the report recommends that public information systems be increasingly utilized to give advance notice to motorists.

"Job Site Protection--Good Enough." Editorial, Rural and Urban Roads.
September 1974.

This paper discusses the need for better traffic control at highway worksites. According to the paper, the major need is not for better plans, but for an effective training program and administration. A study by the Kentucky Department of Transportation is cited to illustrate the inadequacy of existing practices at work zones. The study suggests that improvement is needed, not only in control devices and methods, but also in employee training programs and administrative policies.

"Jobsite Employees Get Safety Training." Rural and Urban Roads. September 1974.

The Florida Department of Transportation has developed a training program aimed at improving traffic control at highway worksites. Safety, maintenance, and construction personnel designed the course intended for employees of all agencies which work on state highway right-of-ways. Graduates of the three-day study course are certified as Instructors of Traffic Control and Safe Practices and are encouraged to teach other employees.

"Highway Construction Zone Safety--Not Yet Achieved." Report CED-78-10. United States General Accounting Office. December 1977.

This report discusses the findings of a study made by the General Accounting Office (GAO) to evaluate the status of work zone safety. This study was prompted by the Federal Highway Administration's (FHWA) concern about construction zone safety in recent years. The GAO visited 26 construction sites and observed unsafe conditions at every site. The GAO also found that worksite traffic control varied widely from state to state and project to project.

The GAO study suggests that the FHWA needs to develop additional program guidance, provide and promote more training, and strengthen the inspection procedures of its field offices. Specific recommendations contained in the GAO study include the following:

- 1) Revise the Manual of Uniform Traffic Control Devices to include specific guidance on how and when to use traffic control devices in construction zones.
- 2) Require training to help insure that Federal and State officials are made aware of the importance of construction zone safety and have the capability to plan for, implement, and inspect these safety measures.
- 3) Establish field office inspecting procedures to identify hazardous conditions and insure that they are corrected.

Anderson, H. L. "Work Zone Safety." Transportation Research Record 693, 1978.

This paper focuses on work zone safety problems, areas requiring improvements, and Federal Highway Administration research projects directed at improving traffic operations in and near work zones. According to the author, worksite safety deserves far more attention than it has received in the past. There are at least 500 workmen killed each year at worksites and the construction site safety problem may increase in the future. Between 1970 and 1977, there was a 400 percent increase in reconstruction activities.

Major deficiencies in work zone traffic control identified in the paper include:

- 1) The inability of management to identify and overcome specific safety problems.
- 2) The use of inadequate barriers and guardrails to protect work areas (blunt end and transition hazards are a particular problem).
- 3) A lack of understanding and concern by construction personnel.
- 4) The ineffective delineation and protection of pavement drop-offs.
- 5) The failure to remove construction materials along the roadside.
- 6) The inadequate removal of old pavement markings.
- 7) The use of damaged or dirty warning signs.

The paper cites a nine-state survey which revealed a number of problems prevalent at work zones throughout the country. The major problem noted is the vagueness of existing standards at work zones which exists, in part, because of a lack of basic knowledge in the area of work zone traffic control.

Thomas, L. W. "Liability for Improper Traffic Signaling, Signing, and Pavement Markings" (Abridgment). Transportation Research Record 693, 1978.

The author summarizes court cases involving liability for improper signals, signs, and pavement markings. Court decisions and recent tort claim acts recognize that states and state agencies should not be held liable for negligent performance of governmental functions that are discretionary in nature. The general view is that the state is not liable for negligence in the performance of functions that involve a high degree of discretion, but is liable for negligence in the performance of ministerial or operational level tasks. A discretionary duty is one involving the power to make choices among valid alternatives and to exercise independent judgment in choosing a course of action. Conversely, ministerial duties are more likely to involve clearly defined tasks that are to be executed with minimum leeway and individual judgment.

The author states that the court rulings indicate that the decision on whether to provide signals, signs, or markings is the exercise of immune discretion at the planning level; however, recent decisions hold that negligence thereafter, in provision or in maintenance of them, is less likely to be protected from liability. After the department has provided the traffic control devices, it is obligated to maintain them in good serviceable condition.

The department ordinarily must act on its own and provide traffic control devices at hazardous or dangerous locations when it has notice of these conditions. The general view is that, in order to hold public authorities liable for injuries, it must appear that the authority knew, or had reasonable cause to know, of the defective condition a sufficient length of time prior to the accident to enable it to repair the road or alleviate the danger.

An analysis of the traffic signal cases by the author appears to support the following main conclusions:

- 1) The plaintiff is least likely to recover where a traffic sign or signal was removed from an intersection under proper authorization and where it was claimed that the traffic control system at an intersection had been negligently planned or designed.
- 2) The plaintiff is most likely to recover for negligence where the highway authority failed within a reasonable time to replace a traffic sign that had been removed by unauthorized persons, to re-erect or repair a sign that had fallen down or had been knocked down or bent over, or to replace a burned-out bulb in an electric traffic signal. Ordinarily, the failure to keep traffic lights and signs in good working condition may result in liability of the department.
- 3) The cases are divided and hold both ways where, for example, there has been a failure to install any traffic signals or lights at an intersection alleged to be dangerous.

Oliver, D. C., "Tort Liability: Special Problems Encountered by Highway Agencies and Contractors in Designing Work Zone Layouts." Transportation Research Record 693, 1978.

This paper discusses some general principles, some considerations involving federal regulations or programs, and some recent cases that provide firsthand knowledge of judicial treatment of tort liability.

Anderson, R. W. and Smith, L. "Planning and Operating Guidelines for Work Zone Management." National Transportation Safety Board. Undated

Safe traffic control in street and highway work zones is increasingly being recognized as an important responsibility of highway agencies and utility companies. In this report, some basic guidelines are presented which are

based on the experiences and research of state and local highway officials, the Federal Highway Administration, the National Transportation Safety Board, research organizations, and private enterprise. The guidelines address: the similarity of motorists' safety needs on permanent roads and in work zones; traffic control plans for work areas; movement of workers and materials; provisions for disabled vehicles; geometrics; reduced speed zoning; clear roadway; flagging; maintenance of traffic control devices; pavement markings; barriers; barricades; accommodation of run-off-the-road incidents; monitoring; and accident records.

Paulsen, R. J., Harwood, D. W., Graham, J. L., and Glennon, J. C., "Status of Traffic Safety in Highway Construction Zones." Transportation Research Record 693, 1978.

This paper identifies methods by which more effective planning, design, and management of construction zones can improve traffic safety. Planning and design issues addressed include: (1) basic considerations, (2) zone selection and scheduling, (3) speed control strategy, (4) geometric design, and (5) traffic control devices. Management concepts include: (1) public information, (2) training, (3) modification of traffic control, (4) removal of inappropriate traffic control devices, and (5) maintenance of traffic control devices.

Humphreys, J. B., Mauldin, H. D., Sullivan, T. D., "Identification of Traffic Management Problems in Work Zones." University of Tennessee. Report No. FHWA-RD-79-4. March 1979.

This report presents a prioritized listing of twenty problem statements relating to traffic safety in construction, maintenance and utility work zones. These problem statements were developed from (1) data collected during 103 site visits, (2) analyses of 30 construction zone "before and during" accident cases, (3) a literature review, and (4) personal experiences of an interdisciplinary, six-person professional staff.

The authors indicate that approximately two-thirds of the work zone safety problems could be ameliorated if current standards and/or knowledge were properly applied. Data relative to traffic control device use, traffic operation, and accident location in work zones are also included.

ACCIDENTS

Doerge, T. C. and Levy, P. S. "Injuries, Crashes, and Construction on a Superhighway." American Journal of Public Health, Vol. 67, No. 2. February 1977.

This report reviews the findings of an accident analysis conducted for work zones in Illinois. The study found that accident rates increased significantly on segments of an Illinois superhighway undergoing major construction, in comparison to accidents on segments not undergoing construction. The study also revealed that separating traffic on those segments under construction resulted in smaller increases in injury accident rates as compared to crossover diversion of traffic from lanes under construction into previously one-way roadways.

Graham, J. L., Paulsen, R. J. and Glennon, J. C. "Accident and Speed Studies in Construction Zones." Report No. FHWA-RD-77-80. Midwest Research Institute. June 1977.

This report documents results of two studies of construction zone traffic control. The first study involved analysis of traffic accidents occurring in 79 work zones in seven states. This study revealed that accident rates increased 6.8 percent, on the average, during work activities. Accident rates are further analyzed by accident type, severity, light condition, roadway type, area type, work area roadway type, construction type, and state.

The second study evaluated the field testing of speed reduction methods. Speeds, erratic maneuvers, and conflicts were measured at three worksites on: an urban freeway, a rural freeway, and an urban street. Results of the speed studies on the urban and rural freeway are included in this report. Results of the urban street studies are included in a special report to be completed at a later time. The field studies summarized in this report examined the effect of the following construction zone parameters on vehicle speeds and traffic safety: sequential flashing arrowboards; speed zoning (advisory and regulatory); enforcement; transverse striping; obliteration of non-appropriate pavement markings; taper length; lane width reduction; and active warning of speed zoning. Recommended guidelines for construction zone traffic controls are also included.

Hargroves, B. T. "Vehicle Accidents at Maintenance and Utility Work Zones," Virginia Highway and Transportation Research Council. Report No. VHTRC 79-K32. October 1978.

The objective of this study was to determine the magnitude and characteristics of safety problems, in terms of reported accidents, that are associated with moving vehicular traffic around and through highway maintenance and utility work zones. This was accomplished by examining 280 maintenance and utility work zone accidents that occurred on the Virginia state highway network over a period of 14 months. These represented approximately 0.2% of the total number of accidents reported during that period. A review of accident reporting procedures by the author, however, indicated that the sample of accidents examined did not include a variety of work zone accidents where the roadway was not under physical repair (e.g., sweeping and landscaping) or where the first event in the accident was not related to the work activity (e.g., driver falling asleep).

The report discusses several characteristics of the maintenance and utility work zone accidents including general and specific locations of the accident, time of the accident, roadway and environmental factors, characteristics of the work zone, cause of the accident, and accident severity. Where data were available, comparisons were made between the maintenance and utility work zone accidents and all reported accidents.

EFFECTS OF LANE CLOSURES

Kermode, R. H. and Myra, W. A. "Freeway Lane Closures." Traffic Engineering. February 1970.

In this report, observed capacity rates for several types of work activities on freeways in Los Angeles are presented. The authors suggest that the capacity at a lane closure depends on a number of factors such as: alignment, grade, percentage of trucks, type of operation, etc. In addition, field observations show that the more exotic or unusual the operation, the more motorists will slow down and "gawk" and, therefore, the capacity will be lower.

Procedures for determining whether a lane closure will result in congestion and for estimating delay during a lane closure when congestion does occur are presented.

Butler, B. C., et al., "The Effect of Traffic Lane Closures on the Highway Motorist." Transportation Research Board Special Report 153, 1975.

This paper deals with the economic impact of work zone lane closures on the motorist. It documents a study made to develop traffic warrants for using premium pavements. This study resulted in the development of a computer program called EAROMAR, Economic Analysis of Roadway Occupancy for Maintenance and Rehabilitation. In general, the program performs these functions:

- 1) It establishes a data matrix of given and assumed information in an initialization routine.
- 2) It determines the specific hours that the roadway will be occupied by work crews annually, together with the maintenance and rehabilitation costs associated with that occupancy.
- 3) It determines the operation, time, and accident costs to the motorist caused by the roadway occupancy.

The program provides output showing that motorist costs increase substantially when a queue occurs. As mentioned earlier, the program was designed to provide warrants for developing a premium pavement, but it can be used to develop closure strategies and to forecast maintenance costs for many types of work activities.

MAINTENANCE AND CONSTRUCTION PROCEDURES

McLean, C., "Traffic Handling Procedures During Maintenance and Reconstruction to Promote Safety and Minimize Delays." Transportation Research Board Special Report 153, 1970.

This report presents a detailed explanation of advance planning for an extensive Interstate repair and maintenance project in Chicago (I-90/I-94). The \$16 million rehabilitation was completed in 15 weeks. The geometrics of the roadway ranged from 4 to 10 lanes. Special attention is given to media coverage, communications planning, community relations, and traffic control during the project.

Byrd, L. G., et al., "Reducing Roadway Occupancy Time by Maintenance Crews." Public Works. March 1973.

This report documents a research study conducted to identify and evaluate techniques used to reduce roadway occupancy time by maintenance crews. The specific activities studied were bridge deck repairs, pavement patching, crack and joint sealing, and mud-jacking.

The study found that a reduction in roadway occupancy time at work zones can be accomplished through mechanization, careful material and technique selection, and effective crew management.

It is recommended that photographic observation of maintenance activities be used to provide a basis for careful, orderly analysis of procedures, for productivity measurements, and for dramatic classroom training of supervisors and maintenance crews.

TRAFFIC CONTROL PLANS

Goodwin, C. A. "It Pays to Minimize Traffic Hazards During Road Construction," Public Works. October 1963.

The basic principles involved in the control and protection of vehicle and pedestrian traffic at construction projects are discussed. Standards and procedures based on widely accepted practices are recommended. The recommended standards and procedures are based on the guidelines in the Manual on Uniform Traffic Control Devices for Streets and Highways.

Cummings, J. V., "Traffic Requirements for Construction Projects." Traffic Engineering. November 1967.

This paper stresses the need for proper planning of traffic control at construction worksites. The authors state that proper coordination between the traffic engineer and the construction design engineer is needed. Traffic requirements for a given construction project should receive the same consideration as that given to other design criteria.

The basic factors to be considered by the traffic engineer with regard to traffic requirements for construction projects are discussed, including: reassignment of right-of-way, turn restrictions, and maintenance of construction traffic control devices.

Additional study and research are recommended in the following areas:

- 1) Development of sound methods of cost estimating in connection with street restrictions and closures.
- 2) Development of standard plans, procedures, and specifications pertaining to traffic detour requirements.

"Traffic Control for Freeway Maintenance." NCHRP Synthesis of Highway Practice Report 1. Highway Research Board. Washington, D. C., 1969.

This report is a synthesis of the useful knowledge and current practices in the area of traffic control for freeway maintenance. The synthesis reports on the various practices without making specific recommendations.

Included in the synthesis are discussions on:

- 1) Planning and scheduling for worksite traffic control.
- 2) Protection of freeway worksites.
- 3) Protection of stationary lane closures.
- 4) Protection of moving worksites.
- 5) Protection of shoulder worksites.
- 6) Protection of worksite recovery areas.
- 7) Protection of worksites adjacent to the right-of-way.
- 8) Traffic control devices.
- 9) Areas requiring additional studies.

"Traffic Control is a Job Pay Item and Contractors Like It." Road and Streets. January 1970.

This report discusses the attention being given to traffic control at worksites in Illinois. The report reveals that traffic protection and control through work areas are now pay items on most Illinois state projects. Making traffic control a pay item allows contractors to make more accurate cost estimates and, in general, results in more attention to work zone traffic control.

Special traffic control requirements are set forth in most project plans; most contracts include a special provision paragraph on traffic control. Project plans usually include sheets on which all standard and special signs, barricades, etc., are sketched. The plans indicate where traffic control devices are to be located during each job phase. These devices are more effective because of their better planned positioning and visibility.

Illinois also requires barricades on widening jobs to be spaced every 50 feet and barricade surfaces to be at least 50 percent reflectorized. Steadyburn amber lights are used for nighttime delineation. Standard orange warning signs are used instead of yellow signs.

Administration of traffic control is an emphasis area.

"Road-Work Warnings by the Book." American City. October 1970.

This report discusses the impact of the Illinois State Manual on Uniform Traffic Control Devices for Streets and Highways on work zone traffic control in cities in Illinois. According to the report, a uniform system of signing and barricading all public and private road construction and maintenance jobs in Illinois has been officially adopted. Directed at the safety of workmen and motorists, state traffic engineers designed the new requirements to facilitate quick and easy passage of traffic through or around a construction zone--both day and night--with a standardized system of warnings that are simple to understand and easily recognized.

Hatton, R. L. "Traffic Controls for Maintenance Operations." Public Works. November 1970.

This article summarizes some of the standards used by the Arizona Highway Department for handling traffic during maintenance operations. The Traffic Control Manual for Highway Construction and Maintenance developed by the Arizona Highway Department is discussed. It presents the basic principles and minimum standards for the design, application, installation, and maintenance of work zone traffic control devices. It indicates that work zone speeds shall be consistent with the prevailing roadway conditions within the immediate zone of activity. Despite the length of a project, speeds should be held down only in those sections where work is in progress. With respect to warning and protective devices, it details specifications concerning the materials that may be used, the minimum dimensions of warning signs, the nature and use of reflective materials and devices, and where and how specific signs, barricades, and warning lights are to be used.

The article contains four tables to be used as design aids: 1) maximum spacing of delineators at curves, 2) required distance for deceleration, 3) taper rates and lengths, and 4) space in feet between barricades or cones.

"Maintenance Traffic Control Handbook." Louisiana Department of Highways, 1973.

The important point that should be mentioned about this article is the process for control system selection that is described. The system is simple and straightforward and has possible application as a technique for field manuals. Typical operations are illustrated that are to be considered as guides.

Chipps, J. A., et al. " Traffic Controls for Construction and Maintenance Worksites: A Research Reference Report." American Public Works Association, 1976.

This report provides information that may be useful to governmental jurisdictions and other agencies in implementing uniform control and safety measures at construction and maintenance worksites. Its application is directed toward both urban and rural worksites, however, special attention is devoted to urban operations. Suggested traffic control procedures are presented for general and specific traffic conditions. The necessary traffic control devices are described. Twenty-one typical worksite layouts depicting common conditions are illustrated. Information on such areas as advance planning, public information needs, project management, training, and record keeping are covered.

The information in this report is based on a literature search, a comprehensive questionnaire sent to state and local agencies, field investigations, and use of a technical advisory committee. The report contains a traffic control manual listing and it provides details for categorizing worksites.

(Authors)

Franklin, J. D., et al. " Traffic Controls for Construction and Maintenance Work Zones, Vol. I - Office Function." American Public Works Association. May 1977.

The material contained in this report is intended to aid local agencies in developing traffic control plans for work zones. The authors provide helpful hints in the following areas:

- 1) Public Information.
- 2) Regulatory Controls and Responsibilities.
- 3) Administration.
- 4) General Traffic Control Principles.
- 5) Special Traffic Provisions.
- 6) Protection of Pedestrians.
- 7) Flagging.
- 8) Speed, Turning and Parking Controls.
- 9) Separation of the Worksite from Traffic.
- 10) Maintenance of Traffic Controls.
- 11) Temporary Pavement Markings.
- 12) Construction Signing and Special Control Devices.
- 13) Temporary Traffic Signals.
- 14) Nighttime Procedures.
- 15) Inspection.
- 16) Utilization of Law Enforcement Personnel.

Franklin, J. D., Doyle, R. R., Kuykendall, C. R., and Chipps, J. A. " Traffic Controls for Construction and Maintenance Work Zones, Vol. II - Field Function." American Public Works Association. May 1977.

This report is intended as a field manual for use by job site supervisors, although others may find it a handy reference document. It is intended to be used as a supplement to local, state, and national standards and regulations for traffic control at work zones. The Appendix of this report contains diagrams of various worksite setups.

TRAFFIC MANAGEMENT APPROACHES

Biggs, R. G. " Traffic Handling Around Maintenance Activities on Freeways." Texas State Department of Highways and Public Transportation. July 1975.

Methods to improve traffic handling around maintenance activities on freeways are discussed in the report. The methods are intended to reduce motorist delay and enhance the safety of motorists and workmen.

According to the author, many maintenance foremen are not fully aware of traffic handling techniques which might be employed to improve traffic flow instability caused by freeway maintenance work. These include the effective utilization of manpower, available capacity, and innovative signs. The report recommends that attempts be made to use new and creative signing. Better use of flagmen and the use of more flagmen are suggested. Flagmen should be better trained. Improved traffic operation can also be encouraged by better use of the police, retiming of traffic signals on frontage roads, and better intra-agency communication.

Forbes, C. E., Smith, J. H., and Schaefer, W. E. "Reducing Motorist Inconvenience Due to Maintenance Operations on High Volume Freeways." Transportation Research Board Special Report 153, 1975.

In this report, the authors present simplified methods for scheduling work operations and controlling work zone traffic that can be used to reduce inconvenience to motorists during maintenance work activities.

It is suggested that good estimates of both traffic volumes and capacity at work zones be computed. Inputting this information into a graphical model presented in this report will allow a maintenance foreman to determine:

(1) when work must start and end to avoid congestion, (2) what the delay to motorists will be if congestion cannot be avoided, (3) how many vehicles will be queued, and (4) how many vehicles will be delayed during the lane closure. By knowing the number of vehicles queued, the expected queue length can be estimated, thus permitting better placement of warning devices.

The authors also discuss the use of shoulders during freeway work activities. This traffic management option was used with some success in California.

Use of the shoulder can be either permissive or mandatory; however, the authors recommend against implementing mandatory use of the shoulder on a short term basis. It is difficult to do because it confuses motorists and requires them to drive on the shoulder whether they want to be there or not.

In contrast, permissive shoulder use takes advantage of the driver's natural desire to minimize his own travel time. As congestion develops, the shoulder is used more and more. If there is no congestion, the shoulder will not be used.

It is important to note that use of the shoulder is not intended to eliminate congestion, but to increase capacity. The capacity increase depends on many factors including: (1) whether the median or right shoulder is used, (2) the grade, (3) the actual layout of the shoulder lane, and (4) the familiarity of the drivers with the system.

Based on limited field studies, the authors cited several examples of capacity increases achieved by permissive use of the shoulder. On the downhill side of a worksite where trucks were not a factor, the left 2 lanes plus the median shoulder handled a maximum of 5,200 vph. For short periods, the median shoulder handled 1,300 vph. The maximum capacity of the outside shoulder was about 900 vph.

On a day when the shoulder could not be used, the 2 lanes could only handle an average flow rate of 3,500 vph.

On the uphill side, short-term flow rates for the 2 lanes plus shoulder reached 4,300 vph using the left shoulder, and about 4,000 vph using the right shoulder.

"Reconditioning High Volume Freeways in Urban Areas." NCHRP Synthesis of Highway Practice Report 25. Transportation Research Board, 1975.

This report summarizes current practices in reconditioning of high volume freeways in urban areas. It contains chapters on project planning, design considerations with a section on traffic controls, and construction

management. The Appendix includes: (1) Detroit Procedures for Handling Traffic During Freeway Rehabilitation, (2) California Procedure for Estimating Lane Closure Delays, and (3) sections on patching, precast slabs, and materials.

Initial efforts in carrying out freeway rehabilitation projects include a comprehensive public information program if the impact of the project on urban traffic patterns is to be controlled. In establishing traffic controls for rehabilitation worksites, the available alternatives include roadway closures and off-site detours, detours within the right-of-way, and lane closures or lane constrictions. Lane reversals in conjunction with median crossovers have been employed successfully by a number of agencies, but safety considerations necessitate special design features when this alternative is selected.

Richards, S. H., and Dudek, C. L. "Field Evaluation of Traffic Management Strategies for Maintenance Operations in Freeway Middle Lanes." Transportation Research Record 703, 1979.

This paper presents results of field studies conducted in Houston to evaluate two approaches for managing traffic during maintenance operations in the middle lane of an urban freeway. The two approaches are: (1) traffic shifting with the use of the shoulder and (2) traffic splitting. The results indicate that compared to the multi-lane closure strategy commonly used at middle-lane worksites (closure of an exterior lane and one or more adjacent middle lanes), both approaches significantly increased work zone capacity. The studies revealed that (1) traffic shifting could be used to manage traffic at relatively long worksites on freeways with discontinuous shoulders and (2) shoulder use at sites where this strategy was employed was greatly influenced by traffic demand. Traffic splitting around an isolated, middle-lane worksite, on the other hand, was used effectively at a relatively short worksite on a freeway section that did not have shoulders.

NIGHT WORK

Lee, D. "Night Time Construction Work on Urban Freeways." Traffic Engineering. March 1969.

According to this article, District 7 of the California Division of Highways (Los Angeles, Orange, and Ventura Counties) believes it is essential that vehicle delays resulting from construction work be held to the absolute minimum. Near the center of the metropolitan area and along heavily traveled corridors, it is impossible to close freeway lanes during the daylight hours without massive traffic jams occurring. Therefore, District 7 performs some types of work at night. The types of work completed at night are: (1) installation of raised pavement markers, (2) installation of median barriers, (3) grooving of concrete and asphalt pavement, and (4) paving additional concrete lanes.

The author suggests using a normal minimum taper length of 1,000 feet for night time freeway work. He also reports that the Traffic Department is experimenting with illuminated traffic cones to provide better night time delineation.

Several figures showing typical lane closures for night time maintenance activities are included.

Gillis, L. R., "The Feasibility of Night Maintenance and Construction," Public Works. April 1969.

The author discusses the advantages and disadvantages of night maintenance and construction activities. A graphical procedure is presented to estimate the vehicle delay depending on when a lane is closed.

The experience of one agency with respect to night work is discussed. This agency does much work during periods of low traffic density (midnight to 5 or 6 am) since it will affect the least number of users. This is, however, the most dangerous period and workmen are less efficient. Analysis of accident records reveals that although the least number of accidents occurs between 3:00 and 5:00 am, the rate is exceedingly high. This illustrates the necessity of exercising stringent safety measures during any maintenance operation involving lane closures in the early morning hours.

Maintenance operations scheduled at night should be those that do not require commercial support and can be terminated daily without affecting the work. An additional consideration is how to overcome the danger and inefficiency of working at night. If night maintenance is expanded, certain complexities would have to be resolved to maintain safety on a regular basis.

FLAGGING

"Directing Traffic Signals and Gestures." Traffic Institute, Texas Department of Public Safety, 1949.

This paper explains the signals and gestures to be used when directing traffic. According to the paper, the objective of effective traffic direction is to tell motorists how, when, and where they may move their vehicles. The information in the paper is intended to give instruction on how to make the meaning of signals and gestures clear to motorists. The two most important aspects to directing traffic are to make gestures visible from a long distance and use uniform signals and gestures.

Longenecker, J. R. "Moving Traffic Through Pavement Resurfacing Operations." Public Works. November 1966.

This article discusses guidance of traffic through pavement resurfacing operations. It explains the need for and how to use flagmen at these work zones. It recommends that at least two advance warning signs be erected upstream of a flagman. In addition, the flagman should be stationed far in advance of the actual work to give drivers a chance to react to his or her signals before entering the work area. The flagger should be visible for a distance of at least 500 feet. Proper flagging signals are reviewed in the article.

In addition to flagging, several other traffic control requirements at resurfacing job sites are discussed. The use of a pilot car and two-way radios are recommended for one-way traffic control situations.

Stevenson, J. L. "How Utah Trains Its Flagmen." Traffic Safety. July 1974.

This article reviews the work zone traffic safety program adopted by the Utah Highway Department. Much of the article is directed toward the requirements of flagging at construction and maintenance sites. The Utah

Highway Department has developed a flagman training course with an accompanying instructor's guide and examination. The course consists of a lecture session and 20-minute training film. The objective of the course is to teach prospective flagmen what to do and also, what not to do.

The article also discusses the findings of a safety committee's study of work zone signing in Utah. The committee recommended that uniform signing be used at all work zones. It also recommended that specific messages presented in a certain sequence be used.

BARRICADES, BARRIERS, AND CRASH CUSHIONS

"Temporary Concrete Barriers Guide Traffic Through 10-Mile Work Site." Rural and Urban Roads. January 1974.

Precast temporary concrete median barriers are credited with keeping motorists and construction workers safe during a massive construction and maintenance operation in Illinois. The temporary barriers were used to separate opposing traffic detoured along adjacent lanes and to fence-off workers in construction areas. The barriers were moved "leap frog" fashion as work progressed and detour locations changed.

No major accidents occurred during this project; whereas, several accidents resulting in 10 fatalities occurred during a similar project where concrete barriers were not used. Although the barriers were struck by errant vehicles occasionally they were easily patched and no severe damage occurred.

Although the initial investment is high for temporary concrete median barriers, they require minimal maintenance and have a long life expectancy.

"Barricades and Warning Devices for Highway Construction Work." National Safety News. March 1974.

The paper outlines Part VI of the Manual on Uniform Traffic Control Devices for Streets and Highways, and presents the recommended revisions by the Executive Committee of the Construction Section, National Safety Council.

"Crash Pads Protect Maintenance Trucks." Rural and Urban Roads. May 1974.

According to the paper, the Connecticut Department of Transportation has developed a rear-end crash barrier for highway maintenance trucks. It consists of 74 liquid-filled plastic tubular cells attached to the back of the vehicle. A canvas wraparound is used to hold the cells in a compact five-deep arrangement. By absorbing much of the energy of a collision, the motorists, as well as the crew members, are protected.

"Crash Cushion Trailer Protects Workers, Doubles Protection Thru Added Security." Transportation Research News, No. 54. 1974.

This article discusses the crash cushion trailer developed by the Texas Transportation Institute. The trailer was designed to protect maintenance crews from traffic.

The crash cushion trailer consists of thirty 55-gallon steel barrels, welded together at the bottom and top rims. The trailer has a single axle and two wheels, and is connected by hitch to a truck. The truck and crash cushion trailer follows the work crew lagging behind by approximately 200 feet. If struck by an errant vehicle, the barrels in the crash cushion absorb most of the vehicle's energy, protecting both the vehicle's occupants and the work crew. A five-point trailer hitch prevents the trailer from jack-knifing if struck at an angle.

According to the article, the crash cushion trailer is a practical, valuable unit which reduces the seriousness of many work zone accidents. Three potential applications for the trailer in maintenance or construction operations are cited: (1) protection of maintenance workers and motorists at detour locations, (2) protection of workers performing routine maintenance on traffic lanes or shoulders, and (3) protection during maintenance operations in traffic.

The article also states that worker productivity can be greatly increased, even doubled, by using the crash cushion trailer. The productivity results from increased security and less time spent avoiding traffic.

Lisle, N. "Evaluation of Timber Barricades and Precast Concrete Traffic Barriers for Use in Highway Construction Areas." Transportation Research Record 693, 1978.

This paper summarizes the results of a study of the performance of the timber barricade and a comparison of its characteristics and performance with those of the precast concrete traffic barrier. The study included (1) a traffic accident analysis of the construction zone on I-495 where the timber

barricade was employed; (2) a comparison of the technical, operational, and economic feasibility of the timber barricade and the precast concrete traffic barrier; and (3) a review of the legal requirements for temporary barrier systems. The frequency of accident occurrence during construction on I-495 was approximately 119 percent higher than that before construction. Of the reported crashes during construction, 52.5 percent involved vehicle contact with the timber barricades. Of the vehicles involved in crashes with the barricades, 73.5 percent straddled or penetrated the barricades. Thus, on the I-495 site, the timber barricades were ineffective as positive barriers. From the technical, operational, and economic analyses, the precast concrete traffic barrier appeared to be superior to the timber barricade. Since the completion of this study, the Federal Highway Administration has banned the use of the timber barricade as a positive barrier on any federal or federal-aid project.

Bronstad, M. E. and Kimball, C. E. "Crash Test Evaluation of Temporary Traffic Barriers." Transportation Research Record 693, 1978.

This paper presents crash test evaluations of some temporary barriers currently being used. According to the authors, there are many traffic barriers with known capacities for containment and redirection; however, these barriers are primarily used for permanent installations. There is a need for barriers that are portable for use during highway construction. Due to this unique requirement of portability, however, these barriers must accomplish their function without benefit of foundation restraint.

Three types of temporary barriers were evaluated and the evaluation results follow:

- 1) 10 x 10 Timber Barrier - Minimal redirection capacity. Upper rail members are not functional and exhibit a potential for "spearing". Lower 10 x 10 inch base is readily mounted by vehicles at normal speeds and angles. Use of this barrier for containment or redirection is not recommended. The 10 x 10 inch base with upper railings removed could be used for very low speed operations where speeds and impact angles are low, and the traffic stream consists of cars only.

- 2) W-Beam/Barrel - An effective containment barrier for impacts characterized by a 4,500 pound vehicle impacting at 45 mph and an angle of 15 degrees.
- 3) Type X Curb - Ineffective in redirecting vehicles. Curb is readily mounted and, even at angles of 8 degrees it does not appear capable of redirecting a 4,500 pound vehicle impacting at 35 mph. Snagging is a problem in that it causes severe damage to both vehicle and barrier segments. In addition, the splice plate cannot be considered a "repeatable" means of decelerating a vehicle due to the intermittent spacing of the splices.

Ross, H. E., Jr., et al. "Use and Delineation of Traffic Barriers in Work Zones -- State of the Art and Current Practice." Interim Report. Texas Transportation Institute. Contract DOT-FH-11-9688. March 1980.

This report presents a review of the state of the art and current practices in the use and delineation of positive traffic barriers in work zones. The review is subdivided into five categories or subject areas: (1) accident data, (2) selection and use of traffic barriers, (3) delineation of barriers, (4) field inspections, and (5) research activities.

SIGNS

Brown, T. J. "Plastic Warning Devices Improve Road Safety." American City. June 1970.

This article reports that the Public Utility Department and the Streets and Bridge Division of Saginaw, Michigan use plastic warning devices at many of their worksites. In common use are plastic A-frame signs, telescoping standards, and breakaway cones. These plastic devices are extremely lightweight and portable, and for this reason, work crews tend to use them rather than allowing them to remain in the truck. In addition, because of their light weight, they cause little or no damage to vehicles when impacted; however, they are durable enough to be reused after even the most severe collision.

"Five-Deep Signs Protect Repair Crew." Rural and Urban Roads. April 1972.

This article discusses workcrew protection methods used by Washtenaw County, Michigan maintenance crews. A series of five warning signs are installed at each maintenance worksite, beginning one mile upstream of the site. Just downstream of the last warning sign (approximately 200 feet from the worksite), a large flashing arrowboard is used. The signs and arrowboard can be installed and removed quickly and are easily carried in a truckbed.

The article also reports that the county maintenance crews prefer to use a STOP-SLOW paddle rather than orange flags for directing work zone traffic.

Seymour, W. M. "Traffic Controls for Maintenance on High Speed Highways." Research Report 327. Kentucky Department of Highways, 1972.

This report compares the effectiveness of orange and yellow warning signs used at construction and maintenance sites. Driver reaction to old versus new signs is also addressed.

According to the report, orange signs are more effective than yellow signs in reducing traffic conflicts and merges near a lane closure. New signs of either color improve driver obedience over old signs. This finding indicates that work zone signs should be maintained in a "like-new" condition.

Driver disrespect for lane closure signs compound and confound the total problem of effective signing. The report indicates that the use of more daring and innovative signs may be the solution to the problem.

Owen, H. Q. "Vehicle-Mounted Traffic Safety Sign." Better Roads. September 1973.

This paper discusses a new traffic safety sign used by the Department of Public Safety of St. Paul and Minneapolis, Minnesota. The sign, the Varicom Mobile Traffic Control System, is mounted on the top of police patrol cars. When in the down position, the sign extends up to 6 1/2 inches. In the up position, it extends up to 52 inches. The message window of the sign measures 30 x 40 inches and any one of eight messages may be displayed in the window. They are: MERGE (with arrow pointing right or left), DIVIDE (with arrows), SLOW TO 30 MPH, STAY IN LANE, ACCIDENT AHEAD, ALL LANES STOP, or CLOSED. The sign itself is visible for at least 1,000 feet. The messages are legible from 600 feet, day or night.

Studies have revealed that use of the sign has almost eliminated the occurrence of secondary accidents; officer efficiency has been increased by 72 percent.

Shah, S. C., and Ray, G. L. "Advance Traffic Control Warning Systems for Maintenance Operations." Louisiana Department of Highways. 1976. (Also published in Transportation Research Record 647, 1977).

This report discusses a study made to determine the effects of sign size, height of installation, and legend on driver response as measured by speed, conflict, and queueing parameters. The performance of electronically

actuated, directional flashing signs are also discussed. The study was conducted in Louisiana at four worksites where a single lane was closed for repairs.

The following findings are presented:

- 1) At rural 2-lane locations, 30-inch signs produced a greater speed reduction than either the 36-inch or the 48-inch signs.
- 2) At Interstate locations, the use of 36-inch signs yielded better overall response than the use of 30-inch signs.
- 3) Sign installation height and sign legend were not a significant factor in driver response.
- 4) Sequencing accumulative bidirectional chevrons greatly enhanced driver obedience to warning signs.

TAPERS AND CHANNELIZING DEVICES

Graham, J. L., Harwood, D. W., and Sharp, M. C. "Effects of Taper Length on Traffic Operations in Construction Zones." Transportation Research Record 703, 1979.

In this report, a study to evaluate the performance of standard and proposed new taper lengths for work zone lane closures is documented. At design speeds below 60 mph, the proposed taper lengths being evaluated are shorter than standard lengths as computed by the formula $L = WS$. A direct comparison of traffic operations using both the standard and proposed taper lengths is presented for four work zones. Speed, erratic maneuvers, traffic conflicts, and lane encroachment data were collected at each site.

Analyses of the data revealed that use of the proposed taper lengths is not any more hazardous than using standard taper lengths. Also, use of the proposed lengths did not produce a greater number of erratic maneuvers and slow-moving vehicle conflicts. There was no indication that the proposed taper lengths resulted in a greater number of passenger vehicle or truck encroachments on adjacent lanes.

Based on the results of this field evaluation, the proposed new taper lengths have been recommended for inclusion in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD). The taper formula $L = \frac{WS^2}{60}$ would be used to compute taper length on urban, residential, and other streets where the posted speeds are 40 mph or less. The standard taper length formula ($L=WS$) would be used on roadways having a posted speed of 45 mph or greater. Sections 3B-8, 3B-13, 6C-2 of the MUTCD would be revised accordingly.

Pain, R. F. and Knapp, B. G. "Experimental Evaluation of Markings for Barricades and Channelizing Devices." Transportation Research Record 703, 1979.

This paper reviews a series of laboratory studies conducted to determine the optimum design characteristics of work zone channelizing devices. The following design characteristics were studied: (1) the design and configuration of stripes, (2) the width of stripes, (3) the color ratio of stripes,

(4) the meaning of various design configurations, and (5) the detectability of visible areas.

Based on the results of the studies, the following limited recommendations are presented in the paper: (1) optimal stripe width is 6 or 8 inches for rails 6 inches or greater in width, (2) the white-to-orange color ratio should be equal or favor white, (3) vertical and then horizontal stripe design configurations are favored, (4) chevrons connote directional meaning to drivers, (5) vertical panels elicit better performance than horizontal bars or trapezoid shapes,, (6) a tall, narrow vertical panel image is recommended over shorter, wider images.

Detectability of lines, angles, and edges does not increase linearly as these geometric forms increase in size. Detectability is influenced more by the interaction between combinations of lines, angle and edges with each other and with the display background.

Cottrell, B. H., Jr. "Evaluation of Chevron Patterns for Use on Traffic Control Devices in Street and Highway Work Zones." Virginia Highway and Transportation Research Council. Report No. FHWA/VA-80/32. February 1980.

The chevron pattern consists of alternate orange and white stripes that form an arrow pointing in the direction in which traffic is being diverted. The objectives of this research were to (1) select the most effective design for the chevron pattern, and (2) evaluate the effectiveness of selected chevron designs under road conditions as compared to presently used designs.

The most effective chevron patterns were selected by a subjective rating of groups of patterns used on channelizing devices. In general, the selected chevron designs were preferred over the presently used patterns. A black stripe separating the orange and white stripes proved effective in reducing haloation.

The measure of performance used in the field tests was the position of lane changing relative to the transition taper. It was found that driver response was not strongly dependent on the channelizing device employed in the taper. The subjective evaluation revealed the chevron patterns to be preferred over the presently used patterns because of their clear directional message.

VISIBILITY REQUIREMENTS

McGee, H. W. and Knapp, B. G. "Visibility Requirements of Work Zone Traffic Control Devices." BioTechnology, Inc. Report No. FHWA-RD-78-143. July 1978.

This report documents a study made to develop performance standards for the detection and recognition of retro-reflective traffic control devices used in work zones.

The performance standards developed in this study are based on the theory of driver information needs and specifically, the requirement for decision sight distance. The standards are presented in terms of visibility requirements, that is, the distance at which motorists should be able to detect and recognize the device at night.

The scope of the study was limited to an analytical exercise, drawing on existing information and data where possible. The discussion focuses primarily on those channelization devices frequently used in work zones, (i.e., drums, barricades, and panels).

The results indicated that the barricade, panel, drum, or cone should be installed and maintained so as to be visible at night under normal atmospheric conditions from a minimum distance of 900 feet when illuminated by the low beams of standard automobile headlights. Included in the report is a recommended program of research which would validate the findings of this study and address several issues related to reflectivity and driver visibility needs.

ARROWBOARDS

McAllister, J. J. and Kramer, D. L. "Advance Warning Arrow Sign Study." State of California, Department of Transportation, 1974.

This report documents a study conducted to determine the effect arrowboards have on approaching traffic. In particular, the effectiveness of arrowboards as a warning device at maintenance worksites was investigated.

As part of the study, 13 arrowboard designs were evaluated at a "mock" expressway work zone. The performance of each arrowboard was determined based on lane occupancy data collected before and during arrowboard operation.

The following conclusions were reached:

- 1) Sign effectiveness was directly related to sign size. During the day, the larger arrowboards performed better. At night the of light intensity and lense spacing of the arrowboards are critical to performance.
- 2) A high light intensity appears to be desirable during daylight; the opposite may be true at night.
- 3) Sequencing patterns are more influential during the day; blinking patterns are better at night.
- 4) There was a wide variation in the distances at which different arrowboards influenced lane occupancy. However, those signs which influenced traffic earliest had the largest overall effect.
- 5) The arrowboards had a significant effect on traffic in the lane adjacent to the arrowboard; however, traffic in other lanes was not significantly effected.
- 6) Operation of the arrowboards reduced vehicle speeds up to 5 mph.
- 7) Sequencing operational modes with no "black-out" interval may give the impression at long viewing distances of movement to the direction opposite that intended.

"Effect of Arrow Board Trucks and Merging Traffic." Illinois Department of Transportation, Bureau of Traffic. January 1976.

This report describes the effect of arrow board trucks on merging traffic to a construction site. The purpose of the construction was the repair of a 4-lane bridge. It was decided that arrow board trucks could be considered effective if they would cause vehicular traffic to move into the appropriate lane farther in advance of the merge point than without the arrow board trucks. Recording traffic counters were used to obtain necessary data. The results showed that the arrow board trucks had a very favorable effect on merging characteristics.

Graham, J. L., Migletz, D. J., and Glennon, J. C. "Guidelines for the Application of Arrowboards in Work Zones." Midwest Research Institute. Report No. FHWA-RD-79-58. December 1978.

This report documents a study conducted to develop objective criteria for the use and placement of arrowboards in work zones. The research was conducted in three phases. In the first phase all available literature on work zone traffic control was reviewed. Human factors investigations were conducted in the second phase to determine driver information requirements, expectancy, and understanding of arrowboards. The third phase of the research was an intensive field study of driver responses to arrowboards in actual work zones.

The research determined that arrowboards are effective at lane closures in work zones because they promote earlier merging into the open lane(s) and fewer vehicles remain in the closed lane at the start of the lane closure taper. Furthermore, arrowboards are more effective when placed on the shoulder of the roadway near the start of the lane closure taper. Arrowboards were not found to be generally effective in traffic diversion applications or splits or for moving operations on the shoulder. They did, however, prove effective in reducing some specific operational problems in these types of work zones.

Knapp, B. G., and Pain, R. F. "Human Factors Considerations in Arrowboard Design and Operation." Transportation Research Record 703. 1979.

This paper addresses three questions: (1) does a flashing arrowboard have more than one inherent meaning to the driver, according to the display configuration? (2) can certain design characteristics of arrowboards be optimized to convey the desired message? and (3) will certain operational characteristics of arrowboards optimize the communication of the display message? The paper documents human factors studies conducted to answer these questions.

Results of the studies indicate that the arrowboard is strongly associated with lane closure. Also, the use of an on-off blinking arrow is favored over the sequencing chevrons or sequencing arrow stem followed by the stem plus head. Arrowboard design and operation can be manipulated and optimized as long as drivers can perceive a discrete, clear directional arrow as an indication of lane closure. Using arrowboards for traffic management purposes other than lane closures leaves drivers uncertain as to exactly what their behavior should be.

The following recommendations are made: (1) the preferred operation of the arrowboard is in the single on-off blinking arrow mode, (2) the blinking arrow should not be used as a cautionary display only, (3) 360 degree lens hoods should be used to cap dispersing light to passing drivers and to direct the flashing lights outward in a straight line, (4) dimming of arrowboard luminance could be upgraded to be more sensitive to inclement weather conditions and to begin dimming with loss of daylight, and (5) arrowboards should be placed at the beginning of the lane closure taper.

Bryden, J. E. "Effectiveness of Flashing Arrow Boards During Moving Maintenance Operations." New York State Department of Transportation. Report No. FHWA/NY/RR-79/73. October 1979.

This report discusses studies conducted on I-81 (rural), I-87 (rural), I-287 (suburban), Rte 20 (rural), and I-90 (urban) by New York State DOT to evaluate the effectiveness of flashing arrow boards during moving maintenance operations.

Board types varied among sites and ranged from 2 by 4 ft. to 3 by 6 ft. A sequential stem arrow mode was used during most of the evaluation studies.

Vehicle speed of vehicles passing the maintenance train and lane change time were used as measures of effectiveness. Lane change time was defined as the total time from the point when the approaching vehicle's front wheel crossed the lane line until it passed the observer positioned in the last maintenance vehicle.

The author concludes that speed reduction near moving maintenance operations and timing of lane changes behind them are sensitive measures of traffic performance. Average reductions of 6 to 10 mph were typically encountered passing the moving train. However, although differences in speed reduction were observed, the protection schemes used apparently had little if any effect.

The author also concludes that the time behind the maintenance train at which traffic vacated the occupied lane was affected by the protection schemes used. Although lane-change timing was affected by other factors, such as traffic density and complexity of competing visual stimuli, clear-cut differences in lane-change location were attributable to the traffic protection schemes. Although little or no improvement was provided by 2- by 4-ft. arrow boards, the 3- by 6-ft board resulted in better lane-change performance over both the no-board and small-board conditions. This appeared to be caused partly by the added target value of the large board, and partly by the stronger directional indication. The large board also effected a marked decrease in vehicles approaching very close to the maintenance train before changing lanes.

WARNING LIGHTS

"ITE Standard for Flashing and Steady-Burn Barricade Warning Lights." Traffic Engineering. August 1971.

This article presents guidelines developed by the Institute of Transportation Engineers for preparing minimum purchase-design specifications for flashing and steady-burn barricade warning lights. Sample specifications are presented for: (1) flash requirements, (2) optical requirements, (3) lens illumination, (4) reflex-reflective performance, (5) lens size, (6) lens chromaticity, (7) lens luminous transmittance, (8) head and housing requirements, (9) photoelectric controls, and (10) painting requirements.

The following table summarizing the recommended standards is presented in the article:

	Type A <u>Low Intensity</u>	Type B <u>High Intensity</u>	Type C <u>Steady Burn</u>
Lens Directional Faces	1 or 2	1	1 or 2
Flash Rate Per Minute	55-75	55-75	N.A.
On-Time	10%	8%	N.A.
Minimum Effective Intensity	4.0 candelas	35 candelas	-----
Minimum Beam Candle Power	-----	-----	2 candles
Hours of Required Operation	Dusk to Dawn	24 hrs/day	Dusk to Dawn

Lanman, M. H., III, Lum, H. S., and Lyles, R. W. " Evaluation of Techniques for Warning of Slow-Moving Vehicles Ahead." Federal Highway Administration. Report No. FHWA-RD-79-79. May 1979.

This report reviews an experiment undertaken to examine the relative effectiveness of roadside signs and vehicle markings for warning motorists of the presence of a slow-moving vehicle on the road ahead in a rural two-lane situation. In the experiment, a staged slow-moving vehicle was introduced

into the traffic stream and data were taken on the reactions of motorists who overtook it. Samples of motorists were exposed to different combinations of roadside signs, vehicle markings and types of slow moving vehicles. The principal finding of the experiment was that the use of standard four-way flashers is an effective means of reducing the hazards associated with the overtaking situation. Flasher use enhances reaction distance and speed reduction.

While the effects of the roadside signs were positive in the vicinity of the sign placement (out of sight of the slow vehicle), there were no lasting effects relative to the actual overtaking maneuver. The experiment was undertaken at the Federal Highway Administration's Maine Facility with cooperation from the Maine Department of Transportation and the University of Maine at Orono.

STRIPING AND RUMBLE STRIPS

"Routine Line Striping Gets Special Attention." Public Works. January 1968.

This article reviews the standard procedures and specifications used by the Virginia Department of Highways in pavement striping operations. Included is a discussion of specifications on: truck engine size, air compressors, spray guns, paint temperature, paint pigments, and paint delivery and storage containers.

"Penn/DOT Cuts Rumble Strips Into Pavements." Public Works. March 1973.

This report details a study conducted by the Pennsylvania Department of Transportation to evaluate the effectiveness of diamond-grooved rumble strips in improving road safety at high accident locations. The rumble strips consist of a series of transverse slots 4 inches wide and 1/2 inch deep spaced 12 inches apart. Eight sets of rumble strips are used at each location. The length of each set and the spacing between sets are varied with approach speed.

The Department is experimenting with different types of slot shapes: one with square corner edges and the other with beveled edges. The beveled edge slots seem to have several advantages. They produce a louder sound as vehicles pass over them and they are less susceptible to damage from dynamic wheel loads and icing in winter. The rumble strips have proven to be a "mechanical" success and their impact on accident rates is under study.

PAVEMENT DROP-OFFS

Stoughton, R. L., Parks, D. M., Stoker, J. R., and Nordlin, E. F. "Effect of Longitudinal Edge of Paved Surface Drop-Offs on Vehicle Stability." Transportation Research Record 703, 1979.

This report documents the results of 50 tests conducted to evaluate the effect of pavement drop-offs on vehicle stability. The tests involved professional drivers maneuvering compact and standard passenger cars and pick-up trucks off of, along, and back onto pavement drop-offs of low-to-medium heights. Two- and four-wheel drop-off tests were conducted. All tests were made at drop-offs from an existing asphalt concrete shoulder onto either compacted soil or an asphalt concrete surface.

The tests revealed that the drop-off heights evaluated had little or no effect on vehicle stability. Steering wheel angles were generally 60 degrees or less; vehicle roll angles were 10 degrees or less. A significant jolt and accompanying front-end noise were noted by the professional drivers at the larger drop-off heights; however, there were no vehicle alignment problems observed. Less than one wheel revolution was required for the first wheel to re-mount all drop-offs and there were virtually no deviations in vehicle trajectory as the vehicles re-mounted the drop-off edge. No encroachment into adjacent traffic lanes was observed during any of the tests.

In summary, the pavement drop-offs evaluated did not cause the vehicle in any of the tests to go out of control or into an unstable condition. No unusual control methods were required by the drivers in any of the tests to get the vehicle off of and back on the drop-off. It should be noted that no attempt was made to study the surprise element in driver reactions to an unexpected drop-off.

EQUIPMENT

"Nimble Maintenance Truck Designed for Expressway Use." Rural and Urban Roads. September 1974.

This article describes a special maintenance truck developed by Toronto's Department of Roads and Traffic. The truck, a 3/4 ton Ford F-350, is specially designed to assist in traffic control at worksites on high volume, high speed roadways. It is equipped with a high-performance engine for rapid acceleration into and out of "coned-off" expressway lanes. It has dual rear wheels with lug-type tires and a specially fabricated bed for carrying traffic cones. A large sequential arrowboard is mounted over the truck cab.

