

Research Report
UKTRP-88-5

REVIEW OF WORK ZONE LITERATURE

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February 1988

1. Report No. UKTRP-88-5	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Review of Work Zone Literature		5. Report Date February 1988	
		6. Performing Organization Code	
7. Author(s) J. G. Pigman and K. R. Agent		8. Performing Organization Report No. UKTRP-88-5	
9. Performing Organization Name and Address Kentucky Transportation Research Program College of Engineering University of Kentucky Lexington, Kentucky 40506-0043		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. KYHPR-86-111	
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, Kentucky 40622		13. Type of Report and Period Covered Interim	
		14. Sponsoring Agency Code	
15. Supplementary Notes Study Title: Traffic Control in Construction and Maintenance Zones (NCP Code A-1)			
16. Abstract A literature search was conducted with the objective of identifying sources of information related to safety in highway work zones. Included is an annotated bibliography of 165 references. From the references, a list of recommendations were made to improve safety in highway work zones. The recommendations were organized into the six categories listed below. 1) Flagging. 2) Delineation 3) Traffic Control Devices 4) Accidents 5) Design 6) Policy			
17. Key Words Highway Work Zones Safety Traffic Control Flagging		18. Distribution Statement Unlimited with Transportation Cabinet approval	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 70	22. Price

INTRODUCTION

A significant amount of research has been conducted in the general area of safety associated with work zones. The objective of this report was to provide a summary of this literature and to make recommendations based on the literature.

This review and summary of literature is the first phase of the study titled "Traffic Control in Construction and Maintenance Work Zones". Following this interim report will be a final report that includes a generalized analysis of work zone accidents in Kentucky and a specific analysis of case study locations. Work zone accidents for the time period 1983 through 1986 will be analyzed and summarized to determine trends on a statewide basis. Case studies representing approximately 10 sites will be analyzed from the standpoint of determining the relationship between traffic control devices used and the accident pattern. Sites selected for evaluation included different types of roads, varying road section lengths, different geometric conditions, and a range of traffic volumes. In addition, the projects were representative of different types and time lengths of construction or reconstruction activities.

An annotated bibliography of 165 references is presented in the Appendix. Following is a list of recommendations based on information found in these references. The recommendations have been organized into the following categories:

1. flagging,
2. delineation,
3. traffic control devices,
4. accidents,
5. design, and
6. policy.

RECOMMENDATIONS

Flagging

1. Require all flaggers to attend a training course before working on any construction or maintenance project.
2. Implement use of the STOP/SLOW paddle.
3. Require flaggers to wear clothing such that he/she can be distinguished from other construction workers. This could involve a specially designed vest or a uniform.
4. Where flaggers' exposure to traffic would represent an unusually high risk, consider use of portable remote-control traffic signals to replace the flagger.
5. Use law enforcement personnel to control traffic through construction zones where other measures have proven to be ineffective. When possible, make special contractual provisions for the inclusion of police officers in the traffic control plan. For maintenance activities, establish a fund for the purpose of employing off-duty policemen and their vehicles.
6. Specify the use of floodlights at the flagger station during nighttime construction activities.
7. Consider the use of temporary stop bars and freestanding, oversized STOP/SLOW paddles where flaggers are used to alternate one-way traffic.
8. Specify that the "flagger ahead" warning sign must be used in advance of the flagger whenever a flagger is used.
9. Equip the flagger with a device to allow him/her to warn workers of an approaching vehicle that did not respond to his/her signals.

Delineation

1. Maintain an approved list of construction zone pavement marking materials (foil-back tape, removable tape, and construction zone markers).
2. Where appropriate, use a modular glare screen system on top of a temporary concrete barrier to reduce headlight glare and the ability of motorists to observe work activities.
3. Consider the use of construction zone markers on high-volume, high-speed roadways (use markers in conjunction with tape where there is a high potential for accidents).
4. Consider the use of removable construction zone tape at locations where the traffic lanes must be changed and the roadway will not be repaved.

5. Develop a policy for the removal of pavement markings in work zones (specify the approved methods of removal and the amount of residue that can remain on the pavement).
6. When temporary concrete barriers are used, prism-lensed delineators should be placed on the barrier face, and the delineation should be cleaned on a regular basis.
7. When cones are used during nighttime, a 28-inch cone must be used and a reflective collar must be used.
8. During nighttime construction projects on high-speed, high-volume roadways, either Type I or Type II barricades or plastic drums should be used rather than cones.
9. Consider use of temporary lighting during nighttime operations to increase the safety of workers within the work zone.
10. Specify that high-intensity sheeting be used on all construction zone signs.
11. Provide adequate delineation of crash cushions.
12. Where appropriate, use performance specification for the retro-reflectivity of construction zone traffic control devices.
13. Specify that all construction and maintenance personnel wear the necessary clothing to increase their visibility.
14. Consider the use of "rollup" type signs to replace standard metal signs, where appropriate.

Traffic Control Devices

1. Increase the use of changeable message signs at work sites on high-speed, high-volume roadways. Utilize guidelines for when and how to use such signs and, where possible, provide for the ability to remotely control the signs to allow for the appropriate message to be displayed.
2. Use only plastic drums; discontinue the use of steel drums.
3. Use flashing arrowboards whenever appropriate. A supplemental arrowboard placed in advance of the lane closure (up to 2,500 feet in advance) should be used where sight distance is restricted. Care should be taken to prevent the misapplication of flashing arrows.
4. When a flashing arrowboard is used at night, provisions must be taken to insure that it is properly dimmed.
5. Establish guidelines for the use of portable concrete traffic barriers.
6. Emphasize the proper maintenance and inspection of traffic control devices in work zones. Where appropriate, establish an inspection schedule with proper documentation.

7. Specify the use of a heavy base cone at high-speed locations where cones are likely to be knocked or blown over.
8. Supplemental signs indicating a lane closure 5, 4, 3, and 2 miles ahead should be considered to encourage early merging at lane closures at high-volume, high-speed locations (especially at sites with limited sight distance). Changeable message signs can be used as a device to promote merging.
9. Changeable message signs should be considered for use at long-term closures when one-directional hourly volumes exceed 1,000 (or AADT exceeds 20,000).
10. Encourage the use of light-weight materials and either flexible or breakaway posts where appropriate.
11. Where advance warning is critical, signs augmented with flashing beacons or supplementary flags should be considered.
12. Emphasis should be placed on removing or covering non-applicable signs.
13. Emphasize the proper placement of traffic control devices.
14. Require that the stability of cones be considered as a factor in their use.
15. At locations where it is difficult and/or impractical to place enough signing and channelizing devices at the ideal locations within the work zone, special word-message pavement markings may be used to supplement the conventional signing and channelization.
15. Establish a review and evaluation process to annually evaluate the traffic control used on selected projects.

Accidents

1. Document all injury accidents in work zones by completing a supplemental accident report in addition to the police accident report.
2. Prepare an annual summary and analysis of work zone accidents.
3. Document and analyze all work zone accidents that have resulted in litigation.
4. Summarize work zone accidents and periodically present results to employees involved with work zone safety (design, construction and maintenance personnel).

Design

1. Eliminate the use of blunt-end guardrail. Temporary guardrail end treatments used in work zones should be installed to the same standards as permanent guardrail.

2. Provisions for the accommodation of pedestrians in the work zone should be made where appropriate (should be included as part of the traffic control plan).
3. Emphasize the proper taper length to use in work zones.
4. Document the Traffic Control Plan (TCP) to be used at any work zone. This could vary from a detailed TCP in the construction plans to noting the configuration used in the MUTCD or Traffic Control Devices Handbook.
5. At appropriate high-volume, low-speed locations, consider the use of a shoulder as a traffic lane when a lane has been closed.
6. Specify the requirement to provide adequate sight distance (based on traffic speed) in advance of a work zone (list the required sight distance as a function of traffic speed).
7. Provide area for the safe storage of materials and workers' vehicles.
8. Design construction zone detours to accommodate expected travel speeds.
9. Avoid sudden changes in either geometric standards or speed limits.
10. Provide crash cushions to protect traffic from point hazards.
11. Insure that a buffer zone is used between shadow vehicles and work areas.
12. Reduce sharp reverse curve design at median crossovers where possible.
13. Increase the taper length for nighttime lane closures on high-volume, high-speed roadways.
14. For six-lane sections, avoid lane closures when the volumes on two open lanes exceeds 1,500 vehicles per lane per hour.

Policy

1. Use a formal policy relative to pavement drop-offs with the objective of reducing traffic exposure (include the required method of warning as part of the policy).
2. Develop a plan to implement the use of truck-mounted attenuators and provide guidance for their use.
3. Utilize a formal policy relative to resurfacing and the time allowed before temporary and permanent striping must be placed.
4. Where possible, specify nighttime construction work on high-volume roadways.
5. Encourage public information of upcoming work zone activities and their anticipated effect on traffic.
6. Require any individual who will be in charge of a work zone activity to attend a work zone traffic control training course.

7. Implement selective traffic enforcement programs at work zones having high accident potential.
8. Consider the use of Highway Advisory Radio at long-term construction projects.
9. Adopt guidelines for the appropriate traffic control to use in mobile operations. The traffic control should include a shadow vehicle. The shadow vehicle should be made highly visible through the use of signs, flashing lights, rotating beacon, and an arrow panel. A truck mounted attenuator also may be used on the shadow vehicle.
10. Provide guidance for when a work zone should be classified as moving, mobile, or stationary and the appropriate traffic control to use in each instance.
11. Provide that a qualified person be designated to have primary responsibility and authority to assure that the TCP and other safety aspects of a contract are effectively administered.
12. Where appropriate, use unit pay items for traffic control on projects (include maintenance and cleaning as a pay item).
13. In special instances, large and/or heavy vehicles may have to be prohibited from traveling through the work zone. In such cases, adequate signing must be used.
14. Where appropriate, incentive and disincentive clauses should be used to accelerate the progress of projects to reduce the period of disruption to normal traffic flow.
15. Develop a handbook for work area traffic control appropriate for utilities and other agencies that perform construction by permit to give to the agency when it obtains a permit.
16. Consider the use of a work zone strategy computer analysis model (such as "Queue and User Cost Evaluation of Work Zones") where major congestion is anticipated.
17. At locations where excessive speed is a problem, consider placing radar guns in some highway department vehicles.
18. Insure that proper records are maintained documenting the traffic control measures used.
19. Consider providing hazardous pay for individuals working in certain high risk work areas.
20. On high-volume roadways, consider conducting across-the-roadway maintenance during non-peak hours.

ANNOTATED BIBLIOGRAPHY

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1. "Abbreviated Marking Patterns in Work Zones", Texas Transportation Institute, FHWA/RD-85/036, September 1985.

This report contains the results of test track studies for the evaluation of temporary pavement markings for work zones. Ten treatments were evaluated. Neither the daytime nor nighttime studies noted any differences in the performance data which would allow for ranking the treatments. Drivers generally found it difficult to follow curves having long gaps or short stripes and preferred 80-foot stripes with 32-foot gaps or the use of raised pavement markers.

2. Abrams, C. M. and Wang, J. J., "Planning and Scheduling Work Zone Traffic Control," FHWA-IP-81-6, October 1981.

Eight basic work zone types are identified as follows:

1. lane construction,
2. lane closure,
3. shared right-of-way,
4. temporary bypass,
5. intermittent closure,
6. crossover,
7. use of shoulder or median, and
8. detour.

The costs and consequences of alternative control strategies are investigated. A process for selecting work zone traffic control strategies is developed.

3. Agent, K. R. and Pigman, J. G.; "Evaluation of Construction Zone Pavement Marking Materials", University of Kentucky Transportation Research Program, Research Report UKTRP-85-24, September 1985.

The objectives of this study were to evaluate all available foil-back and removable tapes as well as construction zone raised pavement markers and to recommend materials that should be included on approved lists for use by the Kentucky Department of Highways. The tapes were placed on transverse test sections and as lane lines and the reflectivity, durability, and appearance were observed. The markers were observed at test sections as well as at construction sites.

Lists of tapes to be included on the approved lists for foil-back and removable tapes were recommended. Tapes manufactured by 3M and Flex-O-Lite were included on the list of acceptable foil-back tapes. The only recommended removable tape was the 3M removable tape. It was recommended that the Stimsonite 66 construction zone marker could be used if the adhesive is completely removed along with the marker.

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

A Federal Highway Administration program to improve safety in construction and maintenance zones is described. Five areas for improvement were stressed: 1) improvements in the MUTCD, 2) training courses, 3) research into new and innovative safety practices, 4) reviews of safety practices at actual work sites, and 4) requiring specific plans and responsibilities relating to work zone safety.

A 1977 review of construction sites noted four major deficient areas: 1) not collecting or using accident data at construction sites, 2) blunt-end guardrail and barrier rail transition hazards, 3) lack of understanding or concern by construction personnel for the motoring public, and 5) pavement dropoffs.

5. Anderson, R. W., "Safety in Highway Work Zones: A Matter of Ethics," Traffic Engineering, May 1977.

The safety problems in highway work zones are discussed and illustrated in a case study. The author suggests that new technology is not necessary to make significant improvements in work zone safety. Instead, the opinion stated is that ethical practices (moral and ethical concern) make the difference and that strong licensing laws with vigorous enforcement by a government entity can provide both ethical engineers and the public with a valuable tool to improve public safety.

6. "Assessment of Changeable Message Sign Technology", Federal Highway Administration, Report No. FHWA/RD-87/025, June 1987.

A study was conducted to determine recent operational experience with three principal types of Changeable Message Signs (CMS) used on freeways and Interstate highways in the continental United States. The three sign types examined are the light bulb matrix, rotating drum, and disc matrix. Also examined was the use of holography for presenting sign messages to motorists.

Rotating drum signs, which offer several fixed messages, were found to be very reliable and are used at sites where the same information needs are repeated daily. Lamp matrix signs offer total flexibility of message presentation and are uncomplicated, but suffer from high operating costs. Disc matrix signs are similar to lamp matrix with the disc used to form legend characters. These low power, micro-programmable signs are gradually replacing lamp matrix signs for all types of applications.

7. "Automated Signs Give Greater Control", Better Roads, March 1987.

The use of responsive, changeable message signs at each end of a 13-mile long reconstruction project by the Kansas Department of Transportation is described. The signs are remotely controlled from the highway patrol communications center. Approximate messages are composed on a computer monitor and sent by modem across telephone lines to a small laptop computer controlling each sign. It takes an average of three minutes to change a sign. The signs selected use disks that either flip to hide or expose brightly painted reflective surfaces.

8. Bates, L., "The Effect of Arrow Board Trucks on Merging Traffic," Illinois Department of Transportation, July 1974.

The study involved an evaluation of truck-mounted arrow boards used for a lane closure situation. It was found that the arrow boards promoted earlier merging of traffic.

9. Bates, L.; "State Tests Show Arrow Boards are Effective Lane Decongestion", Rural and Urban Roads, January 1976.

The use of two truck-mounted arrow boards were evaluated on a project which involved reducing a four-lane roadway to two-lanes. The results of the study showed that arrow board trucks placed near the merge point of two lanes had a profound effect in moving the vehicles from the closed lane to the through lane farther in advance of the detour than without the arrow board trucks.

10. Beason, W. L. and Ross, H. E., Jr.; "Development of a Truck-Mounted Portable Maintenance Barrier," Texas Transportation Institute, Report No. FHWA/TX-84/62+262-5, May 1984.

A truck-mounted portable maintenance barrier is described in this report. The barrier was designed to provide a reasonable degree of positive protection in short duration work zones where it is not practical to use conventional barriers. The barrier consists of a steel barrier section which is supported between two maintenance trucks. The barrier section is towed to the work zone by a crew of two men in 15 minutes or less. The barrier is highly maneuverable in the deployed configuration so it can be easily repositioned as the work progresses. Three full-scale tests were conducted to demonstrate the impact performance of the barrier. The approximate cost of the barrier system, exclusive of the cost of the trucks, is \$8,000 for a 44-foot barrier section.

11. Bender, L. E., "What Should You Do About Detours?", American City, Volume 87, No. 2, February 1972.

This paper presents guidance on how to make street construction work less aggravating and safer for the motorist and the workman. Driver warnings about 1500 feet in advance work well in most urban situations; on an express highway about two miles should suffice. The way the motorist is permitted to approach construction and maintenance work is probably the most important phase of the operation. Illumination can consist of barricade lights, overhead street lights, flood lights, signals, or sign lighting.

12. Bennett, C.; "Some Deadly Facts on Work Zone Accidents," American Transportation Builder, 1985.

While national totals for highway fatalities have leveled off in the last three years to about 44,000, work zone fatalities have shown a 44 percent increase from 489 in 1982, to 609 in 1983, and 703 in 1984. The Fatal Accident Reporting System (FARS) from NHTSA was used to summarize characteristics of fatal accidents in work zones. Most work zone fatal accidents occur at construction sites (76 percent) compared to maintenance (11 percent) or utility sites (2 percent).

13. Booker, S. C.; Ullman, G. L.; and Levine, S. Z.; "Supplemental Devices to Enhance Flagger Safety," Texas Transportation Institute, Texas A & M University, January 1987.

Temporary stop bars and freestanding, oversized STOP/SLOW sign paddles were evaluated at lane closures on two-lane, two-way highways where flaggers were used to alternate one-way traffic. Data collected to evaluate the devices included distances from the flagger at which vehicles stopped, speeds through the work zone, and approach speeds. The data showed that the temporary stop bar and oversized paddle were useful in helping drivers decide when and where to stop in front of the flagger. However, the stop bar and sign paddle had no significant effect on reducing approach speeds or speeds of vehicles directed by the flagger to proceed through the work zone.

14. Brackett, Q.; Stuart, M.; and Carnahan, J.; "Protection of Personnel in Maintenance and Construction Zones," Report 330-1F, Texas Transportation Institute, Texas A & M University, August 1984.

The objectives of the study were to devise means to make construction and maintenance personnel more visible and to develop criteria for "special use" garments for courtesy patrol personnel. The recommended safety vest was a brilliant yellow-green fluorescent/reflective material in a W-shape on a red-orange fluorescent mesh background with strap and loop ties. A uniform of light colored shirt, dark trousers, shoulder patch with department logo, and safety vests should be worn by courtesy patrol personnel.

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

Three temporary barriers which could be used in construction zones were evaluated in crash tests. The three barriers were : 1) 10 x 10 inch timber barrier, 2) W-beam-barrel barrier, and 3) type X curb. The timber barrier and type X curb had minimal redirection-containment capacity, and performance was judged to be poor. The W-beam-barrel concept performed well during a 45 mph, 15 degree angle impact; however, the system was penetrated during a 58 mph, 16 degree angle impact. 16. Bryden, J. E.; "Effectiveness of Flashing Arrow Boards During Moving Maintenance Operations," FHWA/NY/RR-79/73, New York Department of Transportation, October 1979.

Flashing arrowboards used for moving maintenance operations were evaluated. It was found that approaching traffic vacated the occupied lane much sooner when a 3-by 6-foot arrowboard was mounted on the rear maintenance vehicle.

17. Bryden, J. E. and Kenyon, W. D.; "Methods for Removal of Pavement Markings," New York State Department of Transportation, Report FHWA/NY/RR-86/130, May 1986.

Several methods were evaluated to remove existing pavement markings, including sandblasting, water- and hydroblasting, chemical removers, mechanical grinding, high temperature and excess oxygen burning, and manual pulling. Pavement markings included traffic paint, thermoplastic, epoxy, and several types of preformed markings tapes. The degree of scarring that resulted -- both color change and texture change -- related to the removal methods used, the type of marking removed, and the characteristics of the underlying pavement. In some situations, color and texture changes could not be avoided, and the installation of new markings is important to ensure that motorists are not misled by the scars resulting from the removal procedure. A summary of the effectiveness of each of the methods evaluated is provided, and suggested standards for judging the acceptability of results is discussed.

Removable detour-grade tapes were easily pulled up by hand after exposure to heavy traffic. Plastic tape would be removed only by manual pulling and scraping. Foil tapes were easily removed using the excess-oxygen burner. They could not be pulled or scraped off the pavement after exposure to traffic.

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

A computer program was developed to perform an economic analysis of the impact on the motorist created by lane closures associated with maintenance and construction. The analysis accommodates hourly distributions of traffic by direction and generates motorist costs. Included are vehicle and speed and freeway alignment; time costs by trip purpose, income level, and time loss;

and accident costs. Nomographs, derived from computer output, were developed to permit rapid determination of motorist costs for any given occupancy interval, traffic volume, and lane closure.

19. Chadda, H. S. and Brisbin, G. H.; "The Obstacle Course: Pedestrians in Highway Work Zones," Transportation Research Board Record 904, 1983.

A literature review, field visits, and interviews revealed very little formal guidelines for use of any techniques or devices for pedestrian accommodation in work zones. Guidelines for accommodating pedestrians should be developed at the federal level and preferably included in the Manual on Uniform Traffic Control Devices for proper implementation and uniform compliance. Pedestrians should be given the same rights and privileges as vehicles that pass through work zones. Pedestrian accommodation within the work zone was recommended in the following situations: 1) where sidewalks existed prior to construction, 2) where the work-zone site is located along a designated route to a school, 3) where there is evidence of pedestrian use, and 4) where the existing land use generates pedestrian traffic.

20. Chadda, H. S. and McGee, H. W.; "Pedestrian Considerations in Highway Work Zones," ITE Journal, September 1983.

Guidelines and a planning checklist are given for the accommodation of pedestrians in highway work zones. The general guidelines pertained to: the conditions for the need for pedestrian accommodation, types of pedestrian pathways, and pedestrian pathway requirements. The checklist for pedestrian planning in work zones discussed: planning considerations, information needs, pedestrian pathway considerations, intersection crossings, sidewalk closure and blockage, pedestrian protection, and inspection and maintenance.

21. Chadda, H. S.; McGee, H. W.; and Ligon, C. M.; "Pedestrian Accommodation in Highway Work Zones," Transportation Quarterly, July 1982.

Review of current traffic control and construction manuals and handbooks revealed only brief reference to pedestrian planning and safety considerations in work zones. This study provided the following observations and conclusions: 1) Pedestrians (persons not involved with the work zone activity) can be found at nearly every work zone, 2) Pedestrians should have the same right to traverse a work zone as does a vehicle, even if detouring or rerouting is required, 3) Pedestrian routes should be well marked, safe, and easy to follow, 4) In residential and commercial areas, adequate pedestrian access should be provided to properties abutting a work zone, 5) Logical, visible, and direct paths will be followed by pedestrians. Pedestrians have a basic resistance to changing grades or following a prescribed path that is

obviously circuitous to an alternate travel route, and 6) A minimum of special devices should be provided for special user groups such as the elderly and handicapped. Designs should include ramps and curb-free walkways.

To ensure pedestrian safety, guidelines for pedestrian accommodation in highway work zones should be developed at the federal level and included in the MUTCD for uniform compliance.

22. Chips, J. A.; Doyle, R. R.; Franklin, J. D.; and Kuykendall, C. R.; "Traffic Controls for Construction and Maintenance Worksites: A Research Reference Report, Volume I, Project Report", FHWA-RD-76-169.

This study 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. 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 setups depicting common conditions are illustrated. Information on such areas as advance planning, public information needs, project management, training, and record keeping are covered.

This volume details the research process followed and the resulting data. The data sources included a literature search, a comprehensive questionnaire sent to state and local agencies, field investigations, and use of a technical advisory committee. The project report also contains a traffic control manual listing and provides details for categorizing worksites.

23. "Choosing a Local Control for Variable Message Signs", Better Roads, March 1987.

The type of device used as the local control box for variable message signs is described. A method of providing entry and maintain security of the system was needed. A concern was vandals selecting messages through illegal entry. A small laptop computer was selected to provide the needed interface. The advantages and disadvantages of the selected device are presented.

24. Corney, J. F.; "Crash Testing of a Portable Energy-Absorbing System for Highway Service Vehicles," Transportation Research Board Record 833, 1981.

This study involved the testing of a portable energy-absorbing system to be attached to the rear of a highway service vehicle. The energy-absorbing components of the system are four steel pipes connected in a series and cantilevered from the rear of the service vehicle. Full-scale crash tests were conducted to evaluate the performance of the system with respect to (a)

structural adequacy, (b) impact severity, and (c) vehicle trajectory. The results of this testing program demonstrated that this energy-absorbing system provides protection during a collision for both the errant motorist and the state personnel working in the service vehicle. The unit is relatively light, inexpensive to construct and repair, and is compactly designed for use on curved and hilly roads.

25. Cottrell, B. H.; "Use of Chevron Patterns on Traffic Control Devices in Work Zones," Transportation Research Board Record 833, 1981.

The objectives were to select the most effective design for the chevron pattern and to evaluate the effectiveness of selected chevron designs under road conditions as compared with currently used designs. In a supplemental test, the effectiveness of the New Jersey concrete barrier was compared with that of the channelizing devices studied.

The results did not support a recommendation that the chevron patterns be used on all channelizing devices. It was concluded that the effectiveness of a channelizing device is not based primarily on the pattern used. The chevron patterns generally were rated slightly better or equal to the currently used patterns. A supplemental taper of channelizing devices was found effective for use with the New Jersey concrete barrier.

26. "Crew Safety in Construction Zones," Better Roads, April 1985.

Available products which can reduce risk of accidents by either warning or protecting workers are described. One warning system is called a lookout alarm system (LAD) which typically involves voice activated radio headsets. The use of truck-mounted impact attenuators (TMA) is described. A portable, remote-control traffic signal, called the FLAGMAN, has been developed to replace the flagger. A radar surveillance device had been used on the rear of maintenance vehicles to warn drivers if a person or obstacle is in his blind spot.

27. Davis, T. D.; "Construction-Zone Delineation," Transportation Research Board Record 811, 1981.

Delineation concepts were developed and tested in actual construction zones and evaluated for effects on traffic performance and driver visibility. The experiments showed the following:

1. Since 5-x 10-inch yellow retroreflective sheet reflectors did not change vehicle speed averages and variances and did not change the proportion of vehicles using the lane adjacent to the reflectors, they should be considered for use as a supplement or replacement for steady-burn lights on construction-zone barrier curbs.

2. Although tall vertical panels have many advantages over type 3 barricades and did decrease lane encroachments at night, they did not change mean speeds or speed variances.
3. Since raised pavement markers decreased lane changes and encroachments, they should be considered for use as a paint supplement.
4. Since removable tape was easy to install and remove and performed well, it should be considered for use as a paint replacement where paint removal would not be feasible.
5. Since raised ceramic markers decreased lane changes, night lane encroachments, and night brake applications, they should be considered for use as a paint replacement where strong, yet removable, delineation is needed.

It was also recommended that a low-priced, temporary marker should be developed for use in construction zones. Also, a faster, less labor-intensive method of marker installation is needed.

28. Davis, T. D.; "Evaluation of Temporary Day-Night Visible Raised Pavement Marker Adequacy," Transportation Research Board Record 1086.

This study evaluated temporary markers to locate one that would withstand construction-zone traffic. After initial screening, six marker types were tested further for visibility and durability. The features that met the criteria for an adequate day-night visible temporary marker installed with butyl on primer are a stream-lined profile, a microscope cube-corner, sealed prismatic air cell, cube-corner reflex, or multiple-glass lens reflector, and a balance between the reflector area and casing area exposed to the driver. Two marker systems met these requirements: a) a hollow acrylic marker with a sealed prismatic air cell reflector such as the Stimsonite 66B by the Amerace Corporation; and b) a combination of a domed-shaped polyester marker such as the Titan TM-40 by the Traffic Safety Supply Company for day visibility, and a filled ABS shell marker with a cube-corner reflex reflector such as the Ray-o-Lite by I.T.L. Industries, Inc., or equivalent for night visibility.

29. Denny, R. W. and Levine, S. Z.; "Developing a Scheduling Tool for Work Zones on Houston Freeways," Transportation Research Board Record 979, 1983.

The concept of active traffic management in work zones is presented. Active traffic management includes closing or opening entrance ramps, ramp-metering, public information systems such as changeable message signs and radio reports, opening or closing the shoulder, and adjusting traffic signal

timing on the alternative route. The need for active traffic management can be evaluated using a work-zone strategy computer analysis model called Queue and User Cost Evaluation of Work Zones (QUEWZ).

30. Donaldson, G.; "Are Highway Signs Bright Enough?," American Transportation Builder, 1985.

The question of how bright a reflective sign should appear to a motorist driving at night is addressed. The need for retroreflectivity performance standards for signs is given.

31. Dowden, H. E.; "Evaluation of Delineation System for Temporary Traffic Barriers in Work Zone", Iowa Department of Transportation, December 1985.

Temporary traffic barriers in the work zone without some form of delineation tend to blend with the pavement and work surroundings. Various apparatuses and devices were evaluated to increase the target value of the barrier wall surface or the barrier alignment. Six different systems were evaluated. The systems were evaluated both day and night considering effectiveness under various lighting and roadway conditions. Other considerations were inconvenience to construction activity, system maintenance, and overall cost.

The systems included:

1. wide-angle highway reflectors on 10-foot centers (Astro-Optics),
2. an 8-inch x 24-inch hazard marker of construction grade orange and white sheeting at 100-foot intervals,
3. the hazard marker at 150-foot intervals,
4. 12-inch wide continuous strip of reflective paint or tape,
5. a 6-inch x 12-inch reflective cylinder at 100-foot intervals on top of the barrier, and
6. the Safe-T-Spin delineator.

For daytime delineation, the 12-inch band of centerline tape was the most dramatic, but the cost was considered too high to be cost effective. The second most effective delineation for daytime would be any of the systems that were mounted on the top of the barrier rail. The spacing should be reduced to approximately 50 feet and their mounting height kept as low as possible to the barrier rail. For nighttime delineation, the best system was the Astro Optics reflector attached to the side of the barrier rail. The second most effective delineation system during nighttime reviews seemed to be the 6-inch x 12-inch cylinders at 50-foot spacing.

32. Dudash, R. E. and Bullen, A.; "Single-Lane Capacity of Urban Freeway During Reconstruction," Transportation Research Board Record 905, 1983.

The single lane capacity of an urban freeway while under various reconstruction configurations was studied. It was noted that single-lane traffic flow through a construction zone is significantly less than single-lane traffic flow as part of a multilane flow under normal conditions. Single-lane flow alongside an opposing traffic stream has a somewhat lower capacity than single-lane flow with no opposing traffic stream.

33. Dudek, C. L.; "Portable Changeable Message Signs at Work Zones," Texas Transportation Institute, Report 292-4, July 1984.

This report contains several guidelines concerning the use and operation of changeable message signs at highway construction and maintenance work zones. Operational, design, and message considerations are summarized. The report is intended as a quick reference for individuals responsible for the installation and operation of changeable message signs at work zones.

34. Dudek, C. L.; Huchingson, R. D.; and Creasey, F. T.; "Temporary Pavement Markings for Work Zones," Texas Transportation Institute, December 1986.

The objective of the research was to compare the safety and operational effectiveness of one-foot, two-foot, and four-foot markings on 40-foot centers. Field studies included: 1) vehicle speeds, 2) lateral distance from the centerline, 3) lane straddling, and 4) erratic maneuvers. In-vehicle studies were conducted by paid driver subjects. The results do not support the proposed requirement by the Federal Highway Administration that a minimum pattern of four-foot stripes on 40-foot centers should be used because the one-foot and two-foot stripes performed as well.

35. Dudek, C. L. and Richards, S. H.; "Evaluation of Traffic Control Plans at Reconstruction Sites", Texas Transportation Institute, Texas A & M University, Research Report 321-3F, January 1986.

The primary objectives of the study were to:

1. identify innovative traffic management approaches being used at work zones in Texas,
2. evaluate the effectiveness of some aspects of Traffic Control Plans (TCPs) and develop recommendations and guidelines for developing and implementing effective TCPs at reconstruction projects,

3. identify improved ways of transferring new information on traffic management techniques to Resident Engineers in Texas,

4. determine a more effective means of developing and implementing traffic management strategies for planned and emergency work zones.

Information for the first 3 objectives was obtained by a series of visits at several work zone sites in Texas, interviews with numerous district personnel, review of several TCPs for worksites in Texas and several field studies. For the fourth objective, a Special Traffic Handling Crew was organized in one district and work zone traffic management strategies were developed and implemented.

A catalog of several traffic control strategies and devices appropriate for freeway work zones is presented along with current district practices regarding TCPs, district problems in preparing TCPs and possible solutions, and recommendations for improved procedures, methods and guidelines for preparing TCPs. The results of field studies conducted at 3 major reconstruction projects in Texas are given, and the development of a Special Traffic Handling Crew in one district is discussed.

36. Dudek, C. L.; Huchingson, R. D. and Wood, D. L.; "Evaluation of Temporary Pavement Marking Patterns on Work Zones: Proving-Ground Studies," Transportation Research Record 1086, 1986.

Results of proving-ground studies for evaluation of temporary pavement markings for work zones are summarized. The objective was to investigate 10 candidate temporary marking treatments: one base treatment consisted of 4-foot stripes with 36-foot gaps, and nine other candidate marking treatments employed variations in stripe length, gap length, and reflective and nonreflective raised pavement markers (RPMs). The initial studies were conducted during dry-weather, daytime conditions. Based on the findings of the daytime studies, the base treatment and the best six of the nine other marking treatments were evaluated during nighttime, dry-weather conditions employing the same procedures and experimental design. The studies were conducted on the test track at the Texas A & M Research and Extension Center, with a demographically balanced sample of drivers individually driving an instrumented test vehicle. Measures of effectiveness included speed and distance data, erratic maneuver data, and subjective evaluations of treatment effectiveness. The nighttime studies aimed to determine whether the daytime findings were applicable to dry-weather, nighttime driving conditions. The approach was to essentially replicate the daytime study procedures with a matched, but different sample of drivers. The six markings selected were three with striping patterns and three RMP configurations. Daytime treatments deleted were those with 1- and 2-foot stripes, long (48- and 38-foot) gaps, or both.

37. Dudek, C. L. and Richards, S. H.; "Traffic Capacity Through Urban Freeway Work Zones in Texas," Transportation Research Board, Record 869, 1982.

Findings of capacity studies conducted at urban freeway maintenance and construction work zones in Houston and Dallas are summarized. Studies were conducted on five-, four-, and three-lane freeway sections. The results indicate that the per-lane capacities are affected by the number of lanes open during the roadwork. For example, the average capacity on a three-lane section with two lanes open was 1,500 vehicles per hour per lane (vphpl), whereas the average capacity with one lane open was only 1,130 vphpl. Also illustrated is how the data may be used to estimate the effects of the lane closure. The results of the study may be used in scheduling work that involves closures on freeways.

38. Dudek, C. L.; Richards, S. H.; and Buffington, J. L.; "Improvements and New Concepts for Traffic Control in Work Zones, Vol 1 -- Effects of Traffic Control on Four-Lane Divided Highways," Texas Transportation Institute, December 1983.

Nine case field studies were conducted on four-lane divided highways in Texas and Oklahoma to evaluate two alternative traffic control approaches: single-lane closure in one direction vs. a crossover with two-lane, two way traffic operations (TLTWO). The following variables were studied: 1) worker productivity, 2) job duration, 3) construction costs, 4) traffic control device costs, 5) highway user costs, 6) accidents, 7) conflicts, and 8) capacity.

Worker productivity was measured indirectly from job duration and construction costs. Because of limited data, it was not possible to identify the conditions under which one traffic control alternative offers costs savings over the other.

Highway user costs for each study site were calculated using a modified version of a work zone queue and user costs evaluation model. Graphs and tables are presented which show the relationships between hourly traffic volumes and road user costs for the sites studied.

39. Dudek, C. L.; Richards, S. H.; and Wunderlich, R. C.; "Handling Traffic in Work Zones", Texas Transportation Institute, Texas A & M University, Research Report 292-6F, August 1984.

The research focused on numerous topic areas relating to work zone traffic control and safety. Specific details of the research are presented in several Interim Reports and Technical Memorandums and this report is a consolidation of results. The following chapters are presented:

1. speed control in work zones,
2. implementation of work zone speed control measures,
3. changeable message signs,

4. law enforcement personnel,
5. innovative advance warning sign for lane closures,
6. operational guidelines for short-term total freeway closures,
7. traffic capacity through work zones,
8. road user costs associated with work zone lane closures,
9. model to calculate road user costs at work zones, and
10. selecting channelizing devices using value engineering.

40. Eck, R. W. and Malaeb, H. H.; "Reducing Tort Liability on Low-Volume Roads Through Analysis of Case Law," Transportation Research Board, Record 898, 1983.

The study involved an analysis of published legal cases to try to identify common types of low-volume-road safety problems and where they are most likely to exist. Such information could be used to provide highway engineers and administrators with guidelines to use in their decision making relative to low-volume road design and operation. Holes in roadways and bridges and impassable roads were the leading causes of claims on low-volume roads. A disproportionate number of claims involved construction signing which led to the conclusion that additional attention was warranted to the traffic-control plans for construction activities on low-volume roads.

41. Estep, A. C.; "California's Safety Efforts - Past and Present," ITE Journal, April 1979.

A two-day training program titled "Safety Through Construction and Maintenance Zones" which was presented throughout California was described. The two-day training session was to be presented 140 times to an estimated 4,000 employees of state, city, county, contractor, and public utility companies who have a role in providing for the safety of motorists and workmen at work sites. The two-day program was a modification of a three-day course developed by the National Highway Institute of FHWA.

42. Faulkner, M. and Dudek, C. L.; "Flashing Arrowboards in Advance of Freeway Work Zones," Transportation Research Board Record 864, 1982.

The results of controlled field studies to evaluate the effectiveness of flashing arrowboards located in advance of lane-closure work zones was reported. The distance in advance of the work zone ranged from 450 to 4,000 feet. The effects of the supplemental arrowboard were compared with the effects of arrowboards placed in the closure at the end of the taper in each blocked lane. The results indicate that a supplemental arrowboard placed in advance of the beginning of a taper can be effective in shifting traffic from the closed lane if the sight distance to the arrowboard improves the effective sight distance to the work zone. The supplemental arrowboard can be placed up to 2,500 feet in advance of the taper to increase the effective sight distance to the work zone. Placement more than 2,500 feet in advance of the work zone may result in drivers moving back into the blocked lanes.

43. Faulkner, M. and Dudek, C. L.; "Field Evaluation of Moving Maintenance Operations on Texas Urban Freeways," Transportation Research Board Record 864, 1982.

Problem areas identified during the observation of moving maintenance operations were discussed. The operations included striping and the installation of raised pavement markers. Problems related to freeway design occurred at entrance and exit ramps and major interchanges or resulted from horizontal and vertical curvature. Operational problems included the improper use of arrowboards, the lack of uniform procedures for freeway entry and exit, large spacings between caravan vehicles, and unnecessary lane blockage by the caravan. Recommended solutions included improved communications, effective advance signing, ramp control, caravan positioning procedures, caravan length control, specialized interchange signing, and training.

44. Faulkner, M. and Richards, S. H.; "Field Evaluation of Highway Advisory Radio for Traffic Management in Work Zones," Transportation Research Board Record 833, 1981.

Highway Advisory Radio (HAR) was used for traffic management on a work zone on a rural interstate. Studies found that the HAR had little effect on traffic operations because: 1) the conventional signing in the work zone was excellent and the HAR functioned only as a supplemental source of information and 2) the advance signing used to encourage motorists to tune to the HAR broadcasts was inadequate. The HAR hardware performed adequately, and the conclusion was that HAR may have good potential for traffic management in work zones for certain applications.

45. Flowers, R. J. and Cook, J. M.; "Accident Severity in Construction Zones," Texas Transportation Institute, March 1981.

An analysis of 1978 accident data indicated that construction zone accidents tended to be more severe than non-construction zone accidents. The odds for an injury plus fatality accident were 5.1 percent greater for construction zones.

46. Forbes, C. E.; Smith, J. H.; and Schaefer, W. E.; "Reducing Motorist Inconvenience Due to Maintenance Operations on High-Volume Freeways," Highway Research Board Special Report 116, 1971.

Scheduling operations during off-peak hours, closing on-ramps, and using shoulders as a traffic lane were used successfully to reduce congestion and delay on a work project.

47. Fortunicwicz, J. S.; Bryden, J. E.; and Phillips, R. G.; "Crash Tests of Portable Concrete Median Barrier for Maintenance Zones," Transportation Research Board Record 942, 1983.

An 8-foot version of New York's standard 20-foot portable barrier was evaluated through full-scale crash tests. Performance of the 8-foot barrier was found to be comparable to the 20-foot barrier.

48. Franklin, J. D.; Doyle, R. R.; Kuykendall, C. R.; and Chipps, J. A.; "Field Function - Traffic Controls for Construction and Maintenance Work Zones," FHWA-TS-77-203, May 1977.

This report is intended primarily for use by job site supervisors. It addresses the more common situations, problems, and solutions encountered in the field. Descriptions of various traffic control devices used in work zones are given. Field supervisors daily checklists are given along with examples of typical worksite setups.

49. Franklin, J. D.; Sullivan, R. H.; Doyle, R. R.; Chipps, J. A.; Bowman, M.; Kuykendall, C. R.; and Krier, A.; "Office Function - Traffic Controls for Construction and Maintenance Work Zones," FHWA-TS-77-204, May 1977.

This study provides information that can be used to supplement local, state, and national standards. The objective is to illustrate many of the typical worksites describing the most common conditions encountered. More different types of worksites are included than illustrated in the MUTCD.

50. Gardner, D. J. and Rockwell, T. H., "Two Views of Motorist Behavior in Rural Freeway Construction and Maintenance Zones: The Driver and the State Highway Patrolman," Human Factors, Vol. 25, No. 4, August 1983.

Ohio state highway patrolmen and drivers completed two separate questionnaires designed to assess problems related to driver behavior in road construction and maintenance (C&M) zones. The highway patrolmen saw driver inattention, excessive speed, and improper driver behaviors as major causes of accidents in C&M zones and stated that most problems occur in the taper area of lane closures. Patrolmen considered rear-end collisions to be the most typical accident in these zones. The driver questionnaire revealed that when making decisions about speed and lane changes in C&M zones, most drivers rely on their own judgment and cues from other vehicles rather than on signing.

51. Godthelp, H. and Riemersma, J. B. J.; "Perception of Delineation Devices in Road Work Zones During Nighttime," Society of Automotive Engineers, February 1982.

A functional description is given of delineation systems used in work zones. Based on a theoretical analysis, predictions are made about the effectiveness of particular delineation systems as a reference in perceiving direction and speed. A laboratory experiment is described in which the effectiveness of a number of delineation systems as a means of preview guidance was investigated. It was concluded that delineation mounted at eye height, such as lamps mounted on panels and barricades, function poorly in providing a reference for course perception and may have adverse effects for perception of speed, and that improvements can be made by lowering the delineation. A delineation system on the road surface itself, such as raised pavement markers, would be more effective. It was also concluded that the use of a chevron configuration on panels may be effective in conditions where panels are placed somewhat haphazardly or when only a limited number of panels is used.

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

The study dealt with a proposed taper length formula that yielded shorter tapers at design speeds below 60 mph than the existing formula. The existing formula was:

$$L = WS$$

in which L = minimum length of lane-drop taper (feet),
 W = width of offset (feet), and
 S = speed limit or 85th percentile speed (mph).

The new formula was:

$$L = WS^2/60$$

A direct comparison of traffic operation data (speeds, erratic maneuvers, traffic conflicts, and lane encroachments) were collected in the same construction zones using both the standard and proposed taper lengths. The data did not show the proposed taper lengths to be any more hazardous than the standard taper lengths.

53. Graham, J. L. and Migletz, J.; "Design Considerations for Two-Lane, Two-Way Work Zone Operations," FHWA-RD-83-112, October 1983.

This report presents the results of operational and accident studies of 36 construction sites employing either two-lane, two-way operations (TLTWO) or lane closure traffic control. A study of centerline treatments revealed that

zones with double yellow centerline only had higher accident rates and the vehicle encroachment rate into opposing lanes was much higher than for the other centerline treatments studied. Accident rates do not support a requirement for portable concrete barriers at all TLTWO zones. Lower accident rates and smoother speed transitions were found for median crossovers with a flat diagonal design compared to those with reverse curve design. Comparisons of TLTWO and lane closure sites revealed that the lane closure alternative was more cost effective than TLTWO traffic control unless substantial construction cost reduction could be realized with TLTWO.

54. Graham, J. L. and Migletz, J.; "Work Zone Accident Data Process," FHWA-IP-82-15, August 1982.

The work zone accident data process described is a data collection and processing procedure which starts at the construction and maintenance work site and transmits information through the regular communications channels to the state highway agency headquarters. The process is a supplement to regular police accident reporting and is used to provide both short range (immediate project application) feedback as well as long range summaries (statewide application). The process provides a flexible, systemized data gathering method suitable for use at either selected locations, at sites using selected traffic controls, or at all construction or maintenance sites. Sample data collection forms are included.

55. Graham, J. L.; Migletz, D. J.; and Glennon, J. C.; "Guidelines for the Application of Arrow Boards in Work Zones," FHWA-RD-79-58, December 1978.

The purpose of this study was to develop objective criteria for the use and placement of arrow boards 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 arrow boards. The third phase of the research was an intensive field study of driver responses to arrow boards in actual work zones.

The research determined that arrow boards were effective in lane closure work zones because they promoted earlier merging into the open lane and fewer vehicles remained in the closed lane at the start of the lane closure taper. The arrow board was more effective when it was placed on the shoulder of the roadway near the start of the lane closure taper. Arrow boards were not observed to be generally effective in traffic diversions or splits or for moving shoulder closures. However, they did prove effective in reducing some specific operational problems in these types of work zones.

56. Graham, J. L.; Paulsen, R. J.; and Glennon, J. C.; "Accident Analyses of Highway Construction Zones," Transportation Research Board Record 693, 1978.

Accident analyses were conducted for 79 construction projects in seven states. Results indicate an overall increase in the accident rate of 6.8 percent. Thirty-one percent of the projects experienced decreased accident rates during construction and 24 percent experienced rate increases of 50 percent or more. In two of the seven states, rates decreased during construction. The change in accidents during construction ranged from a decrease of 3.4 percent to an increase of 37.6 percent. Case study analyses of three projects having rate increases of 40 percent or more indicate that construction-related accidents were responsible for the accident rate increases.

Accident severity and the proportion of night accidents changed very little during construction activity. Projects where speed limits were reduced had higher increases in accidents than those without speed reductions. Bridge work, followed by reconstruction of existing roadway, experienced the largest percentage accident rate increases. Rates increased a similar amount during construction in urban and rural areas. The first month after construction begins is not significantly different than other months of construction and construction zones do not necessarily have better accident experiences over time. Fixed-object, rear-end, and head-on accidents increase in construction zones but right-angle, turning, and ran-off-road accidents decrease.

57. Graham, J. L.; Paulsen, R. J.; and Glennon, J. C.; "Accident and Speed Studies in Construction Zones," FHWA-RD-77-80, June 1977.

The report includes results of two studies of construction zone traffic control. An analysis of accidents in construction zones and a field testing of speed reduction methods. The following conclusions were reached:

1. The 79 construction zones that were studied experienced an average increase in accidents of about 7 percent, however, 31 percent of the projects studied experienced decreased accident rates during construction (assuming that before and during traffic volumes are equal). Twenty-four percent of the projects experienced rate increases of 50 percent or more.

2. Based on detailed analyses of three construction zones having increased accident rates during construction, the increase in accidents were highly related to the construction.

3. Short duration and short length construction projects experience higher accident rates.

4. Bridge work and roadway reconstruction are the two types of construction that experience the largest increases in accidents.

5. Some construction roadway types, such as 6- or 8-lane freeways reduced to 1-lane in each direction, experience very high increases in accidents.

6. Although the construction zone accident rate is higher for urban projects, the percent increase in accident rates is nearly equal for rural and urban projects. Accident rates for rural projects do, however, vary more than for urban projects.

7. The number of night accidents increased during construction, but the proportion of night accidents to total accidents remained the same.

8. The proportion of fatal and injury accidents in construction zones is nearly equal to the accident experience before construction, with a slight shift toward less severe accidents during construction.

9. Fatal accident rate is not related to any of the construction zone characteristics studied.

10. The presence of construction zones is most likely to increase fixed-object, rear-end, and head-on accidents, while decreasing right-angle, turning, and ran-off-road accidents.

11. The fixed-object accident rate is higher in stationary construction zones than in zones where traffic controls are moved periodically (daily, weekly, monthly).

12. Construction zones having reduced speed limits do not experience lower accident rates than other zones. Field studies indicate that speed zoning does not reduce mean vehicle speed and does increase conflicts in the transition area.

13. Enforcement patrols and lighted sequential arrow panels decrease vehicle speeds near where they are installed, but their speed reduction effect is only effective over a short length of highway.

14. Based on time-trend analyses, the initial period of construction zone traffic control is not more hazardous than later periods.

15. Drivers adjust speed and position based on the environment (geometrics of zone, lateral clearance and devices) more than on signing.

16. Basic national standards for traffic control layouts in work areas are often violated.

58. Gruves, M.; "Mixing Traffic and Construction - The New Combat Zone?", Construction Digest, March 16, 1987.

The article contains a review of problems in construction work zones. Following is a summary of some of the items discussed:

1. the need to improve the section of the MUTCD dealing with work zone safety,
2. the need for better information on work zone accidents,
3. the conclusion that line item bidding for traffic control devices in work zones is preferred over lump sum bidding,

4. the diversity between traffic control procedures used in different states,
5. the need for training for workers and public information for motorists,
6. the need to increase construction zone speed limits, and
7. enforcement of the contractor's responsibilities for project safety.

59. Hahn, K. C. and Bryden, T. E.; "Crash Tests of Construction Zone Traffic Barriers," Transportation Research Board Record 769, 1980.

A 12-inch timber curb with steel splice plates between sections and steel pins driven into the subbase was unable to redirect vehicles in minor impacts. A 16-inch high timber curb with a W-beam steel rail belted to the face was successfully tested at 47 mph and 17 degrees and 38 mph and 14 degrees. This barrier is suitable for use where moderate impacts may occur (40 mph and 15 degrees). The standard portable concrete median barrier with pin-connected joints, which contained an impacting vehicle at 55 mph and 25 degrees without any connection to the pavement except the two terminal sections, appears to be suitable for use in high-speed work zones.

60. Hanscom, F. R.; "Effectiveness of Changeable Message Displays in Advance of High-Speed Freeway Lane Closures," National Cooperative Highway Research Program Report 235, September 1981.

Changeable message signing (CMS) devices were evaluated as a means to effectively provide improved advance warning of freeway lane closures. The evaluative method was based on traffic operational measures (lane change and speed profiles approaching the closure) and driver questionnaires (detection, comprehension, and subjective ratings). Various CMS format characteristics were tested under day and night conditions applied at both right- and left-lane closures using a variety of advance placement schemes.

Before-after studies (CMS versus no-CMS conditions) consistently demonstrated beneficial traffic operational effects resulting from CMS application. Increased advance preparation lane change activity, smoother lane change profiles, and significantly fewer "late exits" were observed. Reduced average traffic speeds approaching the taper were observed at locations characterized by preexisting speeds in excess of 48 mph. All tested CMS devices were nearly equal in their effectiveness. However, an observational study, conducted in a fourth state, demonstrated that advance placement 3/4 mile from the closure produced improved results by comparison with a 2,000-foot advance placement.

Varied CMS characteristics were compared. Five evaluated message combinations were: speed and closure advisories, speed and merge advisories, merge and closure advisories, closure advisory, and speed advisory. Effectiveness differences between message conditions were not clearly discernible on the basis of lane change behavior for the total traffic sample. However, driver interviews consistently favored the speed and closure message combination. Driver ratings of traffic control device adequacy were highest during the presence of this message.

A single traffic behavioral difference was observed between various CMS display types. More preparatory lane change behavior was observed 3/4 mile in advance of the closure during the presence of a 3-line bulb matrix device. However, no lane distribution differences were observed closer to the taper between this display type and the others tested: a 2-line rotating drum and a 1-line bulb matrix device.

The study concludes that CMS application is warranted under certain conditions. Although standard traffic control device characteristics (mostly notably, a properly functioning and placed arrowboard) were seen to exert a consistently greater influence, operational improvement nevertheless resulted from CMS application. Suggested cost-efficient CMS uses are applications for (1) short-term closures characterized by decreased driver expectancy, (2) minimum traffic volume of 900 vehicles per hour, and (3) limited sight distances to the closure.

Four specific guidelines for CMS application resulted from this research:

1. Device format should permit maximum amount of information display at a glance (i.e., use 3-line presentation format with maximum of two message phases).
2. CMS devices should be located 3/4 mile in advance of closure.
3. CMS devices are to be considered supplemental in nature to currently applied standard traffic control device schemes.
4. CMS devices are not to be considered as an alternative to the arrowboard. Arrowboard placement and brightness have a considerably greater impact on operational safety than does CMS use.

61. Hanscom, F. R.; "Effectiveness of Changeable Message Signing at Freeway Construction Site Lane Closures," Transportation Research Board Record 844, 1982.

The effectiveness of changeable message signing (CMS) devices in advance of freeway construction and maintenance zone lane closures was evaluated. Before-and-after studies of baseline (no CMS) versus CMS application consistently demonstrated increased advanced preparatory lane-change activity, smoother lane-change profiles, significantly fewer late exits (within 100 feet of closure), and reduced speeds at the lane-closure point to be associated with CMS use. The most preferable CMS location was found to be 0.75 mile in advance of the lane closures. Of three tested device types (one-line bulb matrix, two-line rotating drum, and three-line bulb matrix), the large obtrusive three-line bulb matrix tended to produce more advance lane-change behavior; however, no difference in the hazardous late exit maneuvers was observed between types. All three were equally effective in eliciting speed reductions at the entrance to the lane closure. Driver interview data tended to favor the three-line device due to its greater information display capacity. Interviewed motorists favored the speed and lane-closure message combination as being the most helpful, providing most response time, and

meeting information needs. The study recommends CMS applications as a supplement to standard device schemes but not as a substitution for the arrowboard. Suggested cost-efficient CMS applications involve (a) short-term closures characterized by decreased driver expectancy, (b) traffic volumes of 900 vehicles/h or greater, and (c) limited sight distance to the closure.

62. Hargroves, B. T.; "Warrants for Barriers in Highway Work Areas," Transportation Engineering Journal of ASCE, May 1982.

A design process was developed to determine the necessity for temporary positive barrier systems in highway work zones. The methodology includes two prescreening steps to determine whether site and traffic conditions constitute a probable or significant hazard. In the third step, the expected number of hazardous vehicle encroachments into the work area is estimated based on the duration and length of the hazard, the roadside clearance and cross slope, the roadway curvature and the traffic speed and volume. The procedure draws heavily on the guidelines developed for the installation of permanent barriers and on empirical results from a number of studies.

63. Hargroves, B. T. and Martin, M. R.; "Vehicle Accidents in Highway Work Zones," FHWA-RD-80-063, December 1980.

An analysis of work zone accidents that occurred in 1977 in Virginia indicated that these accidents were slightly less severe than the average accident when compared by the percentage of property damage only accidents and the number of fatalities or injuries per accident. Also, there were more vehicles per accident in work zone accidents than in the average accident. The average number of pedestrian fatalities or injuries per accident was nearly identical for work zone and all accidents. Fifty-five percent of pedestrian accidents involved pedestrians either working, walking, or standing in the highway. Eighty percent of work zone accidents were attributed to driver error. There was an overrepresentation of work zone accidents involving slow moving vehicles and congested conditions was a contributing factor in 18.1 percent of the accidents. Some aspect of the work zone was a contributing factor in 17.2 percent of the accidents.

64. Harlow, W. A. and Matthews, D. H.; "Safety at Roadworks", Traffic Engineering and Control, Vol. 24, April 1983.

A description of traffic control devices and traffic management techniques used in work zones in England is presented. The summary of equipment included the following:

1. retroreflective materials,
2. traffic cones,
3. traffic cylinders,
4. barriers,

5. reflecting road studs, and
6. temporary white-line markings.

65. Harris, R. M.; "Liability Insurance - The Growing Problem," American Transportation Builder, 1985.

The price increases of contractor liability insurance was discussed. The problem of obtaining certain types of coverage was mentioned. It was concluded that contractors must spend more time on risk management and long-range insurance planning and should begin including future insurance costs in their work.

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

A manual developed by a state highway department is described which gives the basic principles and minimum standards in the design, application, installation, and maintenance of traffic control devices. These devices include signs, signals, barricades, cones, flags, markings, lights, flashers, and flares. Examples of tables developed to aid field engineers in locating and employing signs and barricades included the following: 1) minimum spacing of delineators at curves, 2) required distance for deceleration, 3) taper rates and lengths, and 4) space between barricades or cones.

67. Hostetter, R. S.; Crowley, K. W.; Dauber, G. W.; Pollack, C. E.; and Levine, S.; "Determination of Driver Needs in Work Zones," Federal Highway Administration, FHWA/RD-82/117, September 1982.

The objectives of the study were: (a) to determine what information drivers need to travel through work zones safely and efficiently; (b) to determine how this information can best be conveyed to the drivers' and (c) to determine where improvements to the present system of work zone traffic control are needed. The study began with an analysis of driver tasks for eight major work zone types: lane closure, shoulder closure, roadside, lane diversion, crossover, temporary detour, detour to alternate routes, and reduced lane width. From this effort, a set of information content needs was identified for each work zone type. A further analytic effort using the principles of the Positive Guidance Procedure and the concept of Decision Sight Distance, resulted in the identification of recommended information presentation locations for the various types of information.

These analytic efforts were combined into information requirements which were then evaluated for applicability by exercising each on a series of actual work zones. The requirements were modified where necessary and were then used as the basis for the development of a procedure for the derivation of work zones signing plans.

Another aspect of the project involved the evaluation of individual construction-related signs, in which each device was evaluated with respect to several criteria and problems were identified.

68. Howard, J. and Finch, D. M.; "Visual Characteristics of Flashing Roadway Hazard Warning Devices," Highway Research Board Bulletin 255, 1960.

For flashes of light that are to be above the threshold value of energy required for the detection of the presence of the light by a motor vehicle operator under normal conditions at night, an energy content of at least 0.10 candlepower-seconds of red colored light or 0.25 candlepower-seconds of amber colored light should be developed in the principal viewing directions (assumed to be within 5 degrees of the photometric axis). The flash duration need not exceed 50 milliseconds total time. The flash rate need be no faster than 60 flashes per minute for an effective signal.

It was suggested that an absolute minimum of three random flashing lights should be considered for marking any roadway hazard and that these should be grouped within a visual angle of not more than 1 degree when the driver is 500 feet to the nearest unit and when the driver is in the most critical traffic lane on the road with respect to the hazard.

69. Huchingson, R. D.; Dudek, C. L.; and Woods, D. L.; "Improvements and New Concepts for Traffic Control in Work Zones - Volume 3, Abbreviated Marking Patterns in Work Zones," Texas Transportation Institute, Report No. FHWA/RD-85-036, January 1985.

The results of test track studies of the evaluation of temporary pavement markings for work zones are given. Ten candidate temporary marking treatments were tested. Both daytime and nighttime tests failed to provide any basis for selecting among the various treatments based on speed and distance performance data. Drivers rated the 8-foot stripes with 32-foot gaps and the raised pavement marker treatments as the best.

70. Huddleston, N. D.; Richards, S. H.; and Dudek, C. L.; "Driver Understanding of Work-Zone Flagger Signals," Transportation Research Record 864, 1982.

A human-factors laboratory study was used to evaluate driver understanding of 13 work-zone flagger signals. A sign paddle, a red flag, and/or hand motions were used to perform the various signals. The study indicated that most of the signals that involved the use of a sign paddle and/or hand motion were understood by the drivers but the signals in which a flag alone was used were less effective. The MUTCD addresses only the three

basic flagging messages of stop, slow, and proceed. Consideration should be given to developing signals that convey other messages, such as a) change lanes or merge into one lane, b) turn left or right, c) maintain speed, d) detour or divert, and e) use shoulder. It was also suggested that the development of a special flagger uniform (white overalls and orange vest) may be the best means of promoting flagger visibility and respect.

71. Humphreys, J. B.; "Highway Liability - A Review of Work Zone Accident Cases," ITE Journal, April 1979.

This article reviewed a number of legal actions in which a traffic accident in a work zone resulted in a liability lawsuit against a state highway department. The increasing number of such lawsuits was noted. Specific examples of how failure to properly sign and mark a work zone resulted in an award against a state were documented.

72. Humphreys, J. B.; Maulden, H. D.; and Sullivan, T. D.; "Identification of Traffic Management Problems in Work Zones," FHWA-RD-79-4, December 1979.

The study consisted of site visits to 103 work zones and an analysis of "before" and "during" accident experiences at 30 sites. Some 618 specific problems were identified that were reduced to a list of 20, ranked using a combined hazard risk and preventability score. Some of these 20 "problems" that relate specifically to the design or operation of the work zone control plan were:

1. Unsafe speeds within work zones and ineffective attempts at speed reduction.
2. Abrupt changes in elevation at the edge of through-traffic lanes.
3. Failure to use, or hazardous application of, temporary concrete barriers.
4. Inadequate or inconsistent use of devices and methods in closing roadways and establishing lane closure tapers.
5. Traffic control system design which fails to consider roadway geometric design.
6. Inadequate, improper, and/or inconsistent use of advance warning signs.

72. "Implementation of Work Zone Traffic Control", Texas Transportation Institute, FHWA/RD-85/035, September 1985.

The areas covered include a review of policies and materials related to work zone traffic control; information on work zone traffic control reaching project engineers and foremen; problems experienced in implementing work zone traffic control; and causes of work zone traffic control not being implemented.

It was concluded that personnel training and a firm commitment to improve safety, by agencies responsible for the design and implementation of work zone traffic control, were two of the most effective means of improving the safety of the workers and the motoring public in work zones.

74. Ivey, D. L.; Mak, K. K.; Cooner, H. D.; and Marek, M. A.; "Safety in Construction Zones Where Pavement Edges and Dropoffs Exist", Texas Transportation Institute, 67th Annual Meeting, Transportation Research Board, January 1988.

This paper described the development of "Guidelines for Warning and Protective Devices for Pavement Dropoffs". Included in this development are summaries of pertinent information from the literature, new analyses of vehicle stability and the results of accident probability studies and benefit-cost studies. Three different safety related vehicle-pavement dropoff interactions were analyzed and evaluated. These are referred to as scrubbing, dragging and rolling, and are described in detail in the report. A wide range of vehicle sizes was considered in developing the guidelines, from small automobiles to large tractor semi-trailers.

The guidelines were developed for construction work where continuous pavement edges or dropoffs exist parallel and adjacent to a lane used for traffic. Guidelines recommend either the use of signing, marking, and delineation or a positive traffic barrier (concrete barrier or guard fence). The type of warning device and/or protective barrier selected depends upon several factors including traffic volume, lateral distance from the edge of the travel lane to the hazardous condition, depth of dropoff, duration of the hazardous condition, and shape of the edge or slope of the dropoff.

75. Ivey, D. L. and Robertson, R.; "Barrel/W-Section Barriers for Construction Zones," Transportation Research Board Record 796, 1981.

The history of barrel/W-section construction barriers is traced. Three crash tests conducted by Southwest Research Institute are analyzed to indicate a probable performance zone for the current barrel/W-section design. This design is the 12-gauge W-section mounted on barrels spaced at intervals of 6 feet 3 inch and filled with sand. Three new designs of barrel/W-section barriers are presented. By using a formal comparative structural analysis, the conventional design and the three new designs are analyzed and predictions are made of comparative performance. Stabilized barrel/W-section 3 is shown to perform at much more critical levels of impact than the current barrel/W-section barrier does. However, its use is applicable where large deflections can be accommodated.

76. Kelley, J. F.; "Traffic Safety in Work Zones," Public Works, Vol. 114, No. 12, December 1983.

This article discusses a program to assure compliance with the MUTCD and the traffic control plan. The program is based primarily on a regular inspection and maintenance program.

77. Kemper, W. J.; Lum, H. S.; and Tignor, S. C.; "The Safety of Narrow Lanes for Traffic Control at a Construction Site," Public Roads, March 1984.

The results of using narrow lanes as part of a traffic control plan used for reconstructing and widening five bridge decks was examined in an accident study. The accident rate increased when lane width was narrowed to nine feet but the number of injury accidents decreased due to slower speeds. Accident rates decreased when 10 and 11 foot lanes were used rather than nine foot lanes.

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

A procedure is outlined to enable field personnel to schedule lane closures at a time when they will cause the least inconvenience to traffic. If congestion develops, it will also give field personnel a tool for evaluating the extent of delay to the motorist. The procedure is based on the traffic volume, number of lanes, and type of operation. The delay estimate is based on volume per lane and length of traffic backup.

79. Knapp, B. G. and Pain, R. F.; "Human Factors Considerations in Arrow-Board Design and Operation," Transportation Research Board Record 703, 1979.

A review of literature, limited field studies, and application of human factors expertise and judgments were used. Results indicated that the arrow board is strongly associated with lane closure and that the use of an on-off blinking arrow is favored over the sequencing chevrons or sequencing arrow stem followed by the stem plus head. Recommendations were: a) the preferred operation of the arrow board is in the single on-off blinking arrow mode, b) the blinking-arrow should not be used as a cautionary display only, c) 360 degree lens heads should be used to cap dispersing light to passing drivers and to direct the flashing lights outward in a straight line perpendicular to the arrow board, d) dimming of luminance could be upgraded to be more sensitive to inclement weather conditions and to begin dimming with lesser diminution of daylight, and e) arrow boards should be placed at the beginning of the taper (construction zone).

80. Kuo, N. M. and Mounce, J. M.; "Operational and Safety Impacts on Freeway Traffic of Median High Occupancy Vehicle Lane Construction,

The results of a study to evaluate the operational and safety impacts associated with the retrofit construction of an authorized high-occupancy vehicle lane into the medians of a freeway is presented. Instead of reducing the number of through lanes available to peak period traffic, lane widths were reduced and emergency shoulders utilized. This was found to be the preferable option. Operating speeds and volumes were adversely affected. Reduced lateral clearances on the inside and outside lanes resulted in a higher percentage of trucks and total vehicles using the middle and outer freeway lanes. Traffic safety was adversely impacted during the beginning but, as time passed, drivers adjusted to the geometric restrictions.

81. Lee, C.; "Nighttime Construction Work on Urban Freeways," Traffic Engineering, March 1969.

The heavy volume of traffic on freeways led to initiation of nighttime construction. Analysis of accident records revealed fewer accidents during night construction periods than during ordinary night. Much of the success was attributed to the use of a minimum 2,000 foot taper for a lane closure rather than the normal 1,000 foot minimum. Illuminated traffic cones have been used for better nighttime delineation. The experience was that scheduling construction activities at night eliminated traffic delay and improved traffic safety.

82. Leonard, J. D. and Recker, W. W.; "A Procedure for the Assessment of Traffic Impacts During Freeway Reconstruction", University of California, Irvine, August 1986.

This report presents the results of an effort directed toward developing a consistent methodology to assess the impacts of traffic disruption due to major transportation reconstruction/rehabilitation projects during the period of implementation. In the approach taken by this research, state-of-the-art traffic simulation models are used to estimate the performance of the transportation system during various construction phases. Alternative construction and traffic redirection strategies designed to minimize both the direct and indirect losses associated with the construction/rehabilitation are then evaluated with the development of a systematic, computerized procedure designed to:

- 1) provide for the creation and comparison of multiple and "layered" reconstruction/rehabilitation scenarios;
- 2) minimize the required knowledge of both the detailed interactions with the model as well as the host computer; and
- 3) produce meaningful, comparative outputs that assist in the selection of reasonable alternatives.

The resulting modeling environment is viewed as a convenient tool to assist both the traffic engineer and the transportation planner in selection of reasonable reconstruction/rehabilitation plans and schedules.

83. Levine, S. Z. and Kabat, R. J.; "Planning and Operation of Urban Highway Work Zones," Transportation Research Board Record 979, 1983.

The three problems encountered in the planning and operation of urban work zone activities were identified as: 1) the optimum time to perform the work, 2) the measures to take to warn the public, and 3) the means to protect the highway workers. A threefold campaign was initiated to handle these problem better. The first was public-oriented measures involving advance public information through radio broadcasts and newspapers and placing advance-sign trailers along freeway sections. Second was worker-oriented safety measures which included truck-mounted impact attenuators and the active presence of police officers in work zones. The third was the establishment of a special traffic-handling crew to aid in the planning and operation of urban highway work zones.

84. Levine, S. Z.; "Real-Time Traffic Control for Maintenance Work Zones", Transportation Research Board Circular Number 298, January 1986.

A specially trained crew was formed and assigned the task of handling traffic during maintenance operations on high-volume roadways. With this special crew, the traffic control plan would be modified at the work site to react to changing traffic conditions which was termed "active traffic management".

The following conclusions were drawn from the use of the active traffic management:

- 1) Advance public information of impending work zone activity can minimize public complaints and erratic behavior by motorists.
- 2) The active presence of law enforcement officers in urban highway work zones can minimize erratic behavior by motorists.
- 3) Carefully planned "active traffic management techniques" can allow work zone activity to be done on high-volume urban highways during daylight hours without severely inconveniencing the traveling public and while providing protection to workers from errant motorists.
- 4) Cooperation with law enforcement agencies and other affected governmental agencies is a necessary part of the "active management strategies" employed.

85. Lewis, R. W.; "Performance Criteria for Channelizing Devices Used for Two-Lane Two-Way Operations", FHWA/rd-83-057, August 1983.

Functional requirements are developed for two TLTWO device concepts: (1) an improved flexible, durable, self-restoring device of modest size having a post or paddle shape, and (2) a continuous, raised median with intermittent high-visibility devices mounted thereon. Performance criteria are then determined which will ensure that a channelizing device meets these requirements. Lastly, testing procedures are set forth to evaluate whether the specified performance characteristics are met. The evaluation procedures proposed are limited to tests that can be performed in a laboratory or test track environment.

86. Lewis, R. M.; "Review of Channelizing Devices for Two-Lane Two-Way Operations", FHWA/RD-83/056, June 1987.

This report examines the use, maintenance practices, and cost factors for existing two-lane, two-way operation (TLTWO) channelizing devices. Modified and new device concepts are identified and evaluated with the assistance of a study panel composed of representative potential users (highway agencies and traffic services contractors), national organizations, researchers, consultants and device manufacturers. Eight candidate concepts were prioritized as to the potential value of the concept and the potential payoff for including the concept in the second phase of the study.

The eight candidate device concepts were:

1. continuous raised median with supplemental devices,
2. intermittent array of high-visibility and high durability devices,
3. intermittent array of improved flexible self-restoring devices,
4. continuous raised median without supplemental devices,
5. car deflector to deflect cars at small angles and medium speeds,
6. large raised pavement markers,
7. longitudinal rumble strip, and
8. intermittent array of vertical panels.

Two channelizing device concepts were selected for further study (1) an improved flexible, durable, self-restoring device of modest size having a post or paddle shape, and (2) a continuous, raised median with intermittent, high-visibility devices mounted thereon.

87. Lewis, R. M.; "Safer Work Zone Devices - The Next Generation," American Transportation Builder, 1985.

The traffic control devices commonly used in the work zone were discussed, specifically their impact performance, application, attributes and failings. Included were:

- 1) pavement markings,

- 2) signs,
- 3) barricades,
- 4) vertical panels,
- 5) cones and tubes,
- 6) drums,
- 7) barriers,
- 8) screens,
- 9) shadow vehicles,
- 10) crash cushions, and
- 11) variable message boards.

Methods of reducing impact severity with a traffic control device included reducing the weight of the device, making the device so that it separates from its ballast, employing breakaway features, and utilizing a fall-down or fold-up design. Dynamic performance testing of the devices in the laboratory or, preferably, on a test track was recommended.

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

The performance of the timber barricade was compared to that of the precast traffic barrier. The timber barricades were found to be ineffective as positive barriers since 73.5 percent of vehicles involved in crashes with the barricades either straddled or penetrated the barricade. The frequency of accident occurrence during construction (widening of a freeway) was approximately 119 percent higher than before construction. From the technical, operational, and economic analyses, the precast concrete traffic barrier appeared to be superior to the timber barricade. Use of the timber barricade has been banned by the Federal Highway Administration as a positive barrier on any federal or federal-aid project.

89. Lisle, F. N. and Hargroves, B. T.; "Evaluation of the Performance of Portable Precast Concrete Traffic Barriers," Transportation Research Board Record 769, 1980.

An evaluation of the portable precast concrete traffic barrier as a device for separating high-speed vehicle traffic and construction activities is presented. The evaluation included (a) a review of the literature on the performance of concrete "safety shape" barriers and (b) an examination of traffic operations and safety characteristics in a construction zone where the portable barriers were used. The literature review revealed that in using the barrier (a) the end of the barrier should never be exposed to oncoming traffic; (b) the barrier joints must be tight for the barriers to act as a system; (c) the longitudinal axis of the barriers should be placed parallel to the roadway, except when the barrier system is started with a flare; and (d) the barrier system must have lateral support to prevent vehicle penetration. For conditions at the study site, it was found that (a) there was an average of 49 vehicle contacts with the barrier for every reported accident in which the barrier was involved; (b) there was a definite tendency for motorists to

stay out of the barrier lane, but avoidance of the barrier lane decreased as volume increased; and (c) with an 55-mile/h posted speed limit, vehicle speeds were reduced only slightly when the barriers were in place.

90. Lokken, E. C.; "Portable Precast Concrete Safety Barriers," Public Works, December 1973.

The use of precast concrete safety barriers is described. Precast designs are described as well as methods of transport and placement and bid prices are given for their use. Examples of applications are given.

91. Lum, H. S.; "Economic Feasibility of Using Artificial Lighting in Construction Zones," Public Roads, December 1980.

The economic feasibility of lighting an entire construction zone to reduce night traffic accidents was investigated. A benefit-cost analysis was used. It was concluded that continuous lighting of all construction projects throughout the construction zone is not a cost-effective traffic control safety measure. However, if there are unusual or hazardous conditions in the construction zone, a realistic policy would be to spotlight those locations to give adequate warning to motorists.

92. Lyles, R. W.; "Alternative Sign Sequences for Work Zones on Rural Highways," Transportation Research Board Record 833, 1981.

Experiments were conducted to evaluate the effectiveness of alternate signing sequences for providing warning to motorists of construction and maintenance activities that require a lane closure. The signs included a standard Manual on Uniform Traffic Control Devices (MUTCD) warning sequence, the same signs augmented with continuously flashing beacons, and a sequence of symbol signs. The data showed that the most effective sign sequence was the MUTCD sequence augmented with flashing beacons. Also, the symbol sign sequence appeared to be as effective as the standard sequence and in no instance did the sign sequence appear to cause confusion or potentially dangerous abrupt motorist reaction.

93. Manning, D. G.; "Avoiding the Costs of Closures and Detours During Bridge Deck Rehabilitation," Transportation Research Board, TR News Number 116, January 1985.

The conclusion of NCHRP Synthesis Report 86 was that there was no convincing evidence to indicate that the performance of a concrete deck is degraded by traffic-induced vibrations during placement or curing.

Accordingly, the practice used under certain circumstances by many highway agencies of allowing traffic in adjacent lanes during bridge repairs can be continued and expanded without unnecessary concern for its effect on the long-term durability of the new concrete. As these research findings are used to avoid the cost of closures and detours on many deck-rehabilitation projects, enormous savings will be realized nationwide.

94. Manual on Uniform Traffic Control Devices, Federal Highway Administration, 1978.

National standards are given for traffic control devices. One part deals with traffic controls for street and highway construction and maintenance operations. This part has sections concerning general specifications, signs, barricades and channelizing devices, markings, lighting devices, control of traffic through work areas, and expressways and limited access facilities.

95. Maurer, D. A.; "Paddle-Type Glare Screen", Engineering Technology Division, Pennsylvania Department of Transportation, Research Project 77-19, May 1984.

The report summarizes the applications, details of installation and performance of a paddle-type glare screen during five years of service. It was concluded that the paddle-type system reduced headlight glare satisfactorily and is more cost-effective than a metal mesh screen relative to both installation and maintenance. Use as a temporary control for channelized traffic around a construction work zone was demonstrated to be beneficial when screening was placed at the transition or the taper zone at ends of the work zone. However, placement of screening between traffic and the work zone to prevent gawking or rubbernecking of drivers could not be verified. Although the initial permanent installation failed under traffic due to shearing of the mounting anchors, the glare screen manufacturer's revised mounting bracket and hardware used for replacement has provided satisfactory performance at the evaluation site. Less than five percent replacement was required after five years without maintenance.

96. McCoy, P. T.; Pang, C. M.; and Post, E. R.; "Optimum Length of Two-Lane, Two-Way No-Passing Traffic Operation in Construction and Maintenance Zones on Rural Four-Lane Divided Highways," Transportation Research Board Record 773, 1980.

The equation derived in this study for optimum segment length can be used in the planning and design of crossover-type traffic control in CM zones on rural four-lane divided highways to determine the length of two-lane two-way no-passing traffic operation that will minimize the sum of the increase in road-user costs due to the two-way operation and the cost of traffic control

for the duration of the CM project. Also, the equation derived for computing the sum of traffic control and additional road-user costs enables the cost-effectiveness of crossover-type traffic control to be determined; thus, a basis of comparison with alternative methods of traffic control is provided.

97. McGee, H. W.; Dudek, C. L.; Mason, J. M.; Tignor, S. C.; Williams, W. L.; and McDevitt, C. F.; "Synthesis of Safety Research Related to Traffic Control and Roadway Elements Volume 2," FHWA-TS-82-233, December 1982.

One chapter deals with research concerning construction and maintenance zones. The major areas are work zone accident experience, safety performance of information and guidance systems, safety performance of barriers, and traffic management schemes.

98. McGee, H. W. Joost; D. B.; and Noel, E. C.; "Speed Control at Work Zones", ITE Journal, January 1988.

Information concerning proper speed control in work zones is presented. It was noted that a traffic control plan should be designed on the assumption that motorists will reduce their speed only if they clearly perceive a need. If reduced speeds in a work zone are necessary, a speed reasonable for conditions must be selected. Speed reduction may be accomplished by either reducing the regulatory speed limit or warning of the maximum advisory speed. Recent studies have indicated that hand signaling devices (sign paddles and red flags) and/or law enforcement officers can be effective in accomplishing speed reductions in work zones. Two methods of using police officers are using a stationary police cruiser with lights and radar on or a police traffic controller. (The most effective is using the patrol car with lights and radar). It was suggested to make special contractual provisions for the inclusion of police officers in the traffic control plan. Speed control abuse and misuse (such as using unreasonably low speed limits and leaving reduced speed limits in place after the work is removed) can damage the credibility of work zone speed reduction efforts in general.

99. McGee, H. W. and Knapp, B. G.; "Visibility Requirements of Work Zone Traffic Control Devices," FHWA-RD-78-143, July 1978.

The objective of this study was to develop a performance requirement or standard for the detection and recognition of retro-reflective traffic devices used in work zones. The performance standard developed are established from the principles of driver information needs and, specifically, the requirement for decision sight distance. They are presented in terms of visibility requirements, that is, the distance at which motorists should be able to detect and recognize the devices 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 detection/recognition, decision/response, and maneuver times were estimated to take a total of 10.2 to 11.7 seconds. This time was used along with the 85th percentile speed to determine visibility distances.

100. McGee, H. W. and Knapp, B. G.; "Visibility Requirements for Traffic Control Devices in Work Zones," Transportation Research Board Record 703, 1979.

The objective of this study was to develop a performance requirement or standard for the detection and recognition of retroreflective traffic devices used in work zones. The recommended performance standard, which applied to any device used for channelization, was that the device 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.

101. McGuinness, R. A.; "Driver Opinions on Freeway Signing and Construction Strategies," ITE Journal, July 1983.

The city of Columbus, Ohio developed a questionnaire to obtain some traffic control design and operations information. In the area of road construction, it was determined that most motorists prefer a quick and cheap approach to road construction and repair projects and those drivers who have difficulty in construction zones do not read the signs. It was concluded that further work is needed on additional methods of attracting the motorist's attention to construction signs.

102. Memmott, J. L. and Dudek, C. L.; "Queue and User Cost Evaluation of Work Zones (QUEWZ)," Transportation Research Board Record 979, 1983.

A computer model, Queue and User Cost Evaluation of Work Zones (QUEWZ), developed to estimate the additional user costs resulting from lane closures is described. Hourly as well as daily user costs are estimated, and when vehicle demand exceeds capacity, the model also estimates the length of queue. The model is designed specifically for freeway conditions, but it may be used in other situations if appropriate adjustments are made in the input data.

103. Messer, C. J.; Dudek, C. L.; Friebele, J. D.; Gordon, R. L.; Wattleworth, J. A.; and Reilly, E. F.; "Method for Predicting Travel Time and Other Operational Measures in Real-Time During Freeway Incident Conditions," Highway Research Board, Record Number 461, 1973.

This paper presents the development of a method for predicting the travel time required by a motorist to travel from any selector freeway location to the end of the freeway system during incident conditions. It is predictive in that it computes an estimate of a motorist's travel time if he were to enter the freeway several minutes in the future. Speeds, volumes, and other operational measures may be predicted also. These calculations are made immediately after the incident is detected and the necessary operational measures have been evaluated. Speeds of the various shock waves and travel-time results are also presented. The model was developed for possible use in an operational control strategy of variable-message signs whereby motorists would be diverted to alternate routes if conditions on the freeway relative to selected alternate routes justified the diversion. The model could also be used to predict queue backups and delays due to lane closures caused by scheduled maintenance operations.

104. Michalopoulos, P. G.; and Plum, R.; "Determining Capacity and Selecting Appropriate Type of Control at One-Lane Two-Way Construction Sites," Transportation Research Board Record 905, 1983.

The problem of determining the most appropriate type of traffic control at one-lane two-way construction sites (where one lane is temporarily closed for repairs and the other must be shared by both directions of traffic) is investigated. Possible methods of control include warning signs only (self-regulating), yield signs, stop signs, traffic signals, and flaggers. The most important factor in determining traffic control is sight distance. After sight-distance and safety constraints, capacity alone could determine the most desirable control. Capacity and performance tables and figures are presented for stop-sign, signal, or flagger control.

105. Miller, A. S.; "Breakaway Barricades," Public Roads, June 1976.

The report summarizes results of tests of a Type III barricade constructed of polyvinyl chloride (PVC) pipe. The PVC barricade was observed to be safer, easier to build and transport, and less expensive than conventional wooden barricades. The component parts can generally be salvaged even after high-speed collisions.

106. "Modular Glare Screens Protect Construction Workers, Aid Night-time Traffic", Better Roads, April 1986.

Modular paddle glare screens have been used in construction zones as a method of reducing the problem of headlight glare and also to reduce the ability of motorists to observe work activities. The glare screen is placed on top of the temporary concrete barrier. It is used between opposing lanes as well as between the work area and adjacent traffic lane.

107. Mounce, J. M.; Stokes, R. W.; Brackett, R. Q.; and McCasland, W. R.; "Guidelines for Utilization of Police Officers in Traffic Control and Enforcement on Urban Freeways", Texas Transportation Institute, Texas A & M University, Report Number FHWA/TX-86/75+410-7F, September 1986.

This report presents general guidelines for the use of uniformed police officers in highway maintenance, construction, and other traffic management activities, such as incident management and the operation of high-occupancy vehicle facilities. The guidelines distinguish between "traffic control" and "enforcement" roles for uniformed police officers. The traffic control and enforcement guidelines are discussed in terms of: 1) objectives of using uniformed police officers; 2) requirements for implementing the guidelines; and 3) measuring the effectiveness of the guidelines. Example set-ups of possible applications of the guidelines are given for illustrative purposes. The report also discusses key issues which may need to be resolved if the issues are discussed under the general headings of institutional, legal, and economic issues. The report outlines some general recommendations regarding procedures for reviewing and refining the guidelines for possible adoption, dissemination, and implementation by the agencies responsible for enforcement and traffic control activities.

108. Nemeth, Z. A. and Migletz, D. J.; "Accident Characteristics Before, During, and After Safety Upgrading Projects on Ohio's Rural Interstate System," Transportation Research Board Record 672, 1978.

In 1973, minor safety upgrading projects were conducted at 21 locations on the rural interstate system of Ohio, involving 384 miles of freeways. In 1972, the accident rate per million vehicle miles on these 384 miles was 112.9/100 million vehicle miles. In 1974, the accident rate dropped to 77.9 accidents/100 MVM. To account for the possible effect of the introduction of the reduced speed limit in 1974, accident rates were also compared on 153 miles of the rural interstate system subjected to safety improvement. The difference in proportional reduction in accident rates is statistically significant and favors the 21 study sites. The accident rates increased to 120.8 accidents/100 MVM during the 1973 safety upgrading construction program. However, only 151 accidents were positively identified from traffic crash reports and construction diaries as being construction related. These 151 accidents were studied in detail. Observed patterns included: (a) rear-end (61) and single vehicle, fixed-object (56) accidents were the most frequent; (b) 34 accidents occurred in the relatively short taper area; (c) the

proportion of the lane taper accidents at night and at dawn or dusk was high; (d) the proportion of construction object accidents at night was high; and (e) the proportion of tractor-trailer and bus accidents at night was high; (f) excess speed was listed in 88 cases as a contributing factor, while road defects or construction of traffic control were listed only in 15 cases. Some suggestions are being made regarding traffic control at work zones.

There was an overall seven percent accident rate increase during construction. There were no increases in the fatality and injury accident rates.

109. Nemeth, Z. A.; and Rathi, A.; "Freeway Work Zone Accident Characteristics," Transportation Quarterly, January 1983.

Accident characteristics on freeway facilities where work zone traffic control procedures were of a high standard in terms of current state-of-the-art were studied. Lane closures and crossovers were included. Advance zone, taper, and single lane closure accidents involved low nighttime accidents and low truck involvement. Single lane closure zones had higher injury rates than all turnpike accidents due to the relatively high percentage of rear-end accidents. Some accidents were caused by unstable traffic control devices getting in the path of traffic so the need to monitor these devices (or improve their design) is evident.

There was a high involvement of trucks in accidents at night at crossovers and in bi-directional zones showing the driving task is more demanding at these locations. Physical separation of opposing traffic in bi-directional zones may be necessary (depending on traffic volumes and construction time) to eliminate head-on and sideswipe accidents. Changeable message signs may be necessary to reduce rear-end accidents.

110. Nemeth, Z. A. and Rouphail, N. M.; "Lane Closures at Freeway Work Zones: Simulation Study," Transportation Research Board Record 869, 1982.

The study was aimed at the investigation of merging and speed controls at freeway construction-lane closures through the use of computer-simulation techniques. The field-study results indicate that the effectiveness of the advance-warning devices at freeway construction-lane closures is not determined solely by the design features of the individual devices but also, and perhaps more importantly, by the risk perceived by approaching drivers. The simulation-study results indicate that at sites experiencing approach volumes in excess of 1,000 vph, it is desirable that early merging be encouraged. The implementation of a 45-mph maximum speed control and assumed 100 percent compliance resulted in higher percentages of forced merges in the taper area in the model. The assumption of 100 percent compliance was not meant to be a realistic assumption, but it is still interesting to note that from the point of view of smooth merging, the speed reduction may not even be desirable.

111. Niessner, C. W.; "Raised Pavement Markers for Construction Zone Delineation," Public Roads, September 1979.

The study showed that standard raised pavement markers provide positive daylight and nighttime guidance. Markers used on construction detours tend to reduce the number of accidents. The cost of markers and paint is equal to or less than the cost of paint striping and removal. The additional safety, improved operations, and reduced vandalism provided by the markers, in addition to their acceptance by the public, government, and construction personnel, justify their expanded use.

112. Oliver, D. C.; "Liability in the 1980's: Construction Zones, Intersections, and the MUTCD," ITE Journal, April 1986.

Examples of court cases involving construction zones were given. The examples illustrated that inspection, advance notice, and correction of discovered defects are all reasonable activities for the state. Ignorance of a defect or dangerous situation, or knowledge of such a situation without warning the motorist of the danger, will expose the state to a liability judgment.

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

The report consists of a discussion of general principles, considerations involving federal regulations or programs, and examples of cases that provide first-hand knowledge of judicial treatment of liability of highway agencies and contractors in designing work zone layouts.

114. Orth, E. D.; "Truck-Mounted Attenuators, (TMA's)," AASHTO Highway Subcommittee on Traffic Engineering, June 16-18, 1985

A survey was sent to all states and the District of Columbia to determine the extent of truck-mounted attenuator usage in the United States. The survey revealed that, by the end of 1985, 26 states will be using TMA's in maintenance work zones, six states and the District of Columbia are considering their use within the next one or two years, while 17 states stated they are not presently using TMA's and have no plans to use them in the immediate future. The number used by the state highway and transportation departments varied from one to over 430 in California with approximately 800 TMA's used nationwide. Most TMA's are manufactured commercially (Hi-Dri Cells, Hex Foam Cells, and Hex-Cel) while some were developed "in-house".

Seven states have developed specific guidelines or standards for the use of TMA's. The cost of commercially-manufactured TMA's varied from \$5,000 to \$8,000 with a replacement cartridge costing approximately \$3,500.

115. Pain, R. F.; Hanscom, F. R.; and McGee, H. W.; "Work-Site Traffic Control in the U. S.: Existing and New Technologies", Traffic Engineering and Control, Vol. 24, October 1983.

The article summarizes current practices and new developments used in work-site traffic control. The section dealing with current practice addressed the following:

1. general policy,
2. signs,
3. barricades and channelizing devices,
4. lighting devices,
5. flagging, and
6. one-way traffic control.

The section dealing with refinements and new developments addressed the following:

1. changeable-message signs,
2. advance warning signs,
3. arrowboards for advance warning,
4. channelizing devices,
5. innovative lane-closure strategies,
6. highway advisory radio,
7. device application decision tree, and
8. portable traffic barrier.

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

Laboratory studies were used to determine quantitatively the optimum design characteristics of channelizing devices. Recommendations were: a) the optimal stripe width is an 8- or 6-inch stripe for 6-inch or greater rails, b) the desirable ratio of white-to-orange coloring favors equal white to orange or more white, c) optimal stripe design configurations are first vertical then horizontal, d) chevrons connote directional meaning to drivers, e) vertical panels elicit better performance than horizontal bars or trapezoid shapes, f) there was little useful difference between type 1 and type 2 barricades, and g) a tall, narrow vertical panel image is recommended over a shorter, wider device.

117. Pain, R. F. and Knapp, B. G.; "Motorist Information Needs in Work Zones," ITE Journal, April 1979.

The motorist's most important work zone needs were identified as:

1. adequate relevant advance information,
2. channelizing and delineation of a clear path through the work zone,
3. use of devices and markings consistent with driver expectancies,
4. adequate maintenance of work zone information sources, and
5. credible information systems.

118. Pain, R. F.; McGee, H. W.; and Knapp, B. G.; "Evaluation of Traffic Controls for Highway Work Zones," National Cooperative Highway Research Program Report 236, October 1981.

Recommendations for the use and design of channelization devices for freeway-type operations were developed. The channelizing devices included cones, tubular cones, barricades, vertical panels, drums, and steady-burn lights. For each device, recommendations concerning applicable guidelines, minimum dimensions (if applicable), stripe configuration (if applicable), color, minimum stripe width (if applicable), and spacing were listed. Findings related to five research tasks: 1) literature review, 2) derivation of performance measures, 3) optimization of device design, 4) effectiveness of channelization devices in controlled field studies, and 5) effectiveness of channelization devices in a field evaluation study. It was found that barricades, drums, vertical panels, cones, and tubes, when designed properly, all perform the function of channelization adequately both day and night.

119. Pang, L. and Yu, J. L.; "Concrete Barriers at Transition Zones Adjacent to Two-Way Traffic Operation on Normally Divided Highways," Transportation Research Board Record 833, 1981.

The Federal Highway Administration issued an emergency rule that concrete barriers be placed at the transition zones where four-lane operations change to two-lane and vice versa. The objective of this study was to verify whether barriers are justified at transition zones on the basis of accident experience. The findings indicated that concrete barriers do not appear to be justified at transition zones located on relatively low-volume roadways. Accident data showed head-on collisions at transition zones was nonexistent at the rural sites reviewed. Barriers may be needed during the first days of a project and at transition zones where approach speeds are high.

120. Paulsen, R.; Glennon, J.; Harwood, D.; and Graham, J.; "Traffic Safety in Highway Construction Zones, Part 1 - Problems and Improvements", Rural and Urban Roads, October 1978.

The accident problems detected in construction zones was reviewed. The procedures to determine the basic conditions in the construction zone and to select basic zone type and scheduling are discussed.

121. Paulsen, R.; Glennon, J.; Harwood, D.; and Graham, J.; "Traffic Safety in Highway Construction Zones, Part 2 - Speed Control Strategy," Rural and Urban Roads, November 1978.

The formulation of a speed control strategy and the selection of appropriate traffic controls in the planning and design of construction zones are discussed. Geometric design of roads passing through or around a construction zone, management of the construction zone, and maintenance of the traffic control devices are also discussed.

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

A synthesis of a number of accident studies reveals that the total accident experience in construction zones increases from 2 to 119 percent during construction and that accident experience is related to construction activity. For example, a 61 percent increase in total accidents was reported during 207 two-lane highway resurfacing projects in Georgia.

It was concluded that traffic control in work zones can be improved through better planning, design, and management. More effective planning and design would require a step-by-step planning process including: a) collection of roadway, traffic, and construction data, b) selection of basic zone type and scheduling, c) formulation of a speed control strategy, d) determination of geometric design elements, and e) selection of traffic-control devices and methods. More effective management of construction-zone traffic control should include: a) improved public information, b) training of field personnel, c) review and modification of traffic control, d) removal of inappropriate devices, and e) improved maintenance of traffic-control devices.

123. Pigman, J. G. and Agent, K. R.; "Evaluation of I75 Lane Closures", University of Kentucky Transportation Research Program, Research Report UKTRP-86-19, August 1986.

A project on I 75 in Whitley and Laurel Counties during the 1986 construction season involved numerous lane closures associated with spot

pavement replacement and joint sealing. Traffic congestion associated with heavy volumes and late merges resulted in the use of the following traffic control devices to supplement standard lane closure devices; 1) variable message signs, 2) supplemental lane closure warning signs, and 3) rumble strips placed in the lane to be closed in advance of the taper.

Results showed a decrease in the percentage of traffic in the lane to be closed with each successive traffic control device in addition to the standard lane closure devices. There was a general decrease in speeds as traffic approached the taper. The percentage of trucks in the lane to be closed was lower than the percentage in the open lane when the closure was a left lane. Hourly traffic volumes observed in this study (800 to 1,300 vph) did not appear to influence the percentage of traffic in the lane to be closed. The percentage of trucks in both lanes (8.5 to 14.7 percent) did not influence the percentage of traffic in the lane to be closed.

Recommendations from the study included the following: 1) supplemental signs for all long-term closures in high-volume, high-speed, four-lane roadways; 2) variable message signs when one-way hourly volumes exceed 1,000 A (ADT exceeds 20,000); and 3) application of rumble strips when other devices do not reduce late merges and there is excessive congestion.

124. "Planning and Scheduling Work Zone Traffic Control", Federal Highway Administration, Implementation Package FHWA-IP-81-6, October 1981.

The user's guide was prepared to provide highway agency decision makers with analytical procedures and decision methodologies that can be applied in the early planning and design stages of a major street or highway project to select the most appropriate traffic control strategy to be implemented. The process would assist in formulating decisions regarding the type of work zone (lane closure, detour, crossover) which would be most cost-effective for the project.

125. Plummer, S. R.; Anderson, R. A.; Wijaya, Y. H.; and McCoy, P. T.; "Effect of Freeway Work Zones on Fuel Consumption," Transportation Research Board Record 901, 1983.

The objective of this study was to investigate the effect of freeway work zones on fuel consumption. The development of a procedure for estimating the excess fuel consumption caused by lane closures on 3-, 4-, and 5-lane freeway sections is presented. The procedure is applicable to both undersaturated and oversaturated traffic-flow conditions. Tables and graphs designed to facilitate the implementation of the procedure are included. An example that illustrates the application of the procedure is also presented.

126. "Raised Marking System Stands Up to Traffic", Roads and Bridges, April 1987.

Use and removal of raised pavement markers to simulate a double yellow line in tow-way two lane construction projects was discussed. It was determined that a 10-foot spacing gave adequate day and night delineation. The material/installation/removal cost has been about \$1.30 each per marker giving a total installed/removed cost of \$0.13 per linear foot.

127. Richards, S. H. and Dudek, C. L.; "Catalog of Traffic Control Strategies and Devices", Texas Transportation Institute, Texas A & M University, Research Report 321-1, February 1986.

This report is a catalog of several traffic control strategies and devices appropriate for freeway work zones. The strategies and devices were identified during field studies and interviews conducted at numerous freeway work zones in Texas and reviews of several Traffic Control Plans. The following strategies and devices summarized are listed below:

1. Innovative Traffic Management Strategies

- a. Short-Term Total Freeway Closure
- b. Traffic Splitting

2. Supplemental Traffic Management Strategies

- a. Shoulder Use
- b. Speed Control
- c. Entrance Ramp Closures
- d. Narrow Lanes
- e. Load Zoning

3. Motorist Information Devices

- a. Arrowboards
- b. Portable Changeable Message Signs
- c. Highway Advisory Radio
- d. Special Lane-Blocked Sign
- e. Special Work Message Pavement Marking

4. Traffic Control Services

- a. Flagging
- b. Law Enforcement

5. Safety Hardware

- a. Portable Roadside Barriers
- b. Crash Cushions
- c. Temporary Lighting

6. Implementation

- a. Corridor Management Team
- b. Special Traffic Handling Crew
- c. Advance Notification
- d. Photographic Documentation

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

Two innovative approaches for managing traffic during maintenance operations in the middle lane of an urban freeway were evaluated. They involved: 1) traffic shifting (with use of the shoulder) and 2) traffic splitting. Both approaches significantly increased work-zone capacity compared to the multilane closure strategy commonly used at middle-lane work sites. It was found that: a) traffic shifting could be used to manage traffic at relatively long work sites on freeways with discontinuous shoulders, b) shoulder use at sites where this strategy was employed was greatly influenced by traffic demand, and c) traffic splitting was used effectively at a relatively short work site on a freeway section that did not have shoulders.

129. Richards, S. H. and Dudek, C. L.; "Selection of Work Zone Channelizing Devices Using the Value Engineering Approach," Texas Transportation Institute, Report No. FHWA/TX-85/06+292-3, January 1984.

This report investigates the use of Value Engineering for selecting work zone channelizing devices and their relative performance. Next, an overview of the Value Engineering problem-solving approach is presented. The paper then demonstrates how the Value Engineering approach may be applied to select work zone channelizing devices. For illustration, the approach is used to select devices for a lane closure taper at a rural freeway work zone.

Value Engineering was found to: 1) provide an objective means of evaluating any number of alternative channelizing devices using whatever performance and cost data are available and 2) encourage the selection of low cost devices which are safe and effective under the prevailing work zone conditions.

The investigation further suggested that the Value Engineering approach is most appropriate for use at the Division level. It is an effective analytical tool which may be used in developing standards and for resource planning and allocation.

130. Richards, S. H. and Dudek, C. L.; "Sight Distance Requirements at Lane Closure Work Zones on Urban Freeways," Research Report 228-7, Texas Transportation Institute, April 1981.

The study involved a field evaluation of static advance signing. It was determined that advance signing alone will not encourage lane changing for lane closure situations. There is a need for adequate sight distance.

131. Richards, S. H. and Faulkner, M. J.; "An Evaluation of Work Zone Traffic Accidents Occurring on Texas Highways in 1977," Texas Transportation Institute, July 1981.

An analysis of 1977 accident data revealed that work zone accidents tended to be less severe than other accidents in terms of injuries and fatalities per accident. Rear-end accidents, which tend to be less severe, accounted for 40 percent of the work zone accidents which could be attributed to a high incidence of the slowing of preceding vehicles. Pedestrian accidents in work zones occurred at the same frequency for all roads. Speed violations contributed to 27 percent of the work zone accidents compared to 15 percent of all accidents.

132. Roper, D. H.; Zimanski, R. F.; and Iwamasa, A. M.; "Diversion of Freeways Traffic in Los Angeles: It Worked," Transportation Research Board, Record Number 957, 1984.

The California Department of Transportation implemented a traffic management plan aimed at bringing about voluntary traffic diversion upstream of a section of freeway that needed to be closed for 6 hours for maintenance operations. Without an extensive traffic management effort, delays of more than 2 hours were anticipated. The plan was designed to limit delays on the affected high-volume freeways (160,000 to 225,000 average daily traffic) to a maximum of 20 minutes. The plan included an aggressive public information campaign before the closure by using both media and freeway signing and an extensive use of changeable message signs during the operation. Significant diversion from two freeways that feed the closure area was achieved. Congestion extended about 2.5 miles upstream of the closure at its maximum; actual delays never exceeded the targeted 20 minutes. The plan, how it was developed, and how it was implemented are described. Results of the operation are also presented.

133. Richards, S. H. and Dudek, C. L.; "Implementation of Work-Zone Speed Control Measures", Transportation Research Board Record 1086, 1986.

Recommendations for implementing speed control at construction and maintenance work zones are presented. The following implementation steps are identified and discussed: a) determining the need for speed reduction, b) selecting a reasonable speed, c) selecting a speed control treatment based on effectiveness, practicality and cost, and d) selecting a location for the speed control treatment implementation. Four speed control approaches are studied: flagging, law enforcement, changeable message signs, and effective lane width reduction. The advantages and disadvantages of each of these approaches are discussed. Limited cost data for each of the approaches are also presented. The conclusions and recommendations are based on the results of field studies and observations at numerous street and highway work zones in Texas.

134. Richards, S. J.; Wunderlich, R. C.; and Dudek, C. L.; "Field Evaluation of Work Zone Speed Control Techniques," Texas Transportation Institute, Transportation Research Board Record 1035, 1985.

The results of field studies conducted to evaluate selected methods of slowing work zone traffic to acceptable speeds were summarized. The studies were performed at six work zone sites, including two rural freeway sites, one urban freeway site, one urban arterial site and two rural highway sites. The following work zone speed control methods were studied: flagging, law enforcement, changeable message signs (CMSs), effective lane width reduction, rumble strips and conventional regulatory and advisory speed signing.

The study results indicate that flagging and law enforcement are very effective methods for controlling speeds at work zones. The best flagging treatment tested reduced speeds an average of 19 percent across all sites, and the best law enforcement treatment reduced speeds an average of 18 percent. In contrast, the best changeable message sign and effective lane width reduction treatments tested reduced speeds by only 7 percent each.

Within the primary speed control methods, an innovative flagging procedure, a police traffic controller and stationary patrol car were determined to be the most effective treatments on most highway types. A circulating patrol car and rumble strips were determined to be ineffective treatments for controlling work zone speeds. Although conventional regulatory and advisory signing was judged to be ineffective in reducing work zone speeds, conventional speed signs are an essential component of any work zone speed control effort.

135. Ross, H. E., Jr; Urbanik, T.; Newton, T. M.; Hatfield, N.; Griffin, L. I.; and Woods, D. L.; "Use and Delineation of Traffic Barriers in Work Zones - State of the Art and Current Practice," Texas Transportation Institute, March 1980.

The basic objective of the subject contract was to develop a set of objective guidelines that will enable a highway engineer to determine if a positive traffic barrier is warranted in a given work zone and, if so, the type of barrier delineation device(s) that should be used. Prior to development of the guidelines, a thorough review of the state of the art and current practices in the use and delineation of positive traffic barriers in work zones was made. To accomplish the review, the researchers 1) conducted a review of the literature; 2) made field inspections of selected work zones in various states; 3) consulted highway engineers in a number of states, either in person or through phone calls; 4) consulted researchers who were active in the field of interest; and 5) consulted FHWA officials regarding past and present research activities relevant to the subject matter.

For convenience, the review was subdivided into five categories or subject areas, namely, accident data, selection and use of traffic barriers, delineation of barriers, field inspections, and research activities. This report presented the findings of this review.

136. Roupail, N. M. and Nemeth, Z. A.; "A Driver Based Study of Freeway Construction Lane Closures," ITE Journal, 1982.

Merge and speed control at four-lane rural freeway lane closures was discussed. It is generally recognized that advisory speed signs are ineffective in reducing speeds. A simulation study revealed that full compliance would increase late merge frequencies and a field study detected no more than 3 mph speed reduction when drivers approach work zones having minimum MUTCD standards. Significant speed reductions have been achieved using rumble strips. The simulation study revealed that, if drivers merged at the earliest opportunity, with an advance warning distance of one mile, 90 percent of all merges would be completed prior to the no-recovery zone. Merging is influenced by the perceived urgency to merge. Many drivers delay merging until the construction area is sighted. Changeable message signs can increase the amount of early lane changes, especially when positioned 0.75 mile in advance of the lane closure.

137. Ryan, D. P. and Mettelstedt, D. G.; "An Overview of Developments in National Work Zone Traffic Control," ITE Journal, April 1979.

A listing of FHWA procedures relating to work zone traffic control established on October 13, 1978 was tabulated as follows:

1. Traffic control plans (TCP) shall be developed for all projects.
2. A qualified person at the project level shall be designated as responsible for the TCP.
3. Persons responsible for the TCP shall be adequately trained.
4. Work zone accidents shall be evaluated.
5. The use of unit pay items should be considered in setting up the TCP.
6. The state highway agency shall establish a review and evaluation process.

Findings of the 1978 FHWA task group were summarized as follows:

1. There was very little activity by project personnel to analyze accidents within a project and correlate the results to project deficiencies.
2. Photologging techniques have been used to improve traffic control.
3. Advance warning signs have improved.
4. Better effort needed to store materials and park personal vehicles of workers away from the roadway.
5. There is a need to improve flagging procedures.
6. Problems were found with removing pavement markings no longer applicable.

138. Rubin, D. and Carter, E.; "Work Zone Accident Data Process - Training Guide", Federal Highway Administration, FHWA -IP-85-4, April 1985.

This training guide provides the outline, visual aids and necessary supporting information for three to four short courses on the collection of

work zone accident data. The collection of accident data by law enforcement officials on accidents occurring within construction and maintenance work zones is usually not adequate to assess whether or not the accidents are directly or indirectly related to traffic control or physical roadway features. The job of collecting supplemental data to determine this is typically done by the construction and/or maintenance supervisory staff. These engineers and technicians need to be trained in the techniques of acquiring data related to traffic accidents both for immediate assessment of traffic controls in place and for the statewide assessment of traffic control standards.

139. "Safe Conduct of Traffic Through Highway Construction and Maintenance Zones," National Cooperative Highway Research Program, Research Results Digest 100, February 1978.

A summary of information in the area of traffic safety in construction and maintenance zones is presented. Information concerning the following general areas is summarized.

1. Principles for safe management of traffic at work zones,
2. Training courses,
3. Research activities and results, and
4. Legal aspects.

140. Seymour, W. M.; Deen, R. C.; and Havens, J. H.; "Traffic Control for Maintenance on High-Speed Highways," Transportation Research Board Record 484, 1974.

Observations were made at lane closures on interstate highways to compare effectiveness of yellow and orange signs. Orange signs were slightly more effective than yellow signs in reducing traffic conflicts and merges near the traffic cones. Results of the study tend to support the adoption of orange as the standard color for signing construction and maintenance sites. However, differences between the two colors were rather small. Driver preference polls supported the orange signs more strongly.

141. Shah, S. C. and Ray, G. L.; "Advance Traffic Control Warning Systems for Maintenance Operations," Research Report No. 105, Louisiana Department of Highways, July 1976.

The effectiveness of advance signing as measured by speed, conflicts, and queuing parameters was investigated. Motorists were observed to respond to advance signing by reducing speed, but the speed reduction was less for interstate than two-lane rural roads. The size of the sign was not a factor for two-lane roads, but it was for interstate highways with 36-inch signs yielding a better response than 30-inch signs. An arrowboard (sequencing

accumulative bidirectional chevron) was determined to significantly reduce speeds and queuing for a freeway lane closure application.

142. Shepard, F. D., "Delineation Systems for Temporary Traffic Barriers in Work Zones", Virginia Highway and Transportation Research Council, June 1986.

Temporary concrete barriers have come into use as a means of protecting work crews as well as motorists in work zones. This report discusses four delineation systems for such barriers. Presented is information on the fabrication, installation, durability, and cost of the systems. The systems included: 1) 6-inch by 12-inch cylinders placed on top of the barrier, 2) 8-inch by 24-inch hazard panels placed on top of the barrier, 3) continuous stripe of reflective tape on the barrier face, and 4) steady burn lights on top of the barrier with reflectors on the barrier face.

143. Shepard, F. D.; "Night Work Zone Reflectorization", Transportation Research Board, Circular Number 306, June 1986.

Sign complexity and reflectorization is discussed. Signs should be simple and legible, especially with the array of lights used during night operations. The provision and maintenance of reflectorization is important. Legibility distance has been increased about 15 percent through use of modified lettering on various signs. In addition to signs, various devices are being used to channel traffic in night-work zones including cones with internal lights or reflectorized sleeves on top, Type II barricades, chevrons of different sizes, and barrels.

144. Shepard, F. D. and Cottrell, B. H.; "Benefits and Safety Impact of Night Work-Zone Activities", Virginia Highway and Transportation Research Council, June 1985.

Through a literature review and discussions with highway and transportation officials in several states, information was obtained on questions and concerns relating to the planning, safety, and traffic control aspects of night maintenance and construction activities and their advantages and disadvantages. The information obtained was used to develop general guidelines on when and how maintenance and construction work should be performed at night. The report presents case studies illustrating the activities required in different types of night maintenance and construction activities. The conclusion reached was that, although there are many potential disadvantages of working at night, using the experience of past work and proper planning allows the night alternative to be feasible for selected work.

145. Sickling, D. L.; Ross, H. E., Jr.; Ivey, D. L.; and Hirsch, T. J.; "Portable Traffic Barrier for Work Zones," Transportation Research Board, Record Number 942, 1983.

A portable, positive construction zone barrier is described. The barrier is suitable for use at sites where work will take as little as several hours. It is constructed from used cars and three-beam guardrail. Two full-scale vehicular crash tests of the portable barrier are described that demonstrate its adequacy in terms of impact performance. The barrier can be used in construction zones where conventional positive barriers have been impractical.

146. Skinner, H. B.; "An FHWA Perspective on Devices and Their Use," American Transportation Builder, 1985.

FHWA's experience with work zone devices was discussed. The following items were listed.

1. Delineation

- a. delineators on portable concrete barriers and guardrails,
- b. cleaning and repositioning of channelizing devices, and
- c. adequate delineation of crash cushions.

2. Striping

- a. adequate removal,
- b. temporary raised pavement markers, and
- c. pavement marking tapes.

3. Pedestrians and Bicyclists

- a. physically separating pedestrian and bicycle traffic from vehicular traffic,
- b. delineating hazards, and
- c. staging work activities to minimize conflicts.

4. Choice of Materials

- a. reflective sheeting materials,
- b. plastic drums, and
- c. temporary pavement markers.

5. Flashing Arrow Panels

- a. misapplication of panel and
- b. panel flashed too bright, too dim, too fast, or too slow.

6. Non-applicable Signs Left in Place

7. Flaggers

- a. more extensive use of paddle rather than a flag,
- b. periodic training,

- c. using flagger only where warranted, and
- d. inappropriate traffic control devices.

8. Variable Message Signs

- a. prone to being used where not warranted and
- b. use only where conventional devices are inadequate or where constantly changing conditions warrant use.

9. Accidents

- a. a detailed plan for traffic needs and
- b. separate pay item for traffic control devices.

10. Other Strategies

- a. police cooperation,
- b. contractual requirements for accelerating construction or limiting construction to certain times of the day,
- c. analysis of work zone accidents,
- d. safe storage of materials and worker's vehicles,
- e. use of supplementary flags,
- f. inspection, and
- g. addressing pavement drop-offs.

147. Smith, C. W.; "Experimental Diamond Vertical Panels," Colorado Department of Highways, March 1984.

The study evaluated the use of an orange diamond pattern on white background vertical pattern for barricades for construction zone obstacle marking and traffic channelization. It was observed that there was no discernible difference in motorist reaction/acceptance of the diamond panels as compared to standard striped panels and no action was taken to implement the diamond pattern as an alternate standard to the striped panel.

148. Smith G. M.; "Reflectorized Traffic Regulator Vest", Michigan Transportation commissions, Materials, and Technology Division, Research Report R-1263, August 1985.

This study was performed to determine which design of reflectorized vests would provide maximum protection for flaggers working at night or under heavy overcast or stormy conditions where motorists would use headlights. Field studies were conducted using various patterns, shapes, and colors. The following recommendations were made:

- 1. shape - on the front and back panels of the vest there should be a chevron over an inverted chevron with a two-inch width, on the side, two four by four inch squares should be spaced vertically,
- 2. color - reflectorized yellow for night and fluorescent yellow for day,

3. brightness - a material that will yield a minimum of 15 foot-Lamberts when illuminated by automotive low-beam headlights at 400 feet (the reflectorized pattern on the vest should approximate the brightness of "high intensity" encapsulated bead reflective sheeting).

It was also noted that ventilation for wearer comfort is recommended by means of perforating non-reflective portions of the vest, or using mesh or screen fabric for the base vest material.

149. Stoughton, R. L.; Stoker, D. R.; and Nordin, E. F.; "Vehicular Impact Tests of a Truck Mounted Attenuator Containing Vermiculite Concrete Cells," FHWA/CA/TC-80/26, California Department of Transportation, June 1980.

Crushable packages of energy absorbing materials were developed to be applied to the rear of service vehicles. The system consists of lightweight concrete cartridges on cubes of paper honeycomb impregnated with rigid plastic, a crushable container, a steel backup, and attachment hardware. This system reduced vehicle damage and decelerations at impact speeds of 45 mph for 4,500-pound cars. Crash results were more severe for light-weight cars at the same speed.

150. "Summary Report on Work Zone Accidents", Committee on Highway Traffic Safety, American Associations of State Highway and Transportation Officials, July 1987.

A survey was sent to each state requesting work zone accident data on Federal-aid Interstate and other primary highway systems for 1984 and 1985. There were only slight differences in total work zone accidents between 1984 and 1985 but there was a 14 percent decrease in fatal accidents. Based on the survey data, it was estimated there were 400 fatal accidents, 15,000 injury accidents, and 31,000 property-damage-only accidents in work zones on the Federal-aid Interstate and primary system in 1985 representing a total cost of \$800 million. While most accidents occurred in urban areas, more fatal accidents occurred in rural areas. The Interstate system was observed to be overrepresented in all types of accidents occurring in work zones and should receive priority attention. When compared to all accidents, work zone accidents were found to be more severe. The most common type of work zone accidents were vehicle/vehicle collisions followed by fixed object accidents. Although 70 percent of all work zone accidents occur in daylight, more than half of the fatalities occur at night which emphasizes the need for adequate motorist guidance during hours of darkness. Tractor-trailers were significantly overrepresented in accidents in work zones so special attention should be given to accommodation of tractor-trailer combinations. Approximately 100 of the 700 work zone fatalities each year are pedestrians so adequate consideration must be given to the safety of workers and other pedestrians. The need to design work zones to alleviate problems caused by reduced capacity was noted to reduce the number of vehicle/vehicle accidents during daytime hours.

It was also recommended that each state should monitor their work zone accident experience to determine the accident countermeasures appropriate for their specific accident problems. It was also noted that additional information concerning: 1) work zone worker involvement, 2) type of work zone activity, and 3) measures of exposure for work zone accidents, would be beneficial as future research.

151. Taminini, F. J.; TMA's Coming of Age," American Transportation Builder, 1985.

The increase in usage of the Truck-Mounted Attenuator (TMA) and requirements for performance criteria are discussed.

152. "Temporary Raised Pavement Markers in Highway Work Zones", Minnesota Department of Transportation, Office of Traffic Engineering, November 1984.

The report concerns the development of guidelines and standards for the application of temporary raised pavement markers (TRPM) in highway work zones. The primary area of concern was the use of TRPM's to simulate a solid line. The recommendation was that a 10-foot spacing provided adequate daytime and excellent nighttime delineation when used with conventional channelizing devices and could be used to simulate a solid edge line. The Stimsonite 66 TRPM was used in the tests. It was concluded that the TRPM's provided an excellent delineation system at less cost than temporary lane tape.

153. "Traffic Control Devices Handbook," Federal Highway Administration, 1983.

The Handbook offers guidelines for implementing the standards and applications contained in the MUTCD. One part deals with work zone traffic control. Included are sections relating to: 1) the general area (fundamental principles, driver information needs in work zones, and training), 2) application (traffic control zones, planning for traffic control, function of devices, and typical applications), and 3) installation, maintenance, and inspection (installation and removal, inspection and maintenance program, legal liability, and documentation for protection).

154. "Traffic Control for Freeway Maintenance," National Cooperative Highway Research Program Synthesis of Highway Practice Report Number 1, 1969.

The practices used in traffic control during freeway maintenance are documented. The major sections of the report dealt with: 1) planning and

scheduling for work site traffic control, 2) freeway work site protection and lane closures, and 3) devices used.

155. Turner, J. M. and Dudek, C. L.; "Real-Time Diversion of Freeway Traffic During Maintenance Operations," Transportation Research Board, Record 683, 1978.

Various changeable message signs were displayed in actual field operation in response to freeway maintenance to determine the relative effectiveness of each message. The management of traffic during maintenance conditions was demonstrated to be feasible and advantageous. The addition of diversion information proved to be a benefit. Questionnaire data show a preference by the motorists for some type of information along their route during maintenance operations. Motorists' preferences included diversionary information as well as advisory information. This was exemplified by the greater increase in diversion when diversionary signs were used.

156. Ugwoaba, Godwin U.; "Evaluation of Delineation Systems for Temporary Traffic Barriers", Washington State Department of Transportation, May 1987.

This study investigated the effectiveness of various barrier-mounted reflectors. Barrier delineators come in different shapes and sizes, and their materials and installation labor costs also differ. They may be mounted on the barrier top, the barrier face or even on the pavement. A delineator's level of effectiveness depends on the type of delineator as well as its placement.

This study evaluated the effectiveness of seven concrete barriers delineators: Astro-optics on the barrier, Reflexite on the barrier top, reflective cylinders on the barrier top, hazard panels, raised pavement markers on the barrier face, Astro-optics on the barrier face, and Davidson markers on the edge line.

The study included a literature review, observations of the delineators at a test site, and having motorists drive by the delineators and rate them.

The study concluded that drivers need the guidance of delineators most when they are confronted with opposing traffic headlight glare. Devices placed on top of the barrier are washed out by headlight glare and therefore are not effective. The best placement of concrete barriers is on the barrier face. A delineator loses more than half of its reflectiveness in a short period due to dirt accumulation.

The study recommended that the Manual on Uniform Traffic Control Devices make more of the effect of opposing traffic headlight glare on delineators' effectiveness, that delineators not be placed on the top of concrete barriers, that prism-lensed devices are the most effective, and that delineators should be cleaned regularly.

157. Vacha, A.; "FHWA Reviews Work Zone Traffic Safety Procedures", Roads & Bridges, April 1987.

As a result of review of work zone procedures, FHWA had recommendations in the following areas:

1. preconstruction procedures,
2. work zone monitoring,
3. work zone safety procedures,
4. traffic control devices, and
5. construction operations.

Recent developments aimed at improving safety and traffic flow through work zones were listed as follows:

1. temporary traffic signals,
2. portable changeable message signs,
3. construction raised pavement markers,
4. plastic drums,
5. truck mounted attenuators,
6. use of radio headsets,
7. public information systems, and
8. selective enforcement.

158. Vecellio, R. L. and Culpepper, T. H.; "Work Area Traffic Control: Evaluation and Design", Journal of Transportation Engineering, Vol. 110, No. 4, July 1984.

Comprehensive evaluations of traffic controls for three highway construction projects were conducted. These evaluations consisted of reviews of the traffic control plans, field checks of the implemented traffic controls, and observation of actual motorist behavior in response to the work area traffic controls. The project sites included suburban interstate, urban arterial, and rural highway locations. Field data were collected to develop spot speed characteristics, traffic flow rates, overall and average running speeds, and acceleration noise and mean velocity gradient profiles. Based on these evaluations, guidelines were developed to assist in the design and operation of more effective work area traffic control.

The research indicated some motorist confusion with work zone traffic, traffic control plans frequently not developed with full consideration of actual site conditions, unreliable motorist response to advisory speed signs, inadequate design standards for on-site detours, and problems with maintaining traffic control devices.

Traffic control plans should be as simple as possible and overuse of traffic control devices should be avoided. Traffic control plans must reflect actual site and traffic conditions for maximum effectiveness.

Since motorist compliance with advisory speed reductions are difficult to predict, traffic control plans should be designed such that speed reductions are not required. In traffic control zones where speed reductions are critical to safe operations, consideration should be given to the use of positive measures of speed control to supplement advisory speed signing.

Because on-site detours often result in undesirable traffic operating characteristics, they should be avoided whenever possible. If unavoidable, they should exhibit design standards equal to those of the facility from which traffic is being detoured.

159. Van Winkle, J. V. and Humphreys, J. B.; "Effectiveness of City Traffic - Control Programs for Construction and Maintenance Work Zones," Transportation Research Board Record 833, 1981.

The state of the art of city traffic-control programs for construction and maintenance work zones was evaluated. A questionnaire survey revealed that the amount of importance cities place on traffic-control programs for work zones varies widely and the majority of the cities surveyed do a less than adequate job in controlling construction and maintenance activity. Work zones were studied in eight cities and it was determined that the quality of traffic control in the work zones is dependent on the degree of involvement the cities have in regulating construction and maintenance work zones.

160. Wang, J. J. and Abrams, C. M.; "Planning and Scheduling Work Zone Traffic Control - Technical Report," FHWA-RD-81-049, August 1981.

Accident data were summarized at 109 sites in 11 states, counties, and cities before and during construction. Data were classified by area and road type. There was a substantial variability in accident changes with 40 sites showing a decrease in accidents, six with no change, and 63 sites showing an increase during construction. Considering all data, there was a 28 percent increase in accidents during construction.

161. Warren, D. L. and Robertson, H. D.; "Research in Work Zone Traffic Control: Status Report," ITE Journal 1979.

A summary of major findings of prior research dealing with work zone safety was summarized as well as ongoing research. Following is a listing of some of the findings given:

1. A study of 79 construction sites in seven states revealed that the accident rate increased 6.8 percent during construction.
2. The presence of an enforcement vehicle was noted as the only method that reduced speeds, erratic maneuvers, and conflicts.

3. A time of 10.2 to 11.7 seconds was determined as being required to detect and recognize a channelizing device, decide what to do, and maneuver properly.
4. A study estimated that approximately two-thirds of work zone safety problems could be ameliorated if current standards and knowledge were properly applied.
5. Arrow boards were found to promote earlier merging in lane closure work zones. It was most effective when placed on the shoulder either at or upstream of the start of the taper.

162. "Ways to Increase Work Zone Safety", Better Roads, April 1986.

Various methods of improving traffic control were discussed in the general areas of:

1. pavement markings,
2. barricades,
3. cones and tubes,
4. plastic drums,
5. barriers,
6. screens,
7. shadow vehicles,
8. crash cushions, and
9. signs.

163. Williams, W. L. and Niessner, C. W.; "Take It All Off," ITE Journal, November 1979.

Various methods of stripe removal were evaluated. Chemical methods and high temperature burning were found to offer the most economical and rapid method of removal of pavement markings. However, the success of these methods was limited by the thickness of the paint stripe. A solution to the thick paint problem is to use a combination of a grinder and chemical methods.

164. "Work Area Protection - Guidelines for Public Utilities," American Right of Way Association, Inc., Buckeye Chapter No. 13, undated.

A manual was prepared for use by utility workmen in preparing traffic control at utility work sites. The major sections include: 1) planned work area protection check list, 2) description of equipment, 3) flagmen instructions, and 4) typical work area arrangements.

165. Wunderlich, R. C. and Dudek, C. L.; "Operational Guidelines for Short-Term Total Freeway Closures", Texas Transportation Institute, Report 292-5, August 1984.

Maintenance or construction work which requires closing all the main lanes of an urban freeway creates a need for special traffic management techniques. Field studies were conducted at three freeway closures in Houston to observe traffic operations and identify problem areas and successful management strategies. All three closures were undertaken as part of the sequence of work on construction projects. This report presents general operational guidelines and recommendations based upon the findings of the three field studies. The guidelines are not intended to provide information on all aspects of traffic control at freeway closure work zones. Rather, they were intended to supplement standard work zone traffic control procedures. The guidelines are organized into four broad categories: Advance Planning; Advance Notification; Traffic Management; and Law Enforcement.