

contractor each should assign at least one person on each project to have day-to-day responsibility for assuring that the traffic-control plan is implemented and that any needed operational changes are made. For smaller contracts, the agency and the contractor may assign more than one project to their respective employees.

- Highway agencies should conduct or sponsor training programs that emphasize traffic safety techniques as an integral part of construction and maintenance activities for those who are responsible for the design, implementation, and inspection of traffic-control practices and procedures. This should include those persons who are actually doing the work of setting up and taking down traffic controls. Flaggers should be well trained and understand what they are to do and how drivers can be expected to respond. The job is too important and hazardous to be assigned to an inexperienced person.

- Records of traffic accidents should be maintained and analyzed as a guide to improving the work-zone operation. Every effort should be made to make an engineering analysis of all injury-producing accidents occurring within the work zone. The work zone should be monitored to identify and analyze minor traffic accidents or conflicts and telltale marks left by conflicts, such as skid marks or damaged traffic-control devices, in order to determine needed changes in the traffic-control setup and to gain insights for future projects.

- Work sites should never present a surprise to the motorist. Thus, frequent or abrupt changes in geometrics should be avoided. Well-delineated transitions, long enough to accommodate driving conditions and the speeds vehicles are realistically expected to travel, should be provided at lane drops, reductions in roadway or lane width, detours, etc.

- The roadway should be kept clear of obstacles as much as possible. Flaggers, other workers, and objects such as traffic-control devices and construction equipment should not be permitted in the roadway except when their useful presence clearly outweighs the hazards they present.

- Obsolete pavement markings should be removed in such a manner as to eliminate any misleading cues to drivers under all conditions of light and weather. Where temporary pavement markings are required, consideration should be given to use of highly visible markings that can be easily placed and removed, such as raised reflective markers. On very short-term maintenance projects, removing existing markings for the projects' duration may be more hazardous to both workers and motorists than leaving the existing—and temporarily misleading—markings in place. If so, special attention must be paid to providing additional guidance by other traffic control measures to overcome the misleading effect of the markings left in place. Special treatment should be given to areas where a joint between pavements of different colors or textures may create a misleading cue.

- All devices used in the traffic-control setup should be clearly visible to motorists at all times. This means they must be adequately reflectorized or illuminated, as appropriate, and kept clean and in good repair. All devices should be removed immediately when no longer needed. Signs that do not apply to the existing conditions should be removed, completely covered, or turned so as not to be read by passing motorists.

- Areas outside the travelway should be designed to accommodate errant vehicles. Equipment, materials, and debris should be located as far from the roadway as possible, and protected by effective, safe barriers when within 30 ft of the roadway. Barriers are warranted only at work site locations where the severity of a collision with a roadside feature would be greater than with the barrier or where encroaching traffic may threaten worker safety.

- All vehicles, including workers' and contractor's, should be prohibited from parking adjacent to the traffic lanes. Special parking areas, well out of the recovery area, should be designated.

- Provisions should be made for disabled vehicles or other emergency situations on all but the shortest projects. If it is impossible to provide a continuous, substantial shoulder throughout the project, other alternatives should be provided, such as periodic turn-outs or heavy patrolling of the project.

- When a traffic-control plan has been decided on, a public information campaign should be conducted to alert motorists. The amount and type of effort will depend on the type of control (short time, off-peak periods, etc). In addition, cooperation of the responsible enforcement agencies should be enlisted.

- Work sites should be carefully monitored under varying conditions of traffic volume, light, weather, etc., to ensure that traffic-control measures are operating effectively.

TRAINING

The growing awareness of the importance of traffic controls at construction and maintenance work sites has generated a number of training courses, developed on a national or local level.

National Highway Institute. A comprehensive course titled "Traffic Control for Street and Highway Construction and Maintenance Operations" was developed in 1975 under the sponsorship of the National Highway Institute, FHWA, by Byrd, Tallamy, McDonald and Lewis, Consulting Engineers, and has been presented throughout the United States. The present course offers a comprehensive 3-day technician training program dealing with the planning, design, installation and removal, operation, and evaluation of traffic-control systems at construction and maintenance work sites.

Institute of Transportation Engineers. A training course series titled "Traffic Control Through Construction and Maintenance Work Areas" is being offered by the Institute of Transportation Engineers as a part of its traffic technician "Curriculum 200" series. The courses are being offered as packages of materials including workbooks, audio-visual slides and cassette tapes, and other training aids. Topics included in the training courses are Roadway Signs and Markings, Work Area Traffic Control, Work Area Flagging, Guidelines, and Applications of Traffic Controls in Work Areas.

University of Tennessee. The Department of Civil Engineering, University of Tennessee, also has developed a series of seminars concerning "Traffic Control in Construction and Maintenance Areas." The seminars, which have been presented in a number of locations throughout the State of Tennessee, provide a 1-day program of instruction for supervisors and foremen on the design of traffic-control device systems that will meet motorists' needs as well as applicable state laws and city ordinances. An alternative seminar, presented in one-half day and structured for owners and managers of construction organizations and public agencies, presents information on the need for adequate signing techniques and explores the legal problems that may be encountered as a result of inadequate or improper traffic-control devices.

American Traffic Services Association. The American Traffic Services Association (ATSA), a division of the American Road and Transportation Builders Association, has prepared an audio-visual training package titled "Night

Safety at Work Sites." This 20-min slide and cassette package discusses the need for and proper use of lighted traffic-control devices at night work sites.

ATSA also has developed a two-and-one-half-day training program that is part of their certification program for Work Site Traffic Supervisors. This program is presented periodically at various locations throughout the country and is aimed at training the field supervisor.

Federal Highway Administration. Several slide/tape packages have been developed by FHWA, including "Temporary Barriers in Construction Zones" and "Barricades in Construction Zones."

The FHWA office of Highway Safety plans to develop a training course in the area of construction and maintenance. The course would be developed and presented at the Transportation Safety Institute in Oklahoma City. The present thinking is that the course would be designed for the resident or project engineer and utility company foreman level.

The FHWA Traffic Management Planning Course is a demonstration project developed to provide training to FHWA and state highway personnel in the processes used to develop, implement, and enforce traffic control and safety measures. The training is intended to provide sufficient expertise at the state level to initiate demonstration of traffic management plans on major highway rehabilitation projects.

States. At least ten states have developed training materials including movies, slides, and tapes on traffic controls at construction work sites. A partial list of these training aids includes:

Alabama -	Maintenance Safety Procedures - A slide and tape presentation prepared by the Alabama Highway Department and Roy Jorgensen Associates, Inc. Coverage includes work area safety, maintenance needed and condition reporting, correcting hazardous conditions, and accident and hazardous debris control.
California -	Work Area Protection - 20-min 16-mm color film.
Florida -	Traffic Controls and Safe Practices for Street and Highway Construction, Maintenance and Utility Operations—Consists of 348 slides and small magnetic signs.
Louisiana -	Traffic Control Through Maintenance Work Sites - An audio-visual (197 slides and 5 cassette tapes) course prepared by the LDH Training Unit.
Nebraska -	Flagman Training for Highway Maintenance Personnel - 54 slides and script.
Nevada -	Breakaway Barricade - 20-min 16-mm color film.
North Carolina -	Signing of Work Sites; Construction and Maintenance - Script.
Pennsylvania -	Classification, Use, Erection and Maintenance of Signs - Lesson plan and course outline developed by the Bureau of Maintenance.
Texas -	Traffic - Video tapes and slides for traffic short course and signing.
Utah -	The Flagman - 25-min 16-mm color film.
Wyoming -	Work Site Safety - A self-instructional slide and audio tape presentation.

RESEARCH

Summary of Research Results. There have been several studies that deal either directly or indirectly with construction-zone traffic-control devices, design, and operations. Some of the conclusions resulting from those studies are as follows:

1. Activities located on a roadway generally reduce the amount of roadway available for vehicular travel. Even construction activities taking place off the roadway can also affect travel. Likewise, motorists' curiosity tends to slow down the traffic stream while entering or traveling through a construction area.

2. Motorists often become irritated if construction activities linger on, with the resultant effect being a loss of respect for the traffic control.

3. A review of literature has identified several principles that should be considered in the design of a construction zone: (a) transition areas should be as nearly like the approach as possible and any difference should be clearly apparent; (b) tapers for a lane drop should not be contiguous with a median crossover for a temporary by-pass roadway transition; (c) it is generally better to use flat, diagonal median crossovers rather than reverse curves having extensive superelevation; (d) the effective width of a traffic lane will be reduced by lateral obstructions located closer than 6 ft from edge of pavement; (e) a reduction in one geometric standard can generally be compensated by improvements to another.

4. The volume of traffic on a roadway will affect the selection of types of traffic control to be used in a construction zone. One study has developed the following guidelines:

For two-lane roads (both directions) —

If ADT is less than 1,500 or if the peak-hour traffic is less than 150, maintain one lane.

If ADT is greater than or equal to 1,500, or if the peak-hour traffic is 150 vehicles or more, maintain two lanes.

For four-lane undivided roads (both directions) —

If ADT is less than 10,000 or if peak-hour traffic is less than 1,000, maintain one lane in each direction.

If ADT is 10,000 or more, or if peak-hour traffic is 1,000 or more, maintain three lanes (two in heavy direction).

5. The purpose of using standard signs in construction zones is to assist or direct the driver in making appropriate speed and path decisions. Because a driver can assimilate only a limited amount of information, it is preferable to use only one message per sign. Signs should not clutter the driving environment, and if they must function during darkness they should be as visible as they are during the day.

Accident Studies. A 1965 California accident study of 10 randomly selected construction projects indicated that the total accident rate increased 21.4 percent during construction. Also noteworthy is that the fatal accident rate increased 132.4 percent during construction. A later study of 31 construction projects was made in 1970 after many new

principles for handling construction-zone traffic were put into practice. The results of the two California studies indicate that the new principles may have had some very positive effects. In the second study, the total accident rate increased only 7 percent and the fatality rate decreased 4 percent. However, it is not possible to verify the statistical comparability of these results.

An unpublished report from another state provided results similar to the 1965 California study. The data were for 207 resurfacing projects on two-lane highways and indicated a 61 percent increase in total accidents, 67 percent increase in injury accidents, and a 68 percent increase in fatal accidents during construction. The only conclusion of this analysis is that construction zones for resurfacing projects on two-lane highways appear very hazardous for that one state. What is not resolved is whether these kinds of projects are intrinsically hazardous or whether that state's construction-zone traffic-control practices are inadequate to meet optimum safety requirements.

A report by the Virginia Highway and Transportation Research Council regarding the safety practices in the construction zone of I-495 in northern Virginia indicated a 119 percent increase in the accident frequency, compared to a preconstruction baseline. As in the 1965 California study, the I-495 construction project experienced a large increase in fatal and injury accident rates (320 percent and 35 percent, respectively). The report also noted that although the frequency of accident occurrence was increased along the entire project length (22.1 miles), interchanges and transitional areas experienced an even higher increase. Of the reported accidents during construction, 52.5 percent involved vehicle contact with timber barricades. Among barricade-involved accidents, 73.5 percent involved vehicles that straddled or penetrated the barricades.

Current Research Activities. A number of researchers are actively engaged in studies to improve the safety of the traveling public and workers in construction and maintenance areas. Work is either under way or planned in the following areas:

1. Improvements in accident identification and analysis systems.
2. Development of improved methods for planning and scheduling work-zone traffic controls.
3. Developing guidelines for the improved use of existing standard devices.
4. Development and evaluation of improvements in channelizing devices.
5. Development of safer barriers.
6. Need and application of flashing and steady-burn lights.

Research in progress related to the safe conduct of traffic through construction zones includes:

- "Evaluation of Traffic Controls for Street and Highway Work Zones," NCHRP Project 17-4. This project is to determine the effectiveness of selected types of work-zone traffic-control devices and to determine how these devices should be designed and used to guide drivers as they approach and proceed through a work zone. The research will be restricted to stationary work zones and not consider moving operations. Consideration will be given to worker safety requirements in the installation and maintenance of the traffic-control devices. Evaluations will include day/night, illuminated/nonilluminated, and urban/rural environments. Specific items to be studied include: markings for barricades and channelizing devices; use, size, and spacing of barricades and channelizing devices; need and use of flashing and steady-burn lights; and field evaluations.

- "Methods to Remove Pavement Markings," AAI Corp., Southwest Research Institute, and Midwest Research Institute, sponsored by FHWA. These three agencies are to develop an improved method for removing unwanted thin pavement markings without leaving a noticeable trace of delineation or misleading scar.

AAI Corporation is developing a removal method that involves scoring of the paint stripe followed by removal with pulsed water jets.

Southwest Research Institute developed a process for stripe removal that involves use of high-temperature burning with excess oxygen. In this method a high-temperature flame of propane and oxygen is directed at the pavement marking. A second burner tip directs pure oxygen at the burning surface, which aids in the oxidation/decomposition of the marking material. The result is a rapid flash burning of the marking material with little damage to the pavement. The resulting ash or remnants of the pavement marking are brushed from the surface.

Midwest Research Institute developed a removal method that involves burning of the paint stripe followed by mechanical removal of the residue.

- "Construction Zone Delineation—Raised Pavement Markers," states of Arkansas, Kansas, Massachusetts, Minnesota, North Carolina, Oregon, Pennsylvania, and Washington. Projects in these states will evaluate the use of raised day/night reflective pavement markers as a means of providing improved delineation through construction zones.

- "Evaluation of the Performance of Precast Concrete Traffic Barriers," Virginia Highway and Transportation Research Council. The purpose of this study is to evaluate the performance of the precast concrete traffic barrier used as a traffic-control device to separate high-speed vehicular traffic and construction activities. The specific objectives of the study are to evaluate (1) the efficacy of concrete barriers used in a traffic-control system to provide protection for motorists and workmen, and (2) the effects of the concrete barrier on traffic characteristics.

Future Studies. The following studies are planned for research in the near future:

- "Guidelines for Application of Arrow Boards in Work Zones," FHWA. The objectives are to develop guidelines for the application of arrow boards in work zones with respect to (1) the conditions under which the devices should be used, and (2) where in the zone the devices should be placed so as to provide for the safe and efficient movement of traffic.

- "Planning and Scheduling Work-Zone Traffic Control," FHWA. This study is to develop a procedure for (1) estimating the consequential costs of alternative work-zone strategies under varying traffic demands and environmental conditions, and (2) selecting the appropriate strategy for the given demands and conditions.

- "Identification of Traffic Management Problems in Work Zones," FHWA. The objective is to identify and define the problems associated with the movement of traffic through work zones.

- "Evaluation of MUTCD and Other Traffic Controls for Highway Construction and Maintenance Operations on Two-Lane Highways," FHWA. Experiments are planned at FHWA's Maine facility to evaluate various methods of controlling traffic during construction or maintenance operations on two-lane rural highways. The experiments will be conducted with the following two types of construction or maintenance operations: (1) Work requiring the closing of one

lane for a considerable length of roadway so as to require the use of flagman or traffic signals; and (2) Work requiring the closing of one lane for such a short distance that traffic is self-regulating. Three different traffic-control strategies are planned for each condition.

- "Field Evaluation of Four APWA Setups for Construction and Maintenance Worksites," FHWA. The objective is to evaluate four of the setups developed by APWA for controlling traffic through construction or maintenance work sites. The four setups are related to work sites in the vicinity of at-grade intersections.

- "Development of Safe Barriers for Construction Sites," FHWA. This study is to develop new barriers and their end treatments for use at construction sites so as to provide needed protection to the motoring public and the construction workers. The study will attempt to upgrade the safety performance of existing barrier systems and their end treatments for use at construction sites and explore new design concepts. Barricades that show promise of being successfully upgraded to barrier status will be included in this effort.

- "The Collection of Construction Work-Zone Accident Data," FHWA. The objective is to establish an effective accident collection procedure for highway work zones that would relate accident factors to deficiencies in traffic control.

- "Driver Visual Search in Construction and Maintenance Zones," FHWA Staff Study. The purpose of this study is to determine driver visual search when traveling through construction and maintenance zones.

- "Traffic Management in Construction and Maintenance Zones," FHWA. The objective is to formulate and test safe methods for controlling and directing traffic in and through construction and maintenance zones. A program of experimental laboratory and field studies will be undertaken to form the basis for the development of new concepts, methods, and approaches to traffic management in construction and maintenance zones. Emphasis will be placed on identifying, understanding, and designing signs and marking systems, based on the use of sound human factors principles, that will (1) permit drivers to readily and safely travel through the work areas, (2) provide maximum safety for the construction workers, and (3) not adversely affect construction operations. Recommendations and guidelines will be developed relative to the use of devices and techniques to control traffic in work zones. All recommended guidelines will also consider the economics, maintenance, and enforcement factors associated with implementation.

LEGAL ASPECTS

The legal implications of a highway department's efforts to conduct traffic safely through construction or maintenance activity zones are extremely important. Because these functions generally are performed at the maintenance or operational level, as distinguished from the planning or policy-making level, the highway department is more likely to be held liable for negligence. Moreover, highway employees who are performing maintenance functions (so-called ministerial tasks) may be held personally liable for their negligence. For example, highway departments or their employees have been held liable for their negligence in leaving excavations unguarded; using or permitting misleading highway signs, signals, or markings; or failing to provide adequate warning of dangerous highway conditions or locations.

Discussion of uniform standards for highway construction and maintenance zones has particular legal significance, because the existence of standards may have a profound impact on the highway department in tort litigation. First, safety codes or standards are admissible into evidence in a majority of states. Thus, safety standards, particularly where the highway department has adopted them, may be offered to show the standard of care that the department should have followed and to prove that it deviated from its own self-imposed standards, thereby causing injury or death on the highway. Second, where the standards are mandatory and not merely directory or discretionary, they may be used to stamp the department's conduct as negligent without any further required showing or proof of negligence (*negligence per se*). Because of its possible use against the highway department, the safety standard, of course, should be given careful scrutiny before its adoption. Similarly, the absence of any standards might be cause for an agency to be considered negligent.

BIBLIOGRAPHY

As part of the work on this synthesis topic, a bibliography consisting of 211 items related directly or indirectly to traffic safety in construction and maintenance zones was compiled. A copy of this bibliography may be obtained at a cost of \$2.00 by sending a check or money order, payable to the Transportation Research Board, to Mr. L. M. MacGregor, Administrative Engineer NCHRP, Transportation Research Board, 2101 Constitution Ave. N. W., Washington, D. C. 20418.