to provide warnings by signals, signs, or other markings.

With respect to traffic lights, authorities are split as to whether the state or other public agency is liable for failure to erect them, but most jurisdictions hold that the decision to provide or not to provide traffic lights is either the exercise of immune discretion or the performance of a purely governmental function.

An analysis of the traffic-light cases appears to support the following main conclusions:

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

Considerable interest has been expressed concerning the liability of states arising out of pavement markings. State highway departments have been held liable for accidents caused by improper, inadequate, or misleading pavement markings, as noted earlier.

In a New York case [Dowley v. State, 61 N.Y.S. 2d 59 (Ct. Cl. 1946)], the claimant sued for negligence of the state in construction, maintenance, and safeguard of a state highway. Because of the surface appearance, the road appeared to proceed straight ahead, when, in fact, it curved to the east. No caution, slow, stop, curve, or other sign was on the highway. Moreover, no white line in the center of the highway indicated the highway curve. The court held that the evidence sustained a finding that the curve was dangerous and that the state was negligent in failing to provide proper warnings, barriers, and markings. Special pavement markings are not required at an intersection where, for example, the evidence does not establish the existence of a hazardous or dangerous condition. However, the highway department may be held liable for installation of highway signs that are themselves misleading and dangerous, or for failure to mark the pavement adequately to warn that a four-lane road becomes two lanes, for example.

Finally, states may have certain rules and regulations governing the installation or provision of signs, signals, or pavement markings. These regulations, and more particularly, the Manual on Uniform Traffic Control Devices, generally are admissible into evidence. The courts have held that the regulations are either evidence of the standard of care that should have been used or evidence that the department has failed to meet its own safety standards [State v. Watson, 7 Ariz. App. 81, 436 P. 2d 175 (1968)].

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Status of Traffic Safety in Highway Construction Zones

Robert J. Paulsen, Howard Needles Tammen and Bergendoff, Kansas City, Missouri
Douglas W. Harwood and Jerry L. Graham, Midwest Research Institute, Kansas City, Missouri
John C. Glennon, Transportation Consulting Engineer, Overland Park, Kansas

Evidence is increasing that existing traffic-control practices do not always provide an adequate level of safety in construction zones. Synthesis of a number of accident studies reveals that the total accident experience in construction zones increases from 2 to 119 percent during the period of construction. The literature synthesis also indicates that the increases in accident experience are highly related to construction activity. A study in one state shows that accident experience decreases dramatically when construction-zone traffic-control practices are improved. The paper identifies methods by which more effective planning, design, and management of construction zones can improve traffic safety.

Highway construction zones provide traffic engineers with perhaps the greatest challenge in traffic control they face on any segment of the American highway system. Traffic control in a construction zone must permit the safe and efficient movement of traffic through the zone and at the same time provide a safe work area where construction activity can be conducted efficiently. The traffic-control plan must be tailored to fit not only the changing demands of traffic but also the changing demands of construction activity. Evidence is increasing that existing traffic-control practices do not always provide an adequate level of safety in construction zones.

The traffic-control devices used for highway maintenance and construction operations are specified by Part VI of the Manual on Uniform Traffic Control Devices (MUTCD) (1). These include regulatory and warning signs, hazard beacons and other lighting units, barricades, traffic cones, and flagpersons. MUTCD prescribes minimum standards for the application of these devices but does not relate the selection of a complete set of traffic controls to the geometric and traffic requirements of specific construction zone situations. In addition, new devices that are not included in the MUTCD, such as flashing arrow panels, have come into common use. Therefore, traffic engineers need a more comprehensive and formal procedure for establishing construction-zone traffic controls.

THE PROBLEM

Many construction projects are undertaken to reduce the number of accidents. An increase in accidents during construction activity may be inevitable on some projects, but construction-zone traffic-control practices should be adequate to ensure that the long-term accident reduction benefits are not inordinately offset by higher short-term accident rates during construction. The basis for evaluation of traffic safety in construction zones must be a comparison between accident experience before and during construction activity. Several such comparisons have been made.

The results of a 1965 study (2) of 10 randomly selected construction projects in California indicate that the total accident rate during construction increased by 21.4 percent above the rate experienced before construction. Even more alarming was the increase in the fatal accident rate of 132.4 percent during construction. After improved construction-zone traffic-control practices were put into effect, a second study of 31 projects made in 1970 showed an increase of only 7 percent in the total accident rate and 1.6 percent in the fatal accident rate. This important finding demonstrates the strong influence of traffic-control practices on construction zone safety.

Information furnished by the Georgia Department of Transportation on 207 two-lane highway resurfacing projects in Georgia shows a 61 percent increase in total accidents, a 67 percent increase in injury accidents, and a 68 percent increase in fatal accidents during construction.

Lisle, in a paper in this Record, presents the results of a recent comparison by the Virginia Highway and Transportation Research Council of the traffic-control practices in a construction zone on I-495 in Northern Virginia. He indicates a 119 percent increase in accident frequency over the preconstruction baseline. This project also experienced large increases in fatal and injury accident rates of 320 and 35 percent, respectively. However, the accident severity distribution shifted more toward property-damage accidents. The Virginia study also noted that, although the accident frequency increased throughout the 35.6-km (22.1-mile) project, interchanges and transitional areas experienced the highest increases.

Another recent study (3) analyzed the reports of nearly 3000 accidents that occurred in 21 construction zones on rural Interstate highways in Ohio. Accident experience before and after the construction activity were also analyzed and the following conclusions were made:

1. Accident rates before construction were lower than those during construction but higher than those after construction.
2. Safety upgrading construction projects on the rural Interstate system of Ohio generate traffic accidents, but these accidents are primarily minor in nature.
3. During the construction period, construction-related accidents are less severe than non-construction-related accidents.
4. A large number of improper merge and sideswipe accidents were in lane taper areas, occurred at night, and involved vehicles of the tractor trailer-bus class.
5. Many rear-end accidents were in lane closure areas, occurred during the daylight hours, and involved automobiles and motorcycles.
6. Large numbers of single-vehicle fixed-object accidents involved drums used for lane tapers and lane closures.

A recent study performed by Midwest Research Institute (4) for the Federal Highway Administration (FHWA) evaluated accident rates before and during construction on 79 projects in seven states. Conclusions from this study included the following:

1. The 79 construction zones experienced an average increase in accidents of about 7 percent; however, 31 percent of the projects experienced decreased accident rates during construction (this assumes that traffic volumes are equal before and during construction). Twenty-four percent of the projects experienced increases in accident rates of 50 percent or more.
2. Based on detailed analysis of three construction zones that experienced increased accident rates during construction, the increase in accidents was highly related to the construction.
3. Short duration and short-length construction projects experience higher accident rates. This finding may be the result of a concentration of construction-related accidents in lane taper and transition areas.
4. Bridge work and roadway reconstruction experienced the largest increases in accidents of any construction projects.
5. Although the accident rate was higher for urban construction projects, the percent of increase in accident rates was nearly equal for rural and urban projects. Accident rates for rural projects do, however, vary more than those for urban projects.
6. The number of night accidents increased during construction, but the proportion of night accidents to total accidents remained the same.
7. 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.
8. The presence of construction zones is more likely to increase fixed-object, rear-end, and head-on accidents but decrease right-angle, turning, and ran-off-road accidents.
9. The fixed-object accident rate is higher in stationary construction zones than in zones where traffic controls are moved periodically (daily, weekly, monthly).
10. Construction zones where speed limits have been reduced do not experience lower accident rates than other zones.

Finally, safety problems related to construction and maintenance activity involve construction workers as well as motorists. For example, data from the National Safety Council (5) indicate that state highway workers experience 1.7 times the all-industry average of work injuries per million person-hours worked. Street and maintenance workers in municipalities experience 5 times the all-industry average.

The total accident experience in construction zones has been observed to increase from 2 to 119 percent above that of the period before construction. Case studies by Midwest Research Institute found that such increases are highly related to construction activity. Coupled with the California finding that the number of accidents decreased dramatically when construction-zone traffic-control practices were improved, this indicates a great potential for increasing traffic safety in construction zones.

IMPROVEMENT OF TRAFFIC SAFETY IN CONSTRUCTION ZONES

Traffic safety in construction zones can be improved by two methods: (a) more effective planning and design of construction zones and (b) more effective management and operation of construction zones. Planning and design include those actions taken before construction begins to ensure that the most appropriate traffic-control devices are used in the most effective manner. Management and operations include those actions taken during the construction period to ensure that the traffic-control plan is adhered to or modified to be responsive to the changing demands of traffic and construction activity. More effective planning and management of construction-zone traffic control are needed to obtain an improvement in construction-zone accident experience.

PLANNING AND DESIGN OF CONSTRUCTION ZONES

Traffic-control plans and specifications are essential to provide safe and effective traffic control during construction, just as appropriate designs, plans, and specifications are necessary to successful construction of a roadway improvement. There are five logical steps that should be part of the construction-zone planning and design process:

1. Determine basic conditions, including construction plans, roadway geometrics, and traffic data;
2. Select the basic zone type and scheduling;
3. Formulate speed control strategy;
4. Determine geometric design elements; and
5. Select traffic-control devices and methods.

Basic Conditions

Before a traffic-control plan can be made, the basic conditions that will exist in the construction zone should be identified. Three categories of data are needed: construction data, roadway data, and traffic data. This information provides the foundation for the remainder of the planning and design process. The construction data needed include (a) the lateral location, (b) the longitudinal extent (length), and (c) the expected duration of construction activities.

The lateral location of construction activities determines the degree of interference with normal traffic operations. For example, activities located on the roadway reduce the amount of roadway available for travel. The extent of the impact on traffic operations depends on whether all or just a portion of the roadway is involved. Activities above or adjacent to the roadway and shoulder can also affect travel because curious motorists tend to slow the traffic stream as they enter any construction area (6). Overpass construction, installation of traffic-control devices, public utility construction, and even high-rise building construction can restrict traffic operations. Construction above the roadway may also affect truck traffic due to clearance problems (7).

Side effects of construction activity adjacent to the roadway may also influence traffic operations. Noise and dust are two such side effects. Dust can reduce capacity and create safety problems due to decreased visibility. Excessive noise can cause safety problems for both the motorist and the construction crew. Even when motorists' loss of hearing is minimal, communication among workers, and especially between flagpersons, can be seriously hampered by excessive noise. Therefore, flagpersons should not depend on verbal communication but rather should employ hand signals where excessive noise is expected.

Construction activity on the shoulder of the roadway, such as shoulder reconstruction and addition of lanes to the roadway, will usually affect traffic operations, depending on the amount of lateral clearance between obstructions and the edge of the traveled way. As the lateral clearance is reduced, vehicles tend to both shy away, reducing the available roadway, and slow down (8). This decreases the level of traffic service, decreases the capacity that could be critical under high-volume conditions, and may increase the accident potential through the creation of large speed differentials.

The length of a construction zone can affect the traffic operations in several ways. Short construction zones were found to have higher accident rates than long construction zones; however, drivers in excessively long zones could lose the awareness required to pass safely through the zone. Therefore, drivers should be reminded of the prevailing conditions repeatedly. For example, when a median crossover is used on a divided highway the MUTCD states that a "Two-way traffic sign should be used as needed at intervals to periodically remind drivers that they are on a two-way highway which contains opposing traffic." This is especially necessary for traffic in the direction that does not cross over the median. Often, when the zone is excessively long, large areas within the zone have no visible construction work for days or weeks. Drivers are unlikely to maintain reduced speeds and the required attentiveness when they do not see construction activity (9).

Longer construction zones may lead to higher frequencies of accidents due to the increased exposure. As the length of zone increases, the probability of a vehicle requiring an emergency stop also increases. If shoulders are eliminated and no other place is provided for emergency stops, the vehicle will be forced to stop in the traffic lane, thus becoming vulnerable to rear-end accidents (9). Longer construction zones usually require more traffic-control devices, thus increasing the probability of a hazardous condition if they are not maintained properly (9). In the determination of an appropriate construction zone length, it is important to consider the trade-off between the higher accident rates in short zones and the increased accident exposure in long zones.

The duration of construction activity affects traffic operations and safety in a construction zone in several ways:

1. A long construction period naturally involves greater traffic exposure to construction conditions than does a short construction period. This increased exposure can lead to an increased number of construction-related accidents.
2. Longer construction periods are more likely to involve traffic-control changes in response to the changing demands of construction activity.

One source indicates that motorists usually take a week to become accustomed to different traffic situations (7). As the duration of the construction activity increases, however, local drivers tend to become so familiar with the new conditions that they become complacent. Motorists often become irritated if construction seems to linger on, and they may lose respect for the traffic control (6).

The second category of data needed is roadway data, such as roadway cross-section, number and width of lanes, shoulder width, roadside obstacle clearance, median width, and horizontal and vertical alignment. These data are necessary to determine the type of work area and the roadway geometrics for the construction zone. For example, alignment and median width are important factors in determination of the location and geometrics of a median crossover. Also, the location of existing traffic-control devices, such as signs, signals, and markings, must be known so that they can be altered or deleted if necessary. In general, the same data required to design a new roadway should be employed in the design of the construction zone.

The third kind of data needed for construction-zone planning is traffic data. The normal traffic volume on the roadway will affect the ability to use various traffic controls in construction zones. Average daily traffic (ADT) is most often used in construction-zone planning, but as volumes become more critical, the amount of traffic during peak hours must also be considered. A previous study has established the following guidelines based on traffic volumes (6).

For two-lane roads (both directions):

1. If ADT is less than 1500 or if the peak-hour traffic is less than 150, maintain one lane; or
2. If ADT is greater than or equal to 1500 or the peak-hour traffic is 150 vehicles or more, maintain two lanes.

For four-lane undivided roads (both directions):

1. If ADT is less than 10 000 or peak-hour traffic is less than 1000, maintain one lane each direction; or
2. If ADT is 10 000 or more or peak-hour traffic is 1000 or more, maintain three lanes (two in the heavy direction).

The composition of the traffic flow is also important in the geometric design of a construction zone. Trucks and buses require wider lanes, and a large number of motorcycles may discourage use of rumble strips. Information on the number of pedestrians and their paths through the construction area is important so that construction, traffic, and pedestrians can all be separated and protected.

Various measures of vehicle speed are important to determine the required speed control strategy during construction. The posted speed limit is usually the most accessible piece of information but may not directly relate to actual operating conditions. A spot-speed study on the approach to the zone may be useful.

A good traffic-control plan should also reflect the accident experience of the zone before construction. Locations that have experienced a large number of accidents before construction may have particular problems that should be analyzed and addressed by the plan.

Basic Zone Selection and Scheduling

Once the basic conditions of construction, roadway, and traffic data are established, the type of zone and scheduling of the construction can be determined. The fundamental planning problem is one of separating the traffic and the construction activity. These activities can be separated in either space or time or both. Separation in space is accomplished by lane closure, crossover, temporary bypass, detour, or roadside work zone.

For a lane closure the construction in the work area uses one or more lanes of the roadway, leaving the remaining lanes open to traffic.

For a crossover traffic is channeled into one or more lanes of the roadway normally used for traffic in the opposite direction. On divided highways a temporary or existing connection through the median between the two directional roadways is used to channel traffic to the opposite side. On undivided roadways traffic is channeled across the old centerline of the roadway so that both directions of traffic are using the same side of the roadway.

For a temporary bypass a temporary road is built to carry traffic around the work area. The temporary bypass roadway may be either one-way or two-way.

For a detour the roadway is completely closed for either one or both directions and traffic is rerouted onto alternate routes.

For a roadside work zone the existing roadway is used but with some restrictions placed on it. An example would be shoulder work in which all traffic lanes are maintained.

Separation in time is accomplished by restricting the time that either the traffic or construction activity can occupy a specific section of roadway. A common strategy is the restriction of construction activity during hours of peak traffic flow. In other cases traffic is stopped for a period of time while construction activity occupies the traveled way. Another application of traffic pacing is the use of slow-moving lead vehicles to block all lanes of a roadway to create a gap in traffic so short-term construction activities can be done at the work site. In this case, the pacing is actually a way of time separation rather than a speed control strategy.

Speed Control Strategy

The third step in the planning and design of construction zones is the formulation of the speed control strategy. Two philosophies of speed control through construction zones are currently in widespread use. One philosophy says, "Speed in the construction zone should be similar to the speed on the highway before the start of the construction zone," and argues that changes in speed, per se, and large speed differentials, in particular, produce accidents. The second philosophy says, "The speed of traffic should be reduced in construction zones." This philosophy is based on the opinion that construction zones are intrinsically more hazardous than other sections of roadway and, therefore, traffic speeds should be reduced to provide a reasonable degree of safety for motorists and construction personnel. Conversations with highway officials in several states revealed that, while a majority of those interviewed think that speed reductions are necessary in almost all construction zones, a smaller number believe that speeds should not be reduced unless conditions dictate such a reduction.

If the objective of speed control is to maintain a normal speed through the construction zone, then a design speed equal to that of the approach to the construction zone should be used. All of the geometric design elements and traffic-control devices should be suitable for this design speed. For example, California specifies that, on roads with high approach speeds, detours should be designed to high standards (2). This principle should apply to all roads and its intent is to integrate the construction zone with the surrounding roadway without abrupt changes in design standards.

If the objective of speed control is to reduce traffic speeds in the construction zone, an effective method of speed reduction must be incorporated into the construction zone design. When speeds are actually reduced, a lower design speed can be used to determine geometric design elements and traffic-control devices needed. Of course, in some zones on low-volume highways, it may be necessary to stop traffic. In these zones it is important that vehicles be brought to a stop safely. Some commonly used speed reduction methods are advisory speed limits, regulatory speed limits, signal control, flagging, traffic pacing, and physical restriction of vehicle speeds by methods such as the Iowa weave and reduced lane widths.

The effectiveness of posting speed limits is regarded as poor. A study of construction-zone accidents stated (2), "It has been proved that posting of a speed limit does not cause traffic to slow to that speed. A majority of traffic behaves according to apparent conditions regardless of the posting." Especially where there is no visible construction activity, drivers are more likely to disregard reduced speed limits (7). Two sources indicated that drivers seemed to disregard speed limits unless a patrol vehicle was stationed at the construction zone (4, 6).

Geometric Design

The geometric design of the roadway passing through or around a construction zone should provide for safe, efficient travel with as little change as possible from the approach roadway. Any sudden change in geometric standards can result in inefficient and hazardous conditions. Lowering of geometric standards can contribute to increased accident rates (10).

Once the speed control strategy has been chosen, the construction travel way should be designed consistent with the geometric design standards required for the traffic speed. A California study (2) has indicated that drivers will not usually slow down while entering a construction zone, especially if they are used to sustained high speeds. This emphasizes the need to design the travel way through the construction zone for the speeds vehicles will travel, not for the speed one hopes they will travel.

Several principles that should be followed in the geometric design of construction zones are

1. Transition areas must be as nearly like the approach as possible; what differences there are must be clearly apparent (2);
2. A flat diagonal crossover is better than reverse curves with extensive superelevation (2);
3. Lateral obstructions located closer than 1.8 m (6 ft) from the edge of a traffic lane reduce its effective width (8);
4. Reduction of one geometric standard can sometimes be compensated for by improvement of another (2); and
5. Tapers for lane drops should not be contiguous with crossover of temporary bypass roadway transitions (2).

If standards consistent with the design speed cannot be attained due to right-of-way, cost, or other restrictions, then the speed control strategy should be changed. A roadway with reduced geometric standards can only be safe and efficient if the speed control strategy is successful in reducing speeds.

Traffic-Control Devices

A fifth step in the planning and design of construction zones is the selection of appropriate traffic-control devices. Devices, such as signs, signals, channelization devices, pavement markings, barriers, and lighting devices, are needed in construction zones to alert drivers to the impending conditions, warn them of hazards, and direct them through the proper path. The purpose of using standard signs in construction zones is to assist or direct the driver in making appropriate speed and path decisions. Since a driver can assimilate only a limited amount of information, it is preferable that each sign not contain more than two messages (11). Signs should not clutter the driving environment. If they must function during darkness, they should be as visible as they are during the day (6). In many cases, face-lit, nonreflective signs may be more visible than nonlit reflectorized signs.

In many cases, construction work makes it necessary to divert vehicles from the lanes they normally use. This situation requires that appropriate reflectorized pavement markings be installed and that inappropriate pavement markings be removed.

Timber barricades have been used in some construction zones to serve as both delineation devices and as a positive barrier (6). Such barricades were convenient because they take up little room but were mistakenly supposed by some agencies to be capable of redirecting errant vehicles. Lisle's paper in this Record on the Virginia Highway and Transportation Research Council study corrects this misimpression by demonstrating that the timber barricades were ineffective because 73.5 percent of all vehicles striking the devices either straddled or penetrated them. The Virginia report goes on to say that portable concrete traffic barriers with the safety shape are ideal for use as a protection and redirection device.

FHWA Notice N 5160.27 dated February 2, 1977, contains revised standards for the use of timber barricades, and states that "Timber barricades shall not be approved for use on direct federal or federal-aid projects as a positive barrier at any speed." The notice also states that timber barricades should be used for delineation only in urban areas where operating speeds of 32.2 km/h (20 mph) or less could be expected.

Recently, several new devices have been developed to aid in controlling traffic through construction areas:

1. Delineator poles made of elastomeric material, set in concrete base, and capable of withstanding bumper speeds up to 40 km/h (25 mph) (6): This device is especially useful in areas where traffic cones are knocked over repeatedly. These delineators also maintain higher reflectivity during rain than conventional posts.
2. Portable, 0.9 × 2.1-m (3 × 7-ft) changeable matrix message signs with 45.7 cm (18 in) characters (6): Changeable matrix message signs are very applicable to zones where traffic conditions are changeable. Portability of these signs allows for the freeing of construction equipment usually required for mounting of fixed traffic-control signs.
3. High-intensity reflectorized sheeting incorporating diagonal orange strips (6): This device is very useful when applied to barricades. The manufacturer claims it is nearly three times as bright as engineer-grade materials.
4. Improved equipment to erase inappropriate pavement markings (6): Inadequate removal of unnecessary pavement markings can result in very hazardous conditions if they lead the motorist on an inappropriate path. This new equipment removes the markings more effectively and leaves the pavement with as little scarring as possible.
5. Breakaway barricades (12): This device is assembled without bolts or cement to allow for instant breakaway and parts flying clear of impacting vehicles. Because of breakaway design, most of the parts will not be damaged by collision, and those that are can be easily replaced with interchangeable parts.

Additional research is to be conducted in the near future into the use of arrow boards and flood lighting. Also, an upcoming National Cooperative Highway Research Program (NCHRP) study will evaluate the effectiveness of various channelizing devices.

MANAGEMENT AND OPERATION OF CONSTRUCTION ZONES

The daily operation of the construction zone is even more important than the plan and design of the construction zone. Lackadaisical or inattentive supervision of the daily operations can negate the most complete and thorough plans. Also, even with the most thorough planning, changing field conditions may require immediate, unanticipated changes in the traffic-control strategy. One accident study has indicated that more than half of the accidents reported on road construction projects were caused by operational negligence (13). An Illinois accident study indicated (14), "Too many accident reports state that the driver was surprised by a barricade across the road or a flagperson stopping traffic without advance signs."

Public Information

Invaluable assistance in the management of construction traffic control on major facilities can be provided through advance use of public information. Various methods can be used to inform the public of anticipated delays or congestion resulting from construction activities. These methods include public hearings, press releases, special mailings, personal contacts, and special signs (6, 7, 15). The method and degree to which these techniques are used should vary according to the following project factors: duration, size, season, location, traffic volumes and mix, time of day, day of week, lane use, institutional constraints, available media and expertise, and funding sources (6). As an example, in areas with large tourist traffic, pamphlets can be handed out to alert drivers of the construction activity and show them alternative routes. Once the project is completed, mass media articles and letters to affected parties expressing appreciation for cooperation on the project will enhance the operation of future projects (6).

Training

An important aspect of the management of a construction zone is the training of the personnel who are working in the zone. The resident engineer must be well trained in traffic operations techniques in order to monitor and evaluate the effectiveness of the traffic control.

If flagging is used to control traffic in a construction zone, the flagperson is most directly responsible for controlling the actions of drivers approaching the zone. Therefore, flagpersons should be qualified and knowledgable in flagging procedures. The flagperson should be aware of various procedures, including:

1. Where he or she should be stationed,
2. How to slow traffic,
3. How to stop traffic,
4. How to coordinate traffic movements with another flagperson,
5. How to inform the public,
6. How to control for construction equipment movements,
7. How to handle emergency vehicles, and
8. How to warn construction workers of high-speed or out-of-control vehicles.

Most highway agencies have training programs for field supervisors and flagpersons. Some states even license flagpersons. A notebook designed to train government and contractor personnel in planning, designing, installing, and maintaining signing and marking installations in construction zones was developed by the U.S. Department of Transportation (16). This 1-week training course presents relevant information and then gives the participants an opportunity to use the information in work sessions. Training films have also been developed for these training sessions.

Modification of Traffic Control

As soon as the construction zone is opened to traffic, the operation of the zone should be evaluated. Standards used for the placement of devices may need to be altered because of some unique characteristic of the zone. Several methods are available to observe the operation of the zone, including (16) driving through the zone, viewing the zone from a high vantage point or from an airplane, and time-lapse monitoring. Operational characteristics that may indicate that the traffic-control strategy should be modified include: (a) accidents or near accidents, (b) damaged control devices, (c) skid marks, (d) unusually high or low speeds, (e) queues, and (f) drivers having difficulty in following the correct path. If modification is needed, the situation should be remedied immediately.

Another important aspect of evaluation and modification of construction zones is to make a night observation of controls in effect. California law requires a review of each major phase of change, including a nighttime viewing (2).

Removal of Inappropriate Traffic-Control Devices

An important aspect of efficient management of construction-zone operations is removal or alteration of inappropriate traffic-control devices when conditions warrant. Unfortunately, the public has become accustomed to inappropriate devices in construction zones, such as construction signs, uncovered existing signs, and pavement markings that do not relate to current conditions. These common conditions have led to a careless attitude among construction-zone motorists. FHWA Associate Administrator Howard Anderson recently stated (17), "The recent lack of public respect for the highway engineer is due in part to the public's most direct contact with us controlling traffic through construction sites."

A recent addition to the MUTCD states that markings that are "no longer applicable, which may create confusion in the minds of motorists, shall be removed or obliterated as soon as practicable." Painting over inappropriate markings can result in a highly reflective marking that may be even more visible under wet conditions than the existing markings. The most effective methods for removing inappropriate pavement markings include (18)

1. Sandblasting using air or water;
2. High-pressure water;
3. Steam or superheated water;
4. Mechanical devices such as grinders, sanders, scrapers, scarifiers, and wire brushes;
5. Solvents and chemicals; and
6. Burning.

The removal of inappropriate signs in construction zones is also important. When construction begins, the construction signing should be installed and existing signs that are inappropriate should be removed or covered. As the construction progresses, the signs should be reviewed periodically and whenever changes are made in the traffic-control strategy to ensure that the signs always correspond to the conditions that motorists will encounter. On moving operations, such as resurfacing, warning signs should be moved frequently in order for the traffic control to keep pace with the construction activity.

Maintenance of Traffic-Control Devices

Traffic-control devices must be kept in good condition and in the proper location so that they perform their intended function. Proper maintenance of the devices will help to minimize accident litigation potential, check vandalism, and accommodate adverse environmental conditions (16).

Maintenance of traffic-control devices on very large construction projects can be a substantial part of the project costs. For one construction project on the Dan Ryan Expressway in Chicago, the contractors maintained the devices on a continuous 24-h/d basis by use of a two-person crew equipped with a two-way radio. This crew replaced an average of 70 to 100 barricades/d (7). In California, a contractor was required to survey all traffic-control devices, 24 h/d, every day of the week, for the entire length of the project, and to make any necessary temporary repairs (7). This extensive maintenance effort resulted in a great reduction in the number of accidents that usually accompanied construction projects in that state. Cost of the surveillance was about 2 percent of the project cost.

Generally, the following general guidelines should be followed in the maintenance of traffic-control devices (6, 16):

1. Replace devices damaged from the weather, traffic, or construction activity;
2. Replace missing devices;
3. Remove devices no longer needed;
4. Replace obsolete devices;
5. Clean dirty signs;
6. Remove weeds, shrubbery, construction materials or equipment, and spoil that obscure devices;
7. Repaint faded pavement markings if they are to be used for an extended period of time;
8. Check flasher and delineation light charge levels daily; and
9. Maintain an adequate inventory of devices.

CONCLUSIONS

The traffic-safety problem associated with traffic-control practices in at least some construction zones can be alleviated by improved traffic-control practices. All phases of traffic control in construction zones can be improved, including planning, design, and management. More effective planning and design of construction-zone traffic control should 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.

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