ROLL-AHEAD DISTANCE FOR BARRIER VEHICLES

Weight of Barrier Vehicle (Stationary)	Prevailing Speed (mph)	Weight of Impacting Vehicle to be Contained[a]			
		4,500 lbs	10,000 lbs	15,000lbs	24,000 lbs
10,000 lbs	60-65	50 ft	100 ft[b]	150 ft	200 ft
	50-55	25 ft	75 ft[b]	100 ft	150 ft
	<45	25 ft	50 ft[b]	75 ft	100 ft
15,000 lbs	60-65	25 ft	75 ft	100 ft	150 ft
	50-55	25 ft	50 ft	75 ft	100 ft
	<45	25 ft	25 ft	50 ft	75 ft
24,000 lbs	60-65	25 ft	50 ft	75 ft	100 ft
	50-55	25 ft	25 ft	50 ft	75 ft
	<45	25 ft	25 ft	25 ft	50 ft

[a]Weights of typical vehicles:

Mid-size automobile	2,250 lbs
Full-size automobile	3,500 lbs
Loaded 3/4-ton pickup truck	6,000 lbs
Loaded 1-ton cargo truck	10,000 lbs
Loaded 4-yard dump truck	24,000 lbs

[b]Values suggested for inclusion on Figures3 through 6

Source: *Guidelines for the Use of Truck-Mounted Attenuators in Work Zones*, Jack B. Humphreys and T. Darcy Sullivan, *Transportation Research Record 1304*

Guidelines for the Use of Truck-Mounted Attenuators in Work Zones

JACK B. HUMPHREYS AND T. DARCY SULLIVAN

Truck-mounted attenuator (TMA) usage varies for a number of reasons, including apathy, loss of efficiency (real or perceived), fiscal constraints, and lack of information on when and how to use the devices. Although some individual states have adopted policies, there has not been any coordinated effort to develop guidelines for the use of TMAs on a national basis. A literature review was conducted to determine the extent to which guidelines might have been developed but not widely shared. Five states were visited to solicit information regarding support for, and extent of use of, TMAs. There was a wide range in the number of TMAs presently in use. There was more consistency on other issues including the following: (a) initial support for the use of TMAs came principally from administrators; (b) field support is generally good in states using tilt-up versions of the TMA; (c) reported uses included maintenance activities, construction activities, and emergency incident management (use of TMAs on shadow vehicles was, by policy, the most common application); and (d) there seemed to be little factual basis for the existing application policies. A set of recommended guidelines was developed that included priorities for the deployment of shadow vehicles and TMAs. Two limitations on the significance and suggested use of the guidelines are acknowledged. First, the project did not involve collection and analysis of numerical data. Rather, it represented an effort at bringing together appropriate policies and procedures. Second, the guidelines are more appropriately used as a policy formation and budgeting tool.

The hazardous nature of construction and maintenance work zones on and along streets and highways has been recognized for many years. Unfortunately, knowledge all too frequently is not translated into action; when it is, the time required for transition and implementation of newly developed procedures is sometimes lengthy. Only in recent years, for example, has there been implementation of many of the principles set forth in the 1967 AASHTO publication *Highway Design and Operational Practices Related to Highway Safety* (*1*), frequently referred to as the "Yellow Book." Specifically, that document stated that the use of traffic control plans; improvements in signing, channelization and pavement markings; portable barriers; better training of flaggers; arrow panels; changeable message signs; and improved construction scheduling can all combine to produce safer work zones.

During the late 1970s, work zone safety was considered an emphasis area by the FHWA. The impetus for this emphasis largely resulted from a fatal January 1975 work zone accident on the I-495 beltway around Washington, D.C., and subsequent legal action involving the FHWA and other governmental agencies. Research activity into the identification of work zone safety problems, with recommendations for specific research to address those safety problems, was completed in 1979 (*2*). Extensive changes were incorporated into Part VI of the 1978 *Manual on Uniform Traffic Control Devices* (MUTCD) (*3*), many reflecting the principles set forth in the Yellow Book (*1*). Even further changes are noted in the 1989 MUTCD (*4*).

Even with the changes in the 1978 MUTCD and the FHWA emphasis, the number of work zone accidents nationwide has continued to increase. Between 1982 and 1987, the number of construction zone fatalities increased 43 percent nationally. In Illinois alone, there were 23 fatalities in 1988 work zone accidents (*5*). Much of this increase may be attributed to the fact that more and more highway construction and reconstruction is being performed under traffic.

On the basis of a recent six-state survey by Graham-Migletz Enterprises in conjunction with its Strategic Highway Research Program activity (*5*), the five top operations with the largest number of work zone accidents (based on a total of 324 reported accidents) are as follows:

- Snow and ice control,
- Pavement maintenance,
- Flagging,
- Sweeping, and
- Pavement marking.

Adding to the cost of highway accidents nationally is the expense of lawsuits against governmental agencies. It has been estimated that highway agencies paid $120 million in judgments and settlements from tort liability claims in 1986. This amount does not include an additional $20 million required to defend these cases. Because the rate of such suits is increasing at 17 percent per year, engineers and managers are justifiably concerned (*6*).

In order to respond to these work zone accident statistics, both in magnitude and cost, agencies have promoted work zone safety in a variety of ways. Extensive training programs have been undertaken by many states. The authors, for example, have provided 2- and 3-day seminars several times across the State of North Carolina over the last 10 years through the University of Tennessee Transportation Center. Similar seminars have been given in a number of other states and municipalities by the authors. Training in work zone safety is also offered by the American Traffic Safety Services Association (ATSSA), the Institute of Transportation Engineers (ITE), the National Highway Institute (NHI), and others.

In addition to training, the use of more extensive traffic control plans and the upgrading of traffic control devices have

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both improved and emphasized the need for better work zone traffic controls.

HISTORY OF TRUCK-MOUNTED ATTENUATORS (TMAs)

Other aspects of highway safety have also been recently addressed. During the 1950s, highway agencies became aware of the large number of fixed roadside hazards that were playing an increasing role in the number of fatalities and injuries. In addition to a realization that such hazards should be removed or relocated, attention was directed to the mitigation of the results of such fixed-object impacts. Crash cushions, or impact attenuators, were considered, and development began.

One of the first such attenuators was the steel drum crash cushion system developed in Texas in the mid-1960s (*7*). Extensive research and development by federal and state governmental agencies and by the highway safety industry has since produced a wide variety of impact attenuators that can be adapted to varying site-specific highway conditions or needs. These facilities include water-filled tubes, sand-filled plastic barrels, and crushable, dry energy-absorbing materials.

Success with these crash cushion designs has stimulated development of mobile systems that are attached to work vehicles. Perhaps the first of these was the Texas crash cushion trailer, developed and tested in 1972 (*8*). Adapted from the fixed-drum attenuators developed and in use in Texas, the design consisted of 55-gal steel drums welded together and mounted on a flat trailer, which was then towed behind a truck. According to the researchers, acceptable collision performance was demonstrated in a head-on impact by a 4,000-lb automobile at 60 mph (*9*).

From this early attenuator, other TMA systems soon following. Designs to date include the following (*8*):

- Energy-absorbing cartridges within a frame [Hex-Foam, by Energy Absorption Systems, Inc. (EASI)] (see Figure 1);
- Aluminum honeycomb with frame (Hexcel by Hexcel, Inc., Alpha 1000 by EASI, Alpha 500 by EASI);
- Water-filled tubular vinyl cells (CushionSafe by Transpo-Safety, Inc.); and
- Collapsing (or crushing) steel pipe (developed by University of Connecticut).

The highway safety industry has made extensive improvements to first-generation TMAs. Designs now provide for consistently safe load levels for both light and heavy automobiles over a range of impact speeds, as well as increased maneuverability of TMA trucks because of the tilt-up option with hydraulically activated latching and other improvements (see Figure 2). Overall weights of TMA units have decreased, and the time (and difficulty) of mounting and unmounting the devices from trucks has been greatly reduced. Current TMA designs are thus more effective and easier to use with a vehicle fleet.

USAGE OF TMAs

With the emphasis on work zone safety exhibited by the FHWA and others, improvements in the level of traffic control provided are quite evident in many states. The use of signing, channelization, markings, etc., has improved vastly in most areas, particularly on larger contract work. The use of temporary concrete barriers, arrow panels, and changeable message signs has also improved motorist and worker safety.

Unfortunately, TMAs have not been so readily and uniformly accepted across the United States. Several factors have apparently contributed to this lack of acceptance, among them the following:

- Negative experience with first-generation TMAs, including mounting procedures, inadequate tilt capabilities, etc.;
- *Perceived* loss of productive work time without significant gain in safety for employee;
- Truck tieup (with dedicated TMA usage);
- Lack of positive local accident experience within the agency;
- Initial cost of TMAs;
- The fact that TMAs are not required by MUTCD; and

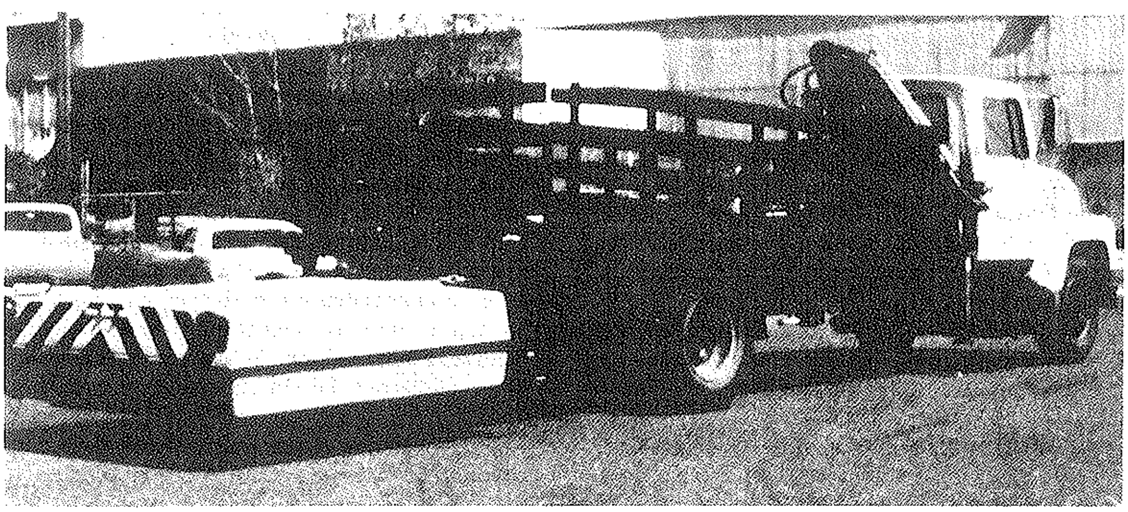


FIGURE 1 Hex-foam TMA by Energy Absorption Systems, Inc.

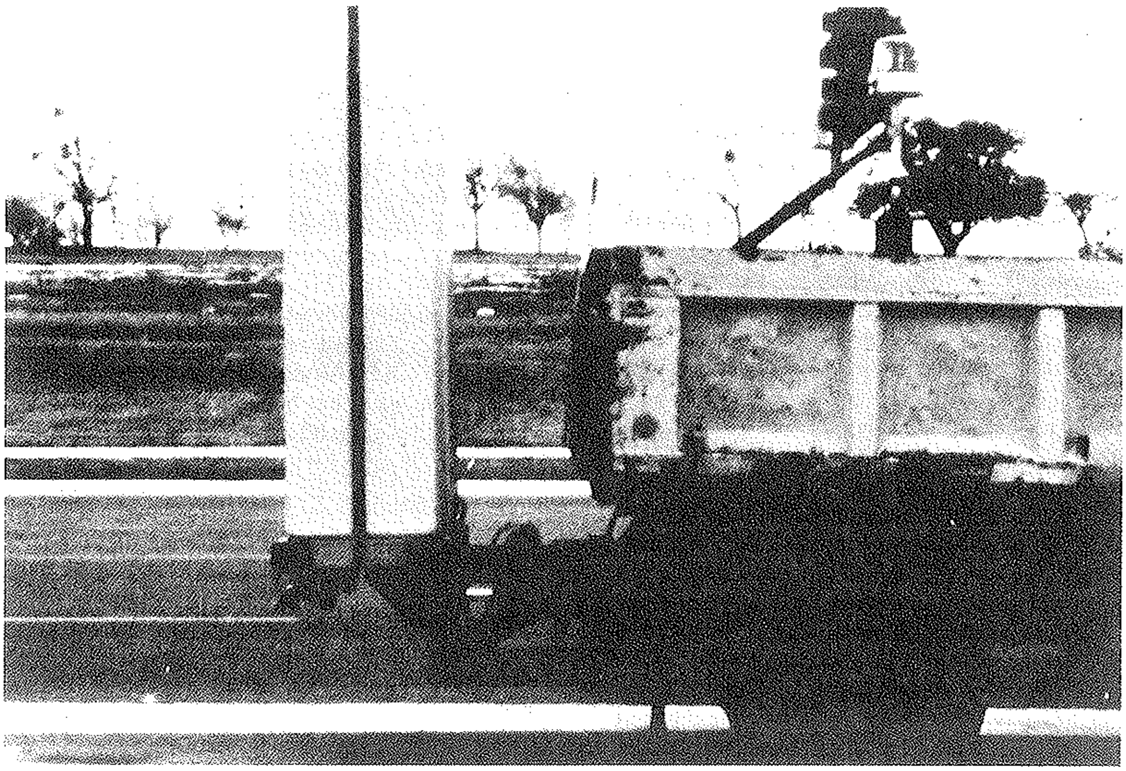


FIGURE 2 Tilt-up capability of TMA.

- Lack of widespread (national) policy and procedures for TMA usage (including both *where* and *how* a TMA should be used).

A partial review of the 1980s' TMA experience across the states provides some indication of the lack of uniformity in TMA usage during that period. Perhaps the earliest most specific reference to TMA use was added in July 1981 to the MUTCD in one state, reading as follows:

> At stationary work areas, a shadow vehicle with an attenuator fastened to the rear should be placed upstream of the work area. For moving work areas, the attenuator should be placed on the rear of the work equipment and/or shadow vehicle. (Source intentionally not included.)

Although this text appears to provide sufficient direction and would suggest extensive TMA use, apparently that state, as of early 1990, has only four TMA units within the highway department—certainly not enough to meet the requirements of their MUTCD.

By 1982, the Oakland County, Michigan, Road Commission had one TMA for each of its seven operating districts. Four additional TMAs were purchased in 1985 for use in its more urban districts (*10*).

By 1984, the Texas State Department of Highways and Public Transportation (SDHPT) had several TMAs in use. Each Texas highway district has funds to purchase equipment, with acquisitions to be approved by headquarters personnel. Region 2, headquartered in Forth Worth, was using two units full time in restriping operations alone. They also maintained five TMA cartridges in inventory to meet immediate replacement needs (*11*).

A 1985 report on highway safety devices, prepared for the Texas legislature by the SDHPT, estimated the value of a TMA in such accidents. Savings of $23,000 per accident in injury and damages were estimated for a vehicle hitting a TMA instead of a stationary vehicle, resulting in a favorable benefit-cost ratio (*12*).

Other states moved quickly to use TMAs in their operations. By 1987, California had approximately 500 TMAs in use. By that time, policy required a TMA on the rearmost vehicle in work-in-progress operations. All vehicles moving significantly slower than prevailing traffic, such as in sweeping or painting operations, also had to be equipped with a TMA. CALTRANS agreed that the life-saving benefits to motorists and workers made the crash cushions worthwhile. In addition, savings have been recognized in the repair and replacement of damaged equipment (*13*).

In 1986, a task force was appointed by the North Carolina state highway chief engineer to develop recommendations concerning safer operations for slowly moving maintenance work. A summary of guidelines for maintenance operations was prepared in 1987. Although many of the operations required only rotating beacons on the equipment (such as contour mowers and broom tractors), shadow vehicles with TMAs were recommended for herbicide spraying operations and painting operations using cones, whereas edge line painting (without cones) had the TMA optional on the trailing vehicle. Those guidelines did not address the issues of exposed personnel on foot doing patching, sealing, or other similar work.

A 1988 shadow vehicle policy distributed to all New York regional highway engineers addressed the issue of the required use of shadow vehicles. However, the policy indicated that TMAs were not required on those vehicles, but would be used "if available and where practical" on both moving and stationary operations on multilane highways. They would be used on two-lane highways "if desirable."

After a St. Louis vehicle struck a TMA involved in a striping operation, with the motorist escaping serious injury, the Missouri Highway Department studied increasing TMA usage. Plans were developed in 1989 to attach TMAs to departmental vehicles performing routine maintenance operations (*14*). Similarly, Florida Department of Transportation officials drafted a set of guidelines for the use of protective equipment, but as of 1989, each district had authority in the decision to require such equipment. In some cases, TMAs are required, such as on contract sweeper operations in Duval County.

Georgia also has developed guidelines for protective equipment, but, as in Florida, those guidelines are not mandatory, and the language is broad. As the assistant state maintenance engineer has stated, TMAs are required "in any instance where there's a high likelihood of impact in an open lane situation" (*15*).

More definitive requirements for TMA usage appeared in the 1987 *Virginia Work Area Protection Manual*, which is a supplement to the Virginia MUTCD; thus, its use is mandatory. Both the 1987 manual and its 1988 revision establish a number of conditions where TMAs are to be used. . . . After July 1, 1988, TMAs were required on all limited access highways," using the following criteria (*16*):

- Pavement marking,
- Stationary lane closures,
- Other mobile maintenance operations, and
- Other situations as warranted.

PURPOSE OF THIS RESEARCH

As suggested earlier, there is a great variance in usage of TMAs among the states, with some states having virtually none, whereas California has over 500 in use. Even in those states with a number of TMAs, guidelines for usage are in general loosely worded, giving field personnel a great deal of leeway in their application. It would be appropriate to develop some set of nationally accepted guidelines, warrants, or priorities to obtain the usage having the greatest probability of increasing overall safety and reducing total costs. The purpose of this research, then, is to address this issue by suggesting priorities as to how and where available TMAs should be deployed. Then, given the availability of one or more TMAs, supervisory personnel would be able to assign them more effectively on a day-to-day basis. Also, if a priority system can be agreed on within a given agency, the total number of TMAs required to cover a certain level of priority can be better estimated more accurately.

DEVELOPMENT OF GUIDELINES

Several states were selected as candidate contacts to determine the status of current TMA programs. The states represented a range of attributes with respect to

- Geographic location,
- Apparent interest in the use of TMAs, and
- Number of units in active use.

The states were contacted to determine their willingness to discuss their use of TMAs with the research staff. Initial contacts with the states simply suggested the possibility of a meeting to discuss how TMAs were being used within the agency and what their experiences (good and bad) had been. States ultimately selected for participation in the process were California, Iowa, North Carolina, Tennessee, and Texas.

Discussion sessions were held during July and August of 1989. Agency personnel attending the sessions were selected by the agency and ranged in number from three to seven. Job responsibilities of those in attendance included maintenance foremen, supervisors, and engineers; traffic engineers and technicians; purchasing agents; occupational safety and training officers; garage repair personnel; and construction engineers.

During the discussions agency personnel were invited to comment on the origins of their TMA programs, the general availability of TMAs to field personnel, what were the most common applications, the basis for the assignment of application priorities, and the acceptance of the devices by a broad range of agency personnel. Although there was a wide range of responses on the number of TMAs presently in active use (from fewer than 10 to over 500), there was far more consistency from state to state on other issues discussed. Some of the issues on which there were strong similarities included the following:

1. The initial support for the use of TMAs came principally from the administrative level. In some cases the concern was primarily employee safety, in other cases primarily motorist safety. Most programs dated from the early 1980s.
2. Support for the use of TMAs among field personnel is generally good to very good in states using the tilt-up versions of the TMA. Some field crews are reported to feel so strongly that they virtually refuse to undertake certain assignments unless a TMA-equipped vehicle is available. When available units did not incorporate the more recent technologies including the tilt-up feature and reasonably easy mounting and dismounting of the units, support among field personnel was absent.
3. Reported uses, in order of reported frequency, included maintenance activities, construction activities, and emergency incident management. The use of TMAs on shadow vehicles to moving operations was, by policy, the most common application. However, there was support among the field personnel involved in the discussions for more frequent use of TMAs on barrier vehicles in stationary operations. The safety of exposed personnel was the primary concern of the field forces.
4. There seemed to be little factual basis for any existing application policies. Only one state had comprehensive data available on accidents involving TMA-equipped vehicles, and those data could not be related to exposure in a statistically meaningful way. When TMAs were used regularly, the field personnel often had vivid recollection of specific incidents that did influence usage policies.

On the basis of the information gathered during the agency visits, a draft of suggested TMA use guidelines was prepared.

Those guidelines attempted to reflect the existing practice of the agencies, the expressed concerns of the field personnel who participated, and the experience of the researchers. These draft guidelines were presented to a large group of industry personnel to determine how they thought such information would be received by the various agencies they called on. The draft was modified to reflect comments received, and then was taken back to two of the states originally visited seeking first-hand response. The response was generally favorable, but the guidelines were considered too complicated to be used by field personnel.

The material was again revised to simplify the format and provide more agency flexibility in the application of the suggested guidelines. Draft materials then were distributed to those in attendance at the January 1990 committee meetings of the TRB A2A04 Committee on Roadside Safety Appurtenances and A3C04 Committee on Traffic Safety in Maintenance and Construction Operations. Committee members and others in attendance were asked to review the draft guidelines and were invited to later provide comments on either the content or format of the guidelines.

On the basis of input from the described sources and a number of other informal contacts by the project staff, a final set of guidelines was developed.

RECOMMENDED GUIDELINES

Before a set of priorities can be established for the uses of TMAs, a system must be available for defining the type of activity taking place. Previously identified factors that affect the type and number of traffic control and protective devices to be used and how they are to be used include the following:

- Speed of traffic;
- Whether the work area is within the roadway, within the shoulder (if one is present), or off the roadway or shoulder;
- Type of activity (moving, intermittent, or stationary);
- Roadway environment: access controlled versus nonaccess controlled and urban versus rural;
- Traffic volumes; and
- Exposure to special hazards.

Although many factors may be important in determining the overall traffic control plan to be implemented at any particular job site, five were selected as particularly relevant to a decision whether or not to use a TMA. Three of those factors are as follows:

- Location of Work Area. Locations of primary concern are those within the traveled lanes and those within all-weather frequently used shoulders. Activities taking place within the traveled lanes are more likely to become involved in an incident than are shoulder activities.
- Type of Activity. Whether the activity is moving, intermittent, or stationary will determine whether or not a standard lane closure or shoulder closure will be implemented. Activities taking place within a formal lane or shoulder closure are less likely to become involved in an incident than are activities fully exposed to approaching traffic.
- Special Hazards. Some activities by their nature expose personnel to greater hazards than do others. Operations involving personnel on foot or located in exposed positions on or within work vehicles (on the platform of a cone pickup truck or in a bucket performing overhead operations, for example) are particularly susceptible to high-severity incidents. Other activities may create conditions that present a significant hazard to vehicles in the passing stream and their occupants.

Table 1 presents a structure for classifying various activities considering the previously discussed lane and shoulder closure and exposure conditions. Examples of typical construction and maintenance activities for each of the closure or exposure conditions also are provided.

Tables 2 and 3 suggest priorities for the assignment of shadow or barrier vehicles and TMAs. Two additional factors that were identified as having an impact on assignment priorities are reflected in these tables.

- Access Control. Access-controlled facilities frequently give drivers a false sense of security with a resulting lower expectation of interruptions to free traffic flow. Therefore, activities on freeways may be more likely to become involved in incidents than are activities on nonaccess controlled facilities in which most drivers are operating at a higher state of alertness.
- Speed Limit. Higher operating speeds leave less time for response, and impacts at higher speeds generally result in more severe injuries and damage. Therefore, activities on facilities with higher speed limits are likely to become involved more frequently and in more severe incidents than are activities on facilities on low-speed facilities.

During the interviews with agency personnel, many of the field personnel felt strongly that the use of a blocking vehicle (generally referred to as a shadow vehicle for moving and intermittent operations and a barrier vehicle for stationary operations) was highly desirable for the protection of exposed personnel *even if* a TMA was not available. Many agencies have a policy regarding the use of blocking vehicles. Those that have a policy may desire to continue to follow that policy. Table 2 suggests priorities that are consistent with the expressed concerns of the field personnel and that may be considered when no policy currently exists.

Table 2 indicates that the suggested priorities for the assignment of blocking vehicles are related directly to protection of agency personnel. In each case in which personnel are exposed, a positive recommendation is provided, with the strength of that recommendation depending on the closure condition, the prevailing speed of traffic, and whether or not the operation is occurring on a freeway.

When exposed personnel are not involved, the use of a blocking vehicle may or may not be justified. That decision will depend on an evaluation of the hazards that exist within the work area and the likely loss if a blocking vehicle is struck. If the evaluation indicates that impact with a blocking vehicle is likely to result in less damage or less serious injury than would impact with a work area hazard or a working vehicle, then a blocking vehicle should be assigned to the operation.

TABLE 1 EXAMPLES OF CLOSURE AND EXPOSURE CONDITIONS

Closure/Exposure Condition	Examples of Typical Construction/ Maintenance Activities	See Figure
No Formal Lane Closure		
Shadow Vehicle for Operation Involving Exposed Personnel	Crack pouring, patching, utility work, striping, coning	3
Shadow Vehicle for Operation Not Involving Exposed Personnel	Sweeping, chemical spraying	3
No Formal Shoulder Closure		
Shadow Vehicle for Operation Involving Exposed Personnel	Pavement repair, pavement marking, delineator repair	4
Barrier Vehicle for Operation Not Involving Exposed Personnel	Open excavation, temporarily exposed bridge pier	4
Formal Lane Closure		
Barrier Vehicle for Operation Involving Exposed Personnel	Pavement repair, pavement marking	5
Barrier Vehicle for Condition Involving Significant Hazard	Open excavation	5
Formal Shoulder Closure		
Barrier Vehicle for Operation Involving Exposed Personnel	Pavement repair, pavement marking, guardrail repair	6
Barrier Vehicle for Condition Involving Significant Hazard	Open excavation	6

Definitions:

- A FORMAL CLOSURE condition (either lane or shoulder) includes a full complement of advance warning devices, a closure taper of channelizing devices, and channelizing devices to define the work area as required.
- A NO FORMAL CLOSURE condition (either lane or shoulder) includes limited (if any) advance warning signs and channelizing devices.
- A SHADOW VEHICLE is a moving vehicle traveling a short distance upstream from a moving operation giving physical protection from approaching traffic.
- A BARRIER VEHICLE is a vehicle parked a short distance upstream from a stationary operation giving protection from approaching traffic.

If the projected damage or injury is greater, then the vehicle should not be assigned. Two examples follow:

- An open excavation several feet deep and several feet across exists on a street in a residential area. A horizontal curve restricts sight distance to the excavation to less than desirable for the 25-mph speed limit. An impact with an appropriate blocking vehicle at 25 mph would probably result in less damage than would driving into a major excavation. Therefore the use of the blocking vehicle would be appropriate.
- A full-depth portland cement concrete patch has been placed and is curing in the right lane of an arterial street with prevailing speeds of >40 mph. An impact with an appropriate blocking vehicle at 40 mph would probably result in greater loss (in both personal and economic terms) than would driving into an uncured patch that might then have to be replaced. Therefore the use of the blocking vehicle would be inappropriate.

Table 3 presents suggested priorities for the assignment of available TMAs. Table 3 indicates that the suggested priorities for the application of TMAs are based primarily on the protection of the approaching motorists. The highest priority is on a freeway where speeds are high and the probability of an impact is greatest. When, because of either the location of the activity or the presence of a formal closure, the probability of an impact is less, a lower priority is assigned.

Figures 3–6 show the use of TMA-equipped vehicles in the closure and exposure conditions identified in Table 1. The relative simplicity of the illustrations compared with illustrations in the MUTCD may be misleading and the following items should be noted:

- In most cases, the use of traffic control devices in the advance warning area and transition area, as defined in the *Traffic Control Devices Handbook* (17), will be appropriate. Because this topic is adequately covered in the MUTCD, in other agency policies, and, where applicable, in the project traffic control plan, those details are not repeated on the figures.
- Figure 3 specifically recommends an arrow panel on the TMA-equipped vehicle. In all of the other figures, it is indicated as an option. In every case, the note indicates that the device is to be operated in accordance with existing agency policy.

TABLE 2 SUGGESTED PRIORITIES FOR THE ASSIGNMENT OF SHADOW AND BARRIER VEHICLES

Closure/Exposure Condition	Ranking*			
	Freeway	Non-Freeway with Speed Limit ≥50 mph	40-45 mph	≤35 mph
No Formal Lane Closure				
Shadow Vehicle for Operation Involving Exposed Personnel	A	A	A	A
Shadow Vehicle for Operation Not Involving Exposed Personnel	E	E	E	E
No Formal Shoulder Closure				
Shadow Vehicle for Operation Involving Exposed Personnel	B	B	C	C
Shadow Vehicle for Operation Not Involving Exposed Personnel	E	E	E	E
Formal Lane Closure				
Barrier Vehicle for Operation Involving Exposed Personnel	B	B	C	D
Barrier Vehicle for Condition Involving Significant Hazard	E	E	E	E
Formal Shoulder Closure				
Barrier Vehicle for Operation Involving Exposed Personnel	C	C	D	D
Barrier Vehicle for Condition Involving Significant Hazard	E	E	E	E

*The ranking letter indicates the priority assigned to the use of a shadow/barrier vehicle. The use of shadow/barrier vehicles:
- A is very highly recommended.
- B is highly recommended.
- C is recommended.
- D is desirable.
- E may be justified on the basis of special conditions encountered on an individual project when an evaluation of the circumstances indicates that an impact with a shadow/barrier vehicle is likely to result in less serious damage and/or injury than would impact with a working vehicle or the hazard.

- When a formal lane closure or shoulder closure is implemented, a buffer area (or buffer space) as defined in the *Traffic Control Devices Handbook* is typically provided. Because this topic is adequately covered in the handbook, the MUTCD, in other agency policies, and, where applicable, in the project traffic control plan, those distances are not repeated on the figures.
- When a blocking vehicle is hit, it will be moved forward some distance. That distance is commonly referred to as the "roll-ahead distance" and varies depending on the weights and speeds of the two vehicles involved, the extent to which the blocking vehicle is restrained, and certain pavement characteristics. All of the factors except vehicle weights and impacting vehicle speed can be accounted for with a series of assumptions. The likely speed of the impacting vehicle is site specific. The weight of the units used as blocking vehicles and the weight of the impacting vehicle to be accommodated by the system are both policy issues.

Tables 4 and 5 present listings of calculated and rounded roll-ahead distances for various vehicle weight and speed conditions. Calculations were made using the classical conservation of momentum equation and the following assumptions:

- Coefficients of friction between truck tires and pavement surface of 0.50,
- Percent of total vehicle weight on rear axles of shadow or barrier vehicles of 75 percent,
- Engine braking effectiveness of moving shadow vehicle of 80 percent, and
- Values rounded downward as appropriate.

Appropriate values reflecting the agency's policy decisions should be taken from Tables 4 and 5 and inserted in the figures before the figures are distributed for use by field forces.

CONCLUSIONS

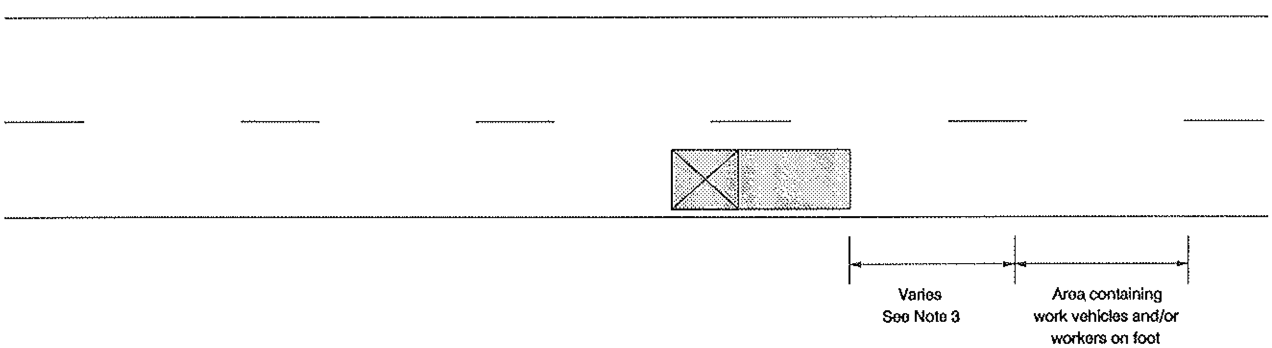
This research effort has resulted in guidelines that may be of assistance in determining the priority of usage of shadow or barrier vehicles and of TMAs. The suggested guidelines

TABLE 3 SUGGESTED PRIORITIES FOR THE APPLICATION OF TMAs

Closure/Exposure Condition	Priority*			
	Freeway	Non-Freeway with Speed Limit ≥50 mph	Non-Freeway with Speed Limit 40-45 mph	Non-Freeway with Speed Limit ≤35 mph
No Formal Lane Closure				
Shadow Vehicle for Operation Involving Exposed Personnel	1	2	3	4
Shadow Vehicle for Operation Not Involving Exposed Personnel	1	2	3	4
No Formal Shoulder Closure				
Shadow Vehicle for Operation Involving Exposed Personnel	2	3	3	3
Shadow Vehicle for Operation Not Involving Exposed Personnel	2	3	4	5
Formal Lane Closure				
Barrier Vehicle for Operation Involving Exposed Personnel	2	3	4	5
Barrier Vehicle for Condition Involving Significant Hazard	2	3	4	5
Formal Shoulder Closure				
Barrier Vehicle for Operation Involving Exposed Personnel	3	4	5	5
Barrier Vehicle for Condition Involving Significant Hazard	3	4	5	5

*The numerical rank indicates the level of priority assigned to the use of a TMA on an assigned shadow/barrier vehicle. The use of a TMA under the defined conditions is:

1 is very highly recommended.
2 is highly recommended.
3 is recommended.
4 is desirable.
5 may be justified on the basis of special conditions encountered on an individual project.



Notes:

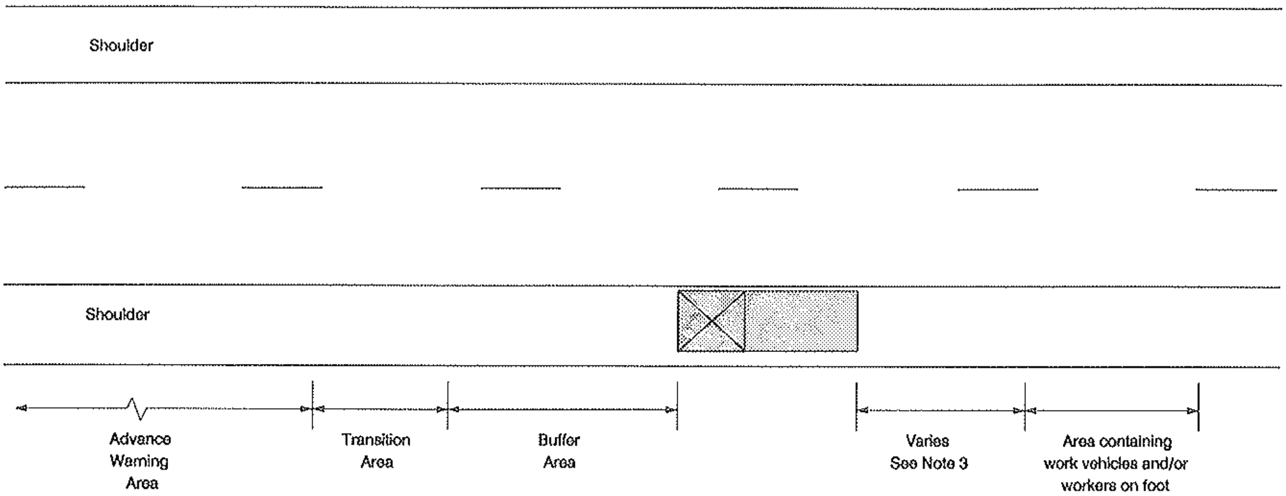
1. Advance warning traffic control devices to be in accordance with MUTCD, TCP, or other agency policies.
2. TMA vechicle should be equipped with an arrow panel operated in accordance with the MUTCD, TCP, or other agency policies.
3. Variable intervening distance to be selected from the following table:

Prevailing Speed (mph)	TMA Vehicle Stationary (ft.)	TMA Vehicle Moving (ft.)
60-65	Appropriate buffer distance to be obtained from Table 4 or 5 based on policy decision defining shadow/barrier and impacting vehicle weights	
50-55		
≤ 45		

Legend:


Vehicle with Attenuator

FIGURE 3 Work area outside formal lane closure (not to scale).



Notes: 1. Advance warning traffic control devices to be in accordance with MUTCD, TCP, or other agency policies.

2. If the TMA vechicle is equipped with an arrow panel, it is to be operated in accordance with the MUTCD, TCP, or other agency policies.

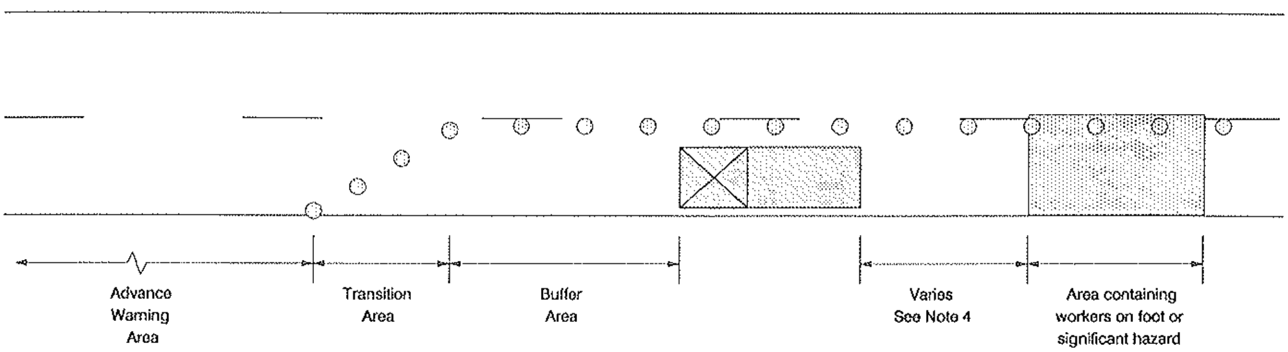
3. Variable intervening distance to be selected from the following table:

Prevailing Speed (mph)	TMA Vehicle Stationary (ft.)	TMA Vehicle Moving (ft.)
60-65	Appropriate buffer distance to be obtained from Table 4 or 5 based on policy decision defining shadow/barrier and impacting vehicle weights	
50-55		
≤ 45		

Legend:

Vehicle with Attenuator

FIGURE 4 Work area on shoulder without formal shoulder closure (not to scale).



Notes: 1. Advance warning and transition area traffic control devices to be in accordance with MUTCD, TCP, or other agency policies.

2. If the TMA vechicle is equipped with an arrow panel, it is to be operated in accordance with the MUTCD, TCP, or other agency policy.

3. Minimum buffer area length to be in accordance with TCP or agency policy.

4. Variable intervening distance to be selected from the following table:

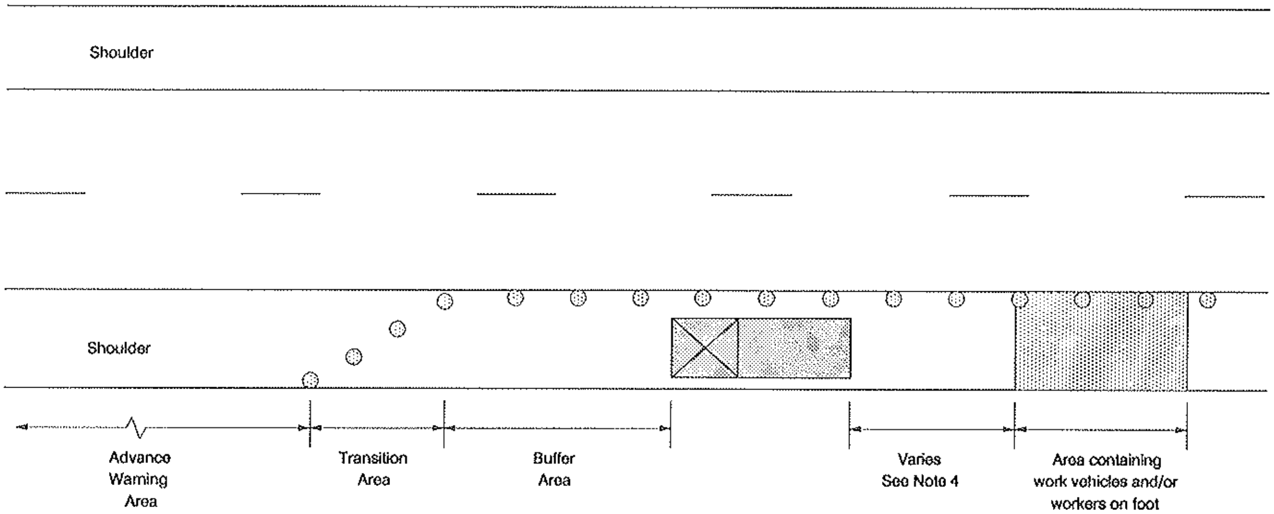
Prevailing Speed (mph)	TMA Vehicle Stationary (ft.)	TMA Vehicle Moving (ft.)
60-65	Appropriate buffer distance to be obtained from Table 4 or 5 based on policy decision defining shadow/barrier and impacting vehicle weights	
50-55		
≤ 45		

Legend:

Channelizing Device

Vehicle with Attenuator

FIGURE 5 Workers on foot or significant hazard within formal lane closure (not to scale).



Legend:

Channelizing Device

Vehicle with Attenuator

Notes:

1. Advance warning and transition area traffic control devices to be in accordance with MUTCD, TCP, or other agency policies.
2. If the TMA vechicle is equipped with an arrow panel, it is to be operated in accordance with the MUTCD, TCP, or other agency policy.
3. Minimum buffer area length to be in accordance with TCP or agency policy.
4. Variable intervening distance to be selected from the following table:

Prevailing Speed (mph)	TMA Vehicle Stationary (ft.)	TMA Vehicle Moving (ft.)
60-65	Appropriate buffer distance to be obtained from Table 4 or 5 based on policy decision defining shadow/barrier and impacting vehicle weights	
50-55		
≤ 45		

FIGURE 6 Work area on shoulder with formal shoulder closure (not to scale).

TABLE 4 ROLL-AHEAD DISTANCE FOR SHADOW VEHICLES

Weight of Shadow Vehicle (moving)[b]	Prevailing Speed (mph)	Weight of Impacting Vehicle to be Contained[a]			
		4,500 lbs	10,000 lbs	15,000 lbs	24,000 lbs
10,000 lbs	60-65	100 ft	175 ft[c]	225 ft	275 ft
	50-55	100 ft	150 ft[c]	175 ft	200 ft
	≤45	75 ft	100 ft[c]	125 ft	150 ft
15,000 lbs	60-65	75 ft	150 ft	175 ft	225 ft
	50-55	75 ft	125 ft	150 ft	175 ft
	≤45	50 ft	100 ft	100 ft	100 ft
24,000 lbs	60-65	75 ft	100 ft	150 ft	175 ft
	50-55	50 ft	75 ft	100 ft	150 ft
	≤45	50 ft	75 ft	75 ft	100 ft

[a]Weights of typical vehicles:

Mid-size automobile	2,250 lbs
Full-size automobile	3,500 lbs
Loaded 3/4-ton pickup truck	6,000 lbs
Loaded 1-ton cargo truck	10,000 lbs
Loaded 4-yard dump truck	24,000 lbs

[b]Distances are appropriate for shadow vehicle speeds up to 15 mph

[c]Values suggested for inclusion on Figures 3, 4, 5, and 6.

TABLE 5 ROLL-AHEAD DISTANCE FOR BARRIER VEHICLES

Weight of Barrier Vehicle (stationary)	Prevailing Speed (mph)	Weight of Impacting Vehicle to be Contained[a]			
		4,500 lbs	10,000 lbs	15,000 lbs	24,000 lbs
10,000 lbs	60-65	50 ft	100 ft[b]	150 ft	200 ft
	50-55	25 ft	75 ft[b]	100 ft	150 ft
	≤45	25 ft	50 ft[b]	75 ft	100 ft
15,000 lbs	60-65	25 ft	75 ft	100 ft	150 ft
	50-55	25 ft	50 ft	75 ft	100 ft
	≤45	25 ft	25 ft	50 ft	75 ft
24,000 lbs	60-65	25 ft	50 ft	75 ft	100 ft
	50-55	25 ft	25 ft	50 ft	75 ft
	≤45	25 ft	25 ft	25 ft	50 ft

[a]Weights of typical vehicles:

Mid-size automobile	2,250 lbs
Full-size automobile	3,500 lbs
Loaded 3/4-ton pickup truck	6,000 lbs
Loaded 1-ton cargo truck	10,000 lbs
Loaded 4-yard dump truck	24,000 lbs

[b]Values suggested for inclusion on Figures 3 through 6.

represent the researchers' views of the relative desirability of using a shadow or barrier vehicle (Table 2) or a TMA (Table 3) under a given set of circumstances compared with other circumstances. They should not be used as a basis for evaluating the relative merit of expending resources on providing shadow or barrier vehicles and TMAs compared with the merit of other projects or programs that may be in competition for the same resources.

TMAs have been available for several years, but their use in most states has been limited. As a result, there are no comprehensive guidelines or suggested application priorities. Soon after the study started, the researchers recognized that there was not an existing data base that would support a rigorous scientific analysis and that a comprehensive scientific study would require information derived from TMA use over diverse geographical areas and under a wide range of work zone types. Required data would include the number and severity of accidents (with and without TMAs) by work zone activity and some measure of the frequency of exposure and activities.

Although no scientific work plan was developed, it appeared obvious that developing an adequate data base would require the cooperation of a number of agencies, over an extended period of time, at a cost that would probably be measured in the hundreds of thousands of dollars—far beyond the budget available for this effort. In the meantime, because of the short-term need for a rational basis for assigning available units, this study was conducted.

The guidelines reflect the existing practices of the agencies contacted, the concerns expressed by field personnel who participated in the discussions, and the collective wisdom of the researchers and others (including agency representatives, other researchers, suppliers representatives, etc.) from whom comments were sought and received. Priorities based on scientific research would be desirable and ultimately will be developed. The researchers hope that the present effort will stimulate discussion toward that end, and believe that in the meantime the guidelines in their present form can be used appropriately as a policy formation and budgeting tool.

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