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16. Abstract

The purpose of this study was to identify new work zone traffic control (WZTC) techniques and devices being used throughout the country to improve worker safety, and to evaluate their appropriateness in Texas and for the Texas Department of Transportation. Various officials from selected state Departments of Transportation and other members of national committees and/or task forces on work zone safety were contacted. Based on input received by these agencies, the sponsor and TTI research staff cooperatively identified those WZTC devices that were reviewed. Ten WZTC devices were reviewed, five of which were included in the Strategic Highway Research Program (SHRP). This documentation provides specific recommendations regarding the potential usefulness of the various WZTC devices evaluated, requirements that must be met for implementation in Texas, an assessment of how to best achieve implementation of those devices, and an assessment of the need for those devices in Texas.

The opposing traffic lane dividers and the drum wraps were judged to be ready for immediate implementation. The direction indicator barricades, radar drones, and water-filled barriers have potential for implementation with modifications. There may be a need for these WZTC devices, but changes are required to TxDOT policy in order to achieve implementation. Researchers found the remaining five devices or technologies (blinking reflectors, portable curbs, portable rumble strips, intrusion alarms, and queue length detectors) would require further improvements in technology, or further evaluation to determine if actual benefits will be accrued.

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# DEVICES AND TECHNOLOGY TO IMPROVE FLAGGER/WORKER SAFETY

by

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## IMPLEMENTATION RECOMMENDATIONS

Ten new devices or technologies proposed to improve work zone traffic control (WZTC) were reviewed in this research.

1. Two WZTC devices were judged to be ready for implementation. These were opposing traffic lane dividers and drum wraps to maintain plastic drum reflective sheeting.

2. Three devices appear to have potential for implementation, but will require some type of change or modification to TxDOT policy in order to achieve implementation. The devices are as follows:

   - direction indicator barriers,
   - radar drones, and
   - water-filled barriers.

3. The remaining five devices or technologies reviewed in this report will either need additional evaluation or improvement before implementation can occur. These devices include:

   - blinking reflectors,
   - portable curbs,
   - portable rumble strips,
   - intrusion alarms, and
   - queue length detectors.

## DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge of this project was Dr. Gerald L. Ullman (Texas P.E. registration #66876).

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## SUMMARY

The purpose of this study was to identify new work zone traffic control (WZTC) techniques and devices being used throughout the country to improve worker safety, and to evaluate their appropriateness in Texas and for the Texas Department of Transportation. Various officials from selected state Departments of Transportation and other members of national committees and/or task forces on work zone safety were contacted. Ten WZTC devices were reviewed, five of which were included in the Strategic Highway Research Program (SHRP). This documentation provides specific recommendations regarding the potential usefulness of the various WZTC devices evaluated, requirements that must be met for implementation in Texas, an assessment of how to best achieve implementation of those devices, and an assessment of the need for those devices in Texas.

Two devices were judged to be ready for implementation. The opposing traffic lane divider satisfies a need in Texas, as well as meeting all existing applicable criteria. SHRP has developed specifications and set up and removal instructions. These devices can be implemented with simple in-house training instructions. Likewise, drum wrap technology (reflective sheets wrapped around plastic drums) is also ready for implementation. It meets all existing applicable criteria. However, post-implementation evaluation would be desirable to determine if the process of using drum wraps offers any advantages to simply placing new reflective sheeting strips over old sheeting when necessary. With respect to implementation needs, TxDOT would need to establish some type of incentive to maintain a high level of reflectivity quality on the plastic drums. Also, a policy to recycle plastic drums would make the drum wraps more desirable and needed.

Three devices appear to have potential for implementation, but require some type of change or modification to the device or to TxDOT policy in order to achieve implementation. A direction indicator barricade is perceived as a favorable device by many state agencies, and has undergone rigorous SHRP testing. If TxDOT wishes to use this device, however, it must petition the National MUTCD for permission to experiment as indicated under Section 1A-5 of the manual. In addition, guidelines need to be established for its proper application (i.e., lane closures, detours, etc.).

Radar drones address a real need in Texas to reduce speeds and the frequency and severity of motor vehicle crashes in work zones. However, before this device can be implemented, the FCC requires that a department policy be established. As part of this policy, a training program should be established for TxDOT personnel to learn how to determine the appropriateness of radar drone use at a work zone site.

The last device in this category is the water-filled barrier. The device functions more as a redirective impact attenuator than a barrier since it does deflect significantly when hit. In certain instances, the device could possibly enhance worker and motorist safety at work zones;

however, to ensure appropriate application of this device, it is suggested that application guidelines be developed within TxDOT before the implementation of this device.

The five remaining devices or technologies will require further improvements in technology, or further evaluation to determine if actual benefits will be accrued. For example, despite the claims of the manufacturer, the blinking reflector currently being marketed cannot be considered equivalent to the battery-powered flashing light. The MUTCD is very specific regarding the flash rate required for battery-powered flashing lights. Because the blink rate of the reflector changes depending on how close the motorist is to the reflector, it does not perform in the same manner as the battery-powered flashing lights.

Meanwhile, advantages of using the portable temporary curb over the use of a temporary asphalt curb need further study as well, particularly for dividing two-way traffic in work zones in urban areas. In addition, research is needed to determine how extensively temporary curbs are used in urban construction zones in Texas.

The last three devices all require modifications to their technology or construction before they could be considered viable alternatives for Texas work zones. The portable rumble strips do not always stay down on the pavement. This problem needs to be resolved before this device should be implemented. In addition, an evaluation to determine if the device actually improves driver reaction to flaggers or otherwise improves work zone safety is needed.

All three types of intrusion alarms reviewed require improved technology as well as increased reliability and reduced set up effects. An extensive training program will also likely be needed to help instruct work zone personnel on how to determine if an intrusion alarm is needed at a location and how to set up the device if its to be used.

Finally, the queue length detector also requires improvements in technology to increase the reliability of the device. In addition, an evaluation of the effectiveness of the device is needed. This device would require training on the set up procedures and message design concepts available in the MUTCD and Manual on Real-Time Motorist Information Displays.

# 1. INTRODUCTION

## BACKGROUND

Highway construction and maintenance work zones can be hazardous locations. Diverse driving patterns such as unexpected lane closures, and altered roadway alignment that drivers encounter during work zones create increased likelihood for crashes. In 1992, there were just under 700 fatalities in work zone accidents nationwide. In 1993, this rate increased 20 percent, resulting in 762 fatalities and an additional 37,800 injuries (*1*). In an effort to increase the safety of workers and the motoring public, new work zone traffic control (WZTC) devices and techniques are continuously under development nationwide.

Texas has made significant strides to improve work zone safety and operational efficiency over the past 25 years. Some of these new techniques and innovative WZTC devices that have been developed and/or evaluated include:

- truck-mounted portable maintenance barriers (*2*),
- supplemental devices to enhance flagger safety (*3*),
- more visible safety vests (*4*),
- innovative advance warning systems (*5*),
- temporary pavement markings (*6*),
- portable changeable message signs (*7*),
- traffic control plans (*8*),
- flashing arrowboards (*9*),
- moving maintenance operations (*10*),
- highway advisory radio (*11*),
- flagger signals (*12*),
- channelizing devices (*13*),
- work-zone speed control (*14-16*), and
- concrete barrier delineation (*17*).

Safety in work zones continues to be a high priority concern within TxDOT with an ongoing interest in new techniques, materials, and devices to improve work zone safety and operations in Texas.

## PROBLEM STATEMENT

### New Products and Techniques

Part VI of the National *Manual on Uniform Traffic Control Devices* (MUTCD) has recently been rewritten (*18*). Extensive changes have been made to this part of the manual to improve worker safety in work zones. In addition, worker safety in work zones continues to be studied by Federal Highway Administration (FHWA), the Texas Department of Transportation (TxDOT), the National Cooperative Highway Research Program, the State Planning and Research Program, the Strategic Highway Research Program (SHRP), and other sponsors.

Significant research has also occurred and continues to be performed on WZTC outside the state. The recent revision to the MUTCD includes many new techniques and WZTC devices to improve worker safety that have been developed as part of the SHRP efforts or other state initiatives.

## Effects of the Strategic Highway Research Program (SHRP)

The SHRP was established in 1987 as a five-year program sponsored by the FHWA to help improve highway safety. SHRP was responsible for the development, testing, and implementation of new traffic control work zone devices to help state and local highway agencies increase work zone safety. More than 131 products were considered, with 26 of these products pertaining to work zone safety (*19*). The 26 products were field tested by state highway agencies and others. These early experiences provided valuable information on the successes and lessons learned from each device to states just beginning the process of evaluating the device. Some of these devices have been enhanced and are currently being marketed. These include the following devices:

- flashing stop/slow paddle,
- portable rumble strips,
- portable all-terrain sign and stand,
- direction indicator barricades,
- opposing traffic lane dividers,
- intrusion alarms, and
- queue detectors.

One of the SHRP devices is particularly relevant and applicable for immediate use in work zones in Texas. There are others that have potential for implementation but require some type of modification. Still, there are others that require additional development or evaluation to make them practical.

## TxDOT WZTC Evaluation Needs

TxDOT has a New Products Testing Committee that is responsible for reviewing and evaluating new WZTC devices for potential use by TxDOT. In recent years, the committee has become inundated by the development of many new products and techniques for work zone traffic control and their introduction into the marketplace by vendors. Consequently, it has become difficult for the committee to fully evaluate and approve or disapprove the various products in a timely manner. Furthermore, the heavy focus on product evaluation has made it difficult for TxDOT officials to keep abreast of emerging technological developments with respect to WZTC, and to explore ways of positioning the Department to take advantage of these technologies. TxDOT needed a systematic evaluation of available products and techniques with respect to Texas needs. There was also a need to assist TxDOT in identifying those new WZTC devices that would best improve worker safety and serve the citizens of the state, and to develop a plan for how to best implement those WZTC devices of value into the existing TxDOT work zone operations. This report provides TxDOT personnel with an updated awareness of a selected group of WZTC techniques and devices that comply with the revised MUTCD, that are relevant to the Texas area, and which should be considered for possible implementation into the work zone operations statewide.

## PROJECT OBJECTIVES

The goal of the study summarized in this report was to identify new WZTC techniques and devices being used throughout the country to improve worker safety. In addition, methods of best implementing these new WZTC devices within Texas were examined. To accomplish this goal, the following objectives were specified:

1. Identify new WZTC devices that are being tested and used by various states to increase worker safety;

2. Develop recommendations for which techniques and devices TxDOT should consider implementing in its procedures and standards; and

3. Develop recommendations about how best to implement the suggested techniques and WZTC devices into TxDOT operations.

## PROJECT SCOPE

This report reviews ten new WZTC devices proposed to improve worker safety in the work zone. Chapter 2 explains the methodology used in the evaluation of the selected WZTC devices. The final chapter (Chapter 3) documents the results of the evaluation of the selected WZTC devices. This documentation provides specific recommendations regarding the potential usefulness of the various WZTC devices evaluated, requirements that must be met for implementation in Texas, an assessment of how to best achieve implementation of those devices, and an assessment of the need for those devices in Texas.

# 2. EVALUATION METHODOLOGY

## EVALUATION CRITERIA

Contacts were made to several state DOT's, members of the SHRP, and several product sales companies to assist in the identification of WZTC devices to review. Based on the input received from these agencies, the TxDOT project director and TTI research staff cooperatively identified those WZTC devices that were reviewed. Five of these devices were included in the SHRP.

The first step in evaluating the selected WZTC devices was to identify what need, issue, or concern that the particular device was trying to address. This need could relate to an operational or safety problem directly (i.e., to provide better positive guidance, to reduce high-speed vehicles, etc.). However, the need could also be to achieve a more efficient method of accomplishing WZTC (i.e., to reduce battery costs for flashing lights, to reuse temporary curbs in work zones, etc.). Once these were established, the device was critiqued in terms of how well it meets that need. This was based on engineering principles, inference from past research, and other states' experiences with the device.

Researchers made inquiries to in-state and out-of-state agencies that are currently testing or using such WZTC devices to determine their perceptions of each device's overall performance. Twenty-three state DOT's, three members of the SHRP, two members of the National Committee on Traffic Control Devices, as well as several private contractors and state police agencies were contacted. Additional information was obtained from the SHRP Information Clearing House, and from promotional literature provided by the vendors. It should be noted that no field testing or evaluation was performed on the selected devices.

The selected WZTC devices were examined to ensure compliance with the new MUTCD and FHWA guidelines, as well as criteria and guidelines outlined in the Manual on Real-Time Motorists Information Displays (*20*), Federal Communication Commission (FCC) requirements, American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide (*21*), and District Barricade and Construction Standard Sheets.

The evaluation of how critical or relevant those needs are in TxDOT work zones was conducted by reviewing past studies of work zone accident characteristics, assessing potential frequency of use and cost of the product, and assessing to the extent possible its potential to increase worker safety.

Finally, the researchers assessed various options regarding implementation of the selected device into TxDOT procedures and standards. The following section discusses the categories of recommendation options established by the researchers.

## RECOMMENDATION OPTIONS

Recommendations regarding implementation of each selected WZTC device are discussed in Chapter 3. In developing these recommendations, researchers identified and examined available training programs and other implementation methods for those WZTC devices that have potential for use in Texas. Some of the device manufacturers have developed their own training sessions for the products they market. It appears that some method of in-house training would be required to implement some of the other devices. Still other devices appear simple enough that special training would not be required. Recommendation options regarding implementation of the WZTC devices are divided into three categories.

Category 1 consists of devices (technologies) that are ready for immediate implementation. The devices satisfy real needs in Texas at this time. They meet existing applicable criteria or restrictions, and the implementation is possible with existing TxDOT mechanisms such as memorandums or demonstrations at conferences.

The devices or technologies in Category 2 have the potential for implementation with some type of modification to the device or change in federal or TxDOT policy. One or more of the following changes may be needed:

- criteria or restrictions must be changed;
- the device must be altered to meet criteria or restrictions; and
- implementation will require a new or innovative approach in order to achieve adoption, such as an extensive training program, specialized personnel, or equipment to support implementation.

The third category consists of devices or technologies that need additional evaluation or improvement before implementation can occur. These devices (technologies) require further evaluation to determine if actual benefits will be accrued, or if the devices or technologies do not or cannot adequately address the need they were designed to meet at this time

It should be noted that as with any new WZTC device used by TxDOT, review and approval from TxDOT must be obtained prior to using the device. The information in this report is not intended as a recommendation of whether or not the device should be used by TxDOT. The recommendations made in this report are based strictly on whether the device meets the need the device was trying to address or if it is in compliance with the new MUTCD and FHWA requirements. These recommendations do not address whether TxDOT should approve a device for use in Texas.

# 3. RESULTS ON DEVICES REVIEWED

This chapter documents the results of the evaluation of selected WZTC devices and technologies. The summary on each device consists of the five following components:

- a general description of the device or technology;
- the work zone safety or operational need the device or technology is attempting to address;
- the effectiveness of the device or technology in addressing that need;
- the potential benefit of implementing the device or technology in Texas; and
- implementation considerations.

In addition, a detailed discussion of each device or technology is included in the appendices. The ten devices discussed in this chapter are:

- Opposing Traffic Lane Dividers,
- Drum Wraps,
- Direction Indicator Barricades,
- Radar Drones,
- Water-Filled Barriers,
- Blinking Reflectors,
- Portable Curbs,
- Portable Rumble Strips,
- Intrusion Alarms, and
- Queue Length Detectors.

## OPPOSING TRAFFIC LANE DIVIDERS

### General Description

The opposing traffic lane dividers are delineation devices designed to convert a normal one-way roadway section to two-way operation (Figure 3-1). The upward and downward arrows on the sign's face indicate the direction of traffic on either side of the divider. The base is secured to the pavement with adhesive to minimize movement caused by a vehicle collision or wind gusts. The sign is placed on a flexible self-recovering support so that if the sign is hit by a vehicle, it will return to an upright position. A detailed description of this device can be found in Appendix A.

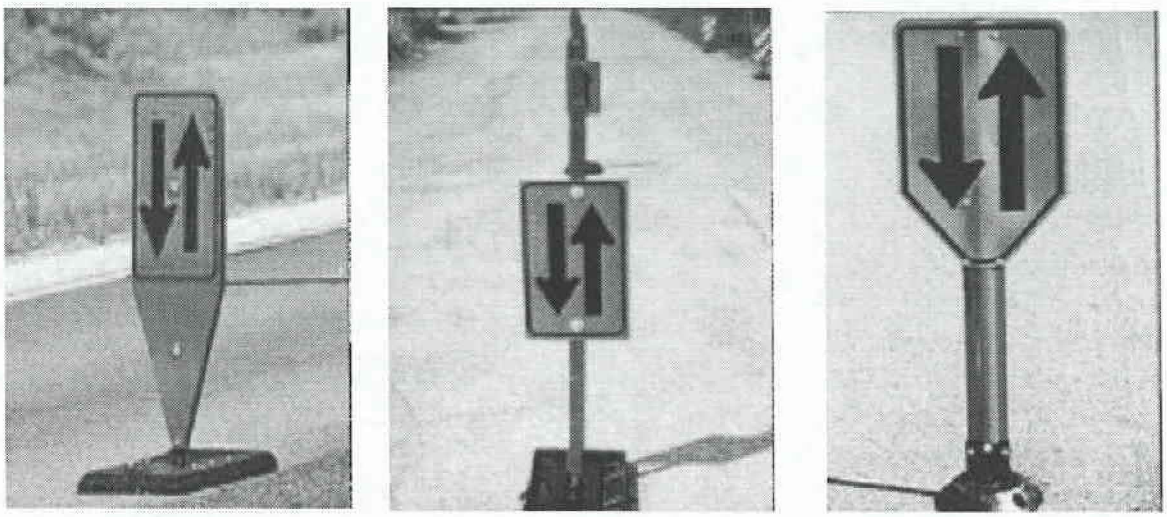

**Figure 3-1. Examples of Opposing Traffic Lane Dividers**

### Need Being Addressed

The opposing traffic lane divider is to be used as delineation in split traffic operations. Reports indicated that it provides a better indication to drivers that the roadway section is operating with two-way traffic. The manufacturers claim that the opposing traffic lane divider reduces channelization costs, labor, and vehicular damage.

### Effectiveness at Addressing Need

The SHRP report on the opposing traffic lane divider stated that this device is one of their better success stories. Other states have indicated that the opposing traffic lane divider was an effective delineation device for split traffic operations. They appear to be cost effective as reported by the Childress District, who estimated a savings of $1.6 million from direct and passive costs. They are as easy to install and remove as the vertical panel, and appear to be understood by the motoring public.

## Potential Benefit of Device in Texas

A significant number of work zones in Texas involve two-way operations where the opposing lane divers could be applicable. The opposing traffic lane divider appears to be an effective delineation for split traffic operations and an alternative to the use of vertical panels. In addition, reports have indicated that the motorists seem to have a clear understanding of the device.

## Implementation Considerations

The opposing traffic lane divider is approved by FHWA as well as the National MUTCD (*19*) and the Texas Manual on Uniform Traffic Control Devices (TMUTCD)(*22*). These documents state that "opposing traffic lane dividers are delineation devices used as center lane dividers to separate opposing traffic on a two-lane, two-way operation." Of the three manufacturers marketing the product, one has already received approval for use by TxDOT. There does not seem to be any significant differences in the products.

Researchers rate this device as being ready for immediate implementation. The device satisfies a need in Texas, as well as meeting all existing applicable criteria. SHRP has recommended specifications and developed setup and removal instructions. These devices can be implemented with simple in-house training instructions.

## DRUM WRAPS

### General Description

Drum wraps consist of standard reflective sheeting on a plastic backing that can be applied around new or used plastic drums. It comes in 102 mm and 203 mm widths, twenty gauge or more in thickness. Figure 3-2 illustrates this device. In addition, a detailed description of this device can be found in Appendix B.

**Figure 3-2. Example of Drum Wraps**

### Need Being Addressed

The manufacturer claims that the wrap can be easily mounted and/or removed with adjustable plastic ties. The wrap is intended to increase the service life of plastic drums by allowing those with damaged or missing reflective tape to be reused. The manufacturer also suggests purchasing plastic drums without reflective tape glued to it and then applying the wraps. This method would cost about the same as purchasing a sheeted plastic drum, but it eliminates the task of stripping the plastic drum before disposing of it. The advantage in this procedure lies in the ultimate disposal of the plastic drum. The manufacturers note that uncontaminated plastic drums (those without reflective sheeting attached by adhesives) are more readily recycled.

### Effectiveness at Addressing Need

This product has only been on the market for a short period of time. There is little information on the field performance of this product. However, one Houston contractor reported that they had used this technique on a few of their plastic drums. He reported that it seemed to be a less expensive method than purchasing new plastic drums. It took two people to resheet a plastic drum.

New plastic drums with reflective sheeting and those installed with drum wraps cost about the same. Although the product supplier suggests that there is a definite advantage in discarding uncontaminated plastic drums, one TxDOT employee (as well as the contractor previously mentioned) stated that most plastic drums are used until they are completely unserviceable, at which time they are discarded.

## Potential Benefit of Device in Texas

Since the initial costs for a drum wrap plastic drum and a sheeted plastic drum are about equal, the primary benefit of the drum wraps would occur if the device increases the ultimate life of a plastic drum (reducing replacement costs). However, at this time there is little evidence to suggest the plastic drum life would be extended in Texas. Reflective sheeting condition is not the primary reason plastic drums are being discarded.

## Implementation Considerations

The Texas MUTCD and the National MUTCD have the same specifications for plastic drums regarding the reflective striping. The requirement is to have alternating orange and white retroreflective stripes (at least two of each). The stripes must be 100-200 mm wide. The drum wraps product meets these standards.

Even with a good performance rate, TxDOT would need to take several actions in order to make this a usable product. These include:

- establishing an incentive to maintain a high level of reflectivity on the plastic drums, and
- establishing a policy to recycle the plastic drums.

The drum wraps are technically ready for implementation at this time. However, elevation is needed to determine if the plastic drum life would be extended by the use of the drum wraps or if they are economically feasible.

## DIRECTION INDICATOR BARRICADES

### General Description

A direction indicator barricade is designed to provide desired directional movement information to drivers that is not always conveyed with normal barricades. The device displays an arrow in conjunction with the conventional diagonal stripes in a single barricade unit (See Figure 3-3). The direction indicator barricade also differs in construction from conventional wooden and metal barricades in a number of ways. It is not a traditional A-frame design, but rather a single panel hinged to a pair of horizontal "feet." An arrow is placed in the top panel of the barricade. A flashing or steady burn light can also be mounted on top of the barricade. The battery is located at the bottom of the barricade below the vehicle bumper so as to reduce the risk of the battery becoming an airborne projectile in the event of a vehicle impact. A more detailed summary on this devices can be found in Appendix C.

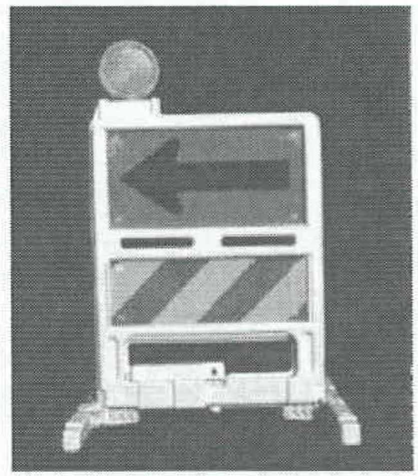

**Figure 3-3. Example of a Direction Indicator Barricade**

### Need Being Addressed

Direction indicator barriers can be placed in a series along the roadway to direct motorists through a taper area and into an adjacent lane. They can be reversed to allow for inside or outside application. When hit, the devices are designed to fall flat and remain down. This reduces the risk of flying debris from the barricade. The manufacturer claims that the device can then be returned to an upright position without damage. They also claim that the device offers speedy installation, easy maintenance, and easy storage. The reflective sheets of diagonal stripes are recessed to prevent scratching and wear. Furthermore, the reflective sheets are replaceable to simplify recycling if desired.

### Effectiveness at Addressing Need

The direction indicator barricade seems to offer additional positive directional guidance to the motorist in work zone taper and transition areas. It has been recommended by SHRP as a desirable enhancement for traffic control in the work zone environment. The price is only slightly greater than new channelization drums. Reports have been that the direction indicator barricade is safer to install than drums because they are easier and faster to place.

## Potential Benefit of Device in Texas

There are numerous work zones in Texas daily which involve lane closures where the direction indicator barricade could be implemented. Any device that reduces set up times where workers are vulnerable to on-coming traffic would be beneficial. The extent to which a taper of such barricades at a closure offers any motorist safety benefits over a taper of drums is not known at this time.

## Implementation Considerations

The direction indicator barricade meets MUTCD specifications on width and length of the striping of barricades. It may qualify as a Type I or Type II barricade since it has two horizontal rails. Texas will need to decide whether or not an arrow is a suitable replacement for the striping on the top rail if the device is to be approved at all. It should be noted that the MUTCD (*18*) indicates in Section 2C-9 that the large arrow sign "is intended to be used to give notice of a sharp change of alignment in the direction of travel. It is not to be used where there is no change in the direction of travel" (ends of medians, center piers, etc.). Accordingly, the device would not be appropriate for situations where there is no change of alignment. Because of this, there appears to be a slightly greater risk of misapplication for the barricade, relative to the plastic drums. For example, it is possible that the device could be displayed with the arrow at locations where no alignment changes are required. It is also possible for the arrow and the striping directions to be accidentally installed in opposite directions, which could increase driver confusion. However, frequent inspections of traffic controls set ups could minimize the potential for these types of misapplications.

The researchers believe that this device has potential for implementation. If TxDOT wishes to use this device, it must petition the National MUTCD for permission to experiment as indicated under Section 1A-5 of the manual. In addition, instructions will need to be established to ensure proper application when using this device.

## RADAR DRONES

### General Description

The radar drone is intended to be used to reduce speeds through work zones. Figure 3-4 illustrates this device. The idea is to activate the radar detectors used by many motorists as they approach a work zone in the hope that they will consequently slow down. There are four different models of the device. Appendix D gives a description of this technology.


**Figure 3-4. Example of a Radar Drone Mounted on a Speed Limit Sign**

### Need Being Addressed

The device is used as a tool to reduce speeds in work zones and increase safety for construction workers in the area. Manufacturers claim a significant decrease in mean speeds and a reduction of high speed vehicles by using these devices. They state that the device lowers the odds of injury to people in construction sites.

### Effectiveness at Addressing Need

Various studies have indicated that while the unmanned radar drone use for speed reduction does not seem to reduce mean speed greatly, its strength lies in reducing the speed of vehicles traveling 16 km/h or more over the posted speed limit.

It appears that truck drivers and the work commuter drivers who travel through a work site on a daily basis may become suspicious if they detect a radar signal repeatedly and never see a law enforcement officer. It may be necessary to move the unit more frequently or supplement its use with the use of law enforcement officers on a random basis.

## Potential Benefit of Device in Texas

Research has shown that it is difficult to reduce vehicle speeds in work zones. Studies have shown that vehicles with radar detectors are more likely to speed than vehicles without detectors (*23*). Also, evidence indicates that vehicles traveling at the highest speeds are more likely to have a radar detector. Meanwhile, accident studies have identified excessive speed as a contributing factor in many work zone accidents (*24, 25*). Evidence indicates that the drone's strength lies in reducing the speed of vehicles traveling 16 km\h or more over the posted speed limit.

## Implementation Considerations

This device seems to have the potential to reduce speeds and the frequency and severity of motor vehicle crashes in work zones and other areas where excessive speed has been a significant factor; however, as required by the FCC, specific guidelines are needed on the appropriate site conditions for drone radar use (i.e. site location, traffic patterns, etc.). Researchers believe that this device has potential for implementation. The Department policy on the use of the radar drone must be established per FCC requirements. This policy must have the following components:

- It must be part of an agency's speed enforcement efforts;
- The selection of a site should be based on problem identification;
- It must adhere to FCC rules;
- It must be under local control and supervision; and
- Program evaluation must be included as part of the policy.

The National Highway Traffic Safety Administration (NHTSA) has developed guidelines on how states might use the device in compliance with the FCC regulations and policy. In addition, one of the manufacturers offers an extensive training program and manual to their customers.

## WATER-FILLED BARRIERS

### General Description

The water-filled barrier is a portable, energy-absorbing, barrier protection device for work crews. Figure 3-5 illustrates this device. Additional uses are said to include channelization of traffic and damage reduction for errant vehicles. The barrier consists of modular polyethylene units interconnected with metal pins and filled with water. Impact energy is absorbed by the water as it erupts from holes on top of the unit. Empty, each unit weighs 63 kg and can be handled by two workers. No specialized tools are necessary. The units can be filled with a water truck and drained through quick release valves. Fork lift holes are located on each unit if the units need to be moved while full. More information on this device is in Appendix E.

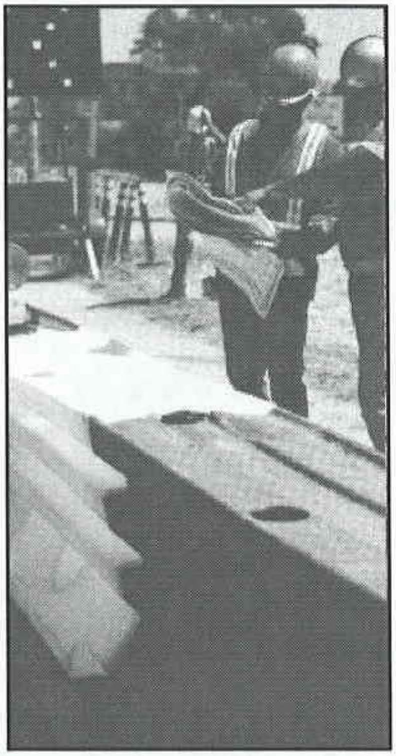

**Figure 3-5. Example of a Water-Filled Barrier**

### Need Being Addressed

The manufacturer claims that this new device increases protection to the work crews, preventing errant motorists from entering into the work area. They state that portable concrete median barriers often deflect an impacting vehicle back into the flow of traffic, whereas common delineation devices allow errant motorists to enter into the work area. In contrast, the device is said to bring the vehicle to a controlled stop without allowing penetration.

### Effectiveness at Addressing Need

Reports indicate that the barrier seems to be an effective tool to increase the safety of workers. According to other state agency experiences, the devices are easy to install and move. However, agencies have noted that they would not recommend this device in lieu of portable concrete barriers due to the much larger lateral deflections that occur with the barrier when impacted. Rather, these agencies suggest that the device might be useful at locations where the only previous protection would have been plastic drums. There has also been evidence that some of the drums were not repairable after collisions.

## Potential Benefit of Device in Texas

The barrier serves as a longitudinal crash cushion. It is possible that the barrier could provide additional worker protection in some instances. However, one agency was concerned with the confusion that could be created by using different types of barriers for different work zone conditions. In addition, concern has been expressed about the water-filled barriers creating a hazard in an event of a crash and causing liquid to flow onto the roadway. Another major question to be answered though, is whether the barrier offers any benefit over truck-mounted attenuators placed in work zone buffer areas.

## Implementation Considerations

The TMUTCD and the National MUTCD are alike in their requirements for barriers. The barrier functions more as a redirective impact attenuator than a barrier since it does deflect when hit. The MUTCD requires attenuators to mitigate the effects of errant vehicles by either smooth deceleration or redirection.

The barrier was not penetrated in the 72 km/h collisions or in the 96 km/h collision tests performed by the manufacturer. Instead, vehicles were slowed to a stop or redirected. As they suggest and the MUTCD mandates, units should be inspected after each impact event and replaced if damaged. Both the TMUTCD and the National MUTCD require barriers to meet AASHTO standards.

The manufacturers believe these barriers will also work in winter conditions. However, vehicle and barrier impact behavior has not been tested when the barrier is frozen. Also, the devices will require forklifts to handle if frozen since they cannot be drained. Therefore, the manufacturer suggests mixing the water with antifreeze to allow drainage in winter conditions.

Researchers believe that the efficient use of truck-mounted attenuators in work zones may accomplish much of the same type of crash cushion protection as the water-filled barrier. Nevertheless, it is possible that the barrier could provide additional protection in some instances. Researchers feel that detailed guidelines on proper application need to be established before the implementation of this device.

## BLINKING REFLECTORS

### General Description

The blinking reflector is a large (approximately 250 $cm^2$) delineator that appears to "blink" (by altering the coefficient of luminous intensity) as the motorist's viewing angle to the device changes. Figure 3-6 illustrates this device. See Appendix F for more detailed discussion of this device.

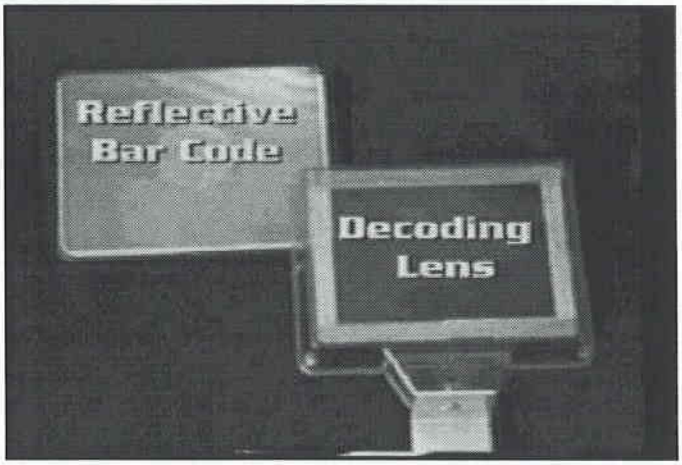


**Figure 3-6. Example of a Blinking Reflector**

### Need Being Addressed

Battery-powered flashing warning lights are expensive (battery costs), and are often vandalized and/or stolen. Manufacturers of the blinking reflector say that the reflector achieves the high target value and attention-getting ability of flashing lights without the battery costs and vandalism/theft problem. Laboratory tests reported by the manufacturer indicate that the luminous intensity of the reflector is greater than that of any of the three types of warning lights (A, B, or C). These intensities have yet to be verified by TxDOT testing procedures, however. The perceived blink rate of the reflector is not constant to an approaching motorist. Rather, the rate increases exponentially as the distance from the motorist to the reflector decreases. The MUTCD specifies acceptable flash rates for lights. The rate at which the reflector blinks generally falls outside of this acceptable range (see Appendix F).

### Effectiveness at Addressing Need

To date, experiences of highway agencies and contractors with the device have been mixed. Some problems with the reflector have been reported relating to the manner in which it was attached to an object. This ultimately affects the maintenance costs of the device. The reflectors have to be properly aligned with oncoming traffic in order to be effective, which may impact their usefulness to contractors and maintenance crews when setting up appropriate traffic control. However, other agencies and contractors using the reflector have not reported these types of problems.

The reflector may have potential application at work zones when used other than as a replacement for required flashing warning lights. The device may have attention-getting characteristics, both by a larger size and by the dynamic luminous intensity characteristics, relative to regular delineators or barrier reflectors. Because the reflector does blink, it cannot be used on channelizing devices when used for lane guidance. Research and field studies are needed to determine if there are other applications where the device may improve safety. Also, laboratory studies should be conducted to determine the benefits (or adverse consequences) of the blinking phenomenon upon motorist perception and driving response in work zone situations.

## Potential Benefit of Device in Texas

Although a goal to replace battery operated flashing lights in work zones is desirable (due to high costs of batteries, vandalism, theft, etc.), the MUTCD is very specific regarding the flash rate required for battery-powered lights. Unless an alternative can meet MUTCD flashing light criteria under all viewing conditions, or the criteria in the manual is changed, the potential tort liability exposure for adopting the reflector as an alternative to flashing lights appears too great at this time. Research is needed to determine if the blinking reflector could be used in lieu of static reflectors in certain situations (those not used for lane guidance, for instance), but data are not yet available to determine whether the "blinking" phenomenon would in fact result in measurable improvement in traffic safety or operations.

## Implementation Considerations

Because the blink rate programmed into the blinking reflector changes, it does not perform in exactly the same manner as a battery-powered flashing warning light. In addition, the reflector does not appear to blink to a motorist in a vehicle that is not moving (i.e., at a stop sign) or to a motorist viewing the reflector from a cross street intersection. Therefore, it cannot be considered an equivalent replacement to a flashing warning light. Also, it is not known whether the reflector meets current TxDOT retroreflectivity specifications for regular delineators or barrier reflectors. If it does, the device could be used as a reflector at the work zone as long as it is not put on channelizing devices used to indicate lane guidance.

Researchers believe that this device needs additional evaluation before it is implemented. Also, detailed guidelines on appropriate traffic operation applications in work zones would need to be developed by TxDOT prior to implementation of this device.

## PORTABLE CURBS

### General Description

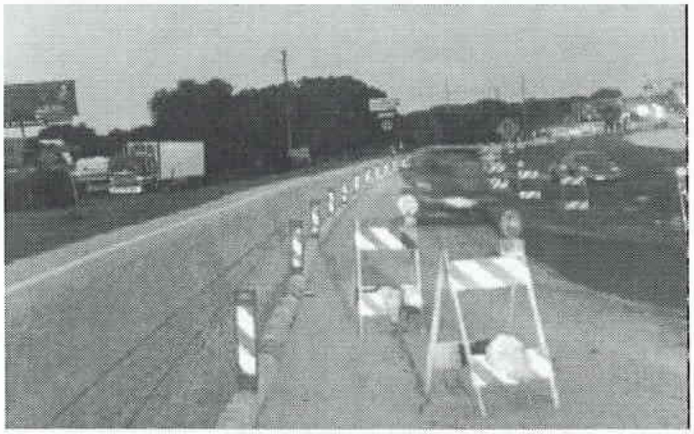

Figure 3-7. Example of Portable Curbs

One manufacturer is marketing a temporary portable curb as a new work zone traffic channelization device. Figure 3-7 illustrates the device. The device consists of one meter strips of a recycled rubber and polyethylene composite interlocked to form an 81 mm high "curb." Vertical reflective panels as well as opposing lane dividers can be attached to the curb every 0.9 to 7.6 meters. The unit relies on its weight and friction for attachment to the pavement. For added visibility, 6-volt light attachments are available. Each curb section has built in reflective arcs (every 0.9 meters). More information on this device is in Appendix G.

### Need Being Addressed

The manufacturer views the portable curb as a potential alternative to the use of temporary asphalt curbs in speed zones of less than 72 km/h. It is primarily recommended for use in dividing two-way traffic in work zones and as an additional guidance for vehicles in lane closures.

The manufacturer presents several advantages of using a temporary portable curb over temporary asphalt curb. They cite the lack of reusability for asphalt curbs for comparison and estimate the installation time at one third that for typical asphalt curbs. They also point out that the device does not damage the road surface or any markings on that surface. The manufacturer states that the product should pay for itself within six applications compared to the expense of putting down and taking up temporary asphalt curbs each time.

### Effectiveness at Addressing Need

Reports from various state agencies indicate that the portable curb is more visible than reflective paint on asphalt curbs. The reflectors on the curb at one meter spacing give the appearance of a channelization device that's easily distinguished night or day. One agency commented that the installation and removal of the device was quick and the product was very visible, eliminating the need for the optional 6-volt light to be mounted on top of the vertical panel. At vehicle speeds up to 80 km/h, the curb displaced very little, even when hit by trucks. The device is easy to use, and requires only two people to assemble and move the device.

## Potential Benefit of Device in Texas

The advantages of the portable curb over the temporary asphalt curb may warrant further evaluation for use in dividing two-way traffic in work zones in urban areas. It was not possible to determine how extensively temporary curbs are used in urban construction zones in Texas. It does not seem feasible to use the portable curb for lane closures.

## Implementation Considerations

The Texas MUTCD states that the channelization devices should yield when struck in a predictable way and should not produce debris that could enter the passengers' compartment. Tests conducted in Germany show that this device does meet these requirements.

The manuals also state that the vertical reflective panels must be at least 200 x 600 mm and have the standard diagonal pattern for reflective material. Three of the four designs sold by the manufacturer meet these requirements. The maximum height for temporary raised islands is 102 mm. The portable curb is only 81 mm tall.

As a special note, the National MUTCD does not specify polyethylene as an acceptable component in vertical panels. As such, Section 6F-5H of the MUTCD would need to be modified to include polyethylene. However, considering the performance in the German tests, establishing polyethylene as a material durable and strong enough for this type of application should not be a problem.

Researchers believe that additional evaluation on this device is needed before implementation can occur. Evaluation on the advantages of the portable curb over the temporary asphalt curb in dividing two-way traffic in work zones areas needs to be determined. In addition, how extensively temporary curbs are used in urban construction zones in Texas also needs to be established.

## PORTABLE RUMBLE STRIPS

### General Description

The portable rumble strip is a tough flexible vinyl strip measuring 462 mm in width, 3 m in length, 3 mm - 29 mm in thickness, weighs approximately 32 kg, and is grey-black in color. Figure 3-8 illustrates this device. The cost is approximately $100 per strip. The device was developed through SHRP. Appendix H is a detailed summary of the portable rumble strip.

**Figure 3-8. Example of a Portable Rumble Strip**

### Need Being Addressed

Portable rumble strips are intended to perform in the same manner as permanent rumble strips with the ability to move them to different locations as required. Their primary use is said to be at flagging operations where moderate speed traffic many need to be stopped intermittently. The strip (or strips) is to be placed about 100 meters in advance of the flagger. When a vehicle runs over the strip the tactile and auditory feedback alerts the driver of potential danger. The manufacturer claims that the device gets the attention of the drivers and protects the workers. They also stated that the device is easy to install from the spool on which it is stored. The manufacturer does not recommend the use of a portable rumble strip in freezing temperatures.

### Effectiveness at Addressing Need

SHRP reported in 1995 at the AASHTO Convention that nearly all the states (*30*) that tried the portable rumble strip had trouble keeping the device in place. The consensus on the use of the device was unfavorable and the recommendation was to not use it at this time because of the difficulty of the strip staying down on the pavement. In addition, while the manufacturer claims that the portable rumble strips can easily unfold and roll into place, reports from other states have indicated that the product was not easy to handle and deploy. In some cases, drivers have thought that the device was debris in the road and then veered around it.

### Potential Benefit of Device in Texas

Reports indicate that the device takes a considerable amount of time to install and remove. The difficulty of the strips staying down could produce a hazard rather than increase the safety of the flagger. No data are available to indicate that the device actually improves driver reaction to flaggers, or improves work zone safety. Until these problems are resolved, it does not seem feasible to pursue implementation of this device at this time.

## Implementation Considerations

The rumble strip meets the specifications in the Texas MUTCD and those in Sections 6F-8d of the revised Part VI of the National MUTCD. They are to be used to supplement standard or conventional traffic control devices, and they may be portable devices.

The SHRP states that the portable rumble strip is intended primarily for flagging operations, and should not be used in high speed applications where intermittent stops are not required. Researchers believe that the difficulty of the strips staying down needs to be resolved before the device can be implemented in Texas. Adverse effects may exist due to unexpected driver responses to the device in the roadway.

## INTRUSION ALARMS

### General Description

The intrusion alarm is intended to detect errant vehicles that stray into the work zone buffer area between vehicles and work crews. If a vehicle intrudes into the buffer area, an alarm sounds almost instantly to warn work crews. Figure 3-9 illustrates this device. Three basic types of intrusion alarms have been introduced on the market. The first is activated by microwave transmissions, the second by an infrared light beam, and the third by pneumatic tubes. The microwave and infrared models mount on traffic cones or plastic drums, and the tube-type systems lie flat on the ground. The detailed description of this technology can be found in Appendix I.

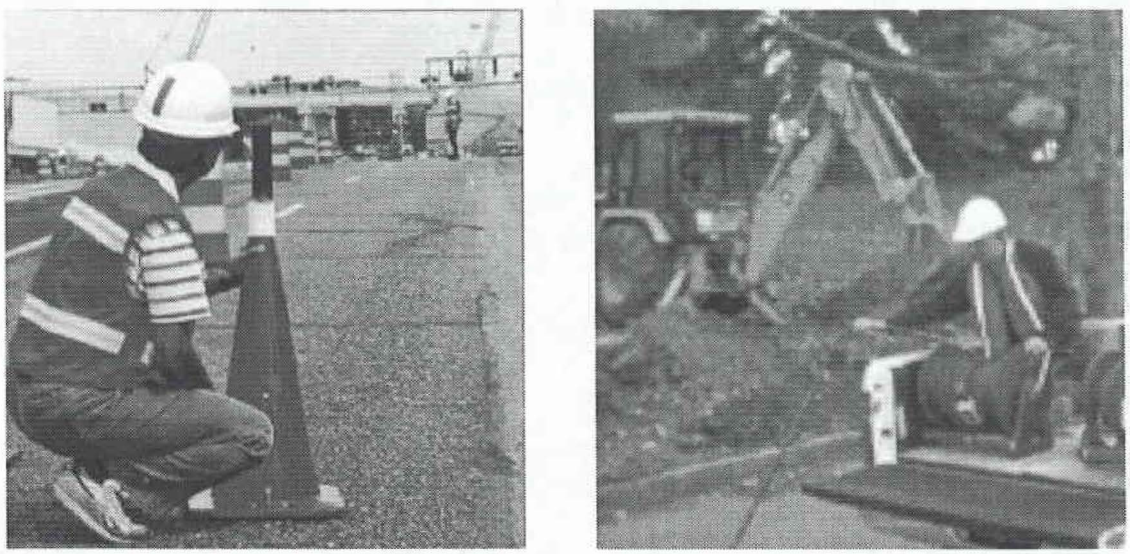

**Figure 3-9. Examples of Infrared and Pneumatic Tube Intrusion Alarms**

### Need Being Addressed

The vehicle intrusion alarm device is intended to help increase worker safety in work zones by monitoring the buffer area between the motorists and the work crew and sounding an alarm if a vehicle crosses into the buffer area. Presumably, this gives workers an extra few seconds to clear out of a vehicle's path. Manufacturers and SHRP claim that it is an effective tool in any work zone, and that it enhances the safety of the workers.

## Effectiveness at Addressing Need

Microwave Models - reports have indicated that this type of system takes too much time to set up. Also, the strobe warning lights were reportedly not bright enough, and the siren was not loud enough. Alignment of the signal was said to be difficult and there were several false alarms triggered by rain, dust, and slight movements of the drums.

Infrared Units - several states reported that this type of alarm system is too sensitive, again resulting in numerous false alarms. Another state reported that the results are inconsistent. Sometimes the system will not activate when it should, and at other times false alarms occurred. The difficulty in alignment limits use of this technology to stationary operations. In addition, traffic cones on very hot days become very flexible causing the infrared beam to become misaligned and trigger a false alarm.

Pneumatic Tube Systems - reports from various agencies stated that this type of system does not give enough warning to workers, that it takes too much time to set up and align the device, it is neither durable nor dependable, and it caused several false alarms.

## Potential Benefit of Device in Texas

This concept has created great interest in the traffic engineering field. No doubt, if the device works appropriately it could enhance safety in most work zones in Texas. However, at this point the device may be cost prohibitive, given such negative reviews. In addition, its true effect upon work zone accidents has yet to be determined.

## Implementation Considerations

The Texas MUTCD and the National MUTCD do not contain any specifications regarding intrusion alarms as this is a relatively new device that has not been used extensively around the country. In Section 6D-2 the Manual states that "judicious use of special warning and control devices may be helpful for certain difficult work area situations." An SHRP test evaluated the crash-worthiness of an infrared model and reported that it performed up to NCHRP standards regarding fragmentation, vehicle damage, and work zone hazards.

Researchers believe that this technology needs additional improvement and evaluation before the devices can be implemented. The devices need to be evaluated to determine if actual benefits will be accrued. Improvements in all three types of intrusion alarm technology will be needed to improve reliability and reduce set up effects. It will also require an extensive training program to help instruct work zone personnel on when and how to set up an intrusion alarm. One manufacturer has developed its own training program which is available when one purchases their product.

# QUEUE LENGTH DETECTORS

## General Description

The queue length detector is designed to be used in areas where traffic flow conditions may change unexpectedly, and where traffic surveillance is not available. It warns drivers when traffic downstream has slowed or has stopped completely so that they may take an alternate route, or be better prepared to stop. Figure 3-10 illustrates the queue length detector. The only device of this type currently on the market transmits an infrared beam across the roadway to monitor traffic flow. The device detects the speed of passing vehicles and sends out a signal when the speed drops below a user defined value (or if traffic stops altogether). This signal can be used to activate a changeable message sign to give motorists information in advance that traffic has slowed down or has completely stopped. The signal could also be hooked up to alert workers to traffic problems, or to inform authorities. It can be linked with cellular, hardwire, or other communication devices. More information on the queue detector can be found in Appendix J.

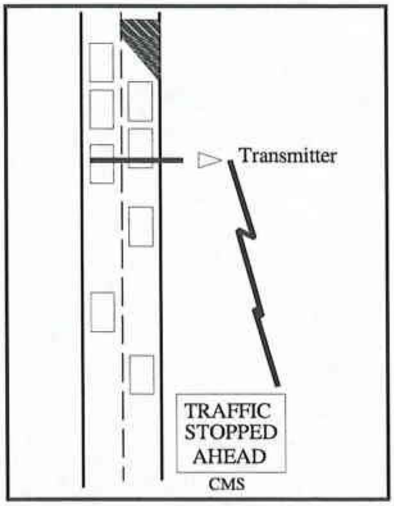


**Figure 3-10. Example of a Queue Length Detector**

## Need Being Addressed

SHRP states that the device is an easy-to-use warning device that can be used near work zones, toll roads, and other areas where there is the potential for traffic to slow or stop unexpectedly. SHRP officials have indicated that they feel that the queue detector could decrease the number of accidents and injuries that occur each year due to traffic queues located in blind spots on roadways. The manufacturer claims that it increases safety, mounts quickly and easily, increases motorist options, and alerts authorities.

## Effectiveness at Addressing Need

There seems to be a problem with various states' willingness to evaluate the device, as well as with finding suppliers to manufacture it. Concerns over detector-CMS communications and false alarms are the most significant problems mentioned by the states contacted. These are typical problems experienced when attempting to use "blind" surveillance systems (where verification via cameras or on-site personnel is not possible).

## Potential Benefit of Device in Texas

It would certainly seem helpful to provide real-time information to motorists prior to the work zone. However, until additional development and evaluation of the effectiveness of the device occurs, it does not appear prudent to pursue immediate implementation of this type of technology.

## Implementation Considerations

The Texas and the National MUTCD do not contain any specifications on the use of a queue detector. The positioning and contents of the message displayed via a changeable message sign (CMS) would need to follow signing guidelines available in the MUTCD and the Manual on Real-Time Motorist Information Displays (*21*). This device would require some training on set up procedures.

Researchers believe that this technology needs to be improved before implementation can occur. Upon technology improvement, TxDOT may want to pursue further evaluation on this device to determine if actual benefits will be accrued.

## PRIORITIZATION OF DEVICES FOR IMPLEMENTATION

Table 3.1 illustrates implementation recommendation options for each device or technology reviewed. These options were discussed in detail in Chapter 2. Based on the reviews of each device in previous sections, two devices appear ready for immediate implementation, three have potential for implementation, and five need additional evaluation or improvement before implementation can occur. Rationale for these recommendations are provided below.

**Table 3.1. Devices or Technology Recommendation Option**

| Device/Technology | Ready to Implement | Potential for Implementation | Additional Evaluation or Improvements Needed |
|---|---|---|---|
| Opposing Traffic Lane Dividers | X | | |
| Drum Wraps | X | | |
| Direction Indicator Barricades | | X | |
| Radar Drones | | X | |
| Water-Filled Barriers | | X | |
| Blinking Reflectors | | | X |
| Portable Curbs | | | X |
| Portable Rumble Strips | | | X |
| Intrusion Alarms | | | X |
| Queue Length Detectors | | | X |

### Devices or Technologies Ready for Immediate Implementation

Table 3.2 is a summary of the two devices that are judged to be ready for immediate implementation. The opposing traffic lane divider satisfies a need in Texas, as well as meeting all existing applicable criteria. SHRP has developed specifications and set up and removal instructions. These devices can be implemented with simple in-house training instructions. Likewise, the drum wrap technology is also ready for implementation. It meets all existing applicable criteria, and provides a high level of reflectivity. However, post-implementation evaluation would be desirable to determine if the process of using drum wraps is advantageous to simply placing new reflective sheeting strips over old sheeting when necessary. With respect to implementation needs, TxDOT would need to establish some type of incentive to maintain a high level of reflectivity quality on the plastic drums. Also, a policy to recycle plastic drums would make the drum wraps more desirable and needed.

## Devices or Technologies That Have Potential for Implementation

Three devices, listed in Table 3.3, appear to have potential for implementation, but require some type of change or modification to the device or to TxDOT policy in order to achieve implementation. The direction indicator barricade is perceived as a favorable device by many state agencies, and has undergone rigorous SHRP testing. If TxDOT wishes to use this device, however, it must petition the National MUTCD for permission to experiment as indicated under Section 1A-5 of the manual. In addition, guidelines need to be established on its proper application (i.e., lane closures, detours, etc.).

The radar drone addresses and satisfies a need in Texas to reduce speeds and the frequency and severity of motor vehicle crashes in work zones. However, before this device can be implemented, the FCC requires that a department policy be established. It is recommended that the NHTSA policy included in the back of Appendix D be used as a guide for establishing a formal TxDOT policy on radar drone use. As part of this policy, a training program should be established for TxDOT personnel to learn how to determine the appropriateness of radar drone use at a work zone site.

The last device in this category is the water-filled barrier. The device functions more as a redirective impact attenuator than a barrier since it does deflect significantly when hit. In certain instances, the device could possibly enhance worker and motorist safety at work zones. However, to ensure appropriate application of this device, it is suggested that application guidelines be developed within TxDOT before the implementation of this device.

## Devices or Technologies that Need Additional Evaluation or Improvement

The remaining five devices or technologies reviewed in this report are shown in Table 3.4. Some of these devices will need additional evaluation or improvement before implementation can occur. In other cases, existing guidelines or specifications will have to be modified to allow the device to be used. For example, despite the claims of the manufacturer, the blinking reflector cannot be considered equivalent to the battery-powered flashing light. The MUTCD is very specific regarding the flash rate required for flashing lights. Because the blink rate of the reflector changes, it does not perform in the same manner as the battery-powered flashing lights.

**Table 3.2. Devices or Technologies Ready for Immediate Implementation**

| New WZTC Device or Technology | Need Device is Addressing | Effectiveness in Addressing Need | Relevance to Texas Work Zones | Efforts Necessary to Achieve Implementation |
|---|---|---|---|---|
| Opposing Traffic Lane Dividers | Improve Delineation in Split Traffic Operations | Highly Effective | Highly Relevant | In-House Training |
| Drum Wraps | Higher Level of Reflectivity<br><br>Increase Service Life of Plastic Drum | Highly Effective<br><br>Unknown at this Time | Somewhat Relevant<br><br>Unknown at this Time | Establish Incentive for High-<br><br>Level of Reflectivity on Drum<br><br>Policy on Recycle of Drums<br><br>Evaluate the Service Life of the Plastic Drum |

**Table 3.3. Devices or Technologies that Have Potential for Implementation**

| New WZTC Device or Technology | Need Device is Addressing | Effectiveness in Addressing Need | Relevance to Texas Work Zones | Efforts Necessary to Achieve Implementation |
|---|---|---|---|---|
| Direction Indicator Barriers | Provide Additional Directional Guidance to Motorists | Highly Effective | Highly Relevant | Petition the MUTCD to Experiment<br><br>Develop Application Guidelines |
| Radar Drones | Reduce Speeds in Work Zone Areas | Somewhat Effective | Highly Relevant | Develop Department Policy per FCC Requirements<br><br>Extensive Training Program |
| Water-Filled Barriers | Provide Crash Cushion Protection to Workers | Somewhat Effective | Somewhat Relevant | Develop Application Guidelines |

**Table 3.4. Devices or Technologies that Need Additional Evaluation or Improvements Before Implementation Can Occur**

| New WZTC Device or Technology | Need Device is Addressing | Effectiveness in Addressing Need | Relevance to Texas Work Zones | Efforts Necessary to Achieve Implementation |
|---|---|---|---|---|
| Blinking Reflectors | Increase Conspicuity of Work Zone Hazards<br><br>Replace Battery-Powered Flashers | Highly Effective<br><br>Not Very Effective | Somewhat Relevant<br><br>Highly Relevant | Develop Application Guidelines<br><br>Evaluation |
| Portable Curbs | Alternative to Temporary Asphalt | Somewhat Effective | Unknown | Evaluation<br><br>Modification of MUTCD |
| Portable Rumble Strips | Alert Drivers of Flaggers | Not Very Effective | Somewhat Relevant | Improve Application of Device<br><br>Evaluation |
| Intrusion Alarms | Warning of Errant Vehicles in Work Zone Area | Not Very Effective | Somewhat Relevant | Technology Improvements<br><br>Extensive Training Program |
| Queue Length Detectors | Warning Traffic of Downtown Congestion | Not Very Effective | Somewhat Relevant | Technology Improvements<br><br>Training on Set up Procedures |

Advantages of using the portable temporary curb over a temporary asphalt curb need further study as well, particularly for dividing two-way traffic in work zones in urban areas. In addition, research is needed to determine how extensively temporary curbs are used in urban construction zones in Texas. If TxDOT chooses to use this device, the MUTCD would need to be modified to include polyethylene as an acceptable component for the vertical panels.

The last three devices listed in Table 3.4 all require modifications to their technology or construction before they could be considered viable alternatives for Texas work zones.

The portable rumble strips meet the criteria stated in the MUTCD. However, the strips do not always stay down on the pavement. This problem needs to be resolved before this device should be implemented. In addition, an evaluation to determine if the device actually improves driver reaction to flaggers or otherwise improves work zone safety is needed.

All three types of intrusion alarms reviewed require improved technology as well as increased reliability and reduced set up effects. An extensive training program will also likely be needed to help instruct work zone personnel on how to determine if an intrusion alarm is needed at a location and how to set up the device if it's to be used.

Finally, the queue length detector also requires improvements in technology to increase the reliability of the device. In addition, an evaluation of the effectiveness of the device is needed. This device would require training on the set up procedures and message design concepts available in the MUTCD and Manual on Real-Time Motorist Information Displays.

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# APPENDIX A.

# EVALUATION OF THE OPPOSING TRAFFIC LANE DIVIDERS

## INTRODUCTION

A new work zone traffic safety device called the opposing traffic lane divider is reviewed in this appendix. The opposing traffic lane divider (OTLD) resulted from the Strategic Highway Research Program (SHRP). The OTLDs are delineation devices designed to convert normal one-way operation on a roadway segment to two-way operation. The OTLD helps delineate the two directions of traffic. The upward and downward arrows on the sign's face indicate the direction of traffic on either side of the divider. The base is secured to the pavement with adhesive to minimize movement caused by a collision or gust winds. The sign is placed on a flexible self-recovering support so if the sign is hit by a vehicle it will return to an upright position.

## SHRP RESULTS

SHRP developed, tested, and implemented new traffic control work zone devices to help state and local highway agencies increase work zone safety. In reference to the OTLD, the SHRP developed the following specifications:

| | |
|---|---|
| Height: | 0.9 meters |
| Sign Dimensions: | 308 millimeters wide<br>461 millimeters high<br>Rectangle |
| Legend: | Two arrows pointing in opposite directions with the arrow pointing up on the right side |
| Sign material & colors: | Background is orange; the background material shall be a minimum of engineer grade reflective sheeting<br>Legend is black |
| Support: | Flexible, must be designed to restore to the upright position after being hit or run over by a vehicle. The support must restore to the upright position after a minimum of 50 hits. |
| Support Base: | The base must be designed for semi-permanent attachment to the pavement surface. Suitable adhesive should be specified with instructions for installation and removal of the support base. |

## COMPARISON OF THE OPPOSING TRAFFIC LANE DIVIDER TO SPECIFICATIONS

The use of the opposing traffic lane divider is approved by both the TMUTCD and the National MUTCD. In the TMUTCD, the panel specifies a maximum of 308 x 615 mm (0.19 square meters). The legend shall be two opposing arrows, and the panels should be made of lightweight material. The National MUTCD criteria specifies a panel size for the opposing traffic lane divider of a minimum of 308 x 462 mm.

Currently, three companies manufacture the OTLD. All three of the companies meet the National MUTCD criteria and have been approved for use by FHWA.

## PERFORMANCE OF THE OTLD

### SHRP Testing of Prototype Devices

SHRP reported that the OTLD was one of their better success stories. According to the documentation, the base can be secured to the pavement, minimizing movement in accidents or adverse weather conditions. In addition, since the sign is placed on a flexible self-recovering support, it is able to return to an upright position if hit by a vehicle.

The SHRP Information Clearing House contained a report by the Indiana Department of Transportation (INDOT) that summarized their use of 100 dividers. INDOT stated that performance was poor. The rubber base was too loose to resist impact, and the post was easily broken by vehicle impact.

The SHRP Information Clearing House also showed that TxDOT has used this device in the Childress District. Good success was noted and a rough savings of $1.6 million from direct and passive costs was estimated.

The Kentucky Department of Transportation reported that they only used the device as part of SHRP testing. The devices seem to be made of cardboard and had to be nailed down in order to remain stationary. Nearly all of their twenty devices broke overnight. They hypothesize that a wide load truck or mobile home went through the area and hit most of the dividers. They have not used them since.

The Illinois Department of Transportation (IDOT) used 50 of these devices on a long stretch of highway and reported that all 50 were broken by the end of two weeks. They believe the reason was that the material could not handle the repeated impacts from vehicles.

The Maryland Department of Transportation was very pleased with the opposing traffic lane dividers they used. The devices were used only in bridge deck repairs. They reported no problems.

**Commercially Manufactured Units**

Based on lessons learned through the prototype testing, modifications to the device were made and marketing began by several manufacturers (three manufacturers currently produce this device).

The New Hampshire Department of Transportation (NHDOT) has used one of the commercial OTLD for a year with varying degrees of success. NHDOT reported no problem when using the device for urban bridge work, but had a little trouble when they tried to use it on interstates. Wind gusts from large trucks seemed to knock over the dividers. To solve the problem, NHDOT took advantage of how the dividers are made. The footing, post, and sign are detachable, so they turned the post upside-down and realigned the sign so that it was at the bottom of the post instead of the top. This cured most problems. In severe cases, the road crews would just glue the dividers to the roadway and pry them off when done.

The Georgia Department of Transportation has used a commercial OTLD during emergency flooding conditions. In one incident, a section of a six-lane highway had to be converted to one lane northbound and two lanes southbound. The OTLD were used to guide motorists through the potentially dangerous areas. The traffic engineer on the job reported that the OTLD was easy to see and marked the appropriate path for approaching vehicles; he felt that they did a very effective job of reminding drivers to stay alert and of the changed traffic pattern. Another traffic engineer in Georgia reported that he had utilized the OTLD to convert a one way bridge to two-way. The OTLD was placed on the centerline of the bridge to indicate to the motorists that the bridge now carried two-way traffic. He stated that they worked very well. He commented that with the dividers being flexible, if one was hit by a vehicle it was less likely to cause damage to a vehicle or to disrupt traffic flow.

The Transportation Training Division of the Texas Engineering Extension Service at Texas A&M University has purchased two OTLD through the Local Technical Assistance Program to use in their training classes to illustrate one of the new SHRP devices. An individual from TEES stated that he felt that the OTLD was a lot easier to understand than the vertical panels.

Two TxDOT districts have used a commercial OTLD for several years. They had trouble keeping the first OTLD's they used staying upright. The sign panels were larger (300 mm x 600 mm) than the ones they are currently using (300 mm x 450 mm). The reduction in size has eliminated the problem of keeping the panels upright.

Another district engineer out of Uvalde had very favorable remarks about the OTLD. They have used the OTLD for about a year on various traffic situations that required changing traffic patterns to a two-way operation from a one-way operation. He commented that they were particularly useful on the raw base of a section of roadway. By using the OTLD, it was not necessary to temporarily stripe the roadway. They usually placed two or three vertical panels and then the OTLD to insure that the two-way traffic pattern was conveyed correctly to the motorists.

Three contractors in Texas were contacted. One contractor out of Ft. Worth reported that he had used the OTLD's device for the last four years. He stated that they are far superior than any other delineation for use in split traffic operations, except for a concrete barrier. He stated he used the adhesive attached OTLD instead of the portable base.

## SUMMARY

The SHRP Information Clearing House had mixed reports on the OTLD. Early studies indicated a problem with the panels staying upright. However, the newer commercially available devices seem to have overcome that problem. One contractor in Texas rated the OTLD as superior to other devices used for delineation in split traffic operations. This was supported by other District engineers, and contractors who indicated that the OTLD was understood by most motorists, and was an effective WZTC device in conveying a two-way operation. An individual from TEES stated that he felt that the OTLD was easier to understand than the vertical panels. They appear to be cost effective as well. The Childress District estimated a savings of $1.6 million from direct and passive costs.

# APPENDIX B.

# EVALUATION OF PLASTIC DRUM REFLECTIVE TAPE WRAP FOR DAMAGED OR NEW BARRELS

## INTRODUCTION

A new work zone traffic safety device called the drum wrap is reviewed in this appendix. Drum wrap is a reflective tape attached to plastic strips that can be wrapped around and attached to new or used plastic drums.

The wrap consists of standard reflective sheeting on a plastic backing. They come in 100 mm and 200 mm widths, twenty gauge or more in thickness. The manufacturer and supplier both state that the reflective sheeting meets all state and federal standards. They claim the wrap can be easily mounted and/or removed with adjustable plastic ties. This increases the service life of plastic drums by allowing those with damaged or missing reflective tape to be reused. The manufacturer also suggests purchasing plastic drums without reflective tape glued to it and then applying the drum wrap. This method would cost about the same as purchasing a sheeted drum, but it eliminates the task of stripping the plastic drum before disposing of it. The advantage in this procedure lies in the ultimate disposal of the drum. The manufacturers note that uncontaminated drums (those without reflective sheeting attached by adhesives) are more readily recycled.

## MUTCD SPECIFICATIONS

The Texas MUTCD and the National MUTCD state the same specifications for drums regarding the reflective striping. The requirement is to have alternating orange and white retroreflective stripes (at least two of each). The stripes must be 100-200 mm wide.

## FIELD PERFORMANCE

This product has just been placed on the market, and little information on its field performance is available at this time. A Houston contractor contacted felt that it would be cheaper to replace the sheeting than to purchase a new drum. However, they had very few drums that they tried to reuse. Most drums that are damaged are usually severely damaged and unsalvageable. The contractor stated that it did take two people to resheet a plastic drum. He felt that it would be cheaper and quicker to use a product that they could just wrap around.

Interestingly, a barricade company in Houston is making and using a similar product that uses 3M reflective sheeting on plastic backing that is tied to the drum with plastic ties. He explained that they did this to ensure that 3M-quality sheeting was indeed used on the drums (not all barrels apparently utilized proper quality reflective sheeting). The company spokesman felt that this process was cost effective, and that in most cases when a drum was damaged they could reuse either the drum or the wrap. They disposed of very few drums.

## COST BENEFITS

New drums with reflective sheeting cost about $55 each. Each wrap (stripe) costs about eight dollars. An unusable drum can be converted to a usable one for approximately $34, much less than the cost of buying a new plastic drum. Furthermore, purchasing a drum without reflective tape costs about $14. Adding $34 for the wrap (four stripes) and $3 for the ties yields a cost of $51. Although the product supplier suggests that there is a definite advantage in discarding uncontaminated barrels, one TxDOT employee (as well as the contractor previously mentioned) stated that most plastic drums are used until they are completely unserviceable, after which they are discarded.

## SUMMARY

With little information on the field performance, it is somewhat premature to evaluate the effectiveness of the product. The manufacturer claims that:

- wrap can be easily mounted and removed;
- it increases the life of plastic drums that have been damaged; and
- it increases the ability to recycle unusable barrels.

However, even with a good performance rate, there are certain actions that TxDOT would need to take in order to facilitate implementation. These include:

- the incentive to maintain a high level of reflectivity on the plastic drums;
- a policy to recycle the plastic drums; and
- evidence that the process of using "the wrap" is advantageous to simply replacing new reflective sheeting strips over old sheeting when necessary.

As with any new WZTC device used by TxDOT, review and approval from the New Products Committee of TxDOT must be obtained.

# APPENDIX C.

# EVALUATION OF THE DIRECTION INDICATOR BARRICADE

## INTRODUCTION

A new work zone traffic safety device called the direction indicator barricade (DIB) is reviewed in this appendix. A DIB displays an arrow along with the conventional diagonal stripes in a single barricade unit. The DIBs are placed in a series along the roadway to direct motorists through a taper area and into an adjacent lane. They can be reversed to allow for inside or outside application.

One manufacturer markets the DIB as a molded plastic barricade that differs from conventional wooden and metal barricades in a number of ways. This DIB is not a traditional A-frame design, but rather a single panel hinged to a pair of horizontal supports. When hit, the DIB falls flat and remains down. This reduces the risk of flying debris from the barricade. The manufacturer claims that the device can then be returned to an upright position without damage. A flashing or steady burn light can also be mounted on top of the barricade. The battery is located at the bottom of the barricade below the bumper line so as to reduce the risk of the battery becoming an airborne projectile in the event of a vehicle impact. The reflective sheets are recessed to prevent scratching and wear, and are replaceable. Furthermore, the replaceable reflective sheets simplify recycling if desired.

## COMPARISON OF THE DIB TO SPECIFICATIONS

The DIB meets specifications on width and length for the striping of barricades. The DIB may qualify as a Type I or Type II barricade since it has two horizontal rails. Type III barricades require three horizontal rails with striping. The device uses the arrow on the top panel of the barricade to qualify it as a DIB. TxDOT will need to decide whether or not an arrow is a suitable replacement for the striping on the top rail if the DIB is to be approved at all. It should be noted also, that the National MUTCD indicates in Section 2C-9 that the large arrow sign "is intended to be used to give notice of a sharp change of alignment in the direction of travel. It is not to be used where there is no change in the direction of travel" (ends of medians, center piers, etc.). Accordingly, the device should not be used in traffic operations where there is no change of alignment, only when there are severe changes in the alignment in the direction of travel.

If an agency wishes to use this device, it must petition the National MUTCD for permission to experiment as indicated under Section 1A-5 of the manual.

## STRATEGIC HIGHWAY RESEARCH PROGRAM

The DIB is one of the work zone safety devices that was developed under the SHRP. By means of the SHRP Information Clearing House, the Arkansas Department of Transportation has reported that they have been very pleased with the DIB they have used. Georgia, Alabama, and

Illinois also participated in the evaluation of the DIB. The next section briefly summarizes their evaluation.

## FIELD PERFORMANCE OF THE DIB

The Georgia Department of Transportation (GDOT) reviewed the DIB and filed a report on their findings. In this report, GDOT said that the barrier performed well in all applications in which they were used. In their opinion, the DIB was preferable to the conventional drums used for channelization because the barriers were compact, easy to install, and seemed to be respected by drivers.

The Alabama Department of Transportation (ADOT) has used the DIB with success and recommends it to other DOT's. According to ADOT, the DIB seemed to require more time for drivers to comprehend because of the complexity of two different symbols (the arrow and the diagonal stripes). The novelty of the DIB may have also increased interpretation time. Despite this increase in comprehension time, ADOT believes that awareness increased and the DIB was more likely to be correctly interpreted. ADOT reported that workers generally liked the DIB, though some did not feel a better sense of protection. The workers stated that there were no maintenance problems with the DIB.

The Illinois Department of Transportation (IDOT) used this type of barricade and highly recommended it. They have received requests from field crews to use more. IDOT indicated that they had no problems with the device and no damage to vehicles, occupants, or workers were incurred. The letter also states that IDOT has started replacing barrels with DIBs.

## SUMMARY

The DIB seems to offer a positive directional guidance to the motorist in taper and transition placement. It has been recommended as a desirable enhancement for traffic control in the work zone environment. However, Texas will have to decide if an arrow is a suitable replacement for the striping on the rail. In accordance with the National MUTCD, the BID should only be used during traffic operations where there is a severe change of alignment in the direction of travel.

The DIB price ranges from $60-$100, depending on the grade of the sheeting and whether or not a light is attached. New plastic drums cost about $55. Reports have been that the DIB is safer to install than drums because they are easier and faster to place.

# APPENDIX D.

# EVALUATION OF THE RADAR DRONE FOR WORK ZONE SPEED REDUCTION

## INTRODUCTION

This appendix provides information on the radar drones for use in work zones. The radar drone is an unmanned unit that sends out a radar signal identical to that used by law enforcement agencies to catch speeding motorists. The idea is to activate the radar detectors used by many motorists in the hope that they will slow down.

Manufacturers with these devices claim a statistically significant decrease in mean speeds and reduction of high speed vehicles. They also report a reduction in speed variation and accidents. These devices are weatherproof and can last up to several days without a battery recharge. Vehicle-mounted units can be plugged into cigarette lighters for even longer performance. It can be mounted on a guardrail, to a sign, or on a moving maintenance vehicle. The cost for the unit is approximately $400 each.

These devices are currently being used by TxDOT on an interstate reconstruction operation in Paris, Texas. The project engineer explained that speed limits were reduced to 80 km/h (from 113 km/h), and the average speed seemed to be 97 to 105 km/h. He had not observed any severe braking attributable to the drone radar. In fact, he had witnessed only a few brake lights overall the first few days the device had been activated. The device is moved to a different location every week. However, he felt that the truck drivers had quickly become aware of the device. He concluded since he had only observed the unit for a short period of time, it was hard to tell if it was effective in reducing speeds.

## NATIONAL AND TEXAS MUTCD AND FCC APPROVAL

The TMUTCD and the National MUTCD do not mention any specifications for radar drones. The FCC regulations on the use of the drone radar are found in 47 C.F.R., Parts 15 and 90. FCC advises agencies to use caution so that the use of radio frequencies does not go beyond the limitations of the rules.

Previously, the FCC required that the drone radar signal reflected from a moving vehicle and returned to the drone unit served some purpose. Recently, at NHTSA's request, the FCC changed that policy to permit the use of unattended, continuously radiating radar (i.e., drone radar) on a controlled basis. However, the FCC does require that any radar units used in drone operations must be type accepted and licensed for police use by the Commission.

The National Highway Traffic Safety Administration (NHTSA) has recognized the use of drone radar as a speed deterrent and has developed guidelines for how states might use drone radar strategies in compliance with the FCC regulations and policy. A copy of the "Drone Radar Operational Guidelines" is included in Appendix K.

The guidelines define drone radar "as the unconventional use of police traffic radar in either an attended or unattended mode for speed deterrent purposes." In developing a department policy on the use of drone radar the following components are required:

- It must be part of an agency's speed enforcement efforts;
- The selection of a site should be based on problem identification;
- It must adhere to FCC rules;
- It must be under local control and supervision; and
- Program evaluation must be included as part of the policy.

The guidelines emphasize that the drone radar should be considered as part of an agency's overall speed enforcement plan. It is recommended that agencies should use caution when establishing a policy for using the drone radar so that they do not develop widespread and unlimited use of the device. NHTSA clearly states that such practice would detract from the purpose of the device and would constitute a violation of FCC rules.

## FIELD PERFORMANCE OF DRONE RADAR

### Research Studies

In 1991, a series of field studies was conducted by the Texas Transportation Institute using a prototype model of a radar drone similar to the current models being manufactured. The overall speed reduction induced by the drone was less than 3.2 km/h, though the effect was higher for trucks and high speed cars. An increase in the amount of severe braking incidents was also reported during the times of drone operation, presumably because drivers hastily tried to avoid getting a ticket from the perceived patrol car (*1*). Researchers for the Insurance Institute for Highway Safety also conducted similar tests in Missouri with similar results (*2*). A field study was also conducted in 1986 and 1987 to evaluate the use of unmanned radar equipment in an effort to improve safety by reducing speeds. The study was conducted by the University of Kentucky's Transportation Research Program, and the results showed that there was a significant reduction in the number of vehicles traveling at excessive speeds (*3*).

### Telephone Interviews

The Rhode Island State Police have used a radar drone for two months and although no specific evaluations have been performed, they feel that work zone speeds have slowed down. They do not report any operational problems with the device and have not witnessed any increase in severe braking incidents. They recommend the device to any other agencies interested. The New Hampshire Department of Transportation (NHDOT) has also used radar drones on a pavement marking operation.

The South Dakota Highway Safety Department (SDHSD) has used radar drones for approximately three years. They have 500 units used on moving maintenance vehicles when doing road patch work and on snow plows. They decided to use the device because of a rapid increase in the number of accidents around maintenance vehicles. SDHSD reported that data collected on changes in crash and speed statistics indicated that a number of cars traveling more than 121 km/h and the number of accidents both decreased. They believe the product paid for itself. It should be noted that the device used by SDHSD is an older version that operates on the X-Band frequency. SDHSD suggested using a K-Band frequency drone which is the frequency that most patrol cars use. SDHSD also noticed an increase in severe braking incidents. However, most erratic vehicle movement occurred as the car passed the maintenance vehicle. Cars would hit the brakes, switch lanes abruptly, and inadvertently cut off the maintenance vehicle. The problem was solved by turning the device off when cars passed the work zone caravan.

The Connecticut Department of Transportation has used radar drones for three years in moving and stationary operations, but does not feel that the devices are particularly effective. They did not notice any severe braking incidents. Officials contacted did feel that the truck drivers had become aware of the Department's use of radar drones after a short period of time. The Missouri Department of Transportation also tested the radar drone for purchase. They did not feel the device was effective.

Finally, the Kentucky Department of Highways reported that they had used radar drones in their moving maintenance vehicles. They stated that they use the device during their paint striping operation and are very impressed with its effectiveness in slowing the vehicles around them. They have not noticed any severe braking incidents.

## SUMMARY

Excessive speeds are commonly cited as a contributing factor in work zone accidents. Studies have shown vehicles with radar detectors are more likely to speed than vehicles without detectors (*4*). Also, evidence indicates that vehicles traveling at the highest speeds are more likely to have a radar detector. While the unmanned radar drone used for speed reduction does not seem to reduce mean speed greatly, its strength lies in reducing the speed of vehicles traveling 16 km/h or more over the posted speed limit.

Drone radar could particularly be beneficial at locations where adequate spaces for traditional speed reduction strategies are not available. This could include bridges, tunnels, and on roadway segments where no shoulder is available, or where the shoulder is being used as a travel lane.

From the reports received, it appears that truck drivers and the work commuter drivers who travel through a work site on a daily basis may become suspicious if they detect a radar signal repeatedly and never see a law enforcement officer. It may be necessary to move the unit more frequently or supplement its use with the law enforcement officers on a random basis.

This device seems to have the potential to reduce speeds and the frequency and severity of motor vehicle crashes in work zones and other areas where excessive speed has been a significant factor. However, as required by the FCC, specific guidelines are needed on the appropriate site conditions for drone radar use (i.e., site location, traffic patterns, etc.).

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# APPENDIX E.

# EVALUATION OF TRITON WATER-FILLED BARRIERS

## INTRODUCTION

A new work zone safety device called the water-filled barrier is reviewed in this appendix. The water-filled barrier is marketed as a portable, energy-absorbing, positive barrier protection device for work crews. The barrier is available at a cost of $558.00 per 2 meters. Additional uses are said to include channelization of traffic and reduction of damage caused by vehicles. The barrier consists of modular polyethylene units interconnected with metal pins and filled with water. Impact energy is absorbed by the water as it erupts from holes on top of the unit.

The manufacturer claims that this new device increases protection to the work crews, preventing errant motorists from entering into the work area. They state that the use of portable concrete median barriers often deflects an impacting vehicle back into the flow of traffic, whereas common delineation devices allow errant motorists to enter into the work area. In contrast, the water-filled barrier is said to bring the vehicle to a controlled stop without allowing penetration.

The manufacturer claims that the barrier will not be penetrated by an 817 kg vehicle at 72 km/h impacting at a 20 angle. Similarly, a 2043 kg vehicle penetrates when impacting at a 25 angle at 72 km/h. They also state that the geometry of the barrier reduces the chance for vaulting and under riding. In addition, the barrier either slows the vehicle to a stop or redirects it at a shallow angle. Vehicle and barrier impact behavior have not been tested when the barrier is frozen. Therefore, the manufacturer suggests mixing the water with antifreeze to allow drainage in winter conditions.

Another advantage covered in the promotional literature is the ease of deployment and retrieval. Empty, each unit weighs 64 kg and can be handled by two workers easily. No specialized tools are necessary. The units can be filled with a water truck and drained through quick release valves. Fork lift holes are located on each unit if the units need to be moved while full.

## COMPARISON OF THE WATER-FILLED BARRIER

The Texas MUTCD and the National MUTCD are alike in their requirements for barriers. The barrier functions more as a redirective impact attenuator than a barrier since it does deflect when hit. The MUTCD requires attenuators to mitigate the effects of errant vehicles by either smooth deceleration or redirection.

The water barrier was not penetrated in the 72 km/h collisions or in the 97 km/h collision tests performed by the manufacturer. Instead, vehicles are slowed to a stop or redirected. The barrier deflected more than standard portable concrete barriers (PCB s). Connections between barrier units are adequate, though the AASHTO guide does not make any concessions for barriers made of materials other than concrete and steel.

## FIELD PERFORMANCE OF THE WATER-FILLED BARRIERS

### Telephone Interviews

The Alabama Department of Transportation (ADOT) has used the water-filled barrier in low speed (72 km/h) work zones to protect work crews who must be working close to moving traffic. They highly recommended the system and reported that the product performed well during actual incidents on the highway. ADOT did say that they do not use the water-filled barrier in lieu of portable concrete barriers, but rather in cases when the only previous protection would have been plastic drums.

The New Hampshire Department of Transportation (NHDOT) did not elect to use water-filled barriers. NHDOT indicated a need for consistency in what they purchased, and did not want to deal with the confusion created when different barriers are used for different situations. They felt that because of this and the fact that the water-filled barriers are only rated to 72 km/h, they could not justify the cost of the barrier. One important cold weather problem was cited by NHDOT. Although the barrier performs adequately when filled with water and antifreeze, a crash would still put liquid on the road. NHDOT felt that liquid on the road, coupled with extreme cold or snow could produce dangerous driving conditions.

The Kentucky Department of Transportation has used water-filled barriers for a year and recommends them to other DOT s. They did emphasize the fact that some barriers were not repairable after collisions. However, they also stated that the water-filled barriers were easy to install and move.

## SUMMARY

Reports indicate that the water-filled barriers seem to be an effective tool to increase the safety of workers. According to agency experiences, the devices are easy to install and move. However, agencies have noted that they would not recommend this device in lieu of portable concrete barriers due to the much larger lateral deflections that occur with the water-filled barrier when impacted. Rather, these agencies suggest that the device might be useful at locations where the only previous protection would have been plastic drums. There has also been evidence that some of the barriers were not repairable after collisions.

One agency was concerned with the confusion that could be created by using different types of barriers for different work zone conditions. In addition, concern has been expressed about the water-filled barriers creating a hazard in an event of a crash and causing liquid to flow onto the roadway. Also, the water-filled barriers are currently only rated acceptable to 72 km/h.

# APPENDIX F.

# EVALUATION OF A BLINKING REFLECTOR FOR WORK ZONE APPLICATIONS

## INTRODUCTION

A blinking reflector and its applicability to work zone situations is reviewed and critiqued in this appendix. The blinking reflector is a large (approximately 250 $cm^2$) delineator that appears to blink (by altering the coefficient of luminous intensity) as the motorist s viewing angle to the device changes.

Both the manufacturer and a local Texas supplier of the reflector suggest that the blinking reflector is cheaper to use than battery-powered flashing warning lights (particularly the Type A low-intensity lights). They cite the high maintenance costs associated with the flashing warning lights (primarily battery replacement estimated at about $150 per year), and point to high vandalism/theft rates of these lights experienced by several contractors in some urban work zone locations. In contrast, the manufacturer claims the blinking reflector does not require batteries, and does not appear to attract the attention of vandals and thieves. The estimated cost of the blinking reflector is around $15/unit.

## COMPARISON OF THE BLINKING REFLECTOR TO SPECIFICATIONS FOR BATTERY-POWERED FLASHING WARNING LIGHTS

The *Texas Manual on Uniform Traffic Control Devices for Streets and Highways* (*1*) (TMUTCD) provides specifications (reproduced in Table F-1) regarding flash rate, flash duration, and light intensity of battery-powered flashing warning lights. These are identical to those listed in the national MUTCD.

**Table F-1. Warning Lights**

| | Type A<br>*Low Intensity* | Type B<br>*High Intensity* |
|---|---|---|
| Flashing Rate per Minute | 55 to 75 | 55 to 75 |
| Flash Duration | 10% | 8% |
| Minimum Effective Intensity | 4 Candela | 35 Candela |

According to the promotional literature (which was reportedly verified by a private testing laboratory in San Diego, California [personal communications with Larry Sparks, January 23, 1996]), the blinking reflector exceeds warning light criteria for both flash duration (with a 4:1 high/low time ratio) and minimum effective intensity (approximately four times the brightness of the Type A flasher and twice the Type B flasher). However, the reflector blink rat e (programmed at 0.83 degrees of subtended motion) is not constant for all travel conditions.

Rather, this rate is a function of the distance of the motorist to the blinking reflector, the speed of the motorist, and the lateral offset of the blinking reflector relative to the motorist s line of travel (see Figure F-1). The resulting flash rate as a function of distance to the blinking reflector are shown in Figures F-2 and F-3. Note that the there is only a relatively small distance over which the reflector blinks at a rate comparable to those for flashing warning lights. Consequently, the reflector could not be considered an equivalent replacement of flashing warning lights at this time.

It should be noted however, that the flash rate for warning lights as indicated in Table F-1 appears to be based primarily on criteria established for flashing beacons at intersections. Whether or not these flash rates are the most appropriate or the only acceptable rates from a target value/conspicuity perspective is not clear. For example, human factors literature (*2*) suggests a considerably faster flash rate (3 to 5 times/sec or 180 to 300 times/minute) as optimum for attention-getting purposes in operator-machine interfaces (such as in control centers). Additional research would be necessary to determine whether faster flash rates for warning lights or reflectors (such as those emulated by the blinking reflector) have any benefits or adverse effects upon driver attention or behavior in work zones.

Y = distance travelled over 0.83° of subtended motion

$$Y = \frac{L^2 \tan(0.83^\circ)}{X + L \tan(0.83^\circ)}$$

$$\text{Flash Rate} = \frac{\text{Velocity}}{Y}$$

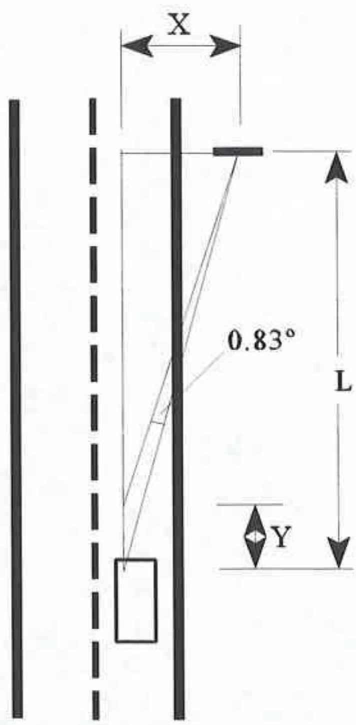


**Figure F-1. Factors Affecting the Blinking Reflector Blink Rate**

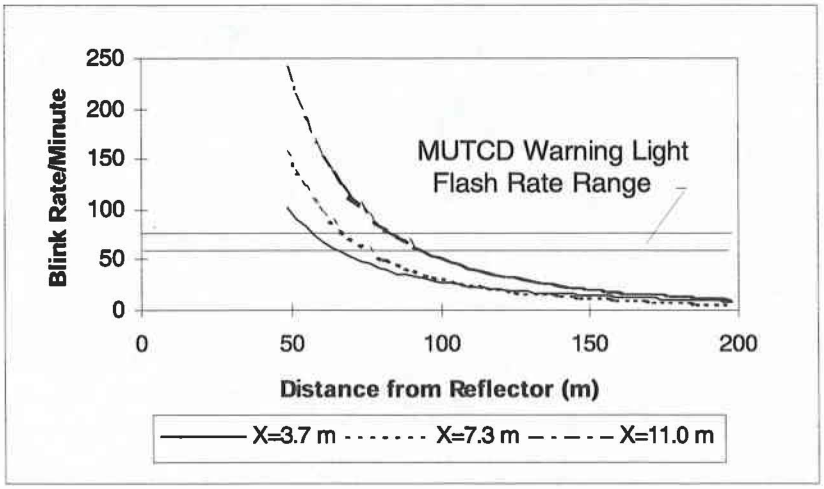


**Figure F-2. Reflector Blink Rate at 40 km/h as a Function of Distance from the Reflector**

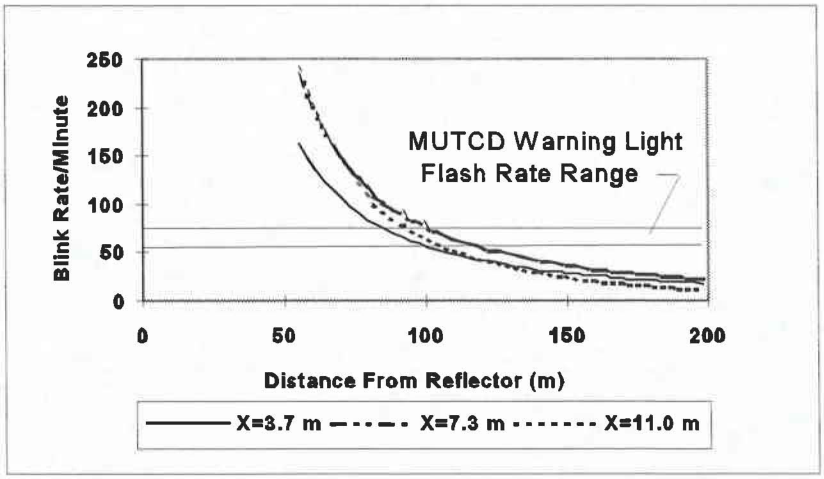


**Figure F-3. Reflector Blink Rate at 97 km/h as a Function of Distance from the Reflector**

## FIELD PERFORMANCE OF THE BLINKING REFLECTOR

The blinking reflector has already been purchased by a few municipalities in Texas and in other states. To assess the application and operational characteristics of the blinking reflector, TTI researchers contacted two city officials and two contractors in Texas, and one out-of-state city official currently using the device. Four of the five contacts were provided by the manufacturer of the reflector. Also, researchers made a trip to Austin, Texas in December 1995 to videotape and view the blinking reflector at an urban arterial work zone in that city. One municipality contacted had used the blinking reflector for three years, while one contractor had used the device for two years. The others had been using the reflectors between six months and a year.

### Phone Interviews

The officials contacted indicated that they mounted the blinking reflector on both permanent and temporary barricades, advance warning signs such as Road Closed Ahead - Bridge Out, on flood gates, and a t temporary lane closures on main city thoroughfares. Some of the comments pertaining to these applications are provided below:

**Alignment** - All of the individuals interviewed agreed that the effectiveness of the blinking reflector was very dependent on their placement. The blinking reflector must obviously face the direction of the oncoming vehicles since the delineator is activated by the motorists headlights, and the movement of the passing vehicle creates the flashing effects. When used on permanent barricades, they can be anchored down to avoid any change in the angle relative to the oncoming vehicles. However, this is not always possible in work zone applications. One contractor in Austin, Texas reported that the brackets they used to connect the reflectors on the barricades did not hold them in place. This caused the reflector to turn when large trucks sped by, to the point that oncoming vehicles could not activate the reflector by their headlights.

**Vandalism** - Three officials noted that vandalism decreased by 80 percent or more with the blinking reflector relative to flashing warning lights. These officials attributed this decrease primarily to the fact that the reflector did not have a battery to steal. One official felt that the blinking reflector s appearance seemed to discourage vandalism. As he stated, ...when you look close at them, they look like they are broken. You cannot tell that they flash. However, another contractor reported a very high vandalism rate for the reflectors. He felt that the weak bracket used to mount the device was an invitation for people to steal them.

**Cleaning** - The blinking reflector is sealed with a smooth plastic covering to make them easy to clean when needed. One official estimated that the required maintenance of the blinking reflector is approximately 80 percent lower than for the battery-powered flashing lights (although specific numbers to support this contention were not available).

**Condensation** - The blinking reflector has a weep hole to help prevent condensation, but according to one source, condensation would not affect the flash rate because of the high-intensity sheeting used within the blinking reflector to protect it. Three individuals interviewed all stated that they had not had any problem with condensation forming within the blinking reflector, but they had not used the blinking reflector during conditions that might cause it to be a problem.

**Replacement** - One official estimated that replacement rates of the blinking reflector were also about 80 percent lower than for the battery-powered flashing lights. (Again, supporting documentation of this were not available, though). However, another individual stated that the replacement rate of the reflectors was extremely high because of theft.

**Overall Performance** - All but one individual interviewed recommended the use of blinking reflectors on temporary barricades and on advance warning signs. One engineer from Missouri said that he would probably recommend them for other applications in work zone areas as well. He felt that the blinking reflector was more convenient and effective than the battery operated lights. One individual interviewed stated he would not recommend the device. He felt that they were not user friendly devices for highway use. In his opinion, the reflectors were too sensitive to misalignment. Presumably an improved bracket design could reduce some problems caused by passing trucks. However, the device will still require more attention to traffic control set-up (especially if the reflectors are mounted on barrels) to ensure proper alignment.

## Site Visit

In December 1995, TTI researchers performed a drive-through to video and examine the application of the blinking reflector in Austin, Texas at South 1 St. and Congress. The work site was a four-lane undivided facility, with a two-lane work zone closure. The blinking reflector was used for a short distance in the middle of the work site at the closure and was mounted on the channelizing devices (barriers) next to the Type C steady-burn lights. To the researchers, the blinking reflectors did seem somewhat brighter than the steady-burning lights. However, the contractor for the job felt that the steady-burning lights were much brighter than the blinking reflectors during the daylight hours.

It should also be noted that the blinking reflectors were mounted on the channelizing devices for testing purposes only. According to the MUTCD, only steady delineation (steady-burn lights or solid reflectors) should be used on channelizing devices to provide guidance at lane closures and other locations (i.e., curves) where the alignment changes.

## NATIONAL AND TEXAS MUTCD

The National and Texas MUTCD state that flashing warning lights (Type A and B) are used to warn drivers. The flashing lights call attention to the motorists and warn them that they are approaching or are in a hazardous area. Type A flashing warning lights are commonly mounted on barricades, drums, vertical panels, or advance warning signs, while Type B warning lights may be mounted on advance warning signs or on independent supports. Both manuals however, specifically state that flashers shall not be used for delineation, as they would tend to obscure the desired vehicle path.

The manuals also indicate situations in the typical traffic control plans in which flashing warning lights may be used. These guidelines are somewhat less stringent than the Department s Barricade and Construction Signing Standard Sheets. In those standards, Type A flashing warning lights are required in several instances. There are many other work zone locations, however, where warning lights are not required, but where a more active form of delineation may increase the conspicuity of the hazard. The active nature of the blinking reflector does appear capable of increased conspicuity. However, the blinking reflector should not be considered as an equivalent alternative to the flashing warning light at this time. The device does not continue to flash when the vehicle is not in motion (as when sitting at an upstream traffic signal prior to entering the work zone, for example). Also, the blink rate of the blinking reflector does not generally fall within the range specified for flashing warning lights. Again, it is not known at this time whether these differences will affect the performance of the blinking reflector relative to that of battery-powered warning lights. Additional research is needed before such a determination can be made. Because of their limited testing to date, data concerning the reflector s potential to reduce accidents and increase safety are not available at this time.

## SUMMARY

In summary, the fact that the blinking reflector is not directly comparable to a battery-powered flashing light does not mean that the device does not have the potential to improve work zone safety. It does seem that the blinking reflector may attract additional attention over regular static retroreflectors. However, this has not been verified to date with an objective human factors study. Similarly, any potential adverse effects of the blinking phenomenon upon drivin g behavior have not been studied.

The blinking reflector is not interchangeable with flashing warning lights. However, the blinking reflector might prove useful at locations where warning lights are not required, but where additional attention needs to be drawn to some hazard. If TxDOT chooses to pursue further evaluation of the blinking reflector as an alternative to the flashing warning light, it would be prudent to complete an FHWA Request to Experiment with the blinking reflector and to establish very detailed and stringent guidelines on where such devices would and would not be appropriate (i.e., on channelizing devices, as curve delineators, etc.). In addition, as with any new WZTC device, prior approval from the Traffic Operations Division of TxDOT must be obtained before the use of the product by TxDOT.

## REFERENCES


1. *Texas Manual on Uniform Traffic Control Devices for Streets and Highways: Part VI, Standards and Guides for Traffic Controls for Street and Highway Construction, Maintenance, Utility, and Incident Management Operations.* Texas Department of Transportation, Austin, Texas, September 1995.

2. R.D. Huchingson. *New Horizons for Human Factors in Design.* McGraw-Hill, Inc., New York, New York, 1981.

# APPENDIX G.

# EVALUATION OF TEMPORARY PORTABLE CURB FOR WORK ZONE APPLICATIONS

## INTRODUCTION

This appendix documents a review of a temporary portable curb for use in work zones. The temporary portable curb consists of one meter strips of a recycled rubber and polyethylene composite interlocked to form a curb. Vertical reflective panels can be attached to the cur b every 0.9 to 7.6 meters. The unit relies on its weight and friction for attachment to the pavement. For added visibility, 6-volt light attachments are available. Each curb section has built in reflective arcs (every 0.9 meters).

The manufacturer views the temporary portable curb as a potential alternative to regular asphalt curbs in speed zones of less than 72 km/h. It is recommended for use in dividing two-way traffic in work zones and as an additional guidance for vehicles in lane closures. As shown in Table G-1, the manufacturer presents several advantages of using temporary portable curb over regular asphalt curb to divide two-way traffic at a construction work area. They cite the lack of reusability for regular asphalt curbs for comparison, and estimate the installation time at one third of that for regular asphalt curbs. They also point out that the temporary portable curb does not damage the road surface or leave any markings on that surface. The estimated cost of the temporary portable curb is $138 per linear meter. The manufacturer states that the product should pay for itself within six applications compared to the expense of putting down and taking up regular asphalt curbs each time.

**Table G-1. Use of Portable Temporary Curb vs. Regular Asphalt Curb**

| Portable Temporary Curb | Regular Asphalt Curb |
|---|---|
| Reusable | Usable one time, seldom recycled |
| Installed by hand or conveyor | Requires asphalt laying equipment |
| Delineators reboundable, (built-in) | Delineators attached to curb with epoxy |
| Super bright reflectors (built-in) | Requires temporary paint on roadway |
| Install in 1/3 the time | Slow, laborious installation |
| Easily removed from roadway | Removal is slow, needs heavy machinery |
| No damage to roadway surface | Temporary paint removal can scar the road |
| No damage to permanent roadway markings | Permanent striping/RPMs usually damaged |

## COMPARISON OF THE TEMPORARY PORTABLE CURB TO SPECIFICATIONS FOR CHANNELIZATION DEVICES

The TMUTCD provides specifications regarding the use, design, and spacing of channelization devices. The temporary portable curb is continuous, so the spacing requirement is not applicable. The temporary portable curb was tested by the German Institute for Highways and found to meet all German standards. When the test vehicle collided at a one degree angle at 80.5 kph, the temporary portable curb was displaced transversely only 15 mm. All 10 vertical panels impacted rebounded with minimal damage, and no damage was found on the vehicle. Tire markings appeared on the curb; thus, it may require painting or replacing to maintain visibility. Performance tests may need to be done in order to verify that the system meets U.S. and Texas requirements.

## NATIONAL AND TEXAS MUTCD

The National and Texas MUTCD state that the channelization devices should yield when struck in a predictable way and should not produce debris that could enter the passenger s compartment. The German tests show that the temporary portable curb does meet these requirements. The manuals also state that the vertical reflective panels must be at least 200 x 600 mm and have the standard diagonal pattern of reflective material. Three of the four temporary portable curb panel types meet this requirement. The maximum height for temporary raised islands is 102 mm. At 81 mm, the temporary portable curb passes this requirement as well.

As a special note, the National MUTCD does not specify polyethylene as a component in vertical panels. As such, Section 6F-5H of the MUTCD would need to be modified to include polyethylene. However, considering the performance in the German tests, specifying polyethylene as a material durable and strong enough for this type of application should not be a problem.

## FIELD PERFORMANCE OF THE TEMPORARY PORTABLE CURB

Several states were listed on the user s list provided by manufacturer. The product was first tested in the United States in February 1996 in Florida. CSX Railroad and the Florida Department of Transportation (FLDOT) were so impressed by its performance that the FLDOT approved its use on highways in two months. The Pennsylvania Department of Transportation stated that they had approved the use of temporary portable curb, but had not used it yet.

### Telephone Interviews

FLDOT used the portable temporary curb on an interstate bridge repair project and on railroad crossing replacement operations. FLDOT reported that the installation and removal of the curb were quick and that the product was very visible, eliminating the need for the optional 6-volt light to be mounted on top of the vertical panels. At vehicles speeds up to 80 km/h, the curb displaced very little, even when hit by trucks on the freeway.

The railroad division of FLDOT used the temporary portable curb for an S-curve on a detour and reported good results. They said that the reboundable vertical panels were superior to the rigid ones normally used with regular asphalt curbs because the panels rebound when hit by wide vehicles. They also liked how easy it was to use, commenting that only two people were needed to assemble and move the device. FLDOT reported no faults with the temporary portable curb, and stated that it was more visible at night than the regular asphalt curb. They did warn that the temporary portable curb does not protect workers and it is not intended to do so.

## SUMMARY

The reports that the temporary portable curb is more visible than reflective paint on regular asphalt curbs, and comes equipped with reflectors on the curb at a minimum of one meter spacing, causes one to conclude that it is a channelization device easily distinguished night or day. The advantages of the temporary portable curb over regular asphalt curb in dividing two-way traffic in work zones may warrant further evaluation. However, it does not seem feasible or logical to use temporary portable curb in lane closures. They offer no additional advantages to other traffic control devices, and offer no additional protection to the work crew.

In closing, it is important to note that the temporary portable curb should not be used where speeds exceed 72 km/h. Also, tests should be done using American standards and techniques to be sure that the device will perform adequately. The number of work zones in Texas where this device would be applicable is not known at this time. If TxDOT chooses to pursue the use of temporary portable curb, the National MUTCD would need to be modified to include the use of polyethylene. Also, approval from the Materials Testing Committee of TxDOT will need to be obtained.

# APPENDIX H.

# EVALUATION OF THE PORTABLE RUMBLE STRIP

## INTRODUCTION

A new work zone traffic safety device called the portable rumble strip (PRS) is reviewed in this appendix. The portable rumble strip is made of a tough flexible vinyl measuring 462 mm in width, 3 m in length, 3 mm - 29 mm thick, weighs approximately 32 kg, and is grey-black in color. The cost is approximately $100 per strip.

Portable rumble strips perform in the same way that permanent rumble strips would, but they can be moved to different locations as required. They are intended for use at flagger operations where moderate speed traffic many need to be stopped intermittently. The strip (or strips) should be placed about 100 m in advance of the flagger. When a vehicle runs over the strip, it causes a jolt to alert the driver of potential danger.

## COMPARISON OF PORTABLE RUMBLE STRIPS TO SPECIFICATIONS

The rumble strip meets the specifications in the TMUTCD and in Sections 6F-8d of the revised Part VI of the National MUTCD. Rumple strips are to be used to supplement standard or conventional traffic control devices, and they may be portable devices. SHRP concurs that the PRS is primarily for flagging operations, and they should not be used in high speed applications where there are no intermittent stops.

### Field Performance

SHRP reported in 1995 that nearly all the states (*30*) that tried the PRS had trouble with keeping the device in place. However, SHRP has a high interest in the device, which may stimulate product enhancements to solve the problem with the strip staying down on the roadway.

The Indiana Department of Transportation filed a report with the SHRP Information Clearing House that noted that PRS moved when trucks passed over the device. Cracks also occurred in the device after a short time. Drivers would veer away from the device since it looked like a flat tire. Also, a lone worker could not move the device easily because of its weight. Indiana does not recommend statewide use of the PRS.

New Mexico DOT also reported that the device wore out quickly and became a hazard due to protruding hold down devices and a separation of the material. NMDOT did feel that the product could be effective, even with improvement.

The report that Arkansas Department of Transportation filed with the SHRP Information Clearing House stated that the PRS would move under traffic and that several drivers had stopped and reported that a piece of debris was in the road.

The Alabama Department of Transportation has used the PRS and reported problems with keeping the device in place. Alabama DOT filed a report with SHRP stating that they had trouble keeping the device stationary and that it was cumbersome to move. The PRS was used in both 80 km/h and 40 km/h speed zones with the same results. Alabama DOT does not recommend the use of the PRS.

### Telephone Interviews

The Illinois Department of Transportation (IDOT), experimented with making their own portable rumble strips without success. They reported that although the device worked well with cars, problems developed when large trucks passed over them. IDOT stated that trucks carrying cars would often move the rumble strips. IDOT has not used portable rumble strips since.

New Hampshire Department of Transportation (NHDOT) reported that they had used PRS for several projects with few problems. Their main application for the strip is in advance of temporary signals. They have also experimented with making their own rumble strips from unusable traffic counting tubes. The tubes wore out quickly and became a maintenance problem, but the cost was very low since broken tubes had been stockpiled for some time and could not be used for any other purpose.

The Maryland Department of Transportation used portable rumble strips without success. Workers reported that they moved too much and required constant repositioning. They also stated that some drivers would veer around the rumble strips.

## SUMMARY

With one exception, the consensus on the use of PRS was unfavorable and the recommendation was not to use PRS at this time because of the difficulty in keeping the stationary on the pavement. While the manufacturer claims that the PRS can easily unfold and roll into place, reports from many states have indicated that the product was not easy to handle and deploy. In some cases, drivers have reported the PRS to be debris in the road and have veered around them.

The PRS does meet specifications set forth in both the Texas MUTCD and the National MUTCD. It is not a speed control device; however, its primary purpose is to alert a driver to the presence of a work zone. SHRP recommends its use in flagging operations on medium- to low-volume facilities where a one-way flagging operation is necessary. It should be placed approximately 100 m upstream of a flagger. As with any new WZTC device used by TxDOT, review and approval from the appropriate Committee must be obtained prior to usage.

# APPENDIX I.

# EVALUATION OF INTRUSION ALARM SYSTEMS FOR WORK ZONE SAFETY

## INTRODUCTION

A new SHRP work zone safety device called the intrusion alarm is reviewed in this appendix. The intrusion alarm detects errant vehicles that stray into the work zone buffer area between vehicles and work crews. If a vehicle intrudes into the buffer area, an alarm sounds almost instantly to warn work crews. Presumably, the few seconds gained by this early warning system help workers in the work area move to safety. Three basic types of intrusion alarms have been introduced on the market. The first is activated by microwave signals, the second by infrared light, and the third by pneumatic tubes. The microwave and infrared models mount on traffic cones or barrels, and the tube-type systems lie flat on the ground.

## MICROWAVE INTRUSION ALARMS

Microwave intrusion alarms include a transmitter that is mounted on a plastic safety drum, and a receiver and siren that are mounted on another drum up to 305 m away. Strobe lights can be attached to alert workers who may not be able to hear the alarm because of loud equipment. The system also includes a radar drone which activates radar detectors within 700 m for added protection. Batteries to power the system can be charged by a solar cell affixed to the top of the plastic drum barrel. SHRP reports a price of $3,000.

### Infrared Systems

The infrared systems to date are mounted on traffic cones. The transmitter cone is placed on the shoulder at the beginning of the taper. An infrared beam is projected to the receiver/siren cone placed diagonally at the opposite end of the detection zone. Presumably, these beams can be linked together to protect an area of 1.6 km/h or more. Sirens, strobe lights and solar rechargers can be used to alert workers and power the device. This model is priced at $3,200.

### Pneumatic Tubes Systems

Pneumatic tube intrusion alarms protect work area distances of 30 to 180 m. Some systems use tubes laid perpendicular to traffic flow at the beginning of the work zone. The tubes are connected to a radio transmitter which activates a remote siren. Strobe lights can also be activated. Costs of pneumatic alarms range between $695 and $3,695, depending on options.

## COMPARISON OF THE INTRUSION ALARMS TO SPECIFICATIONS

The TMUTCD and the National MUTCD do not contain any specifications regarding intrusion alarms as this is a relatively new device that has not been used extensively around the country. In Section 6D-2 it states that judic ious use of special warning and control devices may be helpful for certain difficult work area situations. It does include flagger activated audibl e warning devices that may be used to alert workers to the approach of erratic vehicles.

An SHRP test evaluated the crash-worthiness of an infrared model and reported that it performed up to NCHRP standards regarding fragmentation, vehicle damage, and work zone hazards.

## MICROWAVE SYSTEM FIELD PERFORMANCE

The Iowa Department of Transportation (IDOT) rejected this type of device because it takes too much time to set up and move for each location. IDOT felt that the less time crews spend on the road, the fewer accidents. The Colorado Department of Transportation (CDOT) tested this product and did not approve it for use. They did not feel that the strobe lights were bright enough and the siren was not loud enough. They also reported difficulty in aligning the signal.

The Alabama Department of Transportation (ADOT) reported complete failure with the device. They could not keep the signals aligned. ADOT stated that when trucks passed, the wind gusts would move the system. The device eventually failed mechanically and was returned to the manufacturer for repair. It has not been tested since.

PDOT used this product for stationary operations. Numerous false alarms occurred. These false alarms were triggered by rain, dust, and slight movements of the drums. As a result workers tended to ignore the alarms. Alignment of the signal was difficult and resulted in a long set up time.

## INFRARED LIGHT SYSTEM FIELD PERFORMANCE

CDOT tested this product in-house and during a maintenance operation. The citizen s band (CB) frequency that it ran on received too much interference and therefore gave off false alarms. They rejected the product.

The New York Department of Transportation reported several false alarms when workers interrupted the infrared beams as they left the area for materials or breaks. They suggested the device be limited to specialized applications that did not require workers to enter and exit the zone while the system was operational. The Missouri Highway Transportation Department reported that the intrusion alarms were too sensitive, and the Iowa Department of Transportation stated that they had trouble keeping the beams aligned.

PDOT did not obtain consistent results in its tests. In some instances, the system would not trigger when vehicles crossed, and at other times false alarms were recorded. False alarms were caused by moving trucks. The set up time was from 5 to 20 minutes. The device did not work well in moving operations. The design limited its use to stationary operations.

## PNEUMATIC TUBES SYSTEMS FIELD PERFORMANCE

The New Hampshire Department of Transportation (NHDOT) evaluated demonstrations of this type of alarm and opted not to use it. They felt it was cost prohibitive, and too many false alarms were anticipated as maintenance vehicles crossed over the pneumatic tube.

PDOT tested two different models of the pneumatic tube system intrusions alarms. They tested the first model with varying degrees of success. During some tests, it worked perfectly, during other tests, it would not trigger. The device was found to be very durable and well suited for field use. Set up time was a short 5 minutes since the pneumatic tube eliminated the need for alignment. There were no false alarms or performance problems during the testing. One group of testers believed that the alarm volume should be higher.

The second model tested by PDOT, was regarded as a low quality product. The alarm did not work most of the time, and battery charging caused trouble. The device was hard to set up, taking more than 20 minutes to align. PDOT concluded that the alarm was neither durable nor dependable.

The Iowa Department of Transportation (IDOT) reported that they would not recommend this product. The system takes too much time to set up and move for each location. IDOT felt that the less time crews spend on the road, the less potential that exists for accidents to occur. Alabama DOT also tested this technology and felt that the pneumatic tube system did not give enough warning time for the crews.

Alabama DOT also tested this product and felt that the device did not give enough warning time for the crews. Reports indicated that the device malfunctioned and was returned to the manufacturer. The testing program was subsequently canceled.

## PERFORMANCE SURVEY

In 1995, the New York State Department of Transportation conducted a survey of the three different types of intrusion alarms. A total of 39 evaluations were conducted which included field evaluations and maintenance yard demonstrations.

The results showed that eighty-eight percent of the participants in the survey were interested in purchasing the intrusion alarm system. Ninety-four percent felt that these products were easy to install, and seventy-four percent felt that the device enhances safety in a work zone. Eighty-one percent felt that the products were durable.

## SUMMARY

The NYDOT survey suggested that the intrusion alarm has created great interest in the traffic engineering field. If the device can be made to work appropriately, it could enhance safety in the work zone. However, at this point the device may be cost prohibitive with such negative reviews. Its effect upon work zone accidents has yet to be determined. In summary, things to consider before purchasing the device would be the following:

- a significant amount of time is needed to setup the device;
- the application should be limited to stationary work zones;
- the work activity should be limited to operations which avoid several entrances and exits to and from the work zone;
- training program on the use and to setup the device would be needed;
- a drone radar feature may be needed to help control speeds;
- strobe lights may be needed to help improve visibility; and
- the alarm may need to be enhanced due to loud equipment in the work area.

## APPENDIX J.

## EVALUATION OF THE QUEUE LENGTH DETECTOR

## INTRODUCTION

A new work zone traffic safety device called the queue length detector is reviewed in this appendix. The device is designed to be used in areas where traffic flow may change unexpectedly. It warns drivers when traffic downstream has slowed or has stopped completely so that they may take an alternate route, or be better prepared to stop.

The queue detector is a device developed through SHRP. SHRP states that the device is an easy-to-use warning system that can be used near work zones, toll roads, and other areas where there is the potential for traffic to slow or stop unexpectedly. They state that combining the queue detector and the infrared intrusion alarm system (see Appendix I) as one unit would make the device more marketable and cost efficient. They feel this would not be a difficult task since both devices components are essentially the same.

## QUEUE DETECTOR DEVICE

The device uses an infrared beam and cellular communication technology. A transmitter sends an infrared beam across the roadway and monitors the traffic flow. The device detects the speed of passing vehicles and sends out a signal when the speed drops below a user defined value or if traffic stops altogether. A receiver activates the changeable message sign s cellular communications circuitry. The changeable message sign gives motorists information in advance that traffic has slowed down or has completely stopped. The motorist can then take an alternate route or exit, or at least be prepared for slower traffic. Once the sign has been activated, it stays activated for a user-defined period, even if occasional cars pass through faster than the user-defined speed. The queue detector can use cellular, hardware, or other communication technologies. The cost of the device is about $3,400.

## COMPARISON OF THE QUEUE LENGTH DETECTOR TO SPECIFICATIONS

The TMUTCD and the National MUTCD do not contain any specifications on the use of a queue detector.

## FIELD PERFORMANCE OF QUEUE LENGTH DETECTORS

In a 1995 SHRP status report, four states reported that evaluation of this device was pending. At this time, none of the four states had evaluated the device. One state has observed a demonstration of the device. It did not perform well. They declined to evaluate the device.

The Pennsylvania Department of Transportation (PDOT) has used a queue length detector with little success. The detector itself worked well. The problem was the communication between the detector and the changeable message sign. The communication used cellular technology which was disrupted during high demand periods when many commuters used their car phones. New methods for hardware communication between the sign and the detector are being developed.

The Virginia Department of Transportation looked at queue length detectors a few years ago but found that the devices had problems with false alarms. They have not tested any new products since then.

## SUMMARY

SHRP has proposed that the queue detector could decrease the number of accidents and injuries that occur each year due to traffic queues located in blind spots on roadways.

At this time, states seem unwilling to evaluate the device. Concerns over detector-CMS communications and over false alarms are the most significant problems mentioned by the states contacted. Additional development and evaluation on the effectiveness of the device is required before it can be considered for widespread implementation.

# APPENDIX K.

# DRONE RADAR OPERATIONAL GUIDELINES

U.S. Department of Transportation
National Highway Traffic Safety Administration

DOT HS 807 753
Final Report

August 1991

# Drone Radar Operational Guidelines

This document is available to the public from the National Technical Information Service, Springfield, Virginia 22161.

Technical Report Documentation Page

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16. Abstract

Police executives at Traffic Safety Summit I asked DOT/NHTSA to develop operational guidelines for the use of drone radar. Specifically, they requested that NHTSA develop guidelines on how States might use drone radar strategies in compliance with Federal Communications Commission (FCC) regulations and policy. Drone radar is the unconventional use of police traffic radar in either an attended or unattended mode for speed deterrent purposes.

Except for a few specifically authorized test programs, the FCC had previously prohibited the use of unattended drone radar operations unless the reflected radar signal served some purpose, such as activating signs and warning devices. Based upon a review of the NHTSA guidelines, the FCC has revised their policy and now will permit law enforcement agencies to use attended or unattended radar units, without the requirement that the return signal be used for a specific purpose. This approval is contingent upon a police department's adherence to the limited and controlled use as recommended in the NHTSA proposal.

This report contains guidelines and recommendations for police departments to use in establishing departmental policy on the use of drone radar. The document contains background information on speeding and speed enforcement. Specific guidelines are offered for the use of drone radar as a speed deterrent tool. Lastly, a model policy is presented that can be adopted by individual police departments.

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# DRONE RADAR GUIDELINES

## *BACKGROUND*

The guidelines and model policy for the use of drone radar were developed to assist law enforcement agencies incorporate the use of drone radar into their existing traffic law enforcement programs. The need for these guidelines came as a result of concerns expressed by enforcement officials at the Traffic Safety Summit in Chicago in April 1990. Many of the executives expressed concern about the difficulties in enforcing existing laws on speeding and other unsafe driving behaviors. They noted that the problem of speed limit enforcement stems not from a lack of commitment on the part of police agencies or individual police officers, but instead from a number of factors which combine to make the officers' jobs more difficult.

One of the factors that has contributed to the problem is the increase in traffic congestion. This problem is most severe in the highly populated, urban areas of the country. While the number of cars and trucks has increased dramatically over the last several decades, the number of new roadways available to accommodate these vehicles has not increased proportionally. Traditional means of speed limit enforcement (radar, VASCAR, pacing, etc.) are not always effective on these highly congested roadways. Furthermore, roadway design and construction has increased or eliminated adequate pull-off areas, adding to the inability of the police to effectively and safely enforce speed limits.

This problem is further compounded by the public's lack of support for speed enforcement. A number of focus group discussions recently held by the National Highway Traffic Safety Administration (NHTSA) and the States have identified some perceptions maintained by the public concerning speeding. The results from these discussions indicated that the public, as a whole, does not view speeding as a serious traffic offense. Instead, the public sees speed limits only as "guidelines" and not laws that will be strictly enforced. The participants also were not able to recognize the risk to their personal safety that often results from speeding. In general, the motorists viewed speeding as an acceptable behavior as long as one maintains control of the vehicle. However, the motorists who were interviewed differed as to the definition of what constitutes safe control.

At least one additional factor also impacts upon police officers' ability to effectively enforce the laws on speeding. The use of radar detectors to provide advance warning of police traffic radar has become quite common and widespread. A number of recent studies have highlighted the extent of this practice:

- Evaluation of the New York State Police 55 MPH Speed Enforcement Project. NHTSA, DOT-HS-807-618, August 1989.
- Radar Use Analysis. Missouri State Highway Patrol, August 1990.
- Radar Detector Use and Speeds in Maryland and Virginia. Insurance Institute for Highway Safety, May 1990.
- Radar Detector Use in Large Trucks. Insurance Institute for Highway Safety, July 1990.


The May 1990 study by the Insurance Institute for Highway Safety (IIHS) examined the relationship between the use of radar detectors and vehicle speeds. The researchers measured vehicle speeds at four Interstate highway locations in Maryland and Virginia. Overall, they found that 11 percent of the vehicles in Maryland and 14 percent in Virginia were equipped with radar detectors. A more significant finding was that the vehicles with radar detectors in use were more likely to be travelling in excess of the speed limit than those vehicles without the detectors. Also, the study indicated that the higher the recorded speed, the more likely it was that the vehicle would be equipped with a radar detector.

A second study by IIHS (July 1990) dealt specifically with radar detector use in large trucks. The Institute gathered data from seven eastern States with 55 mph speed limits for commercial vehicles. The study reported that radar detector use in all trucks ranged from 33 percent to 47 percent among the individual States. Reported usage was even higher for truck tractor-semitrailer combinations with as many as 52 percent of these vehicles using radar detectors. As with the previous study in Maryland and Virginia, the researchers found that trucks with radar detectors were more likely than those without to be travelling at speeds in excess of the posted limits.

The Missouri and New York studies also confirmed the relationship between radar detector use and speeding. The Missouri State Highway Patrol gathered data which revealed that during a two month period, 29.6 percent of speeding drivers arrested were using radar detectors. The Patrol also found that as the speed violation range increased, the percentage of violators using radar detectors also increased. The New York State Police study focused on "professional speeders," those drivers who exceed the speed limit by the widest margins and are able to evade the police through the use of radar detectors and CB radios. The results of that project confirmed that the drivers travelling at the highest speeds are also the drivers most likely to have radar detectors.

The presence of radar detectors alone, without an accompanying increase in vehicle speeds, would not be cause for widespread concern. The substance of the matter lies in the fact that recorded speeds on the nation's roadways are increasing. The increases of speeds on the

Interstate highway system have been well publicized with the recent NHTSA "Report to Congress on the Effects of the 65 mph Speed Limit through 1989". That report contains data from 18 of the 40 States that have raised their speed limits on rural Interstates. Some of the findings are:

- The average travel speed is estimated to have increased from 60.6 mph in the fourth quarter of 1986 to 64.2 mph in the fourth quarter of 1989, an increase of approximately six percent.

- The 85th percentile speed on these roadways has increased from 66.6 mph to 71.1 mph for the same period of comparison, an increase of approximately seven percent.

- The percent of vehicles exceeding 65 mph has increased from an estimated 19.7 percent in the fourth quarter of 1986 to 44.6 percent in the fourth quarter of 1989.

- For this same time period, the percent of vehicles exceeding 70 mph has increased from an estimated six percent in 1986 to 20 percent in 1989.

These trends in increased speeds are not limited to the Interstate system. A recent report by the Boston University School of Public Health revealed that fatal crashes in Massachusetts involving speeding drivers increased 25 percent between 1983 and 1987. When these figures were adjusted for increased miles travelled, the number of fatal crashes related to speeding had still increased twelve percent. In fact, Massachusetts recognizes speeding as the single largest cause of fatal crashes. With respect to reconstructed crashes in the State, the Massachusetts State Police concluded that speed was a contributing factor in 60 percent of those crashes. Similar findings were observed in the previously mentioned Missouri study which identified speed as a contributing factor in over 42 percent of the State's fatal traffic crashes. Clearly, speeding does represent a significant problem to both the traffic safety community and the general population.

If law enforcement agencies are to effectively deal with the problem of speeding, they should strive to employ all available strategies in a planned traffic enforcement program aimed to reduce fatalities and injuries and to maintain speeds within the posted speed limits. The police must use strong public information and education campaigns coupled with the latest technological advances in speed limit enforcement. Although the use of drone radar does not constitute a new technology, it does represent a new application of existing technologies to deal with an emerging traffic safety problem. It is with these thoughts in mind that the following guidelines have been developed and distributed.

## *GUIDELINES FOR THE USE OF DRONE RADAR*

These guidelines have been prepared to assist the law enforcement community and police administrators as they consider the use of drone radar as a component to their traffic law enforcement strategy. Drone radar can be defined as the unconventional use of police traffic radar in either an attended or unattended mode for speed deterrent purposes. It should be established at the outset that the use of drone radar should only be considered a part of an agency's overall speed enforcement plan. The effective use of drone radar, when used in this manner, may provide the needed assistance in special situations where traditional enforcement strategies have proved to be ineffective.

At minimum the following components should be considered when developing a department policy on drone radar:

- It must be part of an agency's speed enforcement efforts.
- The selection of a site should be based on problem identification.
- It must adhere to Federal Communications Commission (FCC) rules.
- It must be under local control and supervision.
- Program evaluation must be included as part of the policy.

*Part of an Agency's Speed Enforcement Efforts*. Any use of drone radar must be considered as a part of an agency's strategy to deal with speed limit enforcement. The ultimate goal of any enforcement strategy, whether it be speeding, impaired driving enforcement or another selected problem, is to maximize the deterrent effect and increase the motorists' perception of risk of apprehension. In this light, drone radar can be viewed as an additional tool available to the law enforcement community to increase this perception among the public. Caution must be exercised, however, so that agencies do not embark upon a policy of widespread and unlimited use of drone radar. Such a practice would defeat the purpose of its selective and controlled use and would also constitute a violation of FCC rules.

Ideally, drone radar should be used as a supplemental system to other speed enforcement strategies such as conventional radar, VASCAR, aerial enforcement and pacing.

## *DRONE RADAR*
### *Operational Guidelines*

*Site Selection by Problem Identification*. Any effective use of drone radar must be based upon an objective analysis of where the device will provide the greatest benefit. Based upon crash experience and arrest data, the following locations could receive consideration:

- Crash areas where speeding and speed-related violations have been shown to be contributing factors.

- Construction work zones.

- Other roadway locations. Not all segments of roadway are equally suited to the various means of speed limit enforcement. For instance, in some highly congested urban areas, highway engineers have removed "breakdown lanes" to provide additional travel lanes. This practice has complicated law enforcement's efforts in that adequate space often is not available for safely stopping motorists along the berm. Bridges and tunnels also provide impediments to traditional means of speed limit enforcement.

Regardless of the site selected, police officials should use objective, quantifiable criteria to identify the locations with significant problems relating to speeding.

*Adherence to Federal Communications Commission (FCC) Policy and/or Procedure*. The FCC regulations concerning the use of police traffic radar are found in 47 C.F.R., Parts 15 and 90. Section 90.101 provides for the use of radio methods for "...determination of direction, distance, speed or position for purposes other than navigation." Police have normally found their authority and permission to operate radar within these rules. The use of drone radar, however, provides a unique situation whereby police agencies must use caution so that the use of radio frequencies does not go beyond the limitations of the rules.

In order to satisfy previous FCC requirements, drone radar had to be deployed so that the signal reflected from a moving vehicle returned to the radar set and served some purpose. Radar transmissions that did nothing but radiate an outgoing signal (with no corresponding return) were not deployed in conformance with FCC regulations. At NHTSA's request, the FCC has recently reconsidered this policy and now will permit the use of unattended, continuously radiating radar (i.e., drone radar) on a controlled basis. This revision in FCC policy "...will permit law enforcement agencies to utilize attended or unattended radar units, without the requirement that the return signal be used for some specific purpose." [1] Nevertheless, the Commission continues to require that any radar units used in drone operations must be type accepted and licensed for police use by the Commission.

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[1] *Notification of revision in policy received by NHTSA from the FCC through correspondence dated July 1, 1991.*

## *DRONE RADAR*
### *Operational Guidelines*

Some applications of drone radar that are consistent with FCC rules and policies are:

- Use in conjunction with visual speed displays.
- Use in conjunction with warning devices.
- Use for statistical compilation of traffic speeds.
- Use to gather information about traffic flows.
- Use to regulate speed and to increase the safety of traffic flow.

*Localized Control and Supervision*. The use of drone radar in either the attended or unattended mode should be accompanied by close supervision and control. The radar unit must be adequately protected from both vandalism and adverse weather conditions. Also, the person responsible for the unit must take the proper steps to set up, power up and test the unit. Of paramount concern is that the supervising officer must immediately turn off the unit in the event valid complaints are received concerning radio interference.

Unmanned units should be operated only within the roadway segments and time frames identified through crash and arrest data. The unlimited use of drone radar, deployed for extended distances and over long time periods, should be prohibited. Such deployment would serve no legitimate purpose in improving traffic safety. Furthermore, applications of this nature would constitute clear violations of FCC rules.

*Program Evaluation*. The evaluation of any traffic enforcement effort is dependent upon obtaining accurate information to measure how well the goals of the program are being attained. Therefore, patrol supervisors and commanders should take steps to measure what effect, if any, the use of drone radar has upon vehicle speeds and crash experiences. This information should be gathered for the roadway segments where drone radar is used and then compared to data from prior periods. In this way law enforcement administrators will be able to objectively measure the impact that drone radar has upon motor vehicle speeds and crashes.

*Model Policy*. Before using drone radar, it is recommended that the police agency have an established procedure to outline how the devices should be set up and operated. The policy should clearly establish that the use of drone radar be limited in scope to satisfy all FCC regulations. To assist agencies in establishing their own guidelines, NHTSA has prepared a model policy which incorporates the recommendations previously discussed. Agencies should feel free to use the model policy as a basis for their own individual needs. *(See Appendix A)*

## APPENDIX A

# MODEL POLICY

# DRONE RADAR GUIDELINES

### I. Purpose

The purpose of this policy is to establish operational guidelines for the use of drone radar in both attended and unattended modes.

### II. Definition

For the purposes of this policy, drone radar is defined as the unconventional use of police traffic radar in either an attended or unattended mode for speed deterrent purposes.

### III. Policy

It is the policy of this department to use attended and unattended police traffic radar consistent with the policies and/or procedures for such use established or accepted by the Federal Communications Commission (FCC).

### IV. Operational Guidelines

Unmanned police traffic radar and unconventional manned applications of police traffic radar are to be used as a part of an enforcement program to improve traffic safety. The objectives of the program are:

A. Enhance overall traffic safety by encouraging greater compliance with the posted maximum speed limits in high hazard areas.

B. Reduce the frequency and severity of motor vehicle crashes in areas where speed has been determined to be a prime causative factor.

### V. Procedures

A. Site Selection

In selecting sites for the use of unmanned radar, primary consideration shall be given to those roadway segments on which an identifiable, speed related, motor vehicle crash problem is being experienced. Secondary consideration may be given to those locations where temporary changes in roadway surfaces or traffic patterns will require reduced speed limits for the safety of motorists and pedestrians. In selecting these sites attention must be given to officer safety and equipment security. Although not all inclusive, the following type locations might be considered as eligible sites:

1. High traffic crash areas as identified by appropriate problem identification techniques;

2. Construction work zones; and

3. Roadway locations not subject to traditional enforcement strategies (e.g., bridges, tunnels, etc.) where speed in excess of the posted limit has been identified as a crash causative factor.

The selection of sites shall be made by supervisors based upon identified problems and in support of traffic enforcement efforts.

B. Equipment

All radar equipment shall be of a stationary type approved and licensed for police use by the Federal Communications Commission (FCC)

C. Operation

1. The operation of unmanned stationary radar in a drone mode will be permitted only:

   a. During those time frames and on those roadway segments where a speed-related crash problem is identified.

   b. When construction on a roadway requires reduced speed limits for safety purposes. When used in a construction zone the unmanned units are limited to that part of the roadway signed as a construction zone. This is not to preclude the use of more than one unmanned unit in a single zone or in a single direction within that zone if both sides of a roadway are affected.

2. The use of unconventional manned radar applications such as in highway department trucks will be permitted only:

   a. During those time frames and on those roadway segments where a speed-related crash problem is identified.

b. When construction on a roadway requires reduced speed limits for safety purposes. When radar units are used in unconventional vehicles by non-sworn personnel, the unit should be turned on when entering the designated roadway segment and shall be turned off immediately upon leaving same.

D. Control and Supervision

1. Although the radar units used in the unattended application are technically unmanned, they are not permitted to be unsupervised. In each case where radar is used in a drone mode, the sworn member responsible for that patrol area is also responsible for the supervision of the radar units. This member will set up, power up, calibrate and perform any other required function for the operation of each of the units used in the drone mode. This member is also responsible to immediately turn off any unit in the event a valid complaint is received regarding interference with other licensed radar transmissions or reception.

2. All reasonable steps shall be taken to assure the security of the unmanned units prior to deployment.

3. Unmanned units may be operated only within the roadway segments and time frames identified as high frequency crash hours by the problem identification process.

   a. Operation beyond identified hours is not permitted.

   b. Members are reminded that attempts to deploy units in a drone mode on extended lengths of roadway segments will defeat the purpose for which these units are used -- that is, to limit excessive speed in areas in which same has been shown to contribute to crashes and/or constitute a danger to vehicular and pedestrian safety.

   c. Applications in the drone mode, that exceed roadway segments of three miles (unless a construction zone of greater length), are not appropriate candidate sites.

4. The equipment should be used as a part of an enforcement effort as approved by the sworn member's supervisor.