The highway operations technical research area of SHRP included projects pertinent to pavement surface maintenance, snow & ice control and work zone safety. The work zone safety research was completed via two contracts (H-108 and H-109) with a combined value of $2.3 million (USD). This technical brief consists of the executive summary of the final report *Maintenance Work Zone Safety Devices Development and Evaluation* (SHRP-H-371) supplemented by technical highlights from throughout the report. Information on availability of the devices (as of December 1994) has also been added.

**EXECUTIVE SUMMARY**

The continued problem of protecting maintenance workers from the hazards of traffic was addressed by a national design competition (SHRP H-108). It called for the development of innovative and more effective methods of protecting workers in short-term (one to 12 hour duration) work zones. Prototypes of these new protection and traffic control devices were later developed, fabricated, tested, evaluated and refined under SHRP project H-109.

The design competition yielded 126 proposals which were evaluated by the project staff and an expert task group (ETG). Of those received, 37 proposals were awarded prizes. These proposals, along with ideas from the project staff themselves, were amalgamated into 34 concepts for which prototypes were designed. The concepts were organized into seven groups:

- barriers,
- warning devices,
- rumble strips,
- delineation devices,
- lighting devices,
- signs, and
- promising concepts.

Further refinement of the 34 concepts lead to the recommendation that a group of 25 devices be developed and studied. Duplicate ideas, such as several designs for a portable speed bump, were reduced to a single device. The following is a list of the 25 devices recommended by SHRP H-108 for further development:

- Queue Length Detector
- Portable Rumble Strip
- Direction Indicator Barricade
- Opposing Traffic Lane Dividers
- Snowplow Blade Markers
- Flashing Stop/Slow Paddle
- Portable Sign and Stand
- Remotely Driven Vehicle
- S.CAI barrier
- Personnel Protection Trailer
- Moveable Barrier End Treatment
- Aluminum Can Truck Mounted Attenuator
- Pressurized Pneumatic Tube Alarm
- Traveled Way Rumble Mat
- Rumble Stripe
- Moving Taper
- Portable Soft Barricade
- Maintenance Vehicle Floodlight
- Diverging Lights
- Flagger Gate
- Truck Mounted Message Box
The specific objectives of SHRP Project H-109 were:

To develop new and more effective ways of protecting workers in short-term maintenance work zones from the hazards of nearby traffic.

To secure the detailed design, fabrication, testing and evaluation of prototype work zone safety devices.

To produce training courses and manuals on such matters as the evaluation of site specific work zone traffic controls, on the evaluation of the effect of traffic controls on traffic through the work zone, and on the use of new devices and procedures.

The first step of Project H-109 was the development of an evaluation plan for the devices. This evaluation plan included descriptions of the devices, descriptions of the areas of testing to be conducted on each device, and the evaluation criteria and measures of effectiveness for each test for each device. The evaluation method was a sequential, logical process that included several decision points where the device was either further refined and redesigned or abandoned.

The next step was fabrication of the devices. A fabrication plan was written for each device, which, included detailed drawings of each device, the quantity to be fabricated, a cost estimate for the fabrication, a schedule of fabrication and a list of potential fabricators, if not part of project staff. Each plan was submitted to SHRP for approval and devices were fabricated accordingly.

The third phase was the evaluation of the devices. Ten different test types were formulated. However, not all 10 test types were used to evaluate each device. The test types were:

- human factors,
- computer simulated impacts,
- environmental/material testing,
- electronic evaluation,
- scale model impacts,
- operational testing,
- full-scale crash testing,
- full-scale crashworthiness testing,
- closed track testing, and
- open highway testing.

Performance factors for each test type were developed in order to determine the effectiveness of a device relative to established limits of deflection, in the case of the full-scale crash testing, or relative to a standard traffic control device, in the case of closed track or open highway testing.

Decision points for continuing or dropping a device were included in the testing and evaluation phase of the project. For example, if a new device was not superior to a standard device in at least one performance area, it would fail that phase of testing and either be redesigned or dropped.

The fourth task was the development of specifications and implementation plans for the devices that successfully completed the evaluation. Detailed drawings, specification, and production plans were developed to facilitate the commercialization of the products. Some training and operation manuals were drafted prior to the open highway testing in order to obtain critiques from the highway workers using the devices.

Twelve devices successfully passed the evaluation stage.

**HIGHLIGHTS**

1. **SALT SPREADER/TRUCK MOUNTED ATTENUATOR (TMA) INTERFACE**

   In many states, vehicles serve double duties; they are dump trucks in summer and converted in winter by the addition of a sand/salt spreader unit for snow and ice control. For safety, dump trucks are equipped with TMAs to reduce the severity of any rear-end collision. However, the addition of the spreader unit can physically interfere with the TMA.

   A Salt Spreader/TMA interface was designed to permit the use of a TMA year-round. It is a tubular steel frame adapter between rear-spreading salt spreaders and commercially available TMAs. The interface is a modification of current TMA mounting hardware. It has an opening in the center that allows the spreader assembly to pass through. All of the structural and hydraulic members are mounted on either side of the spinner assembly opening and the interface has a hydraulic package to tilt the TMA for transport. When not in use, the interface compresses to the same approximate size as current TMA mounting hardware.

   Project staff collaborated with Energy Absorption Systems Inc.
who had been working on a similar device. Since EAS already manufactures TMAs, it was felt that the company was best suited to undertake further development, testing, evaluation and marketing of the interface device which has proved successful.

2. PORTABLE CRASH CUSHION (PCC)

Sand barrel crash cushions are used to attenuate the impact of vehicles into roadside hazards. However, because the crash cushion array consists of up to 13 plastic barrels filled with sand, its placement is a time consuming, and therefore, hazardous operation.

The Portable Crash Cushion is an easily placed and retrieved array of impact-attenuating sand barrels. It is comprised of a tilt-bed trailer and a pallet system capable of holding the sand barrels in place during transport, drop-off, and retrieval. The pallet system consists of a set of eight steel plates, each 2.16m wide, 1.10m long and 9mm thick. The plates have two hinges at each plate connection to link them into a chain. The entire length of the system is 9.26m. Each sand module is bolted to the steel pallet using two wooden washers and one steel washer, as well, 25mm rings are welded onto the pallet to ensure that the modules do not slide on the pallet upon impact.

To install the PCC, the trailer moves into a closed lane upstream of a stationary maintenance operation. The trailer is positioned so that the pallet can slide off the tilt-bed onto the roadway. In-lane protection is provided for pedestrian maintenance workers.

Two design modifications from the prototype were identified for the production version Portable Crash Cushion: a source of power for the tilt-bed and winch that will not require frequent recharging, perhaps multiple batteries or an auxiliary power system and a redesigned axle system so the trailer can deliver the crash cushion arranged in either a forward or backward configuration.

Since completion of the SHRP research, further refinement has been pursued by one of the SHRP research contractors, but the device is not yet commercially available.

3. ULTRASONIC DETECTION ALARM (USDA)

The Ultrasonic Detection Alarm was developed to warn workers when an errant vehicle entered the work zone thus allowing them a chance to escape. Motion or proximity sensors are best suited to detect errant vehicles. A basic ultrasonic sensor, was chosen for early evaluation since it needed little modification to fit the application.

The USDA is placed at the beginning of the buffer zone and activates a siren when an intruding vehicle passes into the zone. The detection unit consists of a sensor, an interpretation circuit, a tone encoder, and a transmitter while the receiving unit consists of a receiver, a tone decoder and a horn. In the original design, the decoders and encoders used were those found in touch-tone phones. In this system, two tones are passed on a carrier and have to be matched for the receiver to activate. Since the CB carrier was poor, the unit would hesitate on accepting the signal. Consequently, single tone encoding was adopted.

When a vehicle passes in front of the sensor, the interface board recognizes the sensor output and creates an electronic signal. That signal is passed through the interpretation circuit to the tone encoder which generates a warning tone of 1 kilohertz (kHz). The warning tone is sent out to the transmitter that is set to operate on citizen band (CB) channel 30 and received by a radio in the receiver unit, set to this same channel. The received tone is then passed through a tone decoder and activates a 120-dB horn. The warning should give workers four to seven seconds to escape.

Since completion of the SHRP research at least five variations of the intrusion alarm have become available commercially. However, none of these uses ultrasonic technology, but rather employ other sensing technologies considered more reliable under the field conditions experienced (see infrared intrusion alarm).

4. INFRARED INTRUSION ALARM (IIA)

The Infrared Intrusion Alarm is another type of warning mechanism that alerts workers to the presence of an errant vehicle. It is an infrared retroreflective device, placed at the beginning of the buffer zone. The model evaluated by SHRP directs its infrared beam at a reflector that reflects back to the sensor, allowing for the detection of vehicles at a variety of speeds.
If the IIA's infrared beam is broken, a relay closes and creates an electronic alarm signal. The electronic signal is then passed through an interpretation circuit to a tone encoder which generates a warning tone of 1 kilohertz (kHz). This signal is sent out by the transmitter set at CB channel 30 and picked up by a radio receiver. Finally, the tone is passed to a tone decoder and if it matches a preset tone within the receiver, the horn is activated. The warning should give workers four to seven seconds to react. As with the USDA, single tone encoding was found to be more efficient.

Since completion of the SHRP research, at least five variations of the intrusion alarm have become available. One of these utilizes the infrared technology, while others utilize microwaves or pneumatic tubes for sensing. Both radio transmission and hard-wired systems for transmission are available.

5. QUEUE LENGTH DETECTOR (QLD)

Work crews often are unaware of traffic conditions upstream of the work zone. The Queue Length Detector is designed to detect the presence of a traffic queue so that workers can take action. It consists of an ultrasonic detector placed 200m in advance of the work zone, a work zone receiver and a buzzer with flashing light. The ultrasonic ranging system is readily available commercially.

When a vehicle passes in front of the sensor, the interface board creates an electronic signal. If the vehicle stays in front of the unit for 15 seconds or more, an electronic signal is passed through the interpretation circuit to the tone encoder. The tone encoder then generates a warning tone of 1 kilohertz (kHz) which is sent out by the transmitter set at CB channel 30. The signal is received by the work supervisor via a walkie-talkie. With this warning, the work crew can respond and attempt to move traffic through the zone.

The QLD interface monitors the timer output but it uses the output to operate a re-settable and adjustable counter circuit. This interface circuit consists of a stable oscillator and a three-stage counter circuit with overflow outputs. The output from the timer circuit operates a relay that toggles between the reset and run modes. If no vehicle is present, the counters are held in the reset state. If a vehicle is present, the counter circuit is in run mode and it counts as long as the vehicle is present. After a certain time, the circuit overflows, providing an alert signal. The time elapsed before overflow is determined by the frequency of the oscillator and can be varied: Higher frequencies mean shorter times, lower frequencies mean longer times.

The QLD is commercially available in essentially the same configuration as tested by SHRP.

6. PORTABLE RUMBLE STRIP (PRS)

The PRS is a flexible mat placed on the road, intended to warn drivers of a work zone situation ahead where they may be required to stop. Its raised edge gives drivers a jolt and produces an audible rumble effect when passing over it. The PRS is a rubber mat, 450mm long by 3m wide by 30mm tall. Weighing approximately 30kg, the PRS is composed of a set of 30mm thick neoprene rubber strips, glued on top of the other with epoxy adhesive. It has a rapid rise on its leading edge, followed by a gradual downward slope on the trailing edge.

For best results, the PRS was placed about 150m upstream from the flagger station. It helped drivers recognize the work zone signing and produced a measurable, if not statistically significant, reduction in speeds during open highway testing. The PRS performed well on the road and no circumstances were found during testing in which the device flipped up or presented a hazard during normal operations.

Since the completion of SHRP the PRS has become commercially available. The PRS is designed for use under moderate traffic speed conditions. Poor performance has been reported when mis-applied and used in high speed locations.

7. DIRECTION INDICATOR BARRICADE (DIB)

The DIB was designed to convey unambiguous directional information that marks specific hazards or channelizes traffic. Two prototype designs were tested, using standard barricade dimensions as specified in Part VI of the US Manual on Uniform Traffic Control Devices (MUTCD). One design consisted of a 600-by 300-mm panel hinged to the center of the barricade, with an arrow on each side. The panel is flipped over to change the direction of the arrow. The second design used two sliding panels locked into place above the barricade, each with its own arrow panels.
In crashworthiness testing, the sliding panel design proved to be the most dangerous. Its additional height made it more likely to contact the test vehicle’s windshield, causing vehicle damage. Changes were then brought to the prototype to incorporate the directional arrow (shown to be effective) and a larger-size drum device. Due to its conspicuousness, a drum-type device was found to be safer and sturdier than the metal tubing barricade. The recommended device is a flat-faced drum incorporating a black directional arrow on a reflective white background. It is recommended that production models be made of plastic or other lightweight material.

Since the completion of SHRP research, the DIB has become commercially available and is provisionally allowed for testing purposes under the US MUTCD.

8. **OPPOSING TRAFFIC LANE DIVIDERS (OTLD)**

The OTLD is a centerline delineator for maintenance work zones that conveys necessary travel path changes to motorists. An example application is when four-lane traffic is reduced to two lane two-way traffic. It is a two-way sign mounted on a 900mm tall tubular channel. The sign itself consists of a two-way arrow, in black against a high-intensity orange sheeting and located 300mm off the ground. The heavy 200mm base of the channelizer is attached to the pavement with bitumen adhesive tape and provides additional stability for the sign during impact. While the prototype had helical springs as the joint between the plastic sign and its base, modifications had to be made.

As the prototype was redesigned, the research team learned that a nearly identical device was already in production by a manufacturer in Texas. This mass-produced device cost $30 for the tubular channelizer, whereas the custom-made springs in the prototype cost nearly $300. For cost-effectiveness reasons, it was decided to use the existing device.

It was found that OTLDs can improve drivers’ understanding of certain types of two-lane, two-way work zones. In open highway tests, they appeared to shift drivers away from the centerline which could reduce head-on collisions.

Two alternatives to the OTLD evaluated during SHRP have become commercially available.

9. **SNOWPLOW BLADE MARKERS (SBM)**

Visibility is a problem during most snowplowing operations. Not only do drivers run into the rear of snowplows but snowplow drivers sometimes have trouble seeing the end of the plow blade and hit guardrails or other roadside objects. SBMs are lights mounted at the ends of a snowplow blade to indicate the presence and extent of the blade. Each marker is made from 750mm tall rectangular steel channel with one clear bulb on top and two amber bulbs on the outside of the marker. Inside the plow’s cab is a control box with a dimmer for the clear bulb since its brightness can distract the drivers.

The SBM improved night visibility of the plow blade. Although the markers were visible during the day, a snow cloud, created by plowing deep snow at high speed, could obscure them. The poor durability of the lights themselves was a concern. Aircraft wing lights were used and had to be replaced frequently. In future research or evaluation, the markers should be mounted as high as possible on the plow blade and some type of vibration and shock-absorbing mechanism is needed for the bulbs.

10. **FLASHING STOP/ SLOW PADDLE (FSSP)**

The FSSP resembles a standard flagger paddle (STOP on one side, SLOW on the other) except that it has two lights mounted above and below the STOP message. The flagger activates the lights by pressing a button on the side of the FSSP. These lights, powerful enough to be seen at 600m, flash alternately through 10 cycles at oncoming traffic. The lights are powered by a rechargeable battery pack located in the staff of the paddle.

High-intensity retroreflective sheeting was used on the STOP side and fluorescent retroreflective sheeting was used on the SLOW side. For durability, lightweight and high strength, the FSSP was constructed of anodized aluminum with stainless steel fasteners.

FSSP induced approaching vehicles to slow down at an advance location designated by the flagger. It was especially beneficial under conditions of limited sight distance, where maintenance activity is more likely to surprise motorists. In this scenario, the FSSP can reduce the likelihood of rear-end accidents due to sudden slowing and the likelihood of high speed vehicles entering the work zone.
Since completion of the SHRP research, the US Manual on Uniform Traffic Control Devices (MUTCD) has approved use of this device. Several variations of the SHRP design now exist in the marketplace, with either one or two lights and with varying placement on the sign face. Different options for power supplies are also available, from standard D-cell batteries to rechargeable units either integrated with the sign or worn in a belt unit by the flagger.

11. PORTABLE SIGN AND STAND (PSS)

The PSS is a portable, adjustable sign stand for 1.2m neoprene signs that can be placed on roadside slopes of varying steepness. The sign is attached to a 25mm by 25mm by 1.2m vertical tube. Two fiberglass crosspieces hold the sign rigid. The vertical tube fits into a tube in the stand; the stand assembly stands 1.5m when fully erect and 2.4m with a sign attached. The sign and stand fold to a compact size for transport and storage.

This device is commercially available.

12. REMOTELY DRIVEN VEHICLE (RDV)

The RDV evaluated is a Ford L8000 dump truck that was modified for radio-controlled operation. It eliminates the need to have a driver in the shadow vehicle as the RDV can be operated by someone in the work crew itself. The RDV is positioned about 90m behind the work crew and moves at a maximum speed of 8km/h so that the operator can move with the RDV at normal walking speeds.

The RDV system consists of a set of actuators, digital control circuits, a radio link and sensors to provide for remote control of trucks being used as shadow vehicles. Inside the cab of the truck is an electronic enclosure containing the system safety circuits, controllers for the actuators and any power supplies needed. The radio control system implements the following vehicle functions from the hand-held transmitter: steering, brakes, throttle, transmission, horn, headlights, parking brake, flashers, turn signals and emergency stop. This transmitter is powered by NiCad batteries and has two joysticks for controlling throttle, brakes and steering. Second generation transmitters will have one joystick.

Certain features have been built into the RDV; it does not impair the driver controls when the truck is in normal mode, it is protected against aberrant behavior such as power failures and air pressure loss, it has all-weather capacity, its system electronics are modularized for quick replacement of a defective subsystem, it has proximity sensors that detect objects 4.6m in front of the truck. In case of emergency conditions or equipment failure, the spring brakes on the truck activate automatically. The RDV is designed for enhanced ruggedness and reliability; all actuators are of premium industrial quality and tolerant of salt spray environments. Further research could eliminate some of the complexity of the RDV and lower its costs. It is hoped that RDV can become a modularized kit available to a broad base of users at reasonable cost.

Minnesota Department of Transportation which co-sponsored development of the prototype device during SHRP has continued refinement and field evaluation. No commercial device is yet available.

The remaining 13 devices tested in Project-H-109 did not meet evaluation criteria.

The Diverging Lights failed mostly due to lack of brightness of its lights. The Flagger Gate broke the test vehicle’s windshield upon impact and showed potential for penetration of the passenger compartment. It also presented a hazard to the operator of the Flagger Gate. The S.CAI Barrier, a hollow, plastic New Jersey-type barrier designed to be filled with water or sand, was meant to be an alternative to concrete median barriers. The test units did not meet basic requirements for rigidity, longitudinal strength and water tightness.

The Personnel Protection Trailer was troubled by difficulties in obtaining fabrication bids based on the conflicting requirements for mobility versus protection. The Moveable Barrier End Treatment did not make it to the prototype stage. The Aluminum Can Truck Mounted Attenuator was intended to provide a less expensive, lighter and more easily recyclable TMA than the current model. But despite its potential, the ACT needs more research, especially on the orientation of the cans and their containment.

The Pressurized Pneumatic Tube Alarm, intended to sense either a vehicle passage or device failure and alert workers to the impending danger, would not perform properly without a more sen-
sitive sensor (which was unavailable). The **Traveled Way Rumble Mat** failed to give drivers the desired jolt to alert them of potential hazards and also alert highway workers. The **Rumble Stripe** which did produce the desired driver effect caused vehicles to lose control when skidding over the device on wet pavement and was abandoned until this problem is resolved.

The **Moving Taper** carried a row of traffic delineator cones configured in a taper and was meant to be used in mobile and slow-moving maintenance operations. Its lengthy set-up and take-down times and high costs outweighed its promise. The **Portable Soft Barricade** was an A-frame barricade designed for stability in windy conditions by allowing the sign panels to rotate. Without the use of sandbags, for which the PSB wasn’t equipped, it moved and overturned in windy conditions.

The **Maintenance Vehicle Floodlight** was created from a number of metal straps and a U-shaped bar, arranged so that an array of floodlights could be mounted to point at the rear of a snowplow, making it visible despite blowing snow. Although they increased night visibility, the floodlights were washed out by ambient light in daytime. Moreover, they were completely ineffective while the plow was obscured by a snow cloud.

Finally, the **Truck Mounted Message Box** was designed as a variable message sign to alert approaching drivers to the presence of mobile maintenance operations. The unit was not visible as a lighted device during the day and hardly visible at night. A variety of bulbs were tested ranging in power from 25 to 50 watts, as well as sealed beam headlights, incandescent and halogen sealed beams. None provided satisfactory results.

---

For full details of this research see:

Maintenance Work Zone Safety Devices – Development and Evaluation
SHRP-H-371
Strategic Highway Research Program
National Research Council
Washington, DC 1993

SHRP reports are available for sale:

Transportation Research Board Box 289 Washington, DC 20055
Tel. (202) 334-3214
Fax (202) 334-2519